SELECTION FOR YIELD POTENTIAL, DISEASE RESISTANCE AND CANNING QUALITY IN RUNNER AND SNAP BEAN LINES AND POPULATIONS

By

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DECLARATION

I hereby declare that the work contained in this thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I dedicate this thesis to my beloved parents, Jacinta Njau and Benjamin Njau, my husband Dennis Karani, my son Adrian Mbutei, my brother Isaac Muthii and sisters Jane and Charity and my entire family for their love and support.

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ABSTRACT

Breeding vegetable and grain runner and snap bean (*Phaseolus vulgaris L.*) varieties with high yield, good pod quality, disease resistance, and suitable for processing industries has received virtually no research attention in Eastern Africa. Available imported vegetable runner bean varieties are photoperiod sensitive and fail to flower and set pods under normal day length. Grain type runner bean landraces grown by smallholders for are low yielding, susceptible to diseases and not suitable for use as a vegetable. Snap bean varieties produced for domestic and export markets by smallholder farmers and multinational companies are low yielding, susceptible to diseases and poorly adapted. Although canned runner and snap beans are becoming a major form of grain and vegetable consumption especially in urban areas because of their convenience and distinctive flavor while providing excellence consumer value, no locally developed varieties are available in eastern Africa. The objective of this study was to evaluate and select for high yield potential, disease resistance, canning quality in advanced lines and populations of runner and snap bean developed at the University of Nairobi. The study materials were 11 F_2 populations and F_3 families developed from crosses among six climbing and eight bush snap bean lines between 2012 and 2014; 50 vegetable and 50 grain type runner beans lines selected for tropical adaptation, disease resistance and grain yield from 139 $F_{6.8}$ lines, and 107 new snap bean lines. In 2014, the F_3, F_2 and their parents were grown in an irrigated trial at Mwea Research Station and data collected on maturity, pod length, pod diameter, pod per plant and pod yield. F_2/F_3 regression was used to estimate heritability. Vegetable and grain type runner bean lines were evaluated at Kabete Field Station and Ol Joro Orok in 2012, 2013 and 2014. The best 20 grain and vegetable runner bean lines were further evaluated in an irrigated high input production system at VegPro Farm in Naivasha. One commercial variety and three local varieties were used as checks for comparison. Forty-three runner and 27 snap bean lines, were subsequently evaluated for canning quality and sensory attributes at Njoro Canning Factory, Nakuru in March 2015. Industry references ‘TruFood RB’, a grain type runner bean, and ‘Julia’, a processing type snap bean, were used as checks.

Results showed significant differences ($P< 0.05$) for duration to flowering, pod length, pod diameter, pods per plant and pod yield across the six generations (P_1, P_2, BC_2P_1, BC_2P_2, F_2 and F_3). All the traits showed moderate to high heritability (H_{NS}= give values) but this varied with populations. The new grain and vegetable runner bean lines showed considerable variation for duration to flowering, plant vigour, racemes per plant, reaction to diseases and grain yield. All the test lines flowered and formed pods under short day conditions at the three locations.

Duration to flowering varied from 43 to 49 days in Naivasha, 49 to 53 days in Ol Joro Orok, and from 51 to 55 days in Kabete. The crop was extremely vigorous in Naivasha due to adequate and regular supply of water and nutrients. There were no disease incidences in Naivasha since the trial was conducted during dry spell which was not conducive for disease development. Most of the new vegetable type runner had higher pod yield compared with commercial variety, White Emergo. Outstanding lines included KAB-RB13-1-105/2 (18,354kg ha^{-1}) and KAB-RB13-1-105/3(10,114ha^{-1}). White Emergo, the commercial check variety produced a cumulative pod yield of 896 kg ha^{-1}. KAB-RB13-1-105/3 had the highest percentage of grade I pods (93.9%). Twenty six new lines at Ol Joro Orok, 13 in Naivasha and 62 at Kabete were comparable to White Emergo for pod curvature (straight) and met market pod length requirement of 18 cm.

Grain yield of the new runner bean lines ranged from 1,888 to 7,414 kg ha^{-1} in Kabete and Ol Joro Orok under rain-fed conditions, while under irrigation at Naivasha yield varied from 876 to 14, 472 kg ha^{-1}. Compared with best farmers' variety, the new lines had yield advantage of 80% at Naivasha, 35% at Ol Joro Orok and 32% in Kabete.

Results showed that there were significant differences among snap bean lines for pod yield, pod length, pod diameter, pod per plant and disease resistance. Fifty eight new lines were higher yielding than the checks. For example, KSB15-02 (10,835.4 kg ha^{-1}), KSB15-01 (12, 847.2 kg ha^{-1}), KSB13-11 (9,559.7 kg ha^{-1}) compared to Serengeti (6988.4 kg ha^{-1}) and Samantha (6396.6 kg ha^{-1}). Seventy six lines had round, straight pods with required standards for pod quality and more than 80% proportion of premium grades.

Canning quality tests showed that 35 grain type runner bean lines met the industrial canning standards. Among the best performers at Kabete were KAB-RB13-327-92/1, KAB-RB13-326-207/1B and KAB-RB13-326-207/1B. The best performers among lines grown at Ol-Joro-Orok lines were KAB-RB13-471-117/1, SUB-OL-RB13-275-248/3 and KAB-RB13-310-161/5. KAB-RB13-338-41/1 had the highest proportion of clumps (3). The reference variety had low PWDWT (58%) and brine pH before (5.66) and after incubation (5.68). Twenty snap bean lines met the industrial canning standards. Among the best performers were KSB22-147-2M/1, KSB22-147-2M/2 and KSB52-2M. The reference variety, Julia had low HC (1.1) and high fiber content (20%).

The results of this study showed that photoperiod sensitivity, duration to flowering, pod length, pod diameter, pods per plant and pod yield are highly heritable and could be transferred to the commercial snap bean varieties via phenotypic selection with good genetic gain. The work described is a milestone in the history of breeding runner and snap bean, not only in Kenya, but

also in Africa. The new high yielding grain runner bean lines with resistance to major diseases and tropical adaptation can be used to address food insecurity and poverty alleviation in the country. High pod yield, pod quality and disease resistance of these lines can contribute to increased productivity, reduction in production costs and enhance competitiveness of local products in domestic and export markets. These new grain type runner and snap bean lines will provide the food processing and seed industries with better, readily accessible, high quality raw materials that meet not only producer and consumer's preferences, but also will broaden the range of processed products.

Key words: Runner bean, snap bean, yield, diseases, canning

CHAPTER 1

INTRODUCTION

1.1 Background Information

1.1.1 Importance of Horticulture in Kenyan Economy

Agriculture plays an important role in the Kenyan economy with an annual direct and indirect contribution to gross domestic product (GDP) of 24% and 27%, respectively (Duiker, 2012). This importance is reflected in the positive correlation between growth in the agricultural sector and that of the national economy whereby the economy grows if agriculture grows and vice versa. The horticultural industry is a significant contributor to agricultural GDP. The sector accounts for 33% of the GDP, and continues to grow between 15 and 20% per year (Duiker, 2012). Agricultural sector contributes 30% of the national GDP and accounts for 80% of employment (HCDA, 2013). Over the last two decades, horticulture has emerged as one of the leading sub-sectors in the agricultural sector in terms of foreign exchange earnings, food security, employment creation, and poverty alleviation (GOK, 2012; Ugen et al., 2005; Mutuku *et al*., 2004). Horticulture offers employment to over six million Kenyans directly, and indirectly in commercial farms, processing and logistics operations (Duiker, 2012; http://www.fpeak.org/hca.html accessed on 27th Sep 2014). About 96% of the horticultural production is consumed locally, while the remaining 4% is exported. The domestic value of horticulture production in 2014 amounted to Ksh. 201.3 billion compared to 186.9 billion in 2013. This is equivalent to an increase of eight percent (HCDA, 2014). Over the same period, cultivated area increased by 15 percent from 596,574 ha to 684,912 ha with a total production of 8.4 Million t in 2014 compared to 7.3 million t in 2013. This was an increase of 16 percent (HCDA, 2014). However, in terms of income, the export segment earns the country around Ksh 91.2 billion in terms of foreign exchange (GOK, 2010). The Kenya horticultural industry has grown from its base dominated by small businesses and small farmers to very sophisticated businesses that are becoming increasingly vertically integrated. According to HCDA (2014), export of fresh produce earned Kenya about Ksh.91.4 billion in the year 2011, Kshs.89.9 billion in year 2012, Kshs.83.4 billion in year 2013 and Kshs.84.1 billion in year 2014 (Fig 1.1). The value of Kenya’s horticultural exports grew to Kshs 84.1 billion in 2014, up from 83.4 billion shillings in 2013, representing a 0.8% increase.

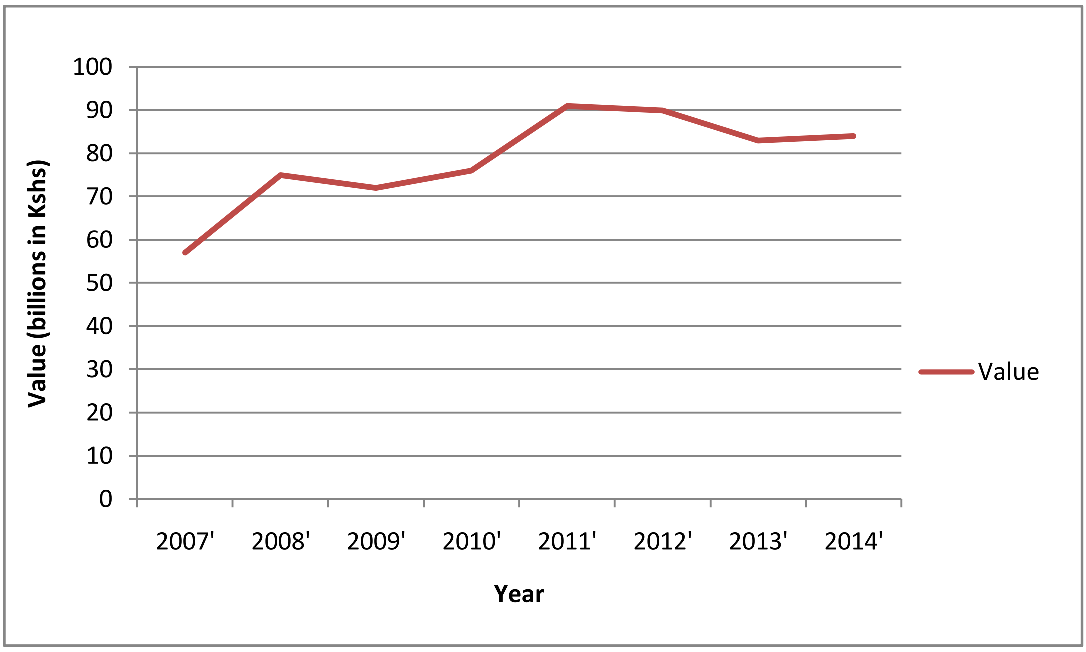


Fig1. 1: The trends of horticultural products export value between 2007-2014

Source: HCD, 2014

In 2014, the total domestic value in the horticultural sector amounted to Ksh 201 billion occupying an area of 684,912 ha with a total production of 220 million t (Table 1.1). Compared to 2013, there was 8% increase in value, and 15% increase in area. The increment in value was associated with improved farm gate prices especially for the vegetables, fruits and medicinal and aromatic plants (MAPs) (HCD, 2014).

Table 1. 1: Area, quantity and value of horticultural crops in Kenya, 2012-2014

Indicators	2012	2013	2014	% Increase
Area (Ha)	529,482	596,574	684,912	15
Production (millions t)	6.49	7.26	8.43	16
Value (millions Kshs)	179,097	186,912	201,251	8
Export volume (‘000’ kg)	205,728	213,884	220,248	3
Export value (millions Kshs)	89,869	83,381	84,084	0.8

Source: HCD, 2014

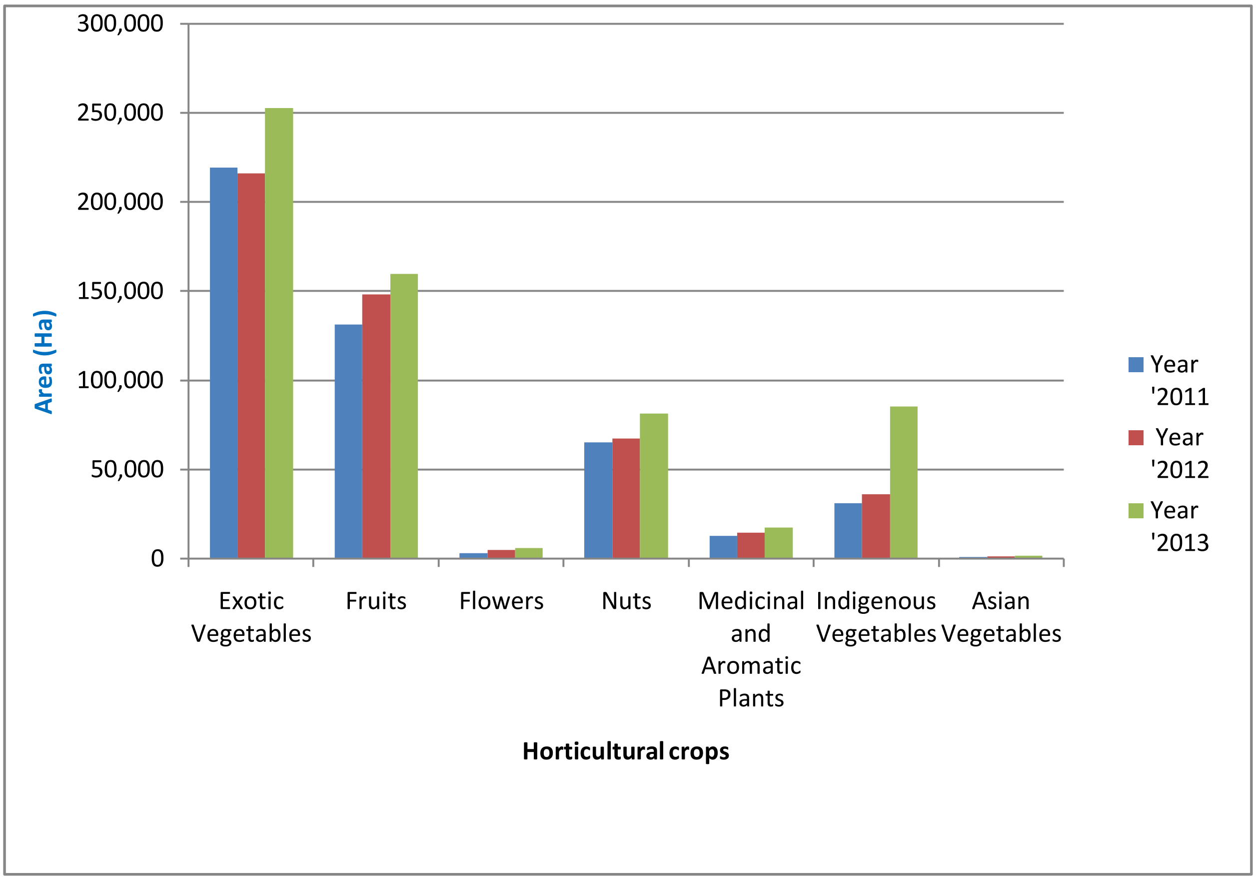


Fig 1. 2: Trends in growth of the horticultural sector

1.1.2 Vegetable crops for domestic and export markets

The overall subsector comprise of a mix of products from the three main subgroups; flowers, fresh fruits and fresh vegetables. The vegetable sub-sector is vital in attaining food security and improving livelihood for small smallholder farmers, who produce 100% of the indigenous African vegetables, and 70% of the exotic and Asian vegetables (HCDA, 2013). In 2014, vegetables contributed 31.8 percent to the domestic value of horticulture. The area, production and value were 280,541 ha, 3.6 million t and Ksh 64.1 billion, respectively. The area increased by 9 percent and production decreased by 0.44 percent while there was a slight reduction in value by 0.64 percent (HCD, 2014) (Table 1.2). The decreased production was occasioned by unfavourable weather conditions that resulted in low yield, thus reducing the value of vegetables particularly leafy ones (HCD, 2014). The main vegetables produced include potato, snow pea, tomato, snap bean, cabbage, kale, spinach, runner bean, carrot, broccoli, indigenous vegetables and Asian vegetables. The leading vegetables in production and value were potato, tomato and cabbage. Indigenous vegetables include pumpkin leaves, leaf amaranth, spider plant, cowpea leaves and stinging nettle. The area under indigenous vegetables increased from 31,864 ha in 2011 to over 40,000 ha in 2013 (HCDA, 2013). However, the Asian vegetables owe their name to the market segment for which they are targeted predominantly, Asians. They include okra, karella, dudhi, aubergines, and tindori, among others. Tomato, cabbage and Snap bean are the most lucrative in terms of enterprise value per hectare (HCDA, 2013) (Fig 1.3). Initiatives by government to ensure planting materials are accessible especially to vegetables that have a bearing on food security and nutrition such as potatoes and sweet potatoes also resulted in the increase (HCD, 2014). However, the main challenge has always been inaccessibility to quality seeds for other vegetables, lack of value addition technologies and high post-harvest losses (HCD, 2014).

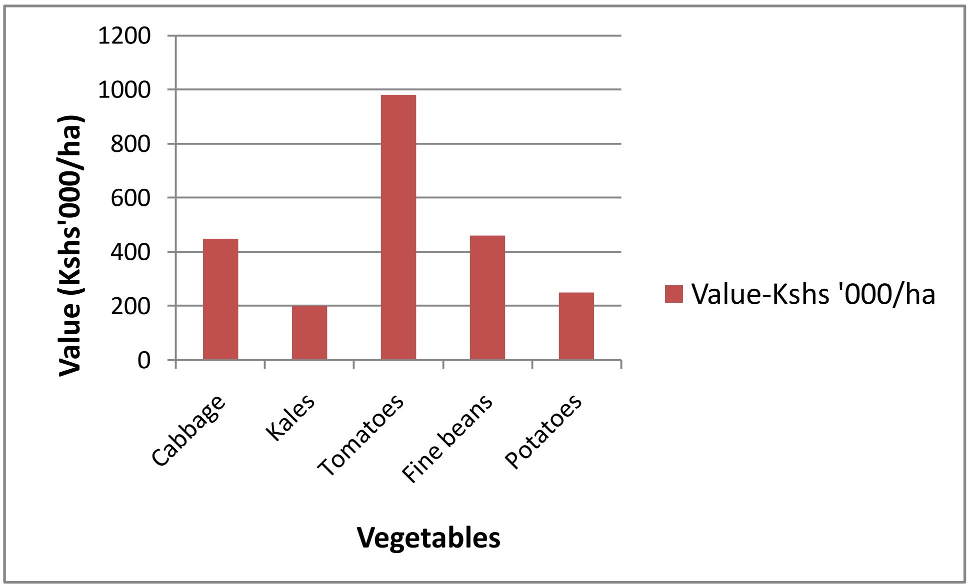


Fig 1. 3: Vegetables’ enterprise value per hectare

Source: GOK, 2012

Exotic vegetables contribute the highest total value among the horticultural crops (37%) due to high domestic demand, expanded area and off season production. However, the area under African leafy vegetables has been increasing over the years from 31,354 Ha in 2011 to over 85,000 Ha in 2013 (Table 1.1) The percentage change in value had a positive growth apart from vegetables and nuts which decreased by 21% and 5%, respectively for the last two years. The decline in vegetable exports is associated to the stringent set of maximum residual levels (MRLs) regulations imposed on Kenyan beans and peas. Inspection levels have increased to every consignment since Dec 2011. This has led to decrease in number of exporters and a decline in exports (GOK, 2012).

Table 1. 2: Horticulture industry performances by category from 2012 to 2014

Product	2012			2013			2014			Share by value 2014 (%)
	Area (ha)	Quantity (t)	Value (Kshs Million)	Area (ha)	Quantity (t)	Value (Kshs Million)	Area (ha)	Quantity (t)	Value (Kshs Million)	
Vegetables	239,994	3,191,908	54,096	258,354	3,629,762	63,686	280,541	3,613,841	64,097	31.8
Flowers	4,039	108,306	64,963	4,049	105,544	55,975	4,085	114,764	59,893	29.7
Fruits	205,354	2,831,007	46,342	232,715	3,118,588	50,042	280,192	4,303,385	60,814	30.3
Nuts	67,528	141,568	7,388	86,901	171,278	9,283	103,801	224,231	9,601	4.7
MAPS	12,567	185,333	6,308	14,855	232,269	7,941	16,293	176,874	6,946	3.4
TOTAL	**529,482**	**6,458,122**	**179,097**	**596,574**	**7,257,441**	**186,927**	**684,912**	**8,433,095**	**201,251**	**100**

Source: HCD, 2014

Kenya is very popular in export of vegetables (Duiker, 2012). It's ranked second largest developing country supplier of vegetables to European Union after Morocco. Runner bean, snap bean and processed beans account for around 54% of Kenya's vegetable export. Kenya is known to be among the producers with the highest quality snap beans. However, consumption of processed food in the country is gaining popularity because they save energy and time (Garcia et al., 2012).

1.1.3 Runner beans

Runner beans are traditionally grown in Kenya for dry seeds but imported varieties are grown for vegetables and exported to European markets. Local white, black, purple and purple black speckled seeded varieties flower and set pod at 1860masl in Kabete, Nyandarua and Nakuru Counties (Kahuro, 1990). However, imported varieties are photoperiod sensitive and fail to flower and set pods under normal day length unless additional lighting is provided (Kimani, 1999). The problem is probably associated to selection of cultivars which are adapted to long days for summer production in United Kingdom (Kimani, 1999). The imported cultivars are white seeded and meet the consumer demands that are required in export markets such as taste, shape, physical appearance, tenderness, cooking and eating quality. Provision of additional lighting is expensive and eliminates small scale farmers from vegetable runner bean production. Vegetable runner beans are produced by large scale growers in Meru, Nyandarua, Nakuru and Migori Counties majorly for export under special conditions whose investments cannot be afforded by small growers (HCD, 2014). In 2014, the grain runner bean was grown on 404 ha giving a production of 1973 t with a value of Kshs 174 million (HCD, 2014). Runner bean production is dominated by large scale companies like Sunripe, Vegpro, Finlays and Frigoken (Fresh Produce Journal, 1995). Although vegetable runner bean is grown by a small number of companies, and on a small production area, it earns the country about Ksh 600 million per year in foreign exchange. In 2013, 1,785,860 kg were produced valued at Kshs 621,995,391 (www.hcda.or.ke accessed 10 May 2014). Yield of vegetable runner bean is estimated to be between 8,750 to 13,750 kg ha^{-1} in United Kingdom, although with efficient crop management the yields could be as high as 37,500 kg ha^{-1} (Kay, 1979). According to Acland (1970), estimation of yield in cultivated fields is difficult, since farmers intercrop *P. coccineus* with other beans or harvest it periodically. It produces 400 to 1000 kg ha^{-1} in shrub forms while for climbing varieties, the yield can be much higher (400 to 4000 kg ha^{-1}) (Acland, 1970). In the United Kingdom, pod yield of more than 23 t ha^{-1} has been recorded (Acland, 1970). According to Kay (1979), P. *coccineus* L is considered to include three botanical varieties, *rubronanus*, a red-flowered bushy type, *albus*, the white Dutch runner and *albonanus*, a bush form with white seeds. Popular cultivars of the red-flowered types of runner bean in United Kingdom include Achievement, Enorma, Kelvedon, Marvel, Princess and Streamline. White-flowered types include Czar, Desiree, Emergo and Prizewinner (Kay, 1979). Brink (2006) gives a pod yield of 10,000 kg ha-^{1}; and 1.5 t ha-^{1} for grain. However, normal pod yield in UK is 8.75 to 13.75 kg ha-^{1} (Kay, 1979).

Grain type runner bean is predominantly grown by small-scale farmers in Meru and Nyandarua counties for domestic consumption. Nyandarua and Meru counties contribute about 96% of the total grain type runner bean produced in the country (Table 1.3). The counties have different yield potential. The yield of grain runner bean ranges from 1,000 to 1,429 kg ha^{-1} with Meru County producing the highest yield. In Kenya, the yields of dry mature seeds from smallholders have been estimated to be about 900 to 1,120 kg ha^{-1} (Kay, 1979). Nakuru and Nyandarua counties are estimated to produce between 500 to 800 t which are marketed annually (Suttie, 1969). Local varieties have different seed colours which range from white, black, purple and purple black speckled.

Vegetable runner bean is grown by large companies due to high cost of production. In 2013, 1,786 t were exported valued at Kshs 622 million (Table 1.4).

Table 1. 3: Production of grain runner bean in selected counties in Kenya, 2012-2014

County	2012			2013			2014		
	Area (ha)	Quantity (t)	Value (Kshs Million)	Area (ha)	Quantity (t)	Value (Kshs Million)	Area (ha)	Quantity (t)	Value (Kshs Million)
Meru	150	1,500	150	120	1,200	120	160	1,600	160
Nyandarua	180	230	7	185	192	6	213	208	6
Migori	27	108	1	25	125	1	20	125	6
Nyeri	5	9	0	2	5	1	4	8	1
Busia	4	30	1	4	30	1	4	30	1
Samburu	1	1	0	1	1	0	1	2	0
Others	8	75	3	8	120	0	2	0	0
Total	**375**	**1,953**	**162**	**345**	**1,673**	**129**	**404**	**1,973**	**174**

Source: HCD, 2014

Table 1. 4: Kenya's vegetable exports, 2013

	Runner beans		Fine beans		Bean processed		Other vegetables		Total	
Month	**kg**	**Kshs**	**kg**	**Kshs**	**kg**	**Kshs**	**kg**	**Kshs**	**kg**	**Kshs**
Jan	187,644	126,897,523	3,000,543	748,685,148	1,581,502	187,295,678	2,608,053	1,011,772,322	7,377,742	2,074,650,671
Feb	156,281	56,997,885	2,365,453	614,247,441	1,439,281	165,163,196	4,138,690	793,980,378	8,099,704	1,630,388,900
Mar	189,315	67,672,781	2,061,859	655,402,632	981,882	116,497,597	2,111,458	985,299,791	5,344,514	1,824,872,801
Apr	151,020	60,701,237	2,890,660	730,835,297	1,442,602	168,962,641	1,879,493	708,961,871	6,363,775	1,669,461,046
May	122,247	44,834,589	2,329,977	686,336,939	882,348	108,473,282	1,856,188	636,646,312	5,190,760	1,476,291,122
Jun	373,080	41,064,680	2,895,855	1,417,850,990	813,395	108,398,994	2,149,807	762,499,448	6,232,137	2,329,814,112
Jul	117,274	44,208,644	2,225,851	64s5,106,491	746,069	95,889,214	2,024,379	655,479,579	5,113,572	1,440,683,928
Aug	55,240	22,855,284	2,505,916	909,508,132	1,357,459	195,262,139	1,847,487	692,551,733	5,766,102	1,820,177,288
Sep	45,010	19,067,155	2,552,927	671,894,605	2,607,728	330,480,378	2,306,640	777,053,426	7,512,305	1,798,495,564
Oct	132,269	45,893,764	3,372,677	1,043,969,470	2,003,856	231,997,625	2,581,898	1,282,750,908	8,090,701	2,604,611,767
Nov	117,984	41,362,406	2,952,619	1,052,239,621	1,033,431	128,968,890	2,558,107	1,336,832,265	6,662,141	2,559,403,182
Dec	138,497	50,399,443	2,789,299	758,012,181	327,627	43,025,221	2,163,458	843,033,012	5,418,881	1,694,469,857
	1,785,860	**621,955,391**	**31,973,639**	**9,934,088,947**	**15,217,180**	**1,880,414,855**	**28,195,654**	**10,486,861,045**	**77,172,334**	**22,923,320,238**

Source: (www.hcda.or.ke accessed 10 May 2014)

1.1.4 Snap bean

In 2013, fine beans contributed the highest proportion of export by volume of 32,000 t valued at Kshs 9.9 billion.

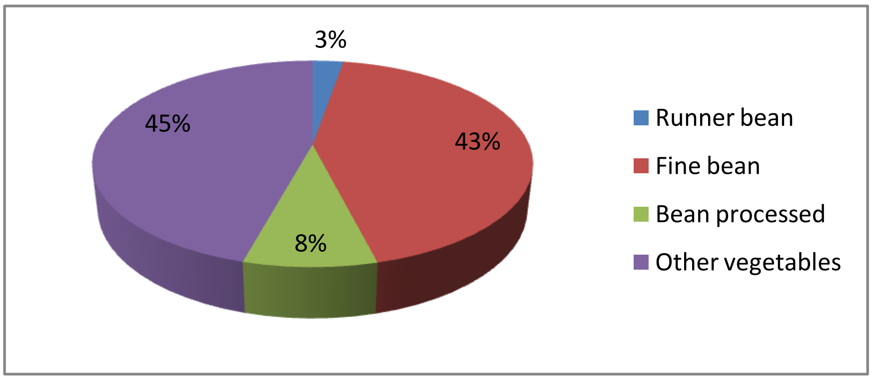


Fig 1. 4: Contribution of runner, snap and processed bean to vegetable exports by value in 2013

In 2013, fine beans accounted for 43 % compared to 3% for runner beans. Processed beans accounted for 8 percent of the vegetable exports. High level of exportation is enhanced by traceability level which ensures the farmers and exporters comply with the KENYAGAP and EUREGAP regulations.

Snap bean production is becoming more important to the socio-economic systems in East and Central Africa, especially for smallholder farmers. Most snap bean varieties produced in East Africa are round and thin, mainly to suit the export market. Snap bean production in Uganda is dominated by small-scale farmers although large commercial companies also grow for export to overseas supermarkets and for the canning industries (Gitta and Kata, 2012). The total production of snap bean by smallholder farmers in 2014 was 112, 409 t valued at Kshs 5.04 billion (HCD, 2014). The area decreased from 4707 ha in 2013 to 4572 ha, while the yields and value increased by 9 percent from 112409 to 122666 t and 15 percent from 4382 to 5038 million respectively. In 2013, the snap bean production in Kenya was 31,974 t valued at 9.9 billion (www.hcda.or.ke accessed 10 May 2014) (Table 1.4). Between 2011 and 2013, the area, yield and value of snap beans have increased by 7.1%, 14.6% and 43.3% respectively. However, in 2014 the area increased by 16%, yield by 15% and value by 8% compared to the previous year (Table 1.2). The leading counties in production are Kirinyaga (47%), Murang'a (25%), Meru (14%) and Machakos (9%) (Table 1.5) The snap bean production has faced challenges such as maximum residue levels (MRLs) which have led to rejections by export markets. However, despite the challenges the snap bean exports managed to recover from 33,520 t in 2012 to 38,398 t in 2013. This was achieved through integration of the traceability system in supply for the exporters to manage monitoring of the chemicals used by the farmers directly.

Table 1. 5: Smallholder production of snap beans in selected counties in 2011-2013

County	2011				2012				2013				% value share
	Area (Ha)	Quantity (t)	Yield (kg ha-1)	Value in millions (Kshs)	Area (Ha)	Quantity (t)	Yield (kg ha-1)	Value in millions (Kshs)	Area (Ha)	Quantity (t)	Yield (kg ha-1)	Value in millions (Kshs)	
Kirinyaga	1918	12114	6,316	398.5	1788	10583	5,919	450.9	1514	15222	11,054	869.4	47.70%
Muran'ga	803	3368	4,194	103.5	861	3848	4,469	118.5	885	4731	5,345	158.8	8.70%
Taita Taveta	50	1497	29,940	52.4	51	1227	24,059	43.5	134	3514	26,223	147.6	8.1
Meru	341	3206	9,402	124.7	326	6615	20,291	261.6	367	3328	9,575	130.3	7.10%
Embu	74	562	7,595	29.5	56	765	13,660	39.9	176	2083	11,835	124.2	6.80%
Machakos	245.8	625.2	2,544	28.7	328.6	1759.6	5,354	75.2	522	2415	4,626	106	5.80%
Laikipia	195	1500	7,692	99	120	1080	9,000	76	185	1380	7,459	89	4.90%
Narok	115	1254	10,904	61.8	148	1718	11,608	101	164	1046	6,378	60.4	3.30%
Others	500	4726	9,452	93.5	518	5924	11,436	106	581	4679	8,053	137.8	7.60%
Total	**4,241.80**	**28,852.20**	**88,039**	**991.5**	**4,226.60**	**33,519.60**	**105,796**	**1,272.70**	**4,528**	**38,398**	**90,548**	**1,823.50**	**100**

Source: HCDA, 2013

Snap bean production in Eastern African countries such as Kenya, Uganda, Tanzania, Zambia and Zimbabwe is dominated by small-scale farmers. It is an important export crop in those countries and over 90% of the crop is exported to regional and global markets (CIAT, 2006). Snap bean production in Eastern Africa is threatened by high cost of quality seeds (Chemining'wa et al., 2012). Most of the commercial varieties are developed by multinational companies like Monsanto, Syngenta and Roy Sluis (Table 1.6 from Chemining'wa et al, 2012). No formal and informal seed production is allowed in Kenya because the varieties are protected by legislation. The seed produced is exported for processing and later re-imported for sale to farmers (Chemining'wa et al., 2012). However, due to high cost of that seed, the farmers end up planting the seed saved from the previous season (Lenne et al., 2005). This phenomenon leads to low yield and quality deterioration.

The main snap bean varieties produced in Kenya include Teresa, Amy, Paulista, Julia, Serengeti, Samantha and Star 2053. They are produced for different pod attributes which include fine, extra fine, bobby and canning (Chemining'wa et al., 2012). In Kenya, snap bean is grown either for fresh market or processing. Some of the varieties grown for fresh market include Amy, Pekera, Teresa, Paulista, Rexas, Samantha and Cupvert. Varieties grown for processing include Julia, Vernadon and Sasa (Ndegwa et al., 2010; HCDA, 2012).

Table 1. 6: List of some of the commercial varieties of snap beans grown in Kenya

Variety	Marketer	Pod quality attributes
Serengeti	Syngenta/Kenya Highland Seed Company	Fine/extra fine
Mara	Syngenta/Kenya Highland Seed Company	Fine
Tana	Syngenta/Kenya Highland Seed Company	Fine
Konza	Syngenta/Kenya Highland Seed Company	Fine
Soleon	Syngenta/Kenya Highland Seed Company	Fine
Teresa	Monsanto	Fine/extra fine
Amy	Monsanto	Fine/extra fine
Paulista	Monsanto	Bobby
Julia	Monsanto	Canning
Alexandra	Monsanto	Fine
Samantha	Monsanto	Fine/extra fine
Bravo	East Africa Seed Company	Fine
Grano	East Africa Seed Company	Fine

Ducato	East Africa Seed Company	Fine
Star 2052	Safari Seed Company	Fine/extra fine
Escalade	Hygrotech Company	Fine

Source: Chemining'wa et al., 2012

1.2 PROBLEM STATEMENT

Horticultural crop production in Kenya is faced with several technical, marketing and logistic challenges. These problems range from low productivity, low soil fertility, to considerable postharvest losses due to inefficiencies in the marketing system.

Improved measures to enhance crop productivity include intensive breeding to develop better adapted varieties of snap beans, improved crop husbandry through irrigation, fertilization, pest and disease control, use of modern machinery and equipment (Duiker, 2012). Most technological packages have been adopted and the application in most cases has reached the economic optimum leading to diminishing returns for extra inputs. New measures are therefore necessary to generate technologies for the 21st century to meet the increasing demand for quality and nutritious food. With the rapid population growth, increased efficiency in use of available land and other resources is of great importance.

To meet the rising demand for food, emphasis has to be put on improving yield per hectare. This is because potential for increasing cropped area is limited, expensive and often results in environmental degradation (Mutunga, 1998). It is therefore necessary to evaluate advanced snap beans for pod yield, pod quality, disease resistance and canning quality to improve crop production with reduced postharvest losses and enhanced competitiveness in the market.

According to Chemining'wa et al., (2012), snap bean breeding in Kenya has been bedevilled by challenges such as lack of funds for breeding and scaling-up seed, limited number of snap bean breeders, drought and limited availability of irrigation facilities which leads to crop failures, limited participation of exporters/multinationals/seed merchants, tight control of snap bean seed sector by multinationals, and limited application of biotechnology tools in selection.

Production of snap beans in Kenya has been faced by challenges which range from lack of high yielding varieties that are resistant to pests and diseases to lack of high quality seeds (Kimani et al., 2004). The seed of commercial varieties are expensive and sometimes not available for farmers. They are produced by multinational companies which have protected their seed by legislation ensuring no informal seed production. Seeds are only available to the contracted farmers curtailing the other farmers from accessing the seeds therefore; they end up using seeds saved from previous season (Lenne et al., 2005). According to Kimani (2006), many of the commercial varieties have succumbed to diseases necessitating evaluation and selection for pod yield, pod quality, disease resistance and canning quality in order to enhance competitiveness in regional and international markets. Small-holders production of snap beans varies from 2 to 8 t ha^{-1} while large scale production attains over 14 t ha^{-1} (CIAT, 2004). Smallholder production is constrained by diseases like rust, angular leaf spot, root rot, bean common mosaic virus and pests like stem maggots, thrips and nematodes (Kimani, 2006). Pod quality requirements in snap beans vary from region to region. Characteristics related to pod shape, length, pod quality (pod fiber content, pod smoothness and straightness, pod colour and flavour) determine the degree to which snap beans are accepted by consumers and processors (Mullins and Coffey, 1990).

The principal quality determining factors for snap beans are low fiber content in pod walls and absence of string in the suture. Characteristics like pod shape, color, curvature and pod length are qualities taken into account by consumers where snap beans are usually consumed fresh (Myers and Baggett, 1999). Due to susceptibility of the commercial varieties to diseases, they fail to achieve the pod quality required hence becoming uncompetitive in the export markets. The University of Nairobi bean research program is mandated to develop new snap bean varieties for the processing industries. The processing industry is constrained by inadequate and erratic supply of snap beans. Due to low local production, the industry does not meet the consumption demand in the market. This has also led to seasonal processing of snap beans. Low production of snap beans is associated to lack of high yielding varieties with resistance to diseases. The farmers rely on commercial varieties of snap beans such as Amy, Monel, Smantha and Paulista. These varieties are low yielding and susceptible to diseases as opposed to the new varieties developed by University of Nairobi Bean Program. The low yielding and disease susceptibility aspects have led to low production of the crop by farmers despite high demand in the market.

Runner beans are traditionally grown in Kenya for dry seeds. However, Kenya has relied on imported varieties of vegetable runner bean for export to European markets (Kimani, 1999). There are no locally developed vegetable or grain type runner bean varieties in Kenya. According to Kahuro (1990) the white seeded grain type variety flowers and sets pods at Kabete, Nyandarua and Nakuru districts. The imported varieties grown around Lake Naivasha (Nakuru County) and Timau (Meru County) fail to flower and set pods probably due to their adaptation to long day photoperiod. The growers are forced to use additional lighting to stimulate flowering and setting of pods. The installation of the lights limits the production to a few hectares. The scarlet runner bean has been used on many occasions for improving the common bean but in very few cases has its own improvement been addressed, although specialists agree on the hardiness of the species against several fungi, bacteria and viruses (Kay, 1979). Despite the production challenges, Kenyan exporters in collaboration with European companies have ventured into runner bean production using artificial lighting (Kimani, 2009). The horticultural products market in Western Europe is believed to be expanding due to domestic production decline caused by increasing cost of production. This creates an opportunity for Kenya to expand exports and take advantage of low production costs and favourable climatic conditions. Production of runner bean seeds is restricted to vegetable types due to high cost of production, eliminating small-scale farmers. The seeds of runner beans are expensive compared to other crops and not always available for farmers. The vegetable type is rarely consumed in Kenya because most of the companies grow it for export. The runner beans are perishable and the quality influences the consumers taste and preference. In export markets, the consumers purchase products which appear fresh and of high quality. The producers are faced with difficulties in organizing the exportation of vegetables due to stringent rules imposed on quality. The products must be handled with care at all stages of the export process, including production, assembly, packing and shipping.

In Kenya, snap bean breeding is mainly conducted at University of Nairobi. The objective of the University of Nairobi snap bean program include development of new bush snap bean varieties with multiple resistance to rust, angular leaf spot and anthracnose, pod quality, marketability, long shelf life and high productivity and resistance to aphids, thrips and bean stem maggot. The program is also developing climbing snap bean lines with multiple resistances to rust, angular leaf spot and anthracnose (Kimani, 2010; Chemining'wa et al., 2012). The program also focus on evaluation of F_4, F_6 and backcrosses, HAB lines, SB lines and climbing snap bean lines for pod quality, pod yield, angular leaf spot, rust and anthracnose resistance (Wahome, 2011; 2013). Activities have focussed on development of segregating populations of both snap and runner beans and identification of marketable snap and runner bean lines with market demanded traits. However, the materials have not been evaluated for agronomic potential, pod yield, pod quality, disease resistance and canning quality.

1.3 JUSTIFICATION

Early generation selection has the potential of identifying high-yielding genotypes possibly as early as the F_2 generation (McKenzie and Lambert, 1961; Shebeski, 1967; Sneep, 1977; De

Pauw and Shebeski, 1973). Early generation testing helps to estimate the genetic potential of an individual line or population at an early stage of inbreeding. It helps to discard inferior individuals, lines, or populations identified early in the inbreeding process. In addition, more than one cultivar may be derived from a population identified as being superior by early generation testing. According to Immer (1941) replicated tests of segregating populations in F_2 or F_3 generation would provide the average yield performance of the different crosses. According to Valentine (1979) the frequency of genotypes possessing desirable alleles on all segregating loci, rapidly declines in subsequent segregating populations. Delay in selection for yield results in an irretrievable loss of valuable genotypes. For yield maximization, better pod quality and improved disease resistance, no opportunity for selection in early generation should be lost in snap and runner bean segregating populations.

Runner beans have shown considerable promise as an export crop due to decline of the domestic production in Western Europe as a result of increasing costs of production. This creates an opportunity for Kenya to expand and take advantage of relatively low cost of production and favourable climatic conditions However, the potential is hindered by photoperiod sensitivity whereby the imported varieties fail to flower and set pods under natural day length. This problem is probably due to selection of cultivars that are adapted to long days for summer production in United Kingdom (Kimani, 2009). The imported varieties meet the consumers demand like taste, shape, tenderness, physical appearance, cooking and eating qualities which are lacking in local varieties produced for grain type for domestic consumption. According to Kahuro (1990) the white seeded Kenyan cultivar flowers and sets pods at altitudes of 1860m and above but it’s produced mainly for dry seeds. Its pod quality for export markets is not known due to limited work in runner beans breeding in Kenya. The two cultivars can only be reconciled through breeding due to their differences in various aspects i.e. local cultivars are well adapted to natural day length but not suitable for snap runner bean export markets. However, imported cultivars, though acceptable to consumers are poorly adapted to production under natural day length.

Development of lines that are adapted to short day length has been done in University of Nairobi and those lines can be grown without extended light (Kimani and Mulanya, 2014; Mulanya et al., 2014). Therefore, evaluation for yield potential, pod quality, disease resistance and canning quality becomes important to reduce the cost of production. This improves production and competitiveness of the Kenyan products in the export markets while expanding the areas under runner bean production. Use of imported varieties and high cost of production has eliminated small scale growers from the market and therefore, evaluation of the materials for yield potential, pod quality, disease resistance and canning quality will lead to development of high quality locally produced runner bean varieties which can be accessed by all farmers' country wide and availability of raw materials to processing industries.

Varieties with increased pod yield, pod quality, disease resistance and canning quality will contribute to efforts aimed at increasing crop productivity, reduce cost of production, alleviate poverty, create employment and provide processing industries with raw materials. The processing industry requires green beans with high pod quality like low pod fiber, pod straightness, pod length, pod diameter and pod colour. Pod quality influences the consumers taste, preference and purchasing power for both fresh and processed products in the markets (Cajiao, 1992).

Vegetable runner and snap beans are highly perishable and unless proper handling and storage measures are undertaken, rapid deterioration is inevitable. Therefore, measures to evaluate advanced runner and snap beans for improved pod yield, increased pod quality, enhanced disease resistance and improved canning quality would be highly welcome to those involved in their production.

Advanced snap beans with improved pod yield, pod quality, disease resistance and canning quality will contribute to efforts aimed at increasing crop production by reducing postharvest losses, increasing profitability of snap bean farming, enhancing competitiveness of Kenyan products in regional and international markets and increased production of processed food.

Kenya exports largely semi-processed and low value produces which account for 91% of total agricultural related exports (GoK, 2012). The limited ability to add value is attributed to low capacity and high cost of value addition infrastructure. Seasonality of production compels many processing firms to operate below capacity and coupled with high cost of production make Kenya's processed products less competitive. The result is country importing products that could be produced locally. Very little has been done on evaluation of grain and snap bean lines for canning quality. In Wisconsin, 25,641 ha of snap bean for processing are grown and pod yield of 7 to 12 tha^{-1} are common (Meyer and Baggett, 1999). According to Duiker (2012), agro processing, packaging, canned and frozen beans and quality standards in the domestic, regional and international market are not fully developed. In particular, value addition, investment in packaging technology is critical during sea freight, whose cost is significant lower compared to the air freight. Deliberate efforts should be made towards investing in this area to increase the produce shelf life, reduce post-harvest losses and improve consumer acceptance both in domestic and international market (Duiker, 2012). Evaluation of runner bean for yield potential, pod quality, disease resistance and canning quality would reduce the cost of production and attract many players in the processing industry. High yielding varieties would ensure availability of raw materials throughout the year overcoming the challenge of seasonality. Therefore, evaluation of pod yield, pod quality, seed yield, disease resistance and canning quality in snap beans and runner bean is very vital to enhance value addition on agricultural related exports.

1.4 OBJECTIVES

The objectives of this study were:

1. Evaluate new climbing snap bean populations for growth habit, pod traits and disease resistance.
2. Evaluate new grain type runner bean lines for performance of agronomic traits.
3. Evaluate new vegetable lines for pod quality, pod yield and disease resistance.
4. Evaluate new snap bean lines for pod quality, pod yield and disease resistance.
5. Determine canning quality and sensory analysis of runner beans.
6. Determine canning quality and sensory analysis of snap beans.

1.5 HYPOTHESIS

1. There are no differences in growth habit, pod traits and disease resistance among segregating snap bean populations.
2. There are no differences in agronomic traits among the runner bean lines and commercial varieties.
3. There are no differences in pod yield, pod quality and resistance to diseases among advanced vegetable runner bean lines and commercial varieties.
4. There are no differences in pod yield, pod quality and resistance to diseases among advanced snap bean lines and commercial varieties
5. There are no differences in canning quality and sensory analysis among the new grain runner bean lines and commercial varieties.
6. There are no differences in canning quality and sensory analysis among the new snap bean lines and commercial varieties.

1.6 CONCEPTUAL FRAMEWORK

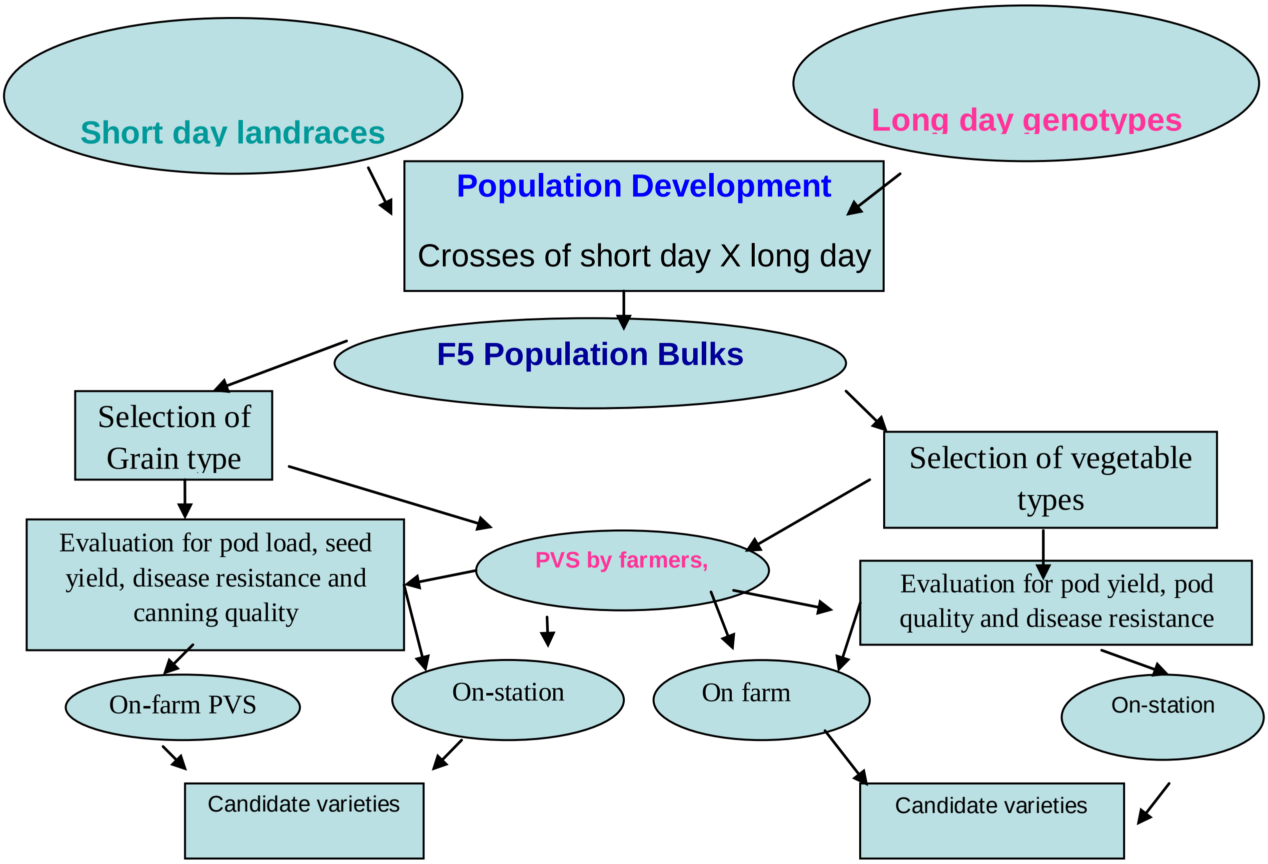


Fig 1. 5: Research approach and conceptual framework for improving runner bean lines in Kenya

Populations were developed from single crosses between short day landraces (Nyeri, Kin 1, Kin 3, Ol –Joro-Orok Dwarf 1, Ol-Joro-Orok Dwarf 2 and Ol-Joro-Orok Dwarf 3) and long day variety, White Emergo at Kabete Field Station (Kimani et al, 2009). Part of the population with desirable characteristics was advanced to F_5 generation by bulk method. The F_5 population will be selected for grain and vegetable type depending on pod quality. The two types of runner beans will undergo on-farm and on-station participatory variety selection (PVS) by farmers, traders and exporters. Also there will be on-farm and on-station evaluation for grain yield and canning quality of grain type and evaluation for pod yield and pod quality of vegetable type. From the rigorous evaluation, candidate varieties will be released to farmers.

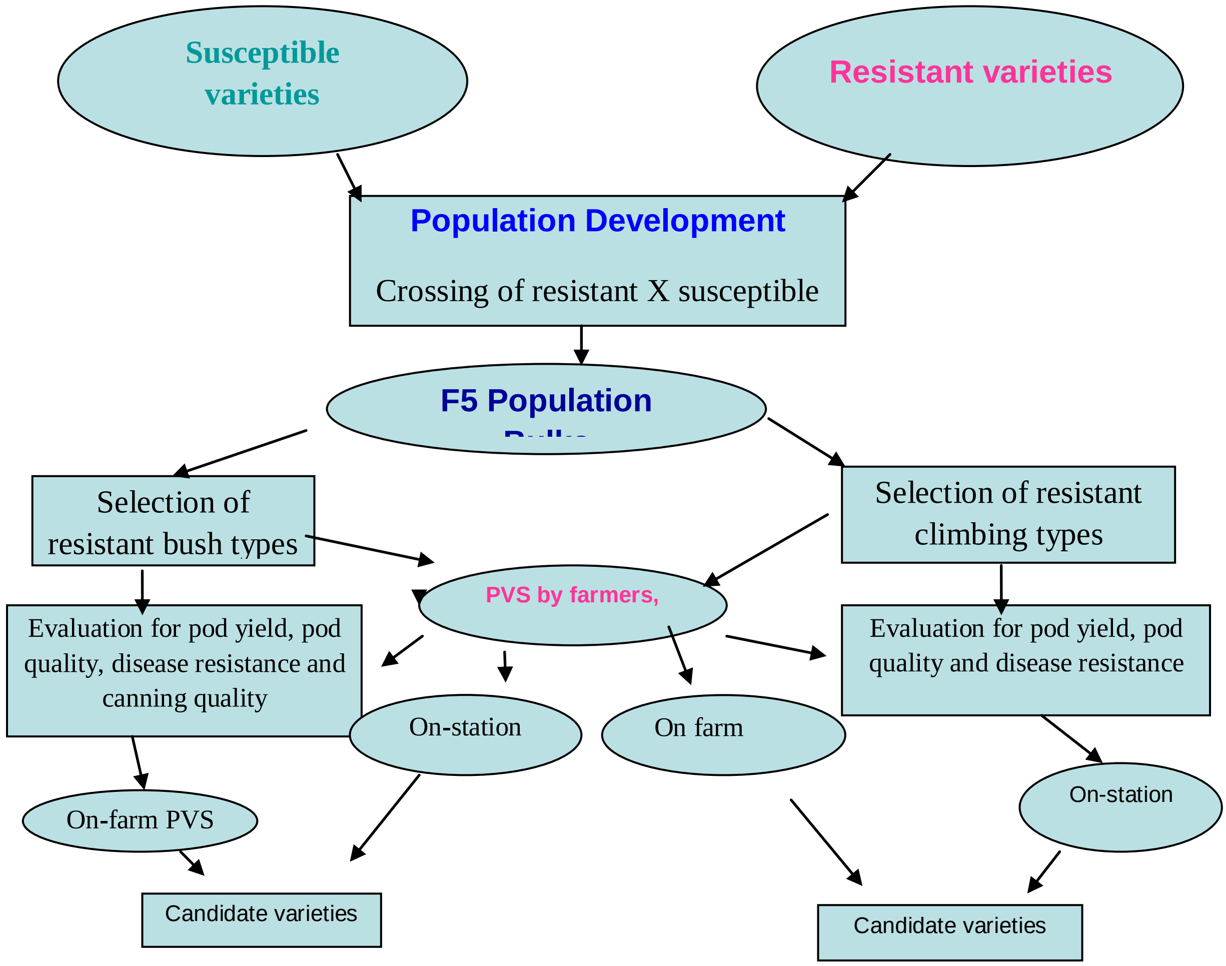


Fig 1. 6: Research approach and conceptual framework for improving snap bean lines in Kenya

F_1 and F_2 populations were developed by single crosses between susceptible and resistant varieties of both bush and climbing snap beans. The population bulks with promising characteristics were advanced to F_5 generation. F_5 population bulks of both bush and climbing snaps were subjected to on-farm and on-station participatory variety selection (PVS) by farmers, traders and exporters. Some of the elite lines are now being validated by KEPHIS. However, second set of advanced lines developed by the University of Nairobi Bean Research Program has not been evaluated for their agronomic potential and canning quality. These lines will be evaluated on-farm and on-station evaluation for pod yield, pod quality, disease resistance and canning quality. This study aims at evaluating new high yielding bush and climbing snap bean varieties with multiple disease resistance, desirable pod quality, and initiate local seed production and dissemination. This will reduce losses associated with diseases, reliance on expensive pesticides, increase productivity, reduce adverse effects of pesticides on the producers and the environment, avail more affordable and high quality seeds, enhance the profitability and competitiveness of Snap bean products in regional and international markets.

CHAPTER 2

LITERATURE REVIEW

2.1 Botanical characteristics of runner bean

The runner bean (*Phaseolus coccineus* L.), also known as butter bean, is one of the cultivated species of *Phaseolus* genus in the large Papillionaceae (Fabaceae) family. Runner bean is believed to have originated from Central America in the uplands of Chiapas and Guatemala (Pulseglove, 1987). Although it is cultivated as an annual crop, *P. coccineus* grows perennially in its natural habitat, in the cool, humid highlands of Guatemala in altitudes above 1800 masl. Runner bean has one centre of domestication in Mesoamerica (Delgado, 1988). Archaeological evidence indicates that scarlet runner bean was a domesticated crop in Mexico around 900 AD. Today, scarlet runner bean is cultivated in temperate countries and occasionally in highland areas of Central and South America, Africa (Ethiopia, Kenya, Uganda, and South Africa) and Asia (Purse glove, 1987 and Brink, 2006)

Runner bean has chromosome complement of 2n= 22, just like other Phaseolus species (Raemarkers, 2001). *P. coccineus* L. has three sub-species namely; *rubronanus, albus and albonanus* based on flower color which is correlated to stem color, seed colour and seed color patterns. The *rubronanus* is a red-flowered bushy type, with purple stems and purple speckled seeds. The *albus* is a white-flowered Dutch climbing runner type, green stems and white seeds. The *albonanus* is a white-flowered type, green stems bush form with white seeds (Santalla et al., 2004; Zeven et al., 1993; Kay, 1979). White seeded sub-species (*albus* and *albonanus*) produce white flowers. Black and red-purple sub-species (*rubronanus*) with few black stripes, and purple seed with many black stripes, produce scarlet flowers. The three sub-species are indistinguishable neither on basis of chloroplast microsatellites nor according to the other quantitative traits (Rodriquez et al., 2013). *P. coccineus* can grow to a height of 4 m or more with green pods being harvested 80 to 90 days from sowing, and for mature seeds after 100-120 days (Purseglove, 1987). Runner bean is a climbing herb with stems which grow 4 to 7 m tall, or a bushy annual herb which grows up to 60 cm tall (Fig 2.1and 2.2). Runner bean is a branching perennial. The roots are thick, fleshy, branched and tuberous. The stems are twisting and slightly ribbed (Fig 2.3). Most varieties have red flowers and multicolored seeds (though some have white flowers and white seeds) (Fig 2.4 and 2.8). Runner bean is often grown as an ornamental climbing plant in certain countries such as United States of America. (Purseglove, 1987; Kay, 1979). The leaves are trifoliolate, with ovate leaflets (Fig 2.5). The inflorescence is an axillary raceme and bears about 12 flowers on long axillary peduncles (Fig 2.6). The vine can grow to two meters or more in length. The green pods are edible whole before they become fibrous, and the seeds can be used fresh or as dry beans. The pods are usually 10 to 30 cm in length but can reach 45cm, often slightly pubescent, with a stout beak and contain 1 to10 very large to broad, oblong seeds (Kay, 1979; Fig 2.7). Seeds are broad-oblong, convexly flattened, dark purple with red marking (Fig 2.8). It differs from the common bean (*P. vulgaris L.*) in several respects: the cotyledons stay in the ground during germination (hypogeal); the plant is a perennial vine with tuberous roots though it is treated as an annual, and it is cross-pollinated with medium to high variation within populations (Brink, 2006; Zeven et al., 1993).

Fig 2.1: Plant height of dwarf varieties of grain runner bean

Fig 2.3: Stems of various runner bean genotypes

Fig 2.2: Plant height of climbing varieties of runner bean

Fig 2. 4: Flower colour of various runner bean genotypes

Fig 2.5: Shape of leaves and leaflets of runner bean plant

Fig 2.6: Arrangement of flowers in an inflorescence of runner bean plant

Fig 2.7: Length and shape of pods of runner bean plant

Fig 2.8: Seed size, shape and colour of local grain, vegetable and new lines of runner bean

2.2 Botanical characteristics of snap bean

French bean, also known as snap bean, is a strain of common bean (*Phaseolus vulgaris* L.) mainly grown for their immature pods, which are either consumed fresh, processed or canned. Like runner bean, snap bean has a genome formula of 2n=2x=22. It belongs to the family Leguminosae consisting of about 600 genera with about 150 species of annual and perennials (CIAT, 2006). Flowers are hermaphrodite and pollination is 98% autogamous. The wings are of the same length or longer than the standard. The keel is spirally coiled, which is the distinctive mark of the genus. The flower has ten stamens, which are diadelphous with free vexillary stamens of equal length. They have uniform anthers while the style is filiform, twisted, bearded on inner curve (CIAT, 1986) (Fig 2.9). There are two major types of snap bean, dwarf and climbing types (Fig 2.10). The dwarf or bush cultivars are day neutral, early maturing, 20 to 60 cm in height, with lateral terminal inflorescence and determinate growth.

These cultivars do not require any support (staking) (Fig 2.10). Climbing or pole cultivars have an indeterminate growth and grow up to 3m in height. They require staking because of their weak stems (Fig 2.10). There are both day neutral and short day cultivars within this group (Njeru, 1989). The pods are narrow and mostly glabrous, straight or curved with colour ranging from dark green and light green to yellow and others are purple (Cajiao, 1992) (Fig 2.11). The seed also vary in colour from white to black (Fig 2.12). In eastern Africa, small seeded white or black varieties are grown (Ndegwa and Muchui, 2001).

Fig 2.9: Structure of a snap bean flower

Fig 2.10: A) Dwarf/ bush snap bean and B) climbing snap bean

Fig 2.11: A) Straight green pods, B) curved green pods and C) straight purple pods of snap bean lines

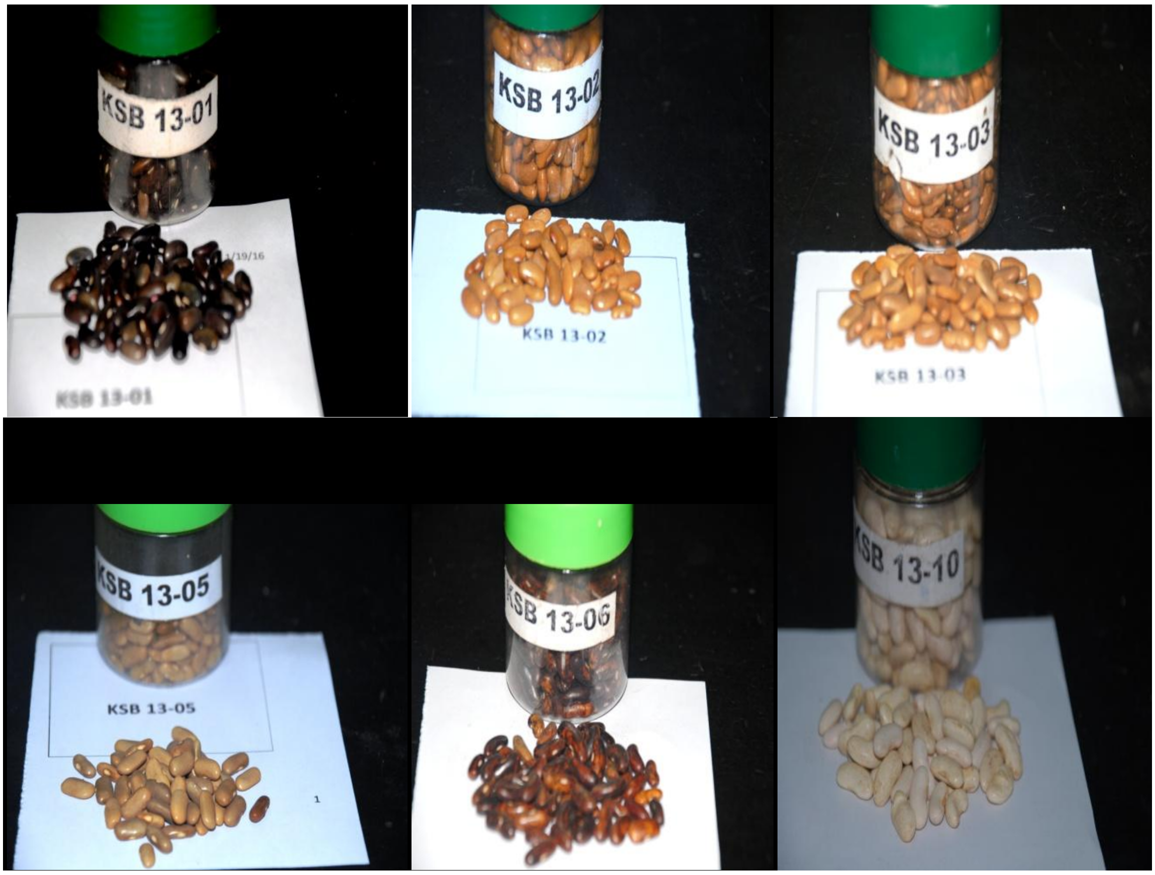


Fig 2.12: Seed size, shape and colour of snap bean lines

2.3 Ecological requirements

2.3.1 Runner bean

Tindall (1983) reported that runner beans are mainly grown in the tropics at high altitude areas above 1800 meters above sea level. Runner beans are more tolerant to cold conditions than other *Phaseolus* species, but damage occurs at temperature below 5^0 C (Kay, 1979). High temperatures also appear to affect fertilization. Prolonged high temperatures (>25^0C) completely inhibit flowering (Smart, 1976). High temperatures above 25^0C also inhibit seed setting (Kay, 1979). Runner bean is a crop for temperate climates but when grown in tropics, it is most successful at altitudes of 1500 to 2000m. In Kenya, the cool high altitude areas above 1800m receive moderately high rainfall which is adequate for runner bean production (Kahuro, 1990). The runner bean plant requires adequate moisture at all times and production is affected by even short periods of droughts. It withstands heavy rainfall and high humidity. Runner beans require a well distributed rainfall throughout the growing period as they are susceptible to water stress conditions and require relatively high humidity to set seed (Kay, 1979).

However, there are conflicts on light requirements of runner beans. Purseglove (1987) describe runner bean as a short day plant which is less sensitive than most *Phaseolus* species to cool summers, hence successful in Britain. Martin (1984) describes it as a short-day plant, but most cultivars are day neutral. Stanton, (1966) stated that there are long-day, short-day and day-neutral types.

High altitude, cool but frost free area with fertile, well drained soils is suitable for runner beans (Suttie, 1969). Runner bean prefers slightly acidic well-drained loam soils (Martin, 1984).

2.3.2 Snap bean

In Kenya, snap beans can be grown in areas with average annual rainfall ranging from 900 to 2000mm, which should be well distributed during the growing season. Under moderate rainfall conditions, supplementary irrigation may be beneficial. In dry conditions, irrigation is absolutely necessary. Heavy rainfall adversely affects flower fertilization, resulting in reduced pod set (Wahome et al., 2011). The ideal altitude ranges between 1500 to 2100m above sea level (Mbugua et al., 2006). At higher altitude the growth period is prolonged and there is increased incidence of diseases. The optimum temperature is between 16 to 24^0C. Below 10^0C, the bean plant are destroyed by chilling, while at temperatures above 30^0C blossom drop is very prevalent and may hamper pod and /or seed set. Snap beans thrive in a wider range of soil types, ranging from light sand to heavy clays. The best soil for growth should be friable, well drained, loam soils with high organic matter (Ndungu et al., 2004)

2.4 Production and economic importance of runner and snap beans

2.4.1 Runner bean

Runner bean is commonly grown in United Kingdom as an annual crop. Private companies in Kenya have been producing vegetable type scarlet runner bean around Lake Naivasha (Nakuru County) and in Timau (Meru County), mainly for export. Grain type varieties have traditionally been grown by small holder farmers in Nyandarua and Nakuru districts (Kahuro, 1990; Brink, 2006). In Kenya, grain type is used for household consumption as either dry or fresh seeds. Dry grain is also canned. Accurate production statistics for scarlet runner beans are not available due to low production. In South Africa, white-seeded cultivars are grown for canning and direct household consumption (Brink, 2006). In United Kingdom, runner bean production is for fresh vegetable market and is also very popular in kitchen gardens (Kay, 1979).

Nyandarua and Nakuru districts produce about 500-800 t of dry beans per annum (Suttie, 1969). The yield of dry mature seeds in Kenya has been estimated to be 900 to 1120 kg ha^{-1} (Kay, 1979). Yield of green pods of 10 t ha^{-1} and of seeds of 1.5 t ha^{-1} are possible (Brink, 2006). However, yield of 30 to 40 t ha^{-1} of fresh runner bean pods has been reported by fresh produce companies under intensive production systems in Kenya (Sunripe Company Manual, 2013). In United Kingdom, pod yield of 8.75 to 13.75 t ha^{-1} has been reported, although, with efficient crop management, pod yield can be as high as 37.5 t ha^{-1}. In 2013, 1,785,860.12 kg valued at Ksh 621,955,391 was exported to various market destinations (HCD, 2013). This accounted for 2% and 3% of the total vegetable exports by volume and value respectively. The grain runner bean production across the four major producing counties in Kenya, ranged from 1000 kg ha^{-1} to 1298 kg ha^{-1} between year 2011 to 2013 (Table 2.1).

The dry runner beans are rich source of protein (Kahuro, 1990). There are different levels of proteins in dry runner beans and vegetable type. The dry beans contain 20.3 g of protein, 12.5 g water, 1415 kJ energy, 1.8 g fat, 62 g carbohydrate, 33 mg ca, 19 mg Mg, 34 mg P, 1.2 mg Fe, 0.2 mg Zn, 0.5 mg thiamine, 0.19 mg riboflavin, 2.3 mg niacin and 2 mg ascorbic acid per 100 g (Leung et al., 1968) in contrast green pods contain 1.6 g protein, 91.2 g water, 93 kJ energy, 0.4 g fat, 3.2 g carbohydrate, 2.6 g fibre, 33 mg Ca, 19 mg Mg, 34 mg P, 1.2 mg Fe, 0.2 mg Zn, 145 µg carotene, 0.06 mg thiamine, 0.03 mg riboflavin, trace niacin and 18 mg ascorbic acid per 100 g edible portion (Holland et al., 1991).

Table 2. 1: Production of grain runner bean in selected counties in Kenya, 2012-2014

County	2012			2013			2014		
	Area (ha)	**Quantity (t)**	**Value (Kshs Million)**	**Area (ha)**	**Quantity (t)**	**Value (Kshs Million)**	**Area (ha)**	**Quantity (t)**	**Value (Kshs Million)**
Meru	150	1,500	150	120	1,200	120	160	1,600	160
Nyandarua	180	230	7	185	192	6	213	208	6
Migori	27	108	1	25	125	1	20	125	6
Nyeri	5	9	0	2	5	1	4	8	1
Busia	4	30	1	4	30	1	4	30	1
Samburu	1	1	0	1	1	0	1	2	0
Others	8	75	3	8	120	0	2	0	0
Total	**375**	**1,953**	**162**	**345**	**1,673**	**129**	**404**	**1,973**	**174**

Source: HCDA, 2013

2.4.2 Snap bean

Snap bean (*Phaseolus vulgaris* L.) is a major vegetable export crop in Kenya. Snap beans in Kenya are mainly grown by small scale farmers, purely for export and as a source of family income (Monda et al., 2003; Okello et al., 2007). These farmers own between 0.5-5.0 acres of land (Ndegwa et al., 2010). In 2007, snap beans were accounting for 60% of all vegetable exports, and 21% of horticultural exports (Nderitu *et al.*, 2007). In the same year, 6,358 ha were under snap beans and produced 63,580 t valued at KES 1.9 billion (MOA, 2007). The total production by smallholder farmers in 2014 was 112,409 t valued at 5.04 billion. The area decreased from 4,707 ha in 2013 to 4,572 ha in 2014 while the yields increased by 9 percent from 112,409 t to 122,666 t and value increased by 15 percent from 4,382 million to 5,038 million (Table 2.2). About 31,973,638.9 kg valued at Ksh 9,934,088,947 was exported to various destinations in 2013. The volume and value accounted for 41% and 43% respectively of all vegetable exports in Kenya (Fig 1.4) (www.hcda.or.ke accessed 10 May 2014). Although the crop is mainly grown for export in Kenya, domestic consumption is increasing particularly in the urban centres (voor den Dag, 2003; MOA, 2008). Compared to dry beans, snap beans have a high market value, mature much earlier and have longer harvest duration (Ugen et al., 2005). They require less energy to cook since they are consumed as vegetables and are rich in vitamins, minerals and dietary fibre (Kelly and Scott, 1992; Ndegwa et al., 2006). The nutritional composition of snap bean pods, raw and ends trimmed is: 90.7 g water, 99 kJ energy, 1.9 g protein, 0.5 g fat, 3.2 g carbohydrate, 3.0 g dietary fibre, 36 mg C, 17 mg Mg, 38 mg P, 1.2 mg Fe, 0.2 mg Zn, 330 µg carotene, 0.05 mg thiamine, 0.07 mg riboflavin, 0.9 mg niacin, 80 µg folate and 12 mg ascorbic acid per 100 g (Holland et al., 1991). About 90% of the crop produced in eastern Africa is exported to regional and international markets. The main importers of Kenyan Snap beans are United Kingdom, France and Germany (Okado, 2000). Snap beans are rich in ascorbic acid, iron, calcium, vitamin A and dietary fibre and hence they can contribute nutritionally in various mixed diets.

2.5 Utilization of runner and snap beans

2.5.1 Runner bean

In Kenya, the grain type runner bean is produced by smallholders for local consumption. White seeded varieties are grown in South Africa for canning and direct household consumption (Kay, 1979)

In United Kingdom, runner beans are produced mainly for fresh vegetable market and are also popular in kitchen gardens (Kay, 1979). In Britain, runner bean is sliced and boiled and eaten as vegetables. The sliced pods are succulent and well flavoured and they are regarded by British consumers as being superior to snap beans. In Kenya, dry mature seeds are consumed as pulses and they are rich in proteins (Kahuro, 1990). However, local companies can grain type runner bean or both local and international market (TruFoods Company, 2014). In Latin America and certain European countries, the runner bean is grown mainly for the production of the mature seeds, which are eaten fresh as a vegetable, or dried and eaten as a pulse.

2.5.2 Snap bean

Most snap bean markets require uniform, fresh, clean, insect and disease free pods. According to Kimani (2006) increased consumption is influenced by supply of quality snap beans conforming to the market demands and changing dietary habits. Snap bean production is undertaken by small-holders in East and Central Africa. Snap bean production in Kenya is mainly for export market with the major outlets being France and the United Kingdom (HCDA, 2012). Kenya is a fresh snap bean supplier although currently it is investigating the possibilities for expanding into the processed (canned and frozen) market (Grisley, 1989). Recently, local companies have ventured into processing snap bean (canned and frozen) both for local and international market (Njoro canning, 2014). China annually exports about

30,000 t of canned snap beans under the brand names "Ma-Lin" and "White Elephant" to Europe and Middle East (Henry and Li Peihua, n.d). In addition, Turkey has attempted to initiate some canned exports though it has not exceeded 300 to 500t (Henry, 1988).

Consumption of fresh snap beans has been on the rise over the past few decades. Most of the fresh snap beans are currently sold through supermarkets and consumed at home. When buying fresh snap beans, the consumers look for product attributes such as firmness, colour and crispiness or whether it snaps when broken. Snap beans can be served as main dish, a side vegetable, in casseroles and soups, in salads with other vegetables, or in blends and mixes with other foods (Vasanthakaalam and Karayire, 2012).

2.6 Constraints to runner and snap bean productivity in eastern Africa

2.6.1 Runner bean

The runner bean production in eastern Africa is constrained by diseases and pests and provision of additional lighting for the plant to flower and set pods. Runner beans are traditionally produced in Kenya for dry seeds. However, imported varieties are grown for their tender pods and exported to various market destinations since 1990 (Kimani, 1999). The local white seeded variety flowers and pods at Kabete, Nyandarua and Nakuru districts (Kahuro, 1990; Suttie, 1969). However, imported varieties grown around Lake Naivasha and Timau fail to flower unless additional lighting is provided. Use of artificial lighting is expensive and limits production to a few hectares (Kimani, 1999).

Several pests affect runner beans. They include the black bean aphid (*Aphis fabae*), capsid bugs (*Lygu*s spp), bean seed fly larvae (*Hylemya platura*), spider mite (*Tetranychus spp*) and bubble bee (*Bombus terrestris*) (Kay, 1979). Black bean aphids colonize the flowers and young shoots resulting into stunted and distorted pods. Capsid bugs cause serious pod distortion and are visible as foliage damage before bloom. Bean stem maggot larva destroys newly sown seeds and this result to stunted plants (Blackwall, 1971). Sparrows cause considerable damages by pecking the flowers and sometimes break the stalk supporting the raceme. Bubble bee causes crop losses due to flower biting, though, it's very useful for pollination (Wright, 1959).

Runner beans are affected by diseases which considerably reduce the yield. The diseases include; seed borne bacterial disease (*Pseudomonas phaseolicola*), fusarium wilt (*Fusarium oxysporum*), bean rust (*Uromyces phaseoli*) and anthracnose (*Colletotrichum lindemuthianum*) (Kay, 1979). Seed borne bacterial disease causes spotting of the leaves and pods, wilting and in severe cases the death of the plant. It reduces yield and can cause complete crop failure. Wilt which is a soil-borne disease is sometimes devastating as bean rust. It causes yellowing of the margins of the primary leaves and the whole leave turn dry and brittle. Bean rust produces numerous brown powdery pustules on the leaves and pods which becomes black as they develop making the pods unsaleabe. In the tropics, the runner beans have been reported to be affected by the anthracnose which appears as red to dark brown lesions on stems, leaf petioles and veins on the under surface of the leaf. On the pods, the lesions appear sunken and circular (Kay, 1979).

2.6.2 Snap bean

Most markets require a uniform, fresh, clean, insect and disease free pods. Production of snap bean with quality characteristics conforming to the market is crucial to increasing consumption (Kimani, 2006). However, snap bean production is constrained by many challenges including low soil fertility, poor infrastructure, lack of varieties tolerant to pests and diseases (Monda et al., 2003). Major diseases include rust (*Uromyces appendiculatus*), anthracnose (*Colletotrichum lindemuthianum*), angular leaf spot (*Phaeoisariopsis griseola).* Bean rust fungus is a major problem in snap bean growing areas (KARI, 2005; MOA, 2006). Severe infection has been estimated to cause 37-65% yield loss (Habtu, 1994; Monda et al., 2003). Snap bean farmers are forced to use expensive fungicides to effectively control bean rust (Ndungu et al., 2004; Monda et al., 2003). Excessive use of pesticides reduces access to European markets because they fail to meet the stringent requirements of Good Agricultural Practice (GAP) as stipulated through various regulations and governing standards such as EUREGAP and KENYAGAP. However, the current trends advocates for safer alternatives like breeding for resistance to diseases.

Angular leaf spot disease develops over a wide range of temperatures with optimum development at 24^0C in humid conditions (Bassanezie et al., 1998). Infected plants have angular shaped spots on the leaves while pods have circular to elliptical red-brown lesions. The leaf lesions start as small, brown or grey spots that become angular and necrotic, being confined by leaf veins. Leaf spots eventually coalesce causing premature defoliation (Saettler, 1991). Angular leaf spot causes premature defoliation resulting in shrivelled pods, shrunken seeds and yield losses of up to 80% (Stenglein et al., 2003).

Anthracnose is a major disease which can cause up to 100% loss if the environmental conditions are favourable (Fernandez et al., 2000). The disease is favoured by cool temperature of about 16^0 C. However, the fungus can survive season to season on infected plant debris or seed (Hagedorn et al., 1986). The symptoms include; red to dark brown lesions on stems, leaf petioles and veins on the under-surface of the leaf. The lesions on the pods appear sunken and circular. Low soil fertility is a major abiotic constrain to snap bean production in Kenya (Kamanu et al., 2012).

Nitrogen is the most deficient nutrient in the snap bean growing areas. Snap bean production is highly intensive in terms of fertilizer use which account for about 20% of the total production cost (MOA, 2004).

Another constraint to snap bean production in Kenya is lack of good quality seed of locally adapted varieties (Kamanu et al., 2012). Farmers rely on imported varieties whose seed availability can be unreliable. Snap beans are perishable and post-harvest losses and lack of varieties with good characteristics conforming to the target markets is also a challenge affecting snap bean production.

2.7 Photoperiodism and its inheritance in *Phaseolus spp*

Photoperiodism is described as the response to day length (Salisbury and Ross, 1992). For flowering to occur, the plant has to integrate both environmental cues and endogenous factors. Photoperiodism, vernalization and hormonal regulation are the main factors, which influence flowering (Sumin et al., 2013). Genetic analysis carried out in common bean showed that landraces grown in the tropics require short photoperiods for flower production, while many tropical small-seeded cultivars grown at mid- to- low elevations have day neutral to intermediate responses (White and Laing, 1989). Little is known about the mode of inheritance of day length sensitivity of runner bean. This constrains breeding tropically adapted runner bean varieties.

White and Laing (1989) showed that there is a considerable genetic variation for the photoperiod response in common bean (*Phaseolus vulgaris* L.). Depending on the latitudes on which the crops are grown, photoperiod response is a major factor affecting adaptation of the crop (Wallace, 1985; White et al., 1992). Beans were domesticated in Latin America both in Mesoamerican (Mexico and Central America) and the Andean region of South America (Gepts, 1988). Sigh et al., (1991) suggested that within the centres of origin, certain sets of germplasm or races predictably have a given photoperiod response. For example, large seeded climbing cultivars of the Andean highlands are predominantly highly photoperiod sensitive, while small seeded bush cultivars from Central America generally show little response to long day lengths (White et al., 1987). These contrasting photoperiod responses suggest that environmental conditions within the centres of domestication contributed to the selection and frequency of specific photoperiod response genes within landrace populations. Most reports on the inheritance of photoperiod response consider photoperiod response to be under qualitative control, with one to two genes being reported (Wallace, 1985). The genes sometimes act in a recessive manner and other times in a dominant manner, depending on the genotypes used and the testing environment (Coyne, 1966; Padda and Munger, 1969; Gniffke, 1985).

Photoperiod can be modified by temperature (Vince-Prue, 1975), but the magnitude of this interaction is genotype dependent (Wallace, 1985), such that under one temperature regime, a genotype may appear to be sensitive to long photoperiods, and in another, may appear to be insensitive. Wallace (1985) proposed that changes in inheritance patterns of photoperiod response may be attributed to the reversal of "floating of dominance" where gene expression is modified by temperature. Other factors that may have contributed to the conflicting inheritance patterns include use of extended photoperiods of intermediate lengths (i.e. 14-16h), which may not permit adequate response differentiation among lines and within segregating populations. Also the effects of changing temperatures and photoperiods on flowering of beans in higher latitudes and use of parental lines that are intermediate, rather than highly sensitive to long photoperiods contributes to the conflicting inheritance patterns. Finally the segregation of other traits such as growth habit, that may affect flowering tendency and in some cases, the use of inadequate population sizes (Julia et al., 1993).

Flowering influence pod set and seed load and later the yield (Egli, 1998). Failure of imported variety, White Emergo, of runner beans to flower and set pods under natural day length in Kenya suggests that, it is probably photoperiod sensitive. The imported variety is adapted to long day in Western Europe hence it flowers under long day length. Therefore, for it to flower, it must be provided with additional lighting to stimulate flowering and pod setting under 12 hour day length in tropical conditions. Additional lighting provides comparable conditions to where the variety was selected from. Fresh produce companies grow the vegetable type of runner beans as an export crop in Naivasha, Nyeri and Timau. These companies use only imported varieties which are long day and they have a problem of failure to flower and set pods under natural day length when grown in tropical climate. The imported cultivars are photoperiod sensitive.

2.8 Selection for pod quality and short day adaptation in runner beans

The principle advantage of imported vegetable runner bean cultivars is that they meet consumers demand such as taste, shape, tenderness, physical appearance, cooking and eating quality. This occurs due to selection of imported cultivars that are adapted to long day for summer production in the temperate climates. No locally adapted vegetable runner bean varieties are currently available to growers. The local white seeded varieties flower and set pods at Kabete, Nyandarua and Nakuru districts (Kahuro, 1990), but have curved and fibrous pods which are not suitable for consumption as a vegetable. Cultivation of imported vegetable cultivars requires extended hours of artificial lighting when grown in Kenya to induce flowering. This poses a constraint to Kenyan small scale producers due to increased cost of production. Large scale producers use artificial lighting reducing competitiveness of local products in export markets. The white seeded Kenyan cultivars flower and set pods at altitudes of 1800m and above but it's primarily grown for dry seeds (Kahuro, 1990). Their pod qualities for export market is not known but have curved and fibrous pods which are not suitable for consumption as a vegetable. Minimal work has been done on runner bean improvement in Africa since breeders have focused mostly on common bean. Consequently, there is very little literature on runner bean. However, a runner bean improvement program was initiated at the University of Nairobi in 2006 (Kimani, 2006). The objective of this program is to support the development of improved varieties with high yield potential, resistance to biotic stresses and consumer preferred pod quality, and short-day adaptation for smallholder production. Runner bean breeding work has been going on in an attempt to develop short day length lines and production practices for increased production for export markets (Kimani, 2009). In 2006, five F_3 populations were developed from crosses between a long day commercial runner vegetable variety and five short day dry grain type, short day varieties (Kimani, 2006). The F_3 progenies were advanced to F_4 and F_5 generations at Ol Joro Orok and Laikipia. Pod set and pod characteristics were the main criteria for selection under short day conditions. The populations showed a considerable segregation for pod traits (Kimani, 2009). The progenies were grouped into six categories depending on pod characteristics namely; long straight, medium straight, short straight, long curved, medium curved and short curved. There was high number of lines with long straight pods that are preferred by exporters. The new runner bean lines have shown high level of resistance to angular leaf spot, root rot, common bacterial blight, anthracnose and frost despite heavy disease pressure which caused severe damage to climbing and bush bean lines in adjacent plots (Mulanya and Kimani, 2014).

About 1154 single plant selections selected from five F_5 bulk populations developed at the University of Nairobi, were grown at Ol Joro-orok, Subukia and Kabete Field Station during the 2009 long rain season. These single plant selections were used to establish progeny rows during the 2009 short rain season and families during 2010 long rain season. The F_5 single plant selections, F_6 progeny rows and F_7 families were constituted into a working collection. During 2012 short rain season, progeny rows from the working collection were evaluated at Kabete Field Station. About 115 lines with long and straight pods and high yield were selected. The selected lines need to be multi-locationally evaluated for yield potential, pod quality, disease resistance and canning quality to ensure that they are able to perform well across the sites. Intermediate and advanced yield trials to validate the lines, expose them to wider range of biotic and abiotic stresses and determine their agronomic potential, canning quality and other characteristics also becomes necessary.

2.9 Breeding snap beans for growth habit, yield potential and disease resistance

The snap bean varieties grown in developing countries are largely introductions from temperate countries. These varieties may not be well adapted in tropical environments (Ndegwa et al., 2009). Low yields of 6 to 8 t ha^{-1} are realized in Kenya. However, in South America and South East Asia, high yields of 15 to 20 t ha^{-1} have been achieved through use of well adapted climbing bean variety and proper management (Ndegwa et al., 2009). The commercial bush snap bean varieties currently grown locally have been observed to flower in a single flush, have a concentrated pod set, short harvest duration of 3-4 weeks with yield ranging between 6 and 8 tons ha-^{1} (Ndegwa and Muchui, 2001). Climbing types which are not grown in this region are generally more productive and have a longer harvesting period (Kimani, 2006). Therefore, well adapted climbing bean variety could be expected to be of particular interest to smallholder farmers wishing to intensify returns to use of family labour (Kimani, 2006; CIAT, 2006).

Snap bean production in East and Central Africa is based on determinate types. However, indeterminate types which are higher yielding and have longer harvesting duration than the determinate types are grown in Latin America (Kimani et al., 2004; CIAT 2006). Small-holder production of snap beans is constrained by diseases especially rust, angular leaf spot, root rot, bean common mosaic virus and pests especially bean stem maggot, thrips and nematodes (Nderitu et al., 1996; Kimani et al., 2004). High disease and insect pressure and excessive use of pesticides become inevitable due to the intensive nature of the crop cultivation. However, the maximum residual limits imposed by export markets have constrained use of chemicals to control diseases and pests of snap beans (CIAT, 2006). In Kenya, snap bean improvement started in 1998 at KARI-Thika with support from CIAT and ECABREN as a regional activity. The program led to development of Kutuless (J12) by KARI-Thika in 2000 (KEPHIS, 2009). Although the line is resistant to rust and has good snapping ability and extra fine green pods it was not released.

A regional snap bean program was initiated in 2001 to develop improved snap bean varieties with high yield potential, resistance to biotic stresses and consumer preferred pod quality, and short-day runner beans for small-holder production (Kimani, 2006; CIAT, 2006). This program was initially supported by ECABREN, and from 2006 to 2011, by ASARECA. The regional program of the snap beans was based at six institutions in four countries namely; Kenya, Uganda, Tanzania and Rwanda. In Uganda, 11 introduced lines were evaluated for three seasons. After four years of screening, six lines were selected because they showed resistance to major diseases namely; rust, common bacterial blight and angular leaf spot . However, line HAB 433 was selected for yield and quality (pod size and shape, length, snappiness and taste) (Kimani, 2010).

In Rwanda, two commercial varieties-*Saxa* and *Loiret*- were introduced for export markets, but became susceptible to diseases (Nyabyenda, 1991). The Rwanda Bean Program initiated a backcrossing breeding program to improve on a commercial climbing bean variety Vunikingi (G685) using exotic donor parents like Teresa and Loiret (Cheminingw'a et al., 2012). New snap bean lines and populations were also introduced from CIAT. Yield of lines introduced from CIAT and local collections varied from 5 to 12 t ha^{-1} (Musoni, 2013). The climbers were yielding better than bush varieties. The most promising lines were Boon, Cabbra, G685, Saxa, Khaki, Ncekarkonnigia and Loiret. However, evaluation for reaction to diseases showed that Tarrot was susceptible to rust, Saxa and Cabbra to anthracnose, and Ncekarkonnigia to BCMV (Musoni, 2013).

Snap bean is a new sub-sector in Tanzania. Snap bean research is based at Selian Agricultural Research Institute (SARI). Activities at SARI have focused on a baseline surveys to understand the major production constraints, marketing environment, evaluation of advanced bush and advanced climbing bean lines introduced from CIAT and University of Nairobi, and the development of agronomic and crop protection management practices (Kimani et al, 2009).

At Moi University, 12 lines were developed and evaluated at muli-locational trials between 2003 and 2004. Four locally adapted cultivars out of the 10 lines were evaluated in national performance trials for improved pod yield, resistance to anthracnose and rust, and marketable pod quality. The highest yield was 13.1t ha^{-1} while the lowest was 9.7t ha^{-1}. However, none of the lines were released.

Climbing bean varieties are morphologically different from bush bean varieties of common beans (*Phaseolus vulgaris* L.). They are characterized by tall growth, long internodes and climbing ability of up to ten metres and above. Climbing ability is an inherent trait in climbing beans (Checa and Blair, 2012). Climbing ability tend to be closely related to a series of component traits like total plant height, internode length and determinacy character (Debouck, 1991). Climbing capacity in beans also depends on the variation in outgrowth of the lateral branches and the degree of vine circumnuation (winding movements) which determines the ability or lack thereof of the plant to climb on staking material. The interaction of vegetative growth pattern with distribution of flowers and pods during reproductive growth can determine whether most of the seed production occurs along the entire length of the climbing bean or only on the lower or upper parts of the plant (Singh, 1982). Environmental conditions such as light quality and day length greatly influence growth habit expression (Kretchmer et al., 1977 ;1979) and the differences between growth habit II and III or between III and IV can be difficult to distinguish in less favourable environments (Singh, 1982). The inheritance of growth habit in common bean is thought to be controlled by a mixture of qualitative and quantitative genes. Climbing ability research started in 1904 when Emerson crossed indeterminate and determinate growth habit plants and identified a single-recessive gene for determinacy. Norton (1985) found dominant gene action for axillary inflorescence over terminal inflorescence, long main stem over short main stem and climbing habit over non-climbing habit. Kooiman (1931) proposed that the trait for determinate or indeterminate growth was simply inherited and attributable to single Mendelian gene. According to Checa and Blair (2012), inheritance of yield components is simpler and of higher heritability than seed yield. When breeders select for earlier flowering they will be selecting for earlier maturity. The results were well known in bush beans, but surprisingly the same relationship holds in climbing bean populations (Checa and Blair, 2012).

Climbing ability is a key to breeding commercial varieties with good yield for tropical environments. Climbing types have a potential of 3:1 productivity advantage over the bush type due to their longer harvest periods and plant size compared to bush types. This fact is expected to be of particular interest to smallholder farmers intending to intensify returns by use of family labour (CIAT, 2008). Climbing snap bean selections are more tolerant to diseases such as angular leaf spot (*Phaeoisariopsis griseola*), anthracnose (*Colletotrichum lindemuthianum*) and rust (*Uromyces appendiculatus*) as compared to bush types and therefore, they serve to act as good source of climbing ability and disease resistance (Wahome et al., 2013). According to Cajiao, (1992), in Colombia, pods that are round in shape, have a medium length (8-15 cm), and have a light green colour are preferred over others. This has necessitated CIAT to search for these characteristics in bush and climbing varieties. More than 6000 ha, with an average yield of 10.5 t ha^{-1}, have been planted in Colombia with the climbing variety Blue Lake for evaluation for productive alternatives, market requirements and pathogens resistance. However, the variety is susceptible to many pathogens, whose chemical control increases farmers' production costs (Cajiao, 1992). Climbing snap bean varieties are popular in Central and South America, unlike East and Central Africa which production is dominated by bush types. The Central and Latin America climbing snap beans have flat pods that are not suitable for European export markets (Schoonhoven and Voyest, 1991). Snap bean breeding program in University of Nairobi aims at selecting climbing snap bean lines with multiple resistances to rust, angular leaf spot and anthracnose and evaluating advanced climbing lines for pod quality, marketability, shelf life and high productivity and resistance to nematodes and root rots. The programme started in 2001, initially supported by CIAT and ECABREN and in 2006 by ASARECA (CIAT, 2006; Chemining'wa et al., 2012). Climbing snap beans are known to be higher yielding and have longer harvest duration compared to bush (Kimani et al., 2004; CIAT, 2006; Wahome et al., 2013). Breeding for resistance to diseases is the most effective strategy and sustainable method for controlling bean diseases (Miklas et al., 2006; Oliveira et al., 2008). Resistant varieties provide the potential for achieving higher productivity due to yield increment obtained when the variety is not under disease pressure (Mooney, 2007).

According to Cheptoo et al., (2014); Wahome et al., (2011; 2013), climbing lines showed combined disease resistance to rust, angular leaf spot and anthracnose. Twenty $F_{5.7}$ KSV climbing snap bean lines were evaluated by Cheptoo et al., (2014). Wahome et al (2011, 2013) evaluated six HAV climbing snap bean lines. The climbing snap bean lines performance was compared with checks such as Samantha, Teresa, Morelli, Star 2053, Paulista among others. The KSV and HAV climbing lines showed higher level of disease resistance compared to the checks, and out-yielded the bush check varieties.

2.10 Breeding runner and snap bean for canning quality

Canning is a form of heat sterilization method whereby all micro-organism in food are destroyed to ensure no residual organisms could grow in the can (van Loggerenberg, 2004). Canning process has two important steps in beans: soaking and sterilization. Soaking helps in removal of foreign materials, facilitating cleanliness and filling through uniform expansion which ensure product tenderness and improves colour (Uebersax et al.,1987) .Sterilization helps in destroying all spores of *Clostridium botulinum* and to prevent the spoilage of product by heat resistant and non-pathogenic organisms (van Loggerenberg,2004).

Traits which determine the processing quality of dry bean include cooking time, water uptake (WU), hydration coefficient (HC), washed drained weight (WDWT), percentage washed drained weight (PWDWT), splits, texture, clumps, percent solids, visual appearance (VA), size and colour (Hosfield et al., 2000; van Loggerenberg, 2004; Warsame and Kimani, 2014). Short cooking time is an important market trait because it saves fuel and time during cooking and processing. These two factors contribute to the final cost of a product. Therefore, fast cooking varieties are preferred (Maryange et al., 2010). WU is important in bean processing. Low WU during canning implies a, larger quantity of beans is required to fill a certain can volume due to less expansion because low amount of water was imbibed (van Loggerenberg, 2004). WDWT is the measurement used by processors to indicate the swelling capacity and water entrainment of beans (Hosfield, 1991) and is a direct indicator of processor yield. Texture of the beans correlate with the acceptance of the products by the consumers (Mkanda, 2007). Sensory analysis of cooked beans done in Department of Food Science, University of Pretoria, showed that consumers prefer soft beans to too soft or hard beans (Mkanda, 2007). The study involved six dry bean varieties commonly grown in South Africa. Size and colour are also important traits. Consumers may reject bean cultivars which lack preferred combinations of seed colour, size and shape (Kelly et al., 1998). Consumers are also influenced by sensory attributes like visual appearance, splitting and clumping. Also they determine the general suitability of beans for commercial processing (van Loggerenberg, 2004).

Local canning companies have focussed on canning dry common beans. There is little done on canning runner beans, although local grain type variety is canned by TruFood Company. Low processing of the products is due to low production as a result of low yielding and disease susceptible varieties of runner bean. To ensure availability of raw materials for canning, evaluation for yield potential, disease resistance and industrial canning quality becomes very crucial.

The processing of bean-based foods in Africa has traditionally been done at home by women. However, consumers in rural areas and low- income earners in urban areas consume beans as boiled grains while canned bean products are consumed by high-income earners due to high cost of the products (Jackson et al., 2012). Due to increased urbanization in the region, demand for canned grain of runner and snap bean is expected to increase. Long cooking time is a common problem in dry beans which hinder their utilization due to high cost of energy (Elia et al., 1997; Garcia et al., 2012). For example, in Kenya, most available varieties of dry bean are long cooking (2-3 hours) (Kimani et al., 2005). Cooking time varies in different legumes and the process of cooking consumes fuel and time (Maryange et al., 2010). Deterioration in cooking quality in legumes is influenced by high temperature and high relative humidity (% RH) (Stanley, 1992; Berrios et al., 1999; Balameze et al., 2008). The storage conditions promote seed hardness which leads to impermeability of the seed coat to water or inability of the cotyledon to be hydrated during cooking (Nassar-Abbas et al ., 2008). Studies show high variation in cooking time in dry bean and it varies from 19.5 to more than 80 minutes (Shimelis and Rakshit 2005; Elia, 2003).

When breeding for canning quality in snap beans, various pod traits are considered which includes stringlessness, low fiber, round pod cross-section, straight and smooth pods, darker green interior and exterior colour, reduced interlocular cavitation and slow seed development (Myers and Baggett, 1999). Edible-podded beans are handled and consumed in several different forms. Traditionally, freshly harvested pods were cooked for consumption, but with the current emphasis on consuming more fresh vegetables, consumption of raw bean pods is increasing (Myers and Baggett, 1999). For example, in Kenya snap beans are used for making salads. For off-season consumption, snap beans are canned, frozen and dehydrated. Pods may be packed whole or subjected to various cuts, which requires sorting of pods into uniform sizes (Table 2.2), as well as using cultivars that mature at a certain pod sieve size.

Table 2. 2: Grade, sieve size and pod cross-section thickness used for sorting snap bean pods

Canner's grade	Sieve Size	Pod cross-section thickness (mm)
1	1	<5.8
1	2	5.8 – 7.5
1	3	7.5 – 8.5
2	4	8.5 – 9.7
3	5	9.7 – 10.9
4	6	10.9
Cull	7 and over	>10.9

(Source: Duncan et al., 1960)

According to Njoro Canning Ltd, (2015) pods with cross-section thickness of <5.5 mm and >5.5 to <6.55 mm were destined for export market while those with cross-section thickness of >6.5 mm were destined for local market.

In U.S, consumers eat most snap beans in canned form (1.8 kg per capita) followed by frozen (0.9 kg per capita) and fresh (0.7kg per capita) products. With the growing recognition that more vegetables are needed in the diets, snap bean consumption should increase in future. Snap beans are consumed in large quantities in developed countries, where there is greater flexibility in foods available, compared to developing countries. On a daily utilization basis, developed countries consumed 3.1g/day compared to 1.1g/day in developing countries (Rubatzky and Yamaguchi, 1997).

Nearly all beans for fresh market and processing have pods with some shade of green. Pod colours range from light to dark green. Fresh market cultivars have traditionally had lighter green colours compared to the processing types, but the gap in colour differences is narrowing (Myers and Baggett, 1999). Many processors would prefer a dark green pod for canning and freezing. Lighter pods are much more acceptable for freezing than canning. Colour has been less critical in freezing than in canning. Length, cross-sectional shape, diameter and length of the spur and pedicel affect pod shape (Myers and Baggett, 1999). Pods of beans for processing are about 10-16 cm in length. Pod lengths greater than 16 cm are too long for existing processing equipment. Processors prefer a round pod because they are fleshier and there is a close relationship between sieve size, quality and maturity when the round pods are sorted in a sieve grader. Sieve size is probably the single most important factor in processed beans. After harvest, unsorted pods are brought into the plant where equipment is used to separate the pods into different sizes based mainly on pod diameter. Pod straightness is important in processing green beans because straight beans make a neater cut or whole pack product and also they flow through the processing equipment more rapidly (Myers and Baggett, 1999). Straightness and fiber content are interrelated qualities. Fresh market beans, which have greater fiber content than do beans used for processing, are also straighter (Silbernagel, 1986). The challenge for breeding processing cultivars is to select for straight pods while maintaining low fiber content. Pod detachment force is a trait of considerable interest to both fresh market and processing industries. Fresh market producers consider breakage at the pod neck a disadvantage because such breakage increases pod discoloration and decay during shipping (Lien and Baggett, 1998). At the processing plant, one of the first procedures to undertake is to snip both ends of the pod to remove the spur and pedicel. Sometimes is difficult to snip off the pedicels and therefore, the processors prefer cultivars with easy picking traits (Lien and Baggett, 1998).

Growing of beans for canning is an important industry in Eastern Africa with Ethiopia taking the lead where the industry has grown tremendously to be a major export earner. Until recently, little has been done to support the bean canning industry in the region. According to Chemining'wa et al., (2014), growth of the bean canning industry is hindered by lack of formal bean seed producers in the country. Management at the Njoro Canning Factory explicitly noted that lack of reliable local supplies and quality certified seeds were a major constraint to the canning industry (Chemining'wa et al., 2014). Table 2.3 shows the local companies involved in canning industries in Kenya and the brand name they use in marketing their products.

Table 2.3: Canned bean brands in the Kenyan market

Brand name	**Company**	**Average unit price (Kshs)**
Golden valley	Njoro canning factory	81 per 420 grams can
Kenylon baked beans	Kabazi canners/Trufoods	81 per 420 grams can
Peptang baked beans	Priemier foods limited	87 per 420 grams can
Heinz baked beans	Gulf food industries (Dubai) (Imported by Fashion 99)	99 per 415 grams can
Americana Garden baked beans	Imported from U.S.A	77 per 400 grams can

Source: Chemining'wa et al., 2014

Grain quality traits related to end-user preferences are of much importance for success of new runner bean varieties. Processing industries in Kenya especially for runner beans depend on importation of seeds due to lack of varieties with promising canning qualities (TruFood Company, 2014). Several runner bean lines with superior agronomic traits have been identified but their potential for use by the processing industries is not known. Therefore, it is important to evaluate runner beans which combine both good agronomic and canning qualities.

2.11 Genetic analysis and heritability of traits

Heritability (h^2) of the characteristics of a population is the proportion of the phenotypic expression of a trait that is due to the genetic causes and is calculated as follow:

h^2=Genotypic variance/ Phenotypic variance (Hosfield, 1991).

Heritability gives the breeder an indication of the relative importance of genetic and non-genetic factors in the expression of a specific property. Heritability would influence the method and effectiveness of selection for that property. Heritability values vary from zero (low h^2) to one (high h^2). Properties with higher h^2 are less affected by environmental factors and could often be selected without testing over multiple localities and seasons. On the other hand properties with low h^2 would be strongly affected by environment (Walters *et al*., 1995). The most important production factor of dry beans for example is yield, which is determined by more than one gene, which each has a small effect on the yield trait (Hosfield, 1991). Other factors than genotype would therefore mostly cause differences in yield of dry beans. This was illustrated by the fact that more variation was found between bean producing localities (903 to 2,835 t ha^{-1}) than between cultivars (1,101 to 2,567 t ha^{-1}) for dry bean yields during 2002/03 (Liebenberg *et al*., 2003). One of the hurdles that has to be overcome when trying to improve a trait by breeding is the unpredictable effects of environment that often cause genotype x environmental (G x E) interactions (Hosfield, 1991). Significant cultivar x locality interactions suggests that cultivars do not perform consistently over localities, necessitating that cultivars be tested in time and space (Ghaderi *et al*., 1984). Season also has a significant effect on canning quality and all traits were more affected by season than by genotype. With the exception of washed drained weight (WDWT) and texture, it was reported by Hosfield *et al.* (1984a) that all canning parameters were more significantly affected by genotype x season (G x Y) interactions than genotype, indicating that strains responded non-uniformly over years. The water uptake (WU) of beans during soaking was indicated to have genetic variability, but gene expression is often environment dependent and subjected to G x E interactions (Hosfield et al., 1984a). Due to the lowh2 of hydration coefficient (HC) the use of the known genetic variation influencing this trait is difficult (Hosfield, 1991). The colour of beans is inherited by major genes (Moh, 1971), but the influence of environment often leads to a wide variation in whiteness values (Ghaderi *et al.*, 1984). Since significant variability in the colour of dry and cooked beans is available (Ghaderi *et al*., 1984), breeders have enough raw materials for selection to improve the colour traits of canned beans (Hosfield, 1991). Canning characteristics, such as visual appearance (VA), clumping and splits are determined subjectively and therefore have a large non-genetic component affecting phenotypic expression, these traits are determined with a high enough degree of accuracy to make them useful selection criteria for breeding (Hosfield, 1991). Despite the significant effect of environment on canning quality, all canning properties (HC, WDWT, VA, solids loss and texture) were found to be moderately to highly heritable. This would suggest that these properties are affected by a few major genes rather than a large number of genes with limited effects. Subjective measurements, such as VA would have lowerh2 values due to the effect of subjective perceptions (Walters *et al*., 1995). Quality evaluation characteristics of dry beans, such as colour , size and shape could be sorted out quite easily in the early stages of breeding (F_3 and F_4), while soaking and canning characteristics should be tested at the later stages of breeding (F_4 and F_5) after yield problems were preliminarily sorted out. This would have a cost saving effect, since the performance soaking and canning tests on a large number of samples would be expensive. At each stage of the breeding process, beans with poor characteristics should be discarded (Ghaderi *et al*., 1984).

Inheritance of climbing ability is mostly additive (Checa et al., 2006) and controlled by a number of quantitative trait loci (QTL) in crosses of indeterminate bush beans x climbing beans (Checa and Blair, 2008). In crosses of determinate bush beans x climbing beans one or maybe two genes control the bush growth habit, while there are gradations of climbing ability in indeterminate segregants (Perez-Vega et al., 2010).

Checa and Blair, (2012) reported high broad-sense heritabilities while evaluating yield and phonological components of a cross between a climbing and bush common bean. The range in broad-sense heritabilities (h^2_{bs}) was up to 95% for the variable days to maturity, length of racemes and seed weight while narrow-sense heritabilities were lower, ranging from 37.8 to 87.8%. The result suggested that some traits are not highly affected by set of environments and genotypes x soil interactions are likely to be low since repetitions proved to be similar in values. This also suggested the possibility of major genes controlling some of these variables.

Heritability influences response to selection and optimal stage in the breeding cycle when it is most effective and efficient to conduct selection for target traits. Therefore, it become important to identify and characterize modes of heritability of growth habit, duration to flowering, pod quality and pod yield with the aim of designing breeding schemes for introducing superior genes to elite snap bean germplasm. Very little has been done to develop improved snap bean varieties combining early maturity, good pod quality and pod yield for smallholder farmers and informal seed producers in Eastern Africa region.

CHAPTER 3

GENETIC ANALYSIS OF POD QUALITY AND YIELD COMPONENTS IN CLIMBING SNAP BEAN POPULATIONS

Abstract

Pod quality and pod yield are very vital traits in snap bean production. High pod quality increases competitiveness of a product in local and international markets. Pod yield influences farmers' adoption of the variety and profitability of his enterprise. However, breeding for these traits in eastern Africa is constrained by lack of information on their heritability. Heritability influences response to selection and optimal stage in the breeding cycle when it is most effective and efficient to conduct selection for target traits. Therefore, it become important to identify and characterize modes of heritability of growth habit, duration to flowering, pod quality and pod yield with the aim of designing breeding schemes for introducing superior genes to elite snap bean germplasm. Very little has been done to develop improved snap bean varieties combining early maturity, good pod quality and pod yield for smallholder farmers and informal seed producers in Eastern Africa region. Very little is known about heritability of maturity, pod quality and pod yield in snap bean germplasm used by improvement programs in eastern Africa. The objective of this study was estimate heritability of duration to flowering, pod quality (pod length and pod diameter) and pod yield traits by parent-offspring regression method. Eleven F_2 populations were developed from crosses among six climbing and eight bush snap bean lines at Kabete Field Station between 2012 and 2014 using backcross breeding method. About 100 plants in each F_2 population, were evaluated for duration to flowering, pod length, pod diameter, pod per plant and pod yield, and 30 superior and 20 inferior individuals for the above traits were selected and self-pollinated to generate F_3 progeny. In 2014, the F_3, F_2, BC_1P_1, BC_1P_2 and their parents were grown in an irrigated trial at Mwea Research Station and data collected on maturity, pod length, pod diameter, pod per plant and pod yield in 2014. F_2/F_3 regression was used to estimate heritability. Results showed significant differences ($P< 0.05$) for duration to flowering, pod length, pod diameter, pods per plant and pod yield across the six generations (P_1, P_2, BC_1P_1, BC_1P_2, F_2 and F_3) which were developed by backcross method. Duration to 50% flowering varied from 28 to 42 days in the 11 populations. Pod length varied from 6.5 to 20.9 cm. Pod diameter varied from 5.4 to 7.99 mm. Pods per plant varied from 3.6 to 27.3. Pod yield varied from 700 to 12,509 kg ha^{-1}. All the traits showed moderate to high

heritability but this varied with populations. Heritability for duration to flowering varied from 0.52 to 0.91, pod length varied from 0.42 to 0.91, pod diameter varied from 0.51 to 0.91, pods per plant varied from 0.75 to 0.94 and pod yield varied from 0.68 to 0.92. Population 2, 4 and 5 were not variable for pod length and pod diameter traits. Populations 7, 8, 9 and 10 were most variable for these traits. The results indicated that duration to flowering, pod length, pod diameter, pods per plant and pod yield are highly heritable and could be transferred to the commercial snap bean varieties via phenotypic selection with good genetic gain.
Key words: parent-offspring regression, pod length, pod yield, populations, snap bean

3.1. INTRODUCTION

Snap bean breeding in eastern Africa is constrained by lack of reliable genetic information on the mode of inheritance of economically important traits such as pod quality, pod yield and growth habit. Pod quality traits are major determinants of marketability of snap beans, prices consumers are willing to pay, and consequently acceptability of new varieties. The marketed product must be of high quality to be accepted by the consumers and high yielding to benefit the farmers. Pod quality requirement in snap beans vary from region to region. Characteristics related to pod shape, length, colour, cross-sectional shape, straightness, smoothness, rate of seed development and fiber content, among others, determine the degree to which snap beans are accepted by consumers and processors (Cajiao, 1992; Meyers and Baggett, 1999). Heritability of these traits is a pre-requisite in developing effective and efficient snap bean breeding programs. The increased demand for high quality snap bean products as enforced by Global Gap has necessitated identification and characterization of heritability of components of growth habit, pod quality and pod yield in snap bean lines to develop high quality products. According to Kimani (2006), one issue raised is that climbing snap bean types could increase productivity especially with declining land parcels. Therefore climbing types could be of special interest to smallholder farmers. But the limited available climbing snap bean germplasm is flat podded because it was developed for Latin America where flat podded types are acceptable. In contrast, round thin podded types are required for markets in Europe and eastern Africa. So any information relating to growth habits observed in F_2 and F_3 (and other generations) would help breeding of round, thin podded climbing types for these markets. So pod quality, pod yield and their relationship to growth habit could provide useful insights.

The heritability (h^2) of a trait can be estimated by various methods, including variance components analysis, analysis of response to selection and parent-offspring (P-O) regression and correlation analysis (Mather and Jinks, 1971; Falconer, 1989). P-O regression analysis is one of the most accurate methods of estimating h^2 and has been used extensively for different traits and in different plant species (Smith and Kinman, 1965; Fernadez and Miller, 1985; Foolad and Jones, 1992; Foolad and Lin, 2001; Foolad et al., 2002). This method is generally free of assumptions (for example normal distribution of data) and often recommended as an empirical and reliable method for estimating narrow-sense h^2 in self-pollinated crops (Dudley and Moll, 1969). Correlation (*r*), rather than the regression coefficient (*b*), is often used as an estimate of h^2 to reduce potential scaling effects of the environment caused by evaluating parents and progeny in different environments (Foolad and Jones, 1992; Foolad et al., 2002). This is because in estimating *r*, the covariance of the parent and progeny is weighted by the variances of both parent and progeny generations, while in estimating *b*, the covariance is weighted only by the variance of the parental generation (Falconer, 1989; Foolad and Jones, 1992). Frey and Horner, (1957) demonstrated that correlation coefficient is equivalent to standard unit h^2 obtained by calculating regression on data coded in standard units. In the present study, this method was employed to estimate h^2 of pod length and pod yield traits in climbing snap bean varieties. Use of generation mean analysis to estimate heritability has not been used in snap bean. However, it has been done in common bean which is relative to snap bean.

Studies have shown that yield of a grain crop is a quantitative trait with low heritability and is controlled by many genes and is subject to environmental influence (Myers and Baggett, 1999). Because of the additional quality factors involved in yield of a vegetable crop, yield is probably even more complex in snap beans. This implies that heritability will also be lower. Meyers and Baggett (1999) suggested that, yield stability could be more important to farmers and processors than higher yield *per se*. Yield stability is achieved in part by incorporating resistance to biotic and abiotic stresses, and breeding for general adaptation to local conditions. Growth habit and plant architecture in snap beans fall into a range similar to that found in dry beans. Type I growth habit is inherited as single recessive gene (*fin*). However, inheritance of growth habit in common bean which is a relative to snap bean, is thought to be controlled by a mixture of qualitative and quantitative genes. Emerson (1904) identified a single –recessive gene for determinacy when he crossed indeterminate and determinate growth habit plants. However, Norton (1915) found dominant gene action for axillary inflorescence over terminal inflorescence, long main stem over short main stem, and climbing habit over non-climbing habit. Climbing habit is controlled by Finitus (*fin (in)*) genes that control growth type (determinate and indeterminate) and torquere (*tor (T)*) genes that control the twining habit of the plants as they climb (Lamprecht, 1947). Pod colour shows genetic variation for both intensity and hue. However, the genetic control of these traits is not known (Meyers and Baggett, 1999). Purple coloured pods trait is controlled by P and V genes, and may be solid coloured or striped depending on the allele at the (C Prp) locus. Pod cross-section shape is controlled by at least four genes (E_a, E_b, I_a and I_b] (Leakey, 1988). However, pod cross-section shape depends on wall thickness, time of harvest and shows quantitative variation (Meyer and Baggett, 1999). Thus a cultivar harvested young may show oval pods, at maturity have round pods, and past prime have crease-back pods. Pod straightness is important in processing green beans because straight beans make a neater cut or whole pack product, and because they flow through the processing equipment more rapidly. Straightness and fiber content are interrelated qualities. Fresh market beans, which have greater fiber content than do beans for processing, are also straighter (Silbernagel, 1986). Three major genes control the switch from highly fibrous dry bean pod type to a relatively fiber free pod typical of snap bean (Leakey, 1988). In snap beans, fibre content is quantitatively inherited, with reported values of 0.02 to 20% of pod fresh weight (Silbernagel and Drake, 1978). Pod suture string is controlled by different modes of inheritance. A single dominant gene (St) prevents string formation (Drifjhout, 1978).

Very little is known about heritability of maturity, pod quality and yield components in snap bean grown in eastern Africa. The objective of this study was estimate heritability of duration to flowering, pod quality (pod length and pod diameter) and pod yield traits.

3.2. MATERIALS AND METHODS

3.2.1 Plant materials

The study materials were 11 populations which originated from crosses among six climbing snap bean lines and eight bush varieties developed by the Legume Research Program, University of Nairobi. The climbing parental lines were HAV 130, HAV 131, HAV 132, HAV133, HAV 134 and HAV 135 were obtained from regional breeding program based at the University of Nairobi. Bush varieties were Star 2053, Morgan, Teresa, Paulista, Morelli, Serengeti, Vernadon and Samantha, which are commercial varieties of snap bean. Each population involved six generations namely; P_1, P_2, BC_1P_1, BC_1P_2, F_2 and F_3. The populations were developed through backcross method whereby the parents were hybridized to produce F_1. The backcrosses were developed by crossing the F_1 to the respective parents. The F_1 was self-pollinated to produce F_2 while F_2 was selfed to produce F_3 generation. F_2 and F_3 generations were used to estimate heritability of duration to flowering, pod quality and pod yield traits. The climbing parents, HAV 130 has resistance to angular leaf spot, anthracnose and rust both in Mwea and Thika during both short and long rain seasons (Wahome et al., 2011). HAV 131, HAV 132, HAV 133, HAV 134 and HAV 135) have resistance to angular leaf spot and anthracnose in Thika and Mwea but intermediate resistance to rust in Thika, poor pod quality and high pod yield compared with commercial bush varieties (Wahome, 2013). Commercial bush varieties have desirable horticultural characteristics, low yield and susceptible to diseases (Wahome, 2011) (Table 3.1). The commercial varieties were hybridized as the pistillate parent with climbing lines, to produce $F_{1,}$ which were selfed to produce F_2 populations at Kabete Field Station in 2013. F_3 families originated from single F_2 plants in each population. F_1 was backcrossed to each parent to generate the backcross populations. The F_2, F_3 and parental lines were used to determine genetic variation and heritability of duration to flowering, pod length, pod diameter, pods per plant and pod yield.

Table 3. 1: Characteristics of parental lines used in the study

Genotype	Growth habit	Duration to flowering	Duration to maturity	Disease reaction: Angular leaf spot	Anthracnose	Rust	Pod length (cm)	Pod diameter (mm)	Pod colour	Pod curvature	Pods plant^{-1}	Pod yield (kg ha^{-1})
HAV 130	Climber	40	77.8	2.9	1.7	1.8	11.4	11	Green	Slightly curved	5.3	2287
HAV 131	Climber	40	81.7	3.1	1.8	3	10.5	11	Green	Straight	6.4	3804
HAV 132	Climber	42	81.1	2.7	1.8	3.4	10.6	10	Green	Straight	6.8	2251
HAV 133	Climber	43	80.5	2.4	1.8	3.1	10.6	10	Green	Straight	6.9	1936
HAV 134	Climber	41.5	78.8	3.4	1.3	3.7	10.5	11	Purple	Slightly curved	6.1	1864
HAV 135	Climber	40	80.8	2.5	1.6	3.4	106	11	Speckled	Straight	5.1	1982
Morgan	Bush	35	73.5	4.3	3.7	5.5	9.7	7	Purple	Straight	7	2447
Paulista	Bush	37	75.3	4.5	2.8	5.4	10.5	6	Green	Straight	6.1	2837
Julia	Bush	37	75.7	3.8	3.7	7.8	10	6	Green	Straight	5.7	2897
Morelli	Bush	37	72.3	4.9	2.7	4.1	9.9	7	Speckled	Straight	6.7	3230
Star 2053	Bush	40	71	4.6	4.5	2.8	10.8	7	Green	Straight	6.1	3364
Vernadon	Bush	35	73.5	4.2	2.5	5.5	9.6	7	Green	Straight	6.6	3678
Samantha	Bush	36	73.7	5	3.8	6.4	11.9	8	Green	Straight	6.2	3967
Teresa	Bush	37	73.5	4.7	4	5	11.2	8	Green	Straight	6.6	4221
Serengeti	Bush	36	67	4	3	3	10.8	5.2	Green	Straight	12	4250

Source: Wahome 2011

Table 3. 2: Pedigree of F_2 populations used in the study

Populations Number*	Pedigree	Number of F_2 individuals
1	Star 2053 x HAV 131	21
2	Morgan x HAV 130	11
3	Teresa x HAV 134	8
4	Teresa x HAV 131	13
5	Star 2053 x HAV 135	14
6	Paulista x HAV 133	6
7	Morelli x HAV 130	10
8	Serengeti x HAV 132	19
9	Samantha x HAV 132	12
10	Vernadon x HAV 134	16
11	Samantha x HAV 131	16

***Populations Number**

3.2.2. Trial sites

Field evaluation of F_2, F_3, backcrosses and their parents for the 11 Populations was conducted at Kirogo Research Station of KALRO-Mwea during the 2014, short rain season.

3.2.2.1. Kirogo Research Station of KALRO-Mwea

Kirogo Research Station of **KALRO-Mwea** is located at $32^0$20' East and $0^0$41' South at an elevation of about 1159m above sea level. It experiences bimodal rainfall with an annual mean of 1037mm with long rains occurring between March and May while short rains are between October and December with a mean of 71 mm and 50 mm respectively. The mean annual maximum and minimum temperatures at long rain season are 27.8^0 C and 15.6^0 C during short rain season (Ndungu et al., 2004).

3.2.3. Experimental design, treatments and crop husbandry

The six generations namely P_1, P_2, F_2, F_3, BC_1P_1 and BC_1P_2 for each population were initially developed at Kabete Field Station green house and later planted in 10^{th} September 2014 at Kirogo Research Station of KALRO-Mwea. The 11 populations were planted in separate experiments each in a randomized complete block design with treatments randomly arranged in each block. Each trial had two replicates. Plants were spaced at 10 cm within rows and 50 cm between rows at KALRO-Mwea. The row length was three meters. Land at the trial site was ploughed and harrowed so as to achieve a moderate tilth in seed- bed. Di-ammonium phosphate (18-46-0) fertilizer was applied at a rate of 200 kg ha^{-1} and thoroughly mixed with soil. At flowering, the plants were top dressed with calcium ammonium nitrate at a rate of 100 kg ha^{-1}. The fields were kept relatively clean of weeds throughout the growing seasons. Pest control was undertaken at Mwea due to dry weather with high prevalence of aphids, thrips and white flies. Several chemicals were applied to control the above pests. Thiamethoxam (Apron Star 42WS, Syngenta, Switzerland) was applied at 0.3 kg ha-^{1} once per week to control white flies. Thiamethoxam (Actara 25WG, Syngenta, Switzerland) at 0.15 kg ha-^{1} rate was applied once in every two weeks to control aphids, thrips and white flies. Pymetrozine (Chess 50WG, Syngenta, Switzerland), was applied at 0.3 kg ha-1 rate every two weeks to control aphids, thrips and white flies. The season (Sep, Oct and Nov) was dry and hence the need for supplemental irrigation (Appendix 3). The crop was irrigated by sprinklers at a rate of 600 litres per hectare during the first two weeks after planting and later by flooding during the subsequent growing stages. Irrigation was done twice per week and the soil was flooded to field capacity.

3.2.4. Data collection

Days to flowering were recorded as number of days from planting to when approximately 50% plants in a plot had at least one opened flower. Pods were harvested six times from all the plants in each plot. Harvesting started 60 days after planting (15th Dec) and ended after 80 days (12th Jan) at an interval of one day. The pods were graded into three commercial categories defined by their pod diameter and length as extra fine (6 mm), fine (6-8mm) and bobby (>8 9 mm) and length of the pods above 10 cm (HCDA, 2009). Weight for each grade category was obtained at each harvest, and the cumulative total weight obtained at the end of the harvest period. The pod yield per harvest was averaged to give pod yield per plant which was then multiplied by the number of plants in one hectare to obtain pod yield per hectare. Pod length and pod diameter was determined from 10 pods randomly from each plot and measured by a standard ruler. Pods per plant was determined by counting the number of pods from each plant in a plot.

3.2.5. Data analysis

Analysis of variance

Quantitative data collected from the experiment was subjected to analysis of variance (ANOVA) using the GenStat software (v. 15, VSN, UK, 2010). ANOVA was done separately for each population to determine the variation for each trait in a population. Differences among the treatment means were separated using the Fisher's protected LSD test at 5 and 1% probability levels.

Separation of means among generations and populations was carried out with Tukey's *w* procedure for multiple comparisons ($P \leq 0.05$) for variables that showed significant differences among generations and populations. Tukey's method was more preferable because the generations were few and it helps to compare means pair-wise.

Genetic analyses

Data on duration to flowering, pod length, pod diameter, pod per plant and pod yield was used to estimate heritability using parent-offspring correlation analysis (Mather and Jinks, 1971; Falconer, 1989). In this method, duration to flowering, pod length, pod diameter, pod per plant and pod yield of F_2 individuals in each parental population, and the mean scores of the corresponding F_3 families in each progeny population were used to estimate the correlation coefficient/ heritability as follows:

$$h^2\,(F_{2:3}) = r_{F2:F3} = \frac{CovF3,F2}{(V_{\overline{F3}}VF2)^{1/2}}$$

$$= \frac{VA+1/2VD}{[(VA+\frac{1}{4VD}+1/nVE)(VA+VD+VE)]^{1/2}}$$

where:

V_A, V_D and V_E are the additive, dominance and environmental variances, respectively,

Cov and *r* are the covariance and correlation between F_2 and F_3.

V_{F2} is the variance of the parental F_2 generation,

$V_{\overline{F3}}$ is the among family variance in the F_3 progeny generation, and

n is the number of individuals in each F_3 family.

3.3. RESULTS

3.3.1 Generation means

Analysis of variance showed highly significant differences for duration to flowering, pod length, pod diameter, pods per plant, growth habit and pod yield among the 11 populations (Table 3.3). However, no significant differences for pod length and pod yield in populations 2, 4, 5 and 6. On the other hand, no significant differences were recorded for duration to flowering, pod length and pod diameter in population 11 (Table 3.3). Tukey's multiple means comparison tests for the six treatments across the eleven populations are shown in Tables 3.4, 3.5, 3.6, 3.7 and 3.8. Variability was based on mean squares of F_2 populations (Table 3.3).

3.3.2 Duration to flowering

Analysis of variance showed highly significant differences for duration to flowering among nine populations. There were no significant differences in duration to flowering for population 6 and 11 (Table 3.3). Population 1 was the most variable for duration to flowering and population 11 the least variable (Fig 3.1). Duration to flowering for Population 1 varied from 29 to 35 days while population 11 varied from 35 to 36 days. Among the parental lines, duration to flowering varied from 27 to 38 days. HAV 131, Star 2053 and Morgan were among the early flowering parents while HAV 130, HAV 134 and HAV 135 were among the late flowering parents. The bush parents flowered earlier than the climbing parents (Table 3.4). Morgan and Star 2053 (32 days) parents were the earliest to flower among the bush parents while Samantha was the latest (37 days). HAV 131 (27 days) parent was the earliest to flower among the climbing parents while HAV 130 was the latest (Table 3.4).

Differences between the parents as well between the F_2 were notable for duration to flowering in Populations 2, 5, 7, 8 and 10 (Fig 3.1). Duration to flowering did not differ for the two parents in Populations 1, 3, 4, 6, 9 and 11 but the F_2 did differ significantly suggesting transgressive segregation. There were no significant differences in duration to flowering between means of F_2 and F_3 in Population 2, 3, 5, 8, 9 and 11.

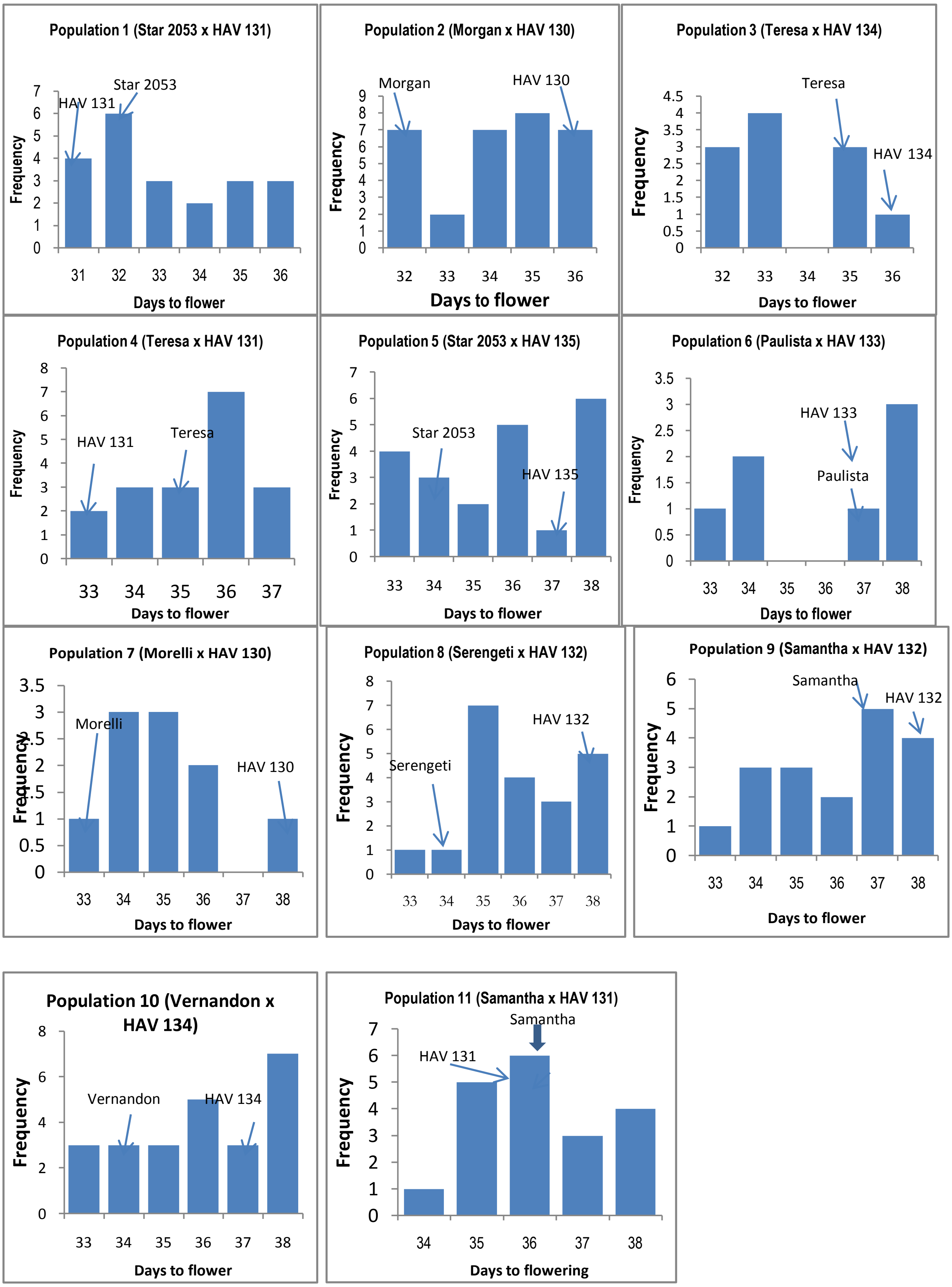


Fig 3.1: Variation in duration to flowering of 11 F_2 snap bean populations

3.3.3 Pod length

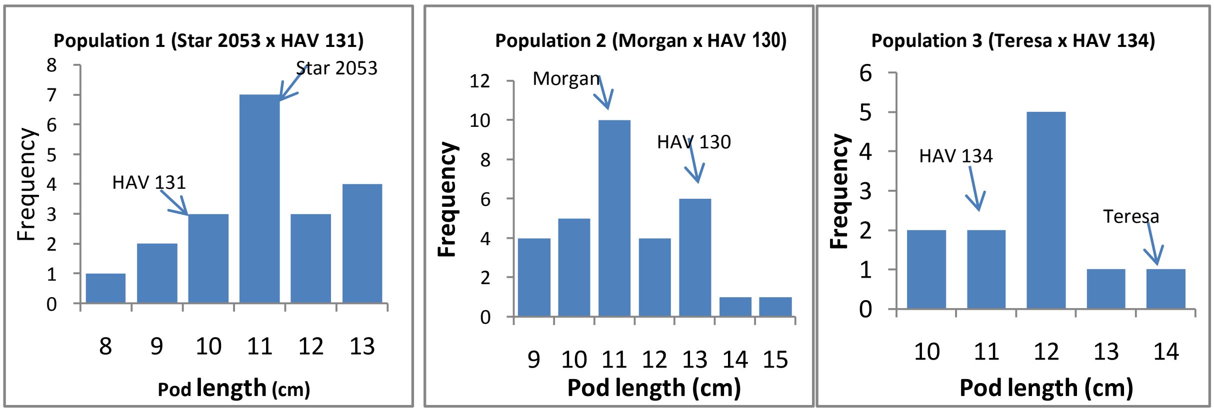
Analysis of variance showed highly significant differences for pod length in six of the 11 populations (Table 3.3). Results indicated that Populations 3 and 6 were the most variable for this trait. Population 8 was the least variable for pod length. Pod length in generations of Population 3 varied from 8.6 to 18 cm and from 7 to 13.6 cm for Population 6.

Among the parents, pod length varied from 9.78 to 13.54 cm. Among the bush parents, Teresa had the longest pods (13.54 cm) while Samantha had the shortest (9.78 cm). Among the climbing parents, HAV 133 had the longest pods (11.86 cm) while HAV 131 had the shortest (10.45 cm). The bush parents had longer pods than the climbing parents.

F_3 progeny in Population 1 had longer pods than both parents (Star 2053 and HAV 131). However, in Population 4 F_2 and F_3 had longer pods than P_2 (HAV 131). Population 9 F_2 and F_3 had longer pods than both parents. Population 10 F_2 and F_3 progeny were significantly shorter than both parents (Fig 3.2)

P1 in Population 1 influenced the backcross progeny because there was no significant difference between their pod lengths. Recurrent parents of all Populations apart from Population 3, 9 and 10, had no significant differences from backcross progeny (Table 3.6).

Normal or near to normal distributions were observed for pod length in Population 1, 3, 4, 5 and 11 suggesting quantitative inheritance for this trait (Fig 3.2). Normal distributions were observed in Population 5 and 11, although the parents were not significantly different. F_2 progeny in Populations 3, 4, 6, 7, 9 and 10 had longer pods than one of the parents or both suggesting transgressive segregation (Fig 3.2).



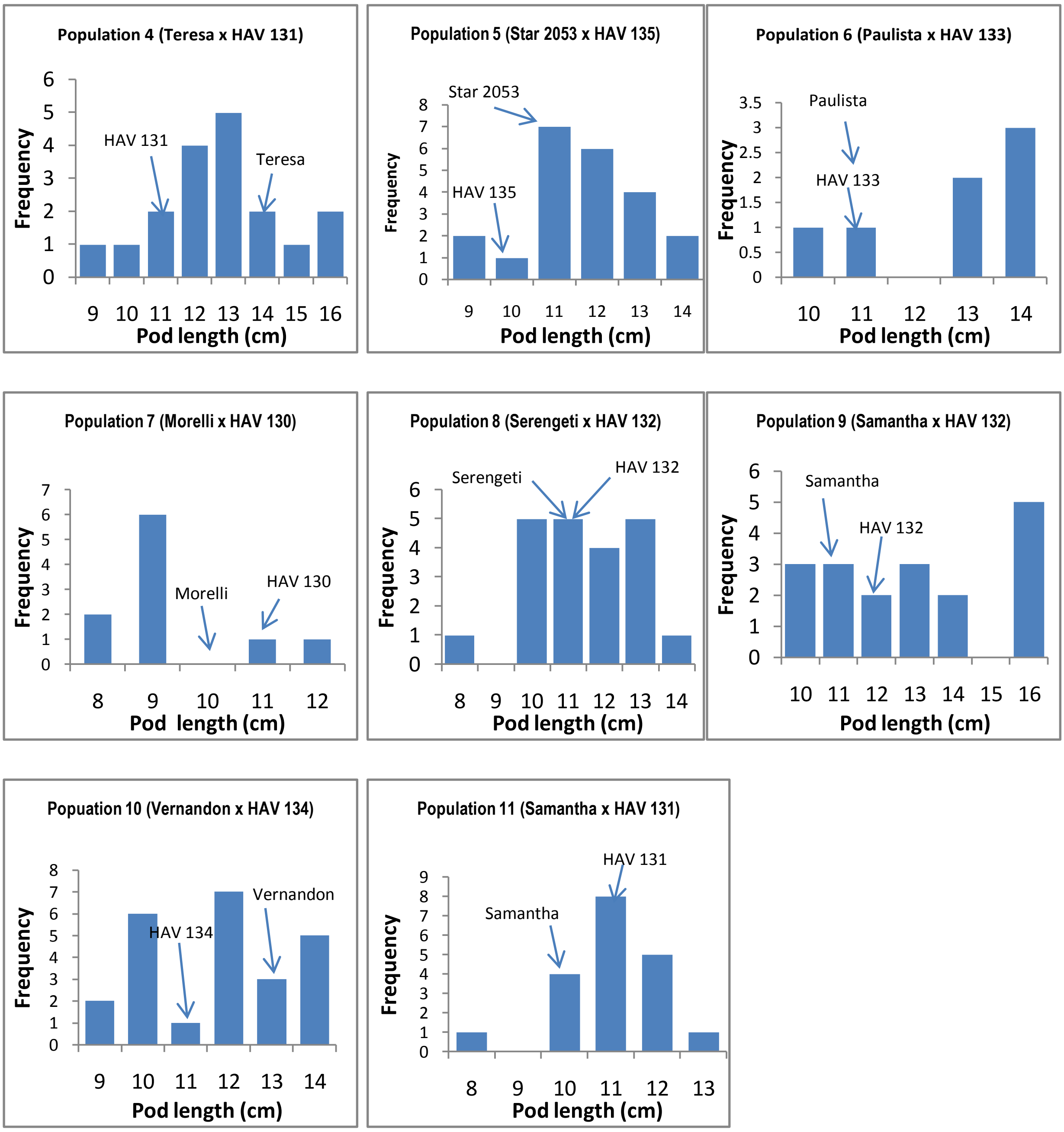


Fig 3.2: Variation in pod length of 11 F_2 snap bean populations

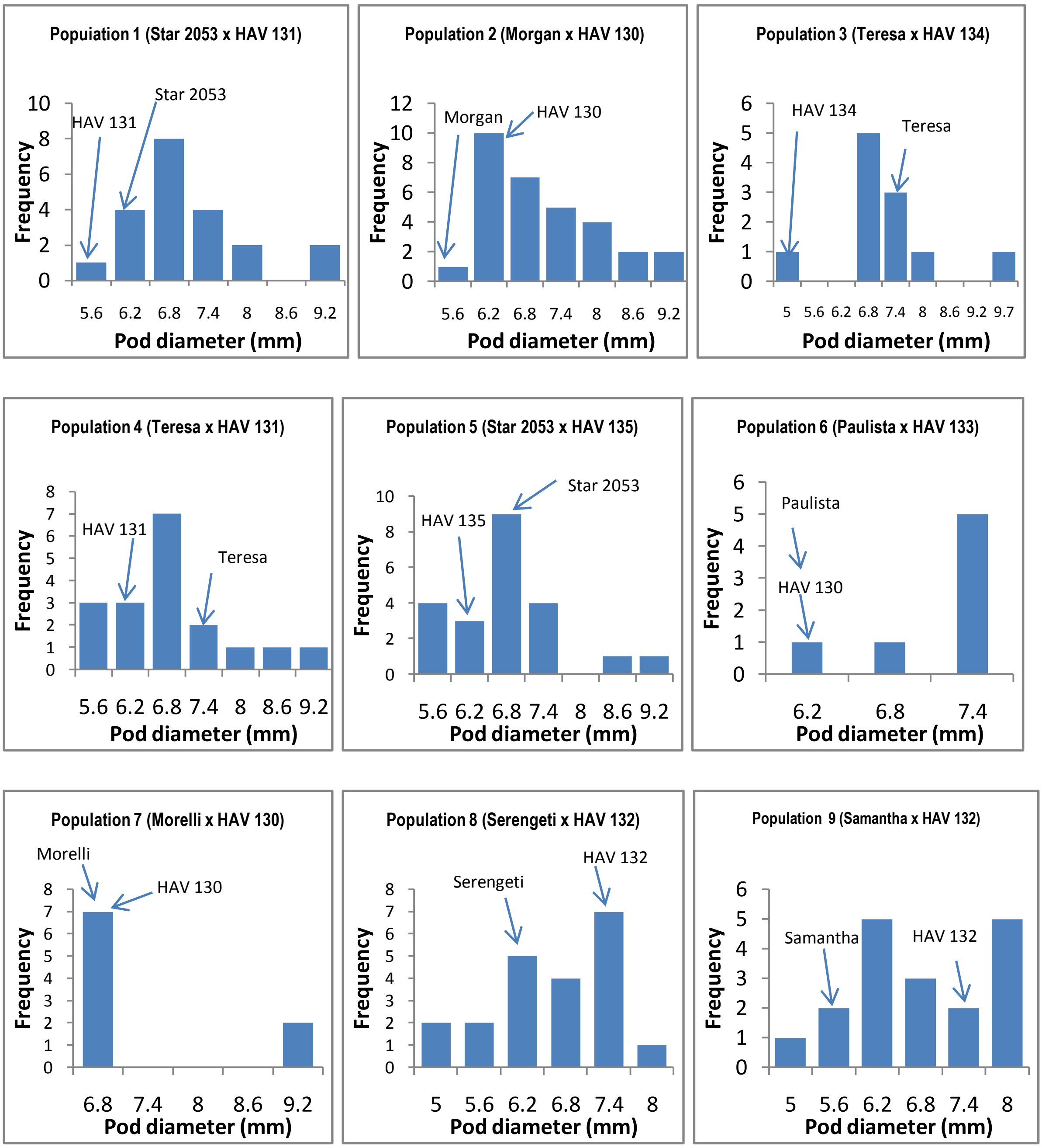
3.3.4 Pod diameter

There were no significant differences in pod diameter among the six generations in seven populations (Table 3.7). Significant differences in pod diameter among treatments were recorded in population 1, 3, 8 and 9. Population 8 was the most variable for pod diameter while Population 1 was the least variable. The parents differed in Populations 3, 8 and 9. Bush parents had thinner pods than climbing parents.

F_3 in Population 1 had thinner pods than both parents. F_2 and F_3 in Population 3 had thinner pods than P_1 (Teresa). F_2 and F_3 in Populations 8 and 9 had thinner pods than P_2 (HAV 132).

Recurrent parents in all Populations apart from Population 3, 8 and 9 influenced backcross progeny (Table 3.7)

Normal or near to normal distributions were observed in Population 1, 2, 4, 10 and 11despite the parents being not significantly different (Fig 3.3) .



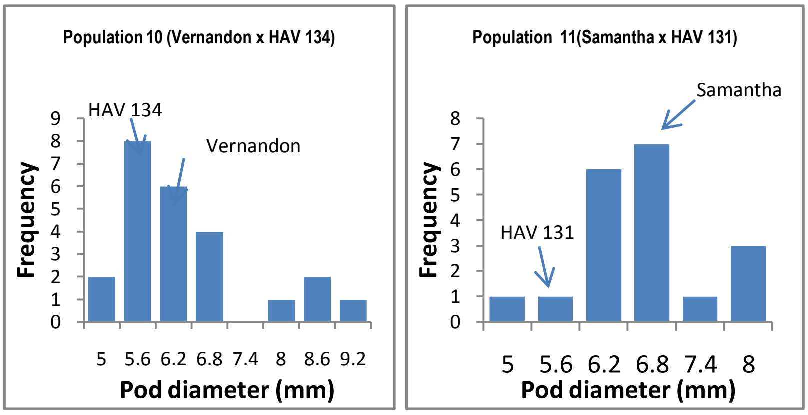
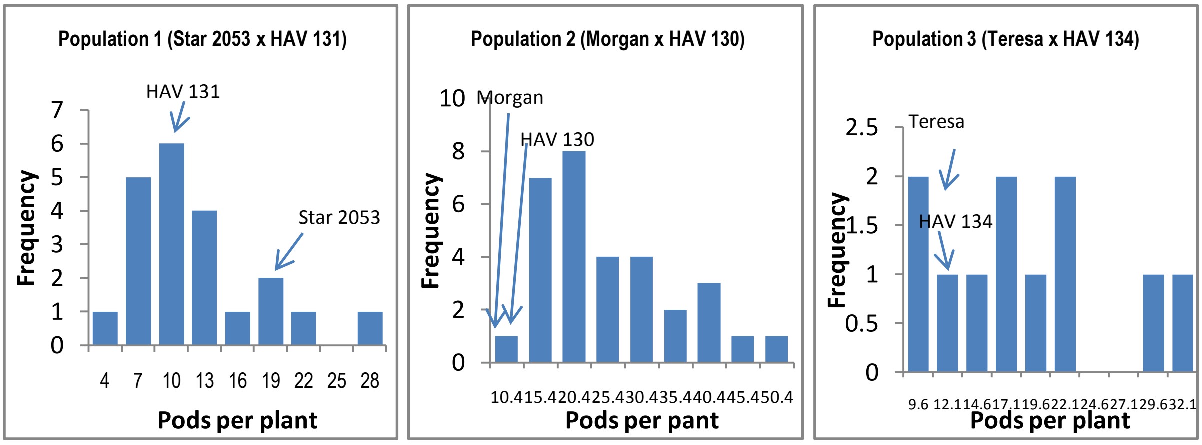


Fig 3.3: Variation in pod diameter of 11 F_2 snap bean populations

3.3.5 Pods per plant

There were significant differences in pods per plant among the generations in all the populations except population six (Table 3.8). Population 2 was the most variable for pods per plant while Population 9 was the least variable. Population 2, P_1, pods per plant varied from 16.7 to 20.7 compared with P_2 which varied from 1.8 to 4.8. F_2 varied from 10.38 to 46.25 while F_3 varied from 5.6 to 27.4. Bush parents had more pods than climbing parents.

Population 2, F_2 had higher number of pods than both parents (Morgan and HAV 130) while F_3 was higher than P_2 (HAV 130). F_2 and F_3 of Population 3, 8 and 9 had more pods than the parents. However, F_2 and F_3 of Population 5, 8 and 11 had more pods than P_2 (HAV 135, HAV 132 and HAV 131) respectively (Table 3.8). In Population 1, 5, 7, and 11 the recurrent P_2 had no significant differences from the backcross progeny and P_1 in Population 9 also had no significant difference from the backcross progeny. Normal distributions were observed in Populations 1, 2, 4, 8 and 11 (Fig 3.4).



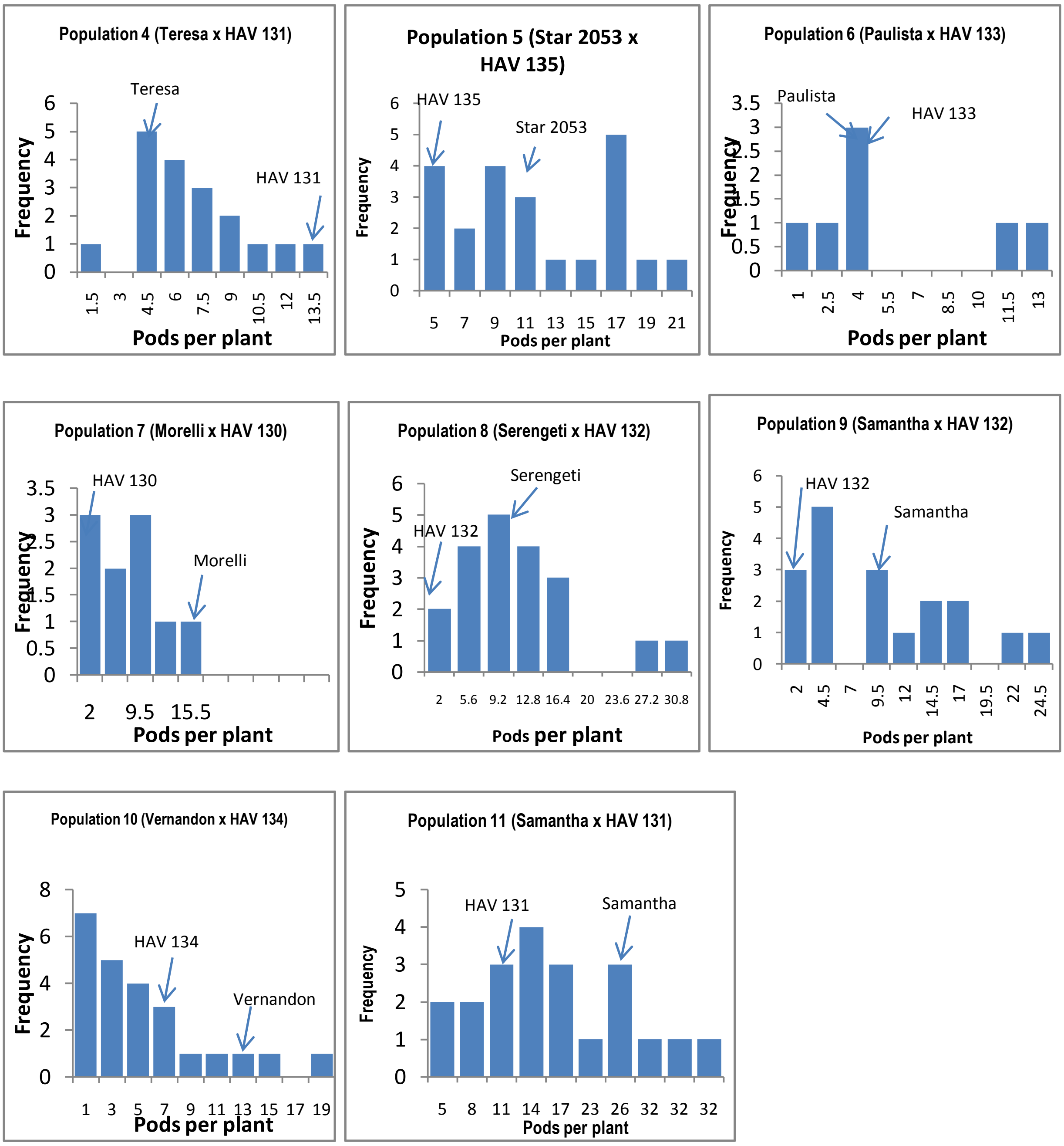
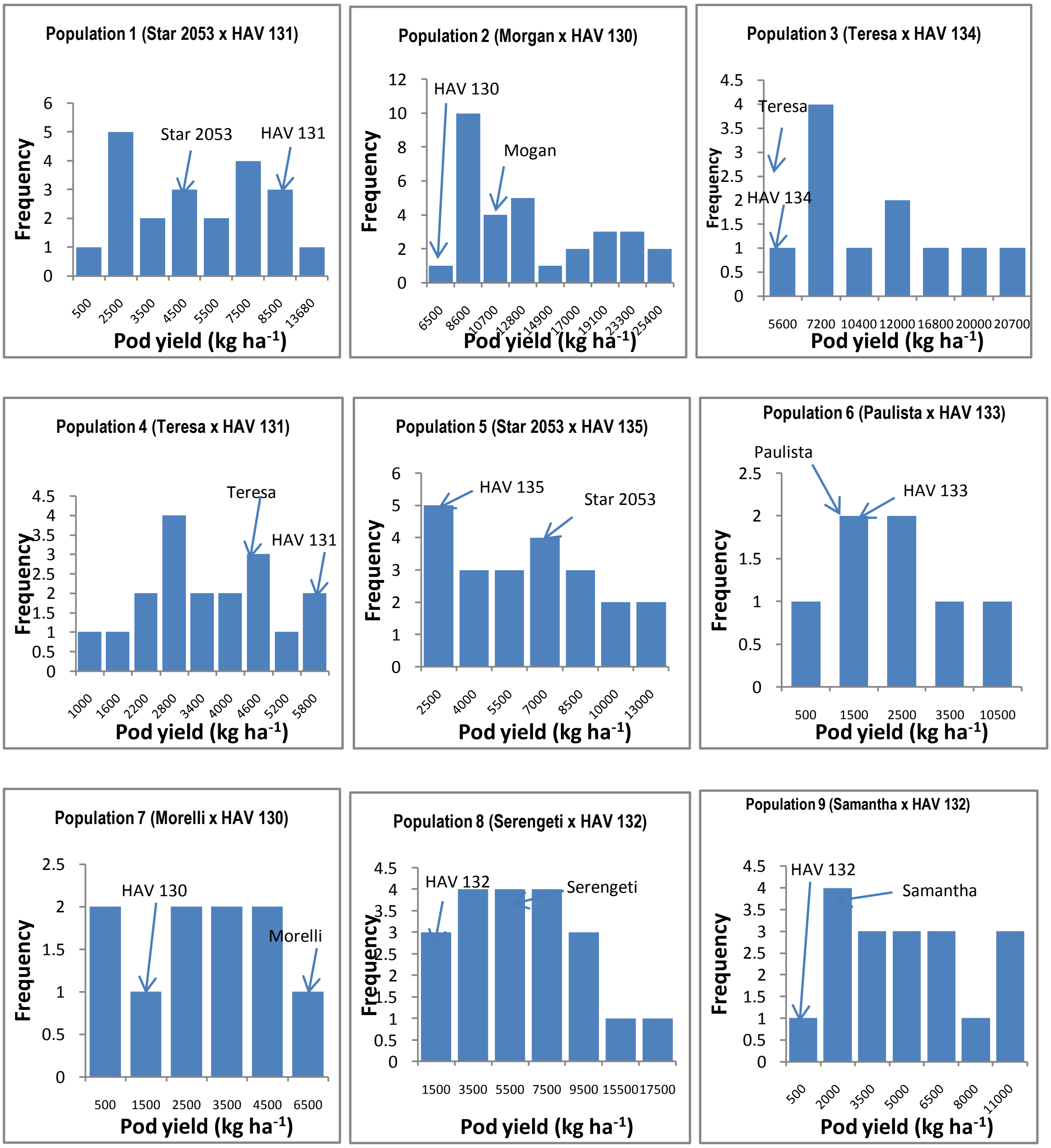


Fig 3.4: Variation in pods per plant of 11 F_2 snap bean populations

3.3.6 Pod yield (kg ha $^{-1}$)

The number of pods per plant determines the pod yield. There were significant differences in pod yield among the generations in almost all populations except population six. Population 2 was the most variable for pod yield while Population 9 was the least variable (Table 3.9). There were significant differences in pod yield between the two parents in all populations except population six, suggesting their contrasting yield potential. The bush parents had higher pod yield than the climbing parents. Population 1, 2 and 11 parents were the most contrasting for pod yield (Table 3.9). There were high variability for pod yield in F_2 populations and F_3 families as demonstrated by large range of pod yield due to segregation. There were no significant differences in pod yield between F_2 and F_3 generations in Populations 1, 4, 6, 6, 7 and 8. Normal or near to normal distributions were observed in Populations 2, 3, 6 and 8 (Fig 3.5). F_2 pod yield varied greatly in Population 2 (6400-23767 kg ha^{-1}), 1 (467-13,680 kg ha^{-1}) and 11 (800-13,833 kg ha^{-1}) perhaps due to high variation between the parents.



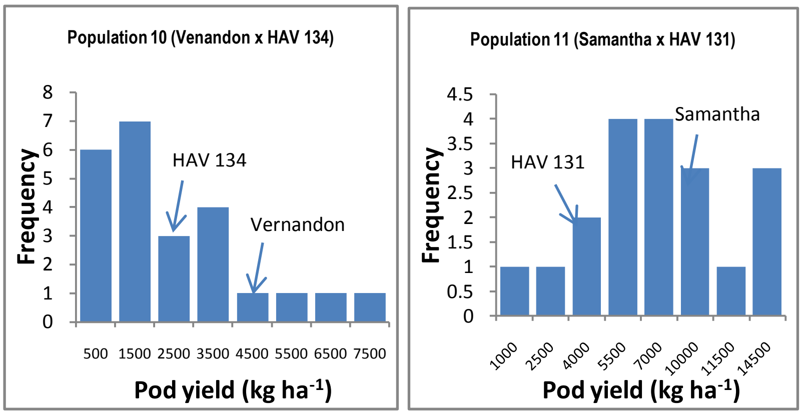


Fig 3.5: Variation in pod yield of 11 F_2 snap bean populations

Table 3.3: ANOVA for duration to 50% flowering, pod length, pod diameter, pod per plant and pod yield among generations in 11 snap bean populations grown at Mwea short rain season, 2014

	Mean squares										
Trait	**Pop 1**	**Pop 2**	**Pop 3**	**Pop 4**	**Pop 5**	**Pop 6**	**Pop 7**	**Pop 8**	**Pop 9**	**Pop 10**	**Pop 11**
Days to flowering	78.469**	31.467**	21.65**	11.67**	15.397**	2.853^{ns}	25.092**	45.3**	20.672**	12.251**	0.773^{ns}
Pod length	13.586**	5.121^{ns}	15.761**	6.682^{ns}	5.432^{ns}	16.294**	6.07**	0.475^{ns}	8.104*	7.746**	1.712^{ns}
Pod diameter	1.8455**	1.2153^{ns}	3.8363**	1.361^{ns}	2.603^{ns}	0.4446^{ns}	1.599^{ns}	5.0478**	4.7722**	0.9276^{ns}	2.2^{ns}
Pod plant $^{-1}$	153.33*	702.19**	192.87**	135.39**	92.56**	17.23^{ns}	664.01**	207.3**	77.34*	186.28**	266.92**
Pod yield (kg ha^{-1})	99040000**	194900000**	92920000**	64130000**	45325617**	5391932^{ns}	119900000**	64350000**	17274822*	24872216**	28910000*

*,** Significant differences at P< 0.01, 0.05 probability levels; ns= not significant

Table 3.4: Comparison of duration to 50% flowering, pod length, pod diameter, pods per plant and pod yield of bush and climbing bean parental lines used to develop the snap bean populations

	Bush genotypes						Climbing genotypes					
Population	**Line**	**Duration to flowering**	**Pod length (cm)**	**Pod diameter (mm)**	**Pods plant-^{1}**	**Pod yield (kg ha-^{1})**	**Line**	**Duration to flowering**	**Pod length (cm)**	**Pod diameter (mm)**	**Pods plant-^{1}**	**Pod yield (kg ha-^{1})**
1	Star 2053	32	11	6.2	19.8	10301	HAV 131	28.6	11.3	6.2	11	4927
2	Morgan	32	11.2	6	18.8	9993	HAV 130	38	11.4	6.5	3.6	1808
3	Teresa	35.1	13.5	7.6	12.2	6619	HAV 134	36.6	11.1	5.9	8	3486
4	Teresa	35.1	13.5	7.6	12.2	6619	HAV 131	33	10.9	6.5	18.7	12509
5	Star 2053	33.7	11.2	7	12.7	7412	HAV 135	36.5	10.5	6.2	6	2330
6	Paulista	37.5	11.9	6.1	4.8	2075	HAV 133	37	11.9	6.3	5.2	2063
7	Morelli	33.6	10.3	6.6	25.9	11122	HAV 130	38	11.4	6.5	3.6	1733
8	Serengeti	34	10.6	6.4	12	5936	HAV 132	39.9	10.7	8	3.6	1651

Continued: Comparison of duration to 50% flowering, pod length, pod diameter, pods per plant and pod yield of bush and climbing bean parental lines used to develop the snap bean populations

	Bush genotypes						Climbing genotypes					
Population	**Line**	**Duration to flowering**	**Pod length (cm)**	**Pod diameter (mm)**	**Pods plant-1**	**Pod yield (kg ha-1)**	**Line**	**Duration to flowering**	**Pod length (cm)**	**Pod diameter (mm)**	**Pods plant-1**	**Pod yield (kg ha-1)**
9	Samantha	37	11.9	5.8	8.4	3764	HAV 132	39.9	10.7	8	3.8	1773
10	Vernadon	34	12.6	5.6	13.6	5350	HAV 134	36.6	11.1	5.9	8	3486
11	Samantha	35.8	9.8	7.2	27.3	10130	HAV131	35.6	10.5	6.2	11	4927
	Trial mean	38.2	9.7	8	8.7	2888	**Trial mean**	38.2	9.7	8	8.7	2888
	LSD $_{0.05}$	0.6	1.3	ns	1.2	1686.7	**LSD $_{0.05}$**	0.6	1.3	ns	1.2	1686.7
	CV (%)	0.3	3.3	2.7	0.2	6.5	**CV (%)**	0.3	3.3	2.7	0.2	6.5

LSD-least significant difference, CV-coefficient variation, ns-not significant

Table 3.5: Duration to flowering of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	**Mean and range**	Days to 50% flowering										
		Pop 1	**Pop 2**	**Pop 3**	**Pop 4**	**Pop 5**	**Pop 6**	**Pop 7**	**Pop 8**	**Pop 9**	**Pop 10**	**Pop 11**
P_1(8)	Mean	32 b§	32 a	35.12 ab	35.12 abc	33.70 a	37.50 a	33.58 a	34.00 a	37.00 a	34.00 a	35.83 a
	Range	32-32	32-32	34-37	34-37	33-34	37-38	32-36	34-34	34-41	34-34	34-37
P_2(10)	Mean	28.6 a	38 d	36.56 b	33.00 a	36.50 b	37.00 a	38.00 c	39.90 c	39.90 b	36.56 b	35.60 a
	Range	28-30	38-38	33-38	33-33	36-37	34-38	38-38	37-42	37-42	33-38	35-37
BC_1P_1(4)	Mean	33 bc	33 ab	34.33 a	34.94 ab	36.40 b	37.00 a	37.67 c	34.80 ab	36.75 a	35.38 ab	36.00 a
	Range	32-36	32-34	33-36	33-37	34-38	34-39	36-38	33-38	35-38	34-38	35-38
BC_1P_2(6)	Mean	34.17 bcde	35.33 c	34.33 a	36.42 c	37.38 b	37.00 a	35.25 ab	36.50 b	38.00 ab	36.67 b	35.50 a
	Range	32-36	35-36	33-35	34-37	35-38	35-39	33-38	34-38	38-38	35-38	34-36

Continued: Duration to flowering of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	Mean and range	Days to 50% flowering										
		Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9	Pop 10	Pop 11
F_2(20)	Mean	33.05 bcd	34.17 bc	33.40 a	35.33 bc	35.50 b	35.67 a	35.00 ab	36.10 b	36.06 a	35.92 b	36.17 a
	Range	31-36	32-36	32-36	33-37	32-38	33-38	33-38	33-38	33-38	32-39	34-38
F_3(50)	Mean	35.1 ce	33.88 bc	33.79 a	34.10 a	36.15 b	37.40 a	35.59 b	34.97 ab	36.92 a	35.65 ab	36.00 a
	Range	32-37	33-36	32-36	32-37	33-38	34-38	33-38	32-38	33-39	32-38	34-39

§Means followed by different letters indicate significant differences at P=0.05

Table 3. 6: Pod length of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	Mean and range	Pod length (cm)										
		Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9	Pop 10	Pop 11
P_1(8)	Mean	11.03 a§	11.17 a	13.54 c	13.54 a	11.21 a	11.89 b	10.28 ab	10.63 a	11.86 ab	12.61 ac	9.78 a
	Range	9-14.6	9-14.16	10.9-18.02	10.9-18.02	9.78-13.32	10.02-13.06	8.26-11.5	9.7-11.7	9.84-13.7	11.04-13.9	7.9-12.1
P_2(10)	Mean	11.25 abc	11.44 a	11.09 b	10.88 a	10.49 a	11.86 b	11.44 b	10.74 a	10.74 a	11.09 ab	10.45 a
	Range	8.42-20.94	9.24-12.5	8.78-13.2	9.6-12.1	10.25-10.74	10.7-13.4	9.24-12.5	9.6-11.9	9.6-11.9	8.78-13.2	8.42-13.26
BC_1P_1(4)	Mean	10.5 a	12.65 a	8.83 a	12.19 a	10.59 a	11.90 b	9.96 ab	11.27 a	13.83 b	13.00 c	10.44 a
	Range	8.8-12.22	11.9-13.4	6.66-9.7	9.28-15.08	5.22-12.96	9.2-13.64	8.12-12	9.4-12.6	11.5-16.56	11.4-14.8	8.8-12.6
BC_1P_2(6)	Mean	10.27 a	12.26 a	10.81 ab	13.17 a	10.04 a	8.90 a	10.67 b	11.01 a	12.45 ab	10.81 a	11.16 a
	Range	8.2-11.68	10.66-13.92	8.6-12.2	9.7-19.1	6.5-13.03	7-10.2	9.1-12.5	9.9-14.5	10.94-14.9	9.5-11.56	8.4-13.2
F_2(20)	Mean	11.04 ab	10.85 a	11.17 b	12.16 a	11.22 a	11.95 b	8.97 a	10.83 a	12.59 b	11.47 abc	10.32 a
	Range	7.8-18.8	8.36-14.32	9.5-12.42	8.62-16.1	8.9-13.64	9.7-13.8	7.82-11.2	4.52-13.9	9.28-15.8	8.1-14	7.4-11.7
F_3(50)	Mean	12.55 ac	10.53 a	11.33 b	11.88 a	9.81 a	11.69 b	10.24 ab	10.97 a	12.69 b	11.48 abc	10.70 a
	Range	9-15.16	8.8-12.6	8.6-14	8-15.58	7.3-12.1	9.8-13.24	7.5-13.8	8.4-14.32	10.2-16.06	9-14.1	7.6-14.2

§Means followed by different letters indicate significant differences at P=0.05

Table 3. 7: Pod diameter of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	Mean and range	Pod diameter (mm)										
		Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9	Pop 10	Pop 11
P_1(8)	Mean	6.237 ab§	6.033 a	7.560 b	7.560 a	7.000 a	6.413 a	6.633 a	6.383 ab	5.762 a	5.607 a	7.157 a
	Range	5-8	5-8	6-9.16	6-9.16	6.1-8.4	5.6-7.9	6.2-7.1	5.8-6.9	4.8-6.3	4.6-6.2	6.34-9.6
P_2(10)	Mean	6.17 ab	6.5 a	5.878 a	6.450 a	6.150 a	6.250 a	6.500 a	7.990 c	7.990 bd	5.878 a	6.170 a
	Range	5.6-7.3	5.4-7.1	4.8-6.9	6-6.8	6.1-6.2	5-7	5.4-7.1	6.6-9.2	6.6-9.2	4.8-6.9	5.6-7.3
BC_1P_1(4)	Mean	6.42 ab	6.45 a	6.517 ab	6.572 a	6.345 a	6.237 a	6.317 a	7.240 bc	6.975 abcd	5.438 a	7.340 a
	Range	5.6-7.1	6.2-6.7	5.6-10.5	4.6-7.9	3.7-10.8	4.8-10.8	5.4-7.9	6.2-9	6.7-7.1	4.2-6.4	5.6-10.5
BC_1P_2(6)	Mean	6.033 ab	6.033 a	6.933 b	7.033 a	6.663 a	6.095 a	7.367 a	6.462 ab	6.617 ab	5.900 a	6.787 a
	Range	5.4-6.6	5.2-6.7	6-8.2	6.1-9.1	5.2-10.5	5.6-7.7	5.6-12	5.4-8	6.4-6.9	4.8-6.8	5.8-7.6
F_2(20)	Mean	6.79 b	6.813 a	6.690 ab	6.803 a	6.508 a	6.733 a	7.240 a	6.275 a	6.593 a	6.132 a	6.350 a
	Range	5.4-9.1	5.4-8.9	5-8	5.4-12	5.2-8.78	6.2-7	6.4-9.8	2.8-7.8	5-7.9	4.2-9.1	4.2-7.8
F_3(50)	Mean	6.004 a	6.269 a	6.841 b	7.000 a	7.316 a	6.070 a	6.823 a	6.527 ab	6.779 abc	6.045 a	6.836 a
	Range	5.2-6.8	6-6.9	5.5-8.7	5.6-12	5.5-11.1	5.6-7.2	5.2-8.8	5.4-8.2	5.6-9.9	5.2-7	5-8.7

§Means followed by different letters indicate significant differences at P=0.05

Table 3. 8: Pod per plant of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	Mean and range	Pod pant $^{-1}$										
		Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9	Pop 10	Pop 11
P_1(8)	Mean	19.84 b§	18.8 bc	12.18 abc	12.18 ab	12.684 ac	4.755 a	25.93 b	12.028 bc	8.390 ab	13.606 ce	27.29 b
	Range	16.69-27.75	16.7-20.7	2.4-24	2.4-24	4.6-26.6	0.7-15.9	10.6-53	8.2-15.5	3.1-15.3	6.4-19.8	21.7-30.8
P_2(10)	Mean	11.02 ab	3.59 a	7.95 ab	18.69 b	5.950 a	5.190 a	3.59 a	3.572 a	3.765 a	7.951 abcd	11.02 a
	Range	6.727-16.5	1.8-4.8	0.6-26.5	15-24.1	5-7.4	0.4-20.4	1.8-4.8	1.7-7	0.7-7	0.6-26.5	6.7-16.5
BC_1P_1(4)	Mean	14.51 ab	18.6 bc	7.06 a	12.27 b	7.584 abc	5.623 a	7.84 a	16.212 c	7.091 ab	12.375 bcde	11.58 a
	Range	Sep-22	16.7-20.5	1.1-12.3	4.1-29.5	2-21.5	1-14.2	5.0-17.1	9.6-25	5.2-9.1	Apr-20	3-20.3
BC_1P_2(6)	Mean	16.86 ab	4.06 a	10.15 abc	10.74 ab	5.921 a	2.581 a	11.25 a	4.502 ab	9.709 ab	7.305 abc	11.78 a

Continued: Pod per plant of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	Mean and range	Pod pant $^{-1}$										
		Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9	Pop 10	Pop 11
	Range	3.5-32.8	3.3-5.3	4.6-16	4.3-18.7	02-Oct	0.6-7.0	2.9-23.9	1.2-7.7	2.6-17.6	2-11.2	0.8-23.9
F_2(20)	Mean	10.7 a	22.8 c	16.93 c	6.23 a	10.532 abc	5.525 a	6.36 a	9.389 ab	8.796 ab	4.645 a	13.76 a
	Range	1.111-27.4	10.38-46.25	2.3-29.6	1.4-13.2	3.2-19.5	1-12.9	0.3-14.7	0.7-28	0.4-22.3	0.1-17.4	1.8-31
F_3(50)	Mean	10.85 a	15.57 b	14.83 ac	10.81 ab	6.246 ab	2.944 a	12.09 a	8.771 ab	10.992 b	6.185 ab	12.08 a
	Range	2.5-51	5.6-27.4	2.8-25.1	4-28.4	2.3-18.8	1.4-4.8	1.2-34	1.4-26	2.9-34	0.6-16.4	2-35.7

§Means followed by different letters indicate significant differences at P=0.05

Table 3. 9: Pod yield of parents, backcrosses, F_2 and F_3 generations of 11 snap bean populations grown at Mwea short rain season, 2014.

Generation and number of individuals	Mean and range	Pod yield (kg ha^{-1})										
		Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9	Pop 10	Pop 11
P_1(8)	Mean	10301 b§	9993 bc	6619 abc	6619 a	7412 d	2075 a	11122 b	5936 ab	3764 ab	5350 b	10130 b
	Range	5725-12200	5725-12200	942.9-14600	942.9-14600	1872.7-10367	371.4-6600	3760-22400	2520-8080	971.4-7933	2950-8200	5280-14320
P_2(10)	Mean	4927 a	1808 a	3486 ab	12509 b	2330 a	2063 a	1733 a	1651 a	1773 a	3486 ab	4927 a
	Range	2700-6850	1200-2755.6	200-11800	8092.3-15975	1200-3460	225-8560	600-2755.6	833.3-3700	133.3-3700	200-11800	2700-6850
BC_1P_1(4)	Mean	8531 ab	8170 abc	3221 a	6314 a	3166 abc	2184 a	4200 a	8849 b	3465 ab	4704 ab	5113 a
	Range	5585-12533	7280-9060	550-5436.4	2030.8-14000	914.3-9433.3	266.7-5900	1800-10563	4525-14900	3022.2-3771	800-8000	1371.4-8466.7
BC_1P_2(6)	Mean	10808 b	2057 a	6071 abc	5669 a	2563 a	700 a	5565 a	2483 a	4611 ab	4174 ab	4616 a
	Range	1280-24760	1466.7-2566.7	3163.6-11160	1840-10446.7	742.9-6100	1714-1800	1400-15050	820-5085.7	1314.3-7600	711.1-7240	400-7657.1
F_2(20)	Mean	5035 a	11838 c	10633 c	3232 a	5630 acd	2859 a	2448 a	5401 ab	4495 ab	1951 a	6550 ab
	Range	466.7-13680	6400-23767	1166.7-20700	880-5745.5	1240-12575	300-10000	160-6114.3	333.3-16000	125-10971	16.7-6680	800-13833.3
F_3(50)	Mean	4104 a	7411 b	7900 ac	4819 a	3158 ab	1192 a	5908 a	5301 ab	5140 b	2984 ab	5747 a
	Range	650-17200	2257.1-13509.1	1140-13540	911.1-15514.3	914.3-8800	600-2250	644.4-16200	585.7-19200	1200-13000	288.9-9542	880-16833.3

§Means followed by different letters indicate significant differences at P=0.05

3.3.7. Heritability

Duration to 50% flowering trait was highly heritable. However, heritability estimated varied among the populations. Heritability was highest in population 5 and 10 (h^2=0.91) while the lowest was recorded in population three (0.52) (Table 3.10). The mean heritability for days to flower was 0.77. Pod length narrow-sense heritability ranged from 0.42 (Population 1) to 0.91 (Population 8 (Table 3.10). The mean heritability for pod length was 0.74. Pod diameter heritability was high. It varied from 0.51 (population 6) to 0.93 (population 4). Heritability of pods per plant in all the populations was above 0.75 suggesting that the trait is highly heritable in all populations (Table 3.10). Heritability ranged from 0.75 (population five) to 0.94 (population eight). Heritability for pod yield ranged from 0.68 (population one) to 0.92 (population five) (Table 3.10). The mean heritability for pod diameter was 0.83, pods per plant was 0.88 and pod yield was 0.86.

Table 3. 10: Narrow sense heritability of duration to flowering, pod length, pod diameter, pod per plant and pod yield of 11 snap bean populations grown at Mwea short rain season, 2014.

	h^2 (F_2: F_3)											
Traits	**Pop 1**	**Pop 2**	**Pop 3**	**Pop 4**	**Pop 5**	**Pop 6**	**Pop 7**	**Pop 8**	**Pop 9**	**Pop 10**	**Pop 11**	**Mean**
50% DF	0.67	0.79	0.52	0.77	0.91	0.70	0.67	0.90	0.79	0.91	0.88	0.77
Pod length (cm)	0.42	0.58	0.64	0.64	0.58	0.84	0.83	0.91	0.87	0.90	0.88	0.74
Pod diameter (mm)	0.74	0.83	0.86	0.93	0.91	0.51	0.89	0.86	0.88	0.87	0.89	0.83
Pod plant $^{-1}$	0.90	0.91	0.88	0.86	0.89	0.75	0.88	0.94	0.88	0.92	0.91	0.88
Pod yield (kg ha $^{-1}$)	0.90	0.68	0.79	0.90	0.92	0.79	0.87	0.90	0.87	0.91	0.88	0.86

3.4 DISCUSSION

3.4.1 Analysis of Variance

3.4.1.1 Duration to flowering

Development of populations with adequate genetic variability is a critical step in breeding new locally adapted snap bean varieties in eastern Africa. The study populations developed from crosses between advanced climbing lines and commercial snap varieties showed considerable variation for duration to flowering. Results showed that there were significant differences in nine of the 11 populations. Population 1 was the most variable, and Population 11, the least. Duration to flowering for individual plants varied from 28 to 39 days. Mean duration to flowering in F_2 generation of all populations was either earlier, intermediate or later compared to the two parents. This implied that early, medium or late mating lines can be developed from transgressive segregants from these populations. Early maturity may be of interest to producers who produce snap beans throughout the year and may wish to fit several crops in a production cycle, or to facilitate rotations in relay cropping systems. Also it facilitates the crop to fetch good prices because it gets to the market early before the crop glut. Late maturity of snap beans is important because it increases harvesting period which might result to higher yield due to increased physiological efficiency. Duration to flowering among the commercial cultivars varied from 32 to 37.5 days. The earliest cultivars to flower were Star 2053 and Morgan while the latest were Paulista and Samantha. This was in agreement with Wahome et al., (2013) who found that among the 10 commercial varieties evaluated at Thika and Mwea during 2009/2010 season, Morgan was the earliest to flower (35 days) during short rain season. However, his research differed with this research where he found that Star 2053 was the last to flower (39.3 days) during short rain season. He found Paulista being the earliest check cultivar to flower (37.2 days) during long rain season. This was contrary to this research which could be probably due to differences in seasons, altitude and location effects. Generally, bush parents flowered earlier than climbing parents. This research agreed with Wahome (2011) who found the duration to flowering among six climbing parents and 10 commercial bush parents varying from 41.5 to 45.2 days and 37.2 to 41.2 days respectively. Means of the backcross generations were significantly different from the means of their respective recurrent parents in six populations implying that the parents did not influence the backcross progeny in those Populations (Table 3.5).

3.4.1.2 Pod length

Pod length is an important trait for both fresh market and processing snap beans. Fine and extra fine beans must be at least 10 cm long Wahome et al. (2011). Beans for processing are about 10 to 16 cm in length (Myers and Baggett, 1999). Pod lengths greater than 16 cm are too long for existing processing equipment. Six study populations (1, 3, 6, 7, 9 and 10) showed significant differences in pod length. Pod length varied from 8 cm to 18 cm among the 14 parental lines. Pod length varied from 7.4 to 18.8 cm among the F_2 plants, and from 7.3 to 16 cm among the F_3 plants. F_2 generation of populations 4 and 9 had the longest mean pod length (11.9 to 12.9 cm), and produced F_3 progeny with the longest pods, suggesting that F_2 plants transmitted this to their progeny. The results indicated that these populations had adequate variability for pod length to facilitate selection of lines which meet the commercial criteria for pod length. F_2 and F_3 mean pod length in population nine and ten were significantly different from the parents suggesting transgressive segregation for the trait in the two populations.

3.4.1.3 Pod diameter

Pod diameter (or pod-cross section thickness) is key quality determinant in snap beans. It is the primary criterion used to determine sieve size (Myers and Baggett, 1999). For example, in USA, canner's grade 1 pods have pod diameter of less than 8.5mm. In Kenya, extra-fine grade must have a maximum diameter of 6 mm. Fine grade pods are 6-8 mm in diameter. Pods with a diameter exceeding 8 mm are classified as bobby. There was considerable variation for this trait among the parental lines, F_2, F_3 and backcross populations in this study. Among the parental lines, pod diameter varied from 5.6 to 8mm, indicating they belong to extra-fine and fine grades. This was not unexpected because most of the parental lines are commercial varieties. This research was in agreement with Wahome (2011) who found the lowest mean pod diameter among commercial varieties being 6 mm. Mean pod diameter for F_2 populations varied from 6.1 for Population 10, to 7.2 mm for Population 7. This was in agreement with Wahome (2011) found F_4 and F_6 populations having a maximum pod diameter of 9 mm. However, there was more variation within populations. Pod diameter of individual F_2 plants varied from 2.8 to 9.8 mm. Among the F_3 families, mean pod diameter varied from 6.0mm in Population 1 to 7.3mm in Population 5. As with F_2, there was more variability within populations, with individual F_3 plants having pod diameters of 5 to 11 mm. These results implied that there was transgressive segregation in either direction for pod diameter. Moreover, lines with a high proportion of extra-fine and fine market classes can be selected from these populations.

3.1.1.4 Pods per plant

Pods per plant is closely related to pod yield (Checa and Blair, 2012). In dry bean, high yield of climbing type varieties is associated with more pods per plant. There was considerable variation in pods per plant among the 14 parental lines. The mean number of pods per plant varied from 3.6 to 19.8. HAV 131 had the highest number of pods per plant (19.8). There was considerable segregation for pods per plant among the F_2, F_3 and backcrosses. Among the F_2 populations, mean number of pods per plant varied from 4.6 in Population 10 to 22 in Population 2. For individual plants, the variation was even greater. Pods per plant varied from less than 1 in Population 10, to 46 in Population 2. Among the backcrosses and F_3 families, Population 2 still had the highest number of pods per plant. Performance of Population 2 strongly suggested transgressive segregation for pods per plant. Other populations with relatively high number pods per plant in F_2 and F_3 generations were Population 11 (13.8 and 12.1) and Population 3 (16.9 and 14.8). These two populations also showed considerable segregation for pods per plant with the best plants having up to 35.7 pods per plant in Population 11, and 25 pods per plant in Population 3. These results indicated potential for developing lines with high pod yields following pedigree selection.

Checa and Blair (2012) found that yield traits such as raceme length, number of pod per raceme, pod length, pods per plant and phenological traits, days to physiological maturity did not differ for the two parents, but the recombinant inbred lines (RILs) did differ significantly, suggesting transgressive segregation for the each of these traits. Backcrosses (BC_1P_1 and BC_1P_2) of all the traits and across populations showed means that tended to deviate from their respective recurrent parents. This result differed from Checa et al., (2006) who found that backcrosses BC_1P1 and BC_1P_2 means tended to be located close to those of their recurrent parents while working on generation mean analysis of climbing beans.

3.1.1.5 Pod yield (kg ha^{-1})

Results showed that there was considerable variation for pod yield among the parental lines. Mean pod yield varied from 2075 kg ha-^{1} for Population 6, to 11,122 kg ha-^{1} for Population7. Among the F_2 populations, mean pod yield varied from 1951 kg ha^{-1} for Population 10, to 11,838 kg ha^{-1} for Population 2. Within population variation was even greater. Among the F_3 families, pod yield varied from 1192 kg ha-^{1} for population 6 to 7900 kg ha^{-1} for Population

3. This implied that variation existed for pod yield to facilitate selection for high yielding lines from these populations. Results indicated that Populations 2 and 3 were the best performing for pod yield. Pod yield of snap bean differ with varieties and production environment and crop management. For example, Meyer and Baggett (1999) reported that pod yield of fresh market snap beans varied from 2.7 t ha^{-1} in South Carolina to 10.8 t ha^{-1} in California, with a mean yield of 5.4 for the country. For processing types, pod yield varied from 5.7 t ha^{-1} in Indiana to 13.6 t ha^{-1} in Oregon with a national mean yield of 8.1 t ha^{-1}. In Kenya, yield of fresh market varieties vary from 4 to 6 t ha^{-1} in smaller holder farms to 14 t ha^{-1} in high input intensive systems of exporting companies (Kimani, 2006). Silbernagel (1986) suggested that breeders should target pod yields of 11 to 16.8 t ha^{-1} in the 21st Century.

3.4.2 Mean Analysis

F_2 and F_3 generation means for duration to flowering was higher than either the highest parent or mid parent in population one, five, ten and eleven. However, for population three and nine, the condition was mostly reversed because the F_2 and F_3 means were lower than the lowest parent or mid-parent (Table 3.5). These results indicated over-dominance or partial dominance for duration to flowering. Similar results were obtained by Singh and Roy (2007), Alam et al., (2008) and Akba et al., (2008) while working on generation mean analysis in maize traits. Shorter duration to flowering indicates early maturity. The F_2 and F_3 generations whose duration to flowering means were lower than the highest parent or mid-parent value indicated positive heterosis to duration to flowering while for those whose means were higher than the highest parent or mid-parent value indicated negative heterosis for duration to flowering. Mohsen et al., (2013) also found negative heterosis for 100 kernel weight, number of leaves, number of leaves above the ear, number of kernels per row, days to silking, days to anthesis and days to physiological maturity while working on generation mean analysis on yield and yield components of maize generations.

3.4.3 Heritability

An important step in determining the utility of a germplasm resource for breeding purpose is to examine the genetic control of the trait(s) of interest in the germplasm. Estimation of trait heritability (h^2), using contrasting parental phenotypes, is one useful approach. This approach helps to determine transgressive segregation and heterosis of the traits evaluated. In this study, narrow-sense heritability values of all the traits across the populations were high and suggested a large contribution of the genetic effects to the phenotypic expression of the traits and that the selection for the traits would be expected to be highly efficient. The heritability varied from 0.42 to 0.94. This imply that the traits namely duration to flowering, pod quality and pod yield are controlled by simple genes and therefore, environmental influence plays no part in their expression. The results were in agreement with Checa et al., (2006) who found broad-sense and narrow-sense heritability values of plant height and internode length in climbing common beans were high. These results are similar to Ortego Ybarra (1968), who found that in three crosses between genotypes with bush (Goiano), prostrate (Costa Rica), and indeterminate (Mexico 50) growth habits, narrow-sense heritabilities for the length of the main stem ranged from 50% to 68%. High narrow-sense heritabilities suggest that all these traits are not highly affected by the environments. This also suggests the possibility of major genes controlling some of these variables. Narrow-sense heritability of duration to flowering ranged from 0.52 to 0.91 across the populations. The mean heritability was 0.77. Narrow sense heritability of time to flowering estimates have ranged from 0.09 to 0.83 (Chung and Stevenson, 1973; Davis and Evans, 1977a; Ortega Y., 1971; Urrea and Singh, 1989). These results disagreed with Checa and Blair (2012) who found narrow-sense heritabilities of days to flowering of climbing beans being 41.1%. Also they found that for some of the yield component traits such as number of pods per raceme and length of pods, heritabilities were slightly lower (59.3 to 68.0%) while for number of pods per plant and for overall yield they were lower still (49.9 and 37.8 % respectively). The latter disagreed with this study because the narrow-sense heritability of pod length ranged from 0.58 to 0.91, number of pods per plant ranged from 0.75 to 0.94 and pod yield ranged from 0.68 to 0.92. This study disagreed with Coyne (1967) and Davis and Evans (1977) who had confirmed the quantitative inheritance of these traits. This study also disagreed with Checa and Blair (2012) who suggested that yield and pod number are polygenic traits with low expression for which heritabilities tend to be low. Bassett and Woods (1978) reported pod length to be controlled by a minimum of four genes with largely additive gene effects and narrow heritability value of 0.55.

3.5 CONCLUSION

This study is the first to report on the heritability of duration to flowering, pod length, pod diameter, number of pods per plant and overall pod yield, all of which are traits of high importance in snap bean breeding. Heritability influences response to selection and optimal stage in the breeding cycle when it is most effective and efficient to conduct selection for target traits. Identification and characterization of modes of heritability of growth habit, duration to flowering, pod quality and pod yield helps in designing breeding schemes for introducing superior genes to elite snap bean germplasm. High narrow-sense heritabilities of the traits are indicative of relatively simple and perhaps qualitative inheritance with few genes involved. Heritability influences response to selection and optimal stage in the breeding cycle when it is most effective and efficient to conduct selection for target traits. Traits with high heritability are not influenced by environment and therefore, they can be phenotypically selected. Such traits can be selected during early generations (F_3 and F_4) compared to traits with low heritability which can only be selected during later generations (F_6 and F_7) increasing cost of carrying out an experiment. When snap bean traits of interest modes of heritability are known, it becomes easier to design breeding schemes for introducing superior genes to elite snap bean germplasm. Although the trial was carried out in a single site, it would be interesting to determine if parent-offspring regression results would be similar in additional environments because genotypes x environment interactions have been reported.

CHAPTER 4

AGRONOMIC PERFORMANCE OF NEW GRAIN TYPE RUNNER BEAN LINES

Abstract

Runner bean (*Phaseolus coccineus* L.), also known as butter bean, is utilized as both vegetables and grain for domestic consumption. Production of grain type runner bean is predominantly undertaken by small-scale farmers for domestic use and canning. Runner bean has been used on many occasions for improving the common bean but in very few cases has its own improvement been addressed, although specialists agree on the hardiness of the species against several fungi, bacteria and viruses. The grain runner bean produced locally are low yielding and susceptible to diseases. Therefore, it is important to develop grain runner bean varieties which are high yielding and resistant to diseases to meet both producer and consumer requirements. The objective of this study was to evaluate disease resistance, grain yield and agronomic traits of new runner bean lines. Fifty lines selected for tropical adaptation, disease resistance and grain yield from 139 $F_{6.8}$ lines grown at Kabete Field Station and KALRO Ol Joro Orok in 2012 and 2013, were evaluated in both sites during 2014 long rain season in a randomized complete block design with three replicates. Twenty of the best lines from both sites were evaluated in an irrigated high input production system at Naivasha Vegpro farm during short rain season, 2014. Data was collected on duration to flowering, vigour, flower set, reaction to diseases and grain yield. Data was analyzed using Genstat software Version 15. Plant vigour and diseases were scored on 1 to 9 scale, where 1 to 3 is resistant/ vigorous, 4 to 6 intermediate and 7 to 9 susceptible/ poor vigour for all the sites. Results showed considerable variation for duration to 50% flowering, plant vigour, racemes per plant, reaction to diseases and grain yield. All the test lines flowered and formed pods under short day conditions at the three locations. Duration to 50% flowering varied from 43 to 49 days in Naivasha, 49 to 53 days in Ol Joro Orok, and from 51 to 55 days in Kabete. The crop was extremely vigorous with a score of one in Naivasha due to adequate and regular supply of water and nutrients. In the low input system at Ol Joro Orok and Kabete, plant vigour ranged from 3 to 6 although plants had lower mean vigour at Kabete. The mean number of racemes per plant in Kabete was 21, at Naivasha 19 and 7 at Ol Joro Orok. There were no disease incidences in Naivasha since the trial was conducted during dry spell which was not conducive for disease development. Major diseases recorded at Kabete and Ol Joro Orok were angular leaf spot, anthracnose, bean common mosaic virus (BCMV), common

bacterial blight (CBB), powdery mildew and rust. Angular leaf spot and BCMV were severe at Ol Joro Orok and varied from 1 to 4 while powdery mildew was severe at Kabete and varied from 1 to 5. Number of pods per plant varied from 16 to 66. Test lines had more pods per plant at Ol Joro Orok than at Kabete. The new lines showed resistant reactions to rust and CBB. Grain yield ranged from 1888 to 7414 kg ha^{-1} in Kabete and Ol Joro Orok under rain-fed condition while under irrigation at Naivasha it ranged from 876 to 14, 472 kg ha^{-1}. Compared with best farmers' variety, the new lines had yield advantage of 80% at Naivasha, 35% at Ol Joro Orok and 32% in Kabete. The results indicated that new high yielding grain runner bean lines with resistance to major diseases and tropical adaptation can be used to address food insecurity and poverty alleviation in the country.

Key words: Disease resistance, grain yield, runner bean

4.1. INTRODUCTION

Grain type runner beans have traditionally been grown by smallholder farmers in Nyandarua and Nakuru Counties mainly for household consumption and sale in urban and rural markets (Suttie, 1969; Kahuro, 1990), and recently for sale to canning factories. Farmers have relied on unimproved climbing type local varieties such as Kinangop 2 and Nyeri 1, and the recently introduced bush type varieties such as Dwarf 2 and Dwarf 3, which are grown mainly in Nyandarua County. Grain runner bean production takes place at high altitudes (>1500m) on small plots that are usually less than 0.25 ha. The crop may be intercropped with maize, but more frequently on pure stands. During 2014, runner bean was grown on 404 ha giving a production of 1,973 t with a value of Kshs 174 million (HCD, 2014). Little interest in production has led to scarcity of accurate production statistics for grain runner bean.

Recently, local canning industries have started canning grain runner bean (Kimani et al., 2009). However, the local varieties are low yielding and susceptible to diseases especially angular leaf spot, anthracnose, common bacterial blight, bean common mosaic virus and powdery mildew. Although local varieties are adapted to short-day conditions, their pods are tough, non-succulent and stringy, and therefore, not suitable for use as vegetables (Kimani et al., 2009). The yield of dry mature seeds in Kenya has been estimated to be 900 to 1120 kg ha^{-1} (Kay, 1979). According to Suttie, (1969) Nyandarua and Nakuru districts are estimated to 500 to 800 t of dry beans per annum. Runner bean has received very little research attention. As a result, there are very few runner bean improvement programs in the world, and virtually none in Eastern Africa (Kimani et al., 2009). The local landraces of grain runner bean are low yielding and susceptible to diseases and farmers shun from growing them because production has become uneconomical. Selection for short day adaptation, high grain yield potential with resistance to diseases suitable for cultivation under tropical conditions has been done (Kimani et al., 2014). Considering the increasing demand for grain runner bean, especially for the canning industries and consumer preferences of a wide range of runner bean types, evaluation of grain runner bean varieties which combine disease resistance and high yield potential will contribute to increased production, food security and poverty alleviation. In addition, it will lead to availability for raw materials to manufacturing industries. Therefore, the objective of this study was to identify agronomically superior lines with less duration to flowering, high number of racemes, resistant to diseases and high grain yield from advanced grain type runner bean lines that were previously selected for short-day adaptation.

4.2. MATERIALS AND METHODS

4.2.1. Plant Materials

One hundred sixty five F_7 advanced grain runner bean lines selected at Kabete Field Station and Ol Joro Orok during 2012/2013 season were used in this study. These lines originated from 1154 single plant selections which were selected from F_5 bulk populations grown at Ol Joro Orok, Subukia and Kabete Field Station during the 2009 long rain season. The best 20 lines from both sites were evaluated in an irrigated high input production system at Naivasha Vegpro farm. Four checks namely, Nyeri, Kin 2, Dwarf 2 and Dwarf 3 were used for comparison. The checks were obtained from local farmers in Nyandarua and Nakuru Counties.

4.2.2. Trial Sites

During 2014 long rain season, experiments were conducted in low input production system sites at Kabete Field Station and KALRO-Ol Joro Orok. The study materials were also evaluated in a high input production system at Naivasha during 2014 short rain season.

4.2.2.1. Kabete Field Station

Kabete Field Station of the University of Nairobi lies at an altitude of 1737 m above sea level and on latitude 1^0 15’ S and longitude 36^0 44’ E (Mburu, 1996). It falls under the Upper

Midland (UM) agro-ecological zone number three (Jaetzold et al, 2006). The area has a bimodal rainfall pattern with peaks in April and November. The annual rainfall is around 1000 mm which is spread over the long rain (March to May) and short rain (October to December) seasons. The site has maximum and minimum mean temperatures of 24.3^0 and 13.7^0C respectively. The dominant soils are Nitosols, which are very deep, well-drained, dark reddish, deep friable clay type resistant to erosion (Jaetzold et al., 2006).

4.2.2.2. Ol Joro Orok

KALRO- Ol Joro Orok research station is located in Nyandarua County. The area has a hilly topography at an altitude of 2400 m above sea level. According to Jaetzold and Schmidt (1983) the area is classified as upper highland wheat-pyrethrum zone. Two major soils are found in the area; moderately well drained, dark reddish brown luvisols ranging from 0.8 to 1.8 m depth, and extremely deep (>1.80 m), well drained, red to reddish-brown nitisols (Kenya Soil Survey, 1982). The soils of the area have a moderate to low fertility. Water holding capacity is moderate with moderate to good soil work-ability (Jaetzold and Schmidt, 1983). The subtropical highland climate of the area is influenced by its proximity to the equator and its altitude (Ojany and Ogendo, 1973). Mean annual rainfall is around 980 mm, with rainfall falling throughout the year and peaks in April and July/ August. The mean temperature ranges from as low as 14^0 to 23^0C throughout the year (Jaetzold et al., 2006).

4.2.2.3. Naivasha Vegpro Farm

Naivasha Vegpro farm is located south of Lake Naivasha ($0^0$50'S, $36^0$22'E) at an altitude of 1940 m above sea level. Average annual rainfall is 685 mm with a bimodal distribution. The first rainy season, also known as the long rains occur between April and the beginning of July. The second rainy season, the short rains, occurs from the end of August to the beginning of December (Fig 4.1). However, occurrence of rainfall is very variable and not reliable. Water from the lake is used for irrigation purposes.

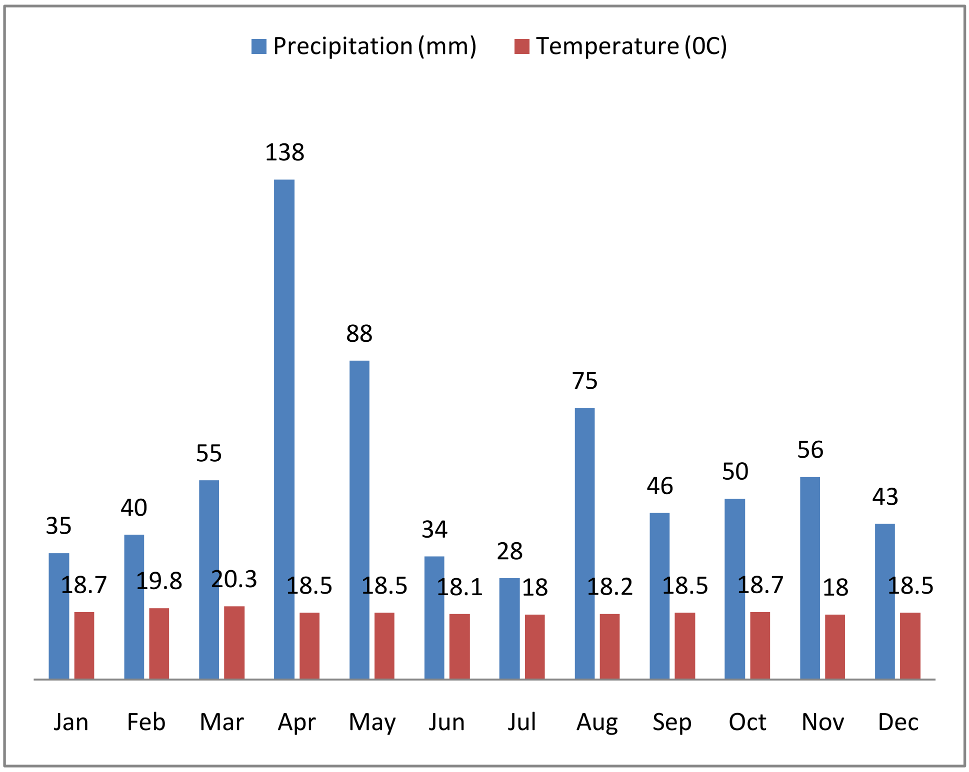


Fig 4. 1: Fifteen year average precipitation and mean temperature for Vegpro farm, Naivasha (Based on data from Jaetzold et al., 2010)

According to the classification made by Jaetzold et al., (2010) Naivasha is partially located within the Livestock-Sorghum Zone (UM5) with very short to short cropping seasons and very uncertain second rainy season and partially in the Lower highland Ranching Zone (LH5), hence the need for irrigation. The UM5 has a good yield potential for crops if farm management and water conservation are of the highest standard. Soil type which is nitisol is classified as well drained, moderately deep to deep, dark brown, friable and slightly smeary, fine gravelly, sandy clay loam to sandy clay, with a humic top soil (Jaetzold et al., 2006).

4.2.3. Experimental design, treatments and crop husbandry

The field experiments were laid out in a randomized complete block design with treatments randomly arranged in each block. Each trial had three replicates. Plants were spaced at 30 cm within rows and 75 cm between rows at KALRO- Ol Joro Orok and Kabete Field Station. A plot consisted two rows each with ten plants leading to a total plant population of 20 plants per 4.5 m^2 or 4.4 plants m^{-2}. Rows were 3 m. At Naivasha Vegpro farm, the row length was three meters at spacing of 30cm by 1 m. The plots had two rows, each with ten plants leading to a total of 20 plants per 6 m^2 or 3.3 plants m^{-2}.

The land of the experiments was ploughed and harrowed so as to achieve a moderate tilth in seed- bed. Di-ammonium phosphate (18-46-0) fertilizer was applied at a rate of 200 kg ha^{-1} and thoroughly mixed with soil. During flowering, the plants were top dressed with calcium ammonium nitrate at a rate of 100 kg ha^{-1}. The fields were kept relatively clean of weeds throughout the growing seasons in both Kabete and Ol Joro Orok sites. In Naivasha Vegpro farm, supplementary irrigation of 600 l $ha-^{1}$ was provided using overhead pivot throughout the season. Irrigation was undertaken three times per week. Therefore, the crop received 50 irrigations for the whole season. Different fertilizers were used interchangeably throughout the season. DAP, urea, calcium nitrate, potassium sulphate, magnesium sulphate, N:P:K 17:17:17, Borax and phosphoric acid fertilizers were each used after every three weeks at a rate of 150 kg ha^{-1}. Gypsum (CaSo4) with active ingredient of SO3-40%: Ca-12% was also applied at a rate of 500 kg ha^{-1}. Pest control was undertaken due to high prevalence of aphids, thrips and white flies. Several chemicals were applied to control the above pests. Apron Star 42WS chemical with active ingredient of Thiamethoxam, 0.3 kg ha^{-1} rate of application was applied once per week to control white flies. Actara 25WG chemical with active ingredient of Thiamethoxam, 0.15 kg ha^{-1} rate of application was applied once in every two weeks to control aphids, thrips and white flies. Chess 50WG chemical with active ingredient of Pymetrozine, 0.3 kg ha^{-1} rate of application was applied once per two weeks to control aphids, thrips and white flies. Foliar feeds were also applied to boost vegetative growth of the crop. Symbion K, Calmabon, Super nitrohumic, Calmagro and Polyfeed were used weekly at a rate of 3 l ha^{-1}. The chemicals were applied by boom sprayers.

4.2.4. Data Collection

Data on duration to 50% flowering, plant vigour, number of racemes per plant, disease resistance, pods per plant and grain yield were recorded using standard system for the evaluation of bean germplasm described by van Schoonhoven and Pastor-Corales, (1987). Disease and vigour scoring was done from flowering to pod filling stages using a nine point severity scale (1-9), where a score of 1 to 3 was considered resistant/ vigorous, 4 to 6 intermediate resistance/ vigour, and 7 to 9 as susceptible/ poor vigour. The test lines were screened for natural epiphytotics of angular leaf spot, anthracnose, bean common mosaic virus (BCMV), common bacterial blight (CBB), powdery mildew and rust. Days to flowering were recorded as number of days from planting to when approximately 50% plants in a plot had at least one opened flower. Yield was determined by counting the number of pods per plant and harvesting all the plants in a plot and recording the weight of the dry grains by use of top loading laboratory weighing balance (Delmer, Z-2 Budget, Vadodara, Gujarat, India).

4.2.5. Data Analysis

All data was subjected to analysis of variance in Genstat software (v. 15, VSN, UK, 2010) with replicates and genotypes as factors and the measurements as variables. Data from each site was analyzed separately. Fisher's least significant difference at 1 and 5% probability levels was used for mean separation.

4.3. RESULTS

4.3.1. Weather

Weather data was obtained from Kabete weather station, KALRO-Ol Joro Orok weather station and Delamere Vegpro farm weather station. Kabete received a total of about 473 mm of rain during the long rain season, Ol Joro Orok received a total of about 625 mm and Naivasha received a total of about 348 mm. The mean temperatures were 18.7 ^{0}C (Kabete), 15.1 ^{0}C (Ol Joro Orok) and 19 ^{0}C (Naivasha) (Appendix 1 and 2). The highest rain was received in Ol Joro Orok while the lowest was received in Naivasha. Mean rainfall in Naivasha was very low apart from the last month of the growing season and this necessitated use of irrigation throughout the growing season. The highest mean temperature was recorded in Naivasha (19 ^{0}C) compared to Kabete (18.7 ^{0}C) and Ol Joro Orok (15.1 ^{0}C) (Appendix 1 and 2). The mean rainfall in Kabete was too low as compared to rainfall description of Jaetzold et al., 2006. The mean temperature was almost the same as that of Jaetzold et al., (2006). Mean rainfall in Ol Joro Orok was also lower than Jaetzold et al., (2006) rainfall description but he mean temperature was within the range of 14 to 23 ^{0}C. Mean rainfall in Naivasha is almost half the mean rainfall description of Jaetzold et al., (2006). However the mean temperature was within the range of 18 to 20 ^{0}C.

4.3.2. Days to 50% flowering

Days to 50% flowering varied significantly among advanced lines ($p<0.01$) in both Kabete and Ol Joro Orok (Table 4.6 and 4.7). Site varied significantly ($P<0.05$). There was interaction between genotypes and sites ($P<0.05$). However, there were no significant differences for duration to flowering among the advanced lines at Naivasha (Table 4.8). At Ol Joro Orok, duration to flowering varied from 49 to 53 days with a mean of 50 days. In

Kabete, duration to flowering ranged from 50 to 55 days with a mean of 52 days. The test lines took longer to flowering at Kabete compared to Ol Joro Orok (Appendix 6). The check varieties flowered in 49 to 50 days. The earliest check to flower was Nyeri and the latest was Kin 2. Some of the new lines such as KAB-RB13-321-190/1, KAB-RB13-301-174 and SUB-OL-RB13-312-252 were as early maturing as the checks. Dwarfs flowered earlier than most of the climbing types. Duration to flowering in Naivasha ranged from 42 to 49 days with a mean of 45.2 days. Nyeri and Kin 2 reached 50% flowering in 48 to 49 days. However, three new lines (KAB-RB13-408-220/1, KAB-RB13-364-212/1 and KAB-RB13-319-182/4) flowered earlier at Naivasha than the check varieties (Table 4.2). There was no correlation between 50% duration to flowering and other traits (Table 4.9).

4.3.3. Vigour

There were significant differences ($p<0.01$) in plant vigour among the new lines at Kabete and Ol Joro Orok (Table 4.6 and 4.7). There were no significant differences between sites. There was no interaction between genotypes and sites. However, there were no significant differences among advanced lines in Naivasha (Table 4.8). In both Ol Joro Orok and Kabete, vigour ranged from 3 to 6. Kabete lines had slightly poorer vigour than Ol Joro Orok lines (Appendix 6) KAB-RB13-329-166, KAB-RB13-364-212/2 and KAB-RB13-334-130 were among the new lines with the best vigour across the sites. At Naivasha, all the lines rated vigorous with a score of one (Table 4.2). A clear effect of crop management practises was observed. Vigour correlated negatively with number of racemes per plant ($r= -0.42$, $P=0.01$), pods per plant ($r= -0.24$, $P=0.05$) and grain yield ($r= -0.27$, $P=0.01$) (Table 4.9).

4.3.4. Number of racemes per plant

Number of racemes per plant varied significantly ($p<0.01$) among the new lines at both Kabete and Ol Joro Orok (Tables 4.6 and 4.7). There were no significant differences between sites. Also there was no interaction between genotypes and sites. However, there were no significant differences among new lines at Naivasha (Table 4.8). In Ol Joro Orok, the number of racemes per plant varied from 3 to 14, compared to 11 to 34 at Kabete, and 13 to 23 at Naivasha. The highest number of racemes per plant was recorded in Kabete while the least was in Ol Joro Orok (Tables 4.1, 4.2 and Appendix 6). Most of the lines in all sites had higher number of racemes per plant than the checks. This is clear evidence that selection for short day adaptation was effective i.e. the lines flowered normally without any extended lighting. Among the check varieties, Kin 2 had the highest number of racemes per plant

(16.9). Dwarf 3 formed the least number of racemes. Ten new lines had more racemes per plant than the best check (Kin 2). KAB-RB13-326-207, SUB-OL-RB13-312-252 and KAB-RB13-334-137 lines showed the most profuse flowering at Kabete and Ol Joro Orok (Table 4.1). However, KAB-RB13-403-149, KAB-RB13-364-212/1 and KAB-RB13-364-212/2 lines were the best flowering in Naivasha (Table 4.2). There was positive correlation between number of racemes per plant and grain yield (r= 0.32, P=0.01).

Table 4. 1: Duration to 50% flowering, vigour and number of racemes per plant of grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season

Genotype	50% DF			Vigour			No. of racemes plant^{-1}		
	OJ[§]	KAB[§]	Mean	OJ	KAB	Mean	OJ	KAB	Mean
KAB-RB13-297-144/2	50.7	52.3	51.5	4.3	4.3	4.3	8	22.7	15.3
KAB-RB13-308-217	50.3	51	50.7	3.7	4.3	4	6	26.5	16.3
KAB-RB13-312-160	50.7	53	51.8	3.7	4.3	4	7	24.9	15.9
KAB-RB13-313-127/1	49	50.7	49.8	3.3	5	4.2	9	26.9	18
KAB-RB13-313-127/2	50	51.7	50.8	4	4.3	4.2	10	25.2	17.6
KAB-RB13-321-185/1	48.7	52	50.3	4.3	5	4.7	11	18.8	14.9
KAB-RB13-321-185/2	49.7	52	50.8	2.7	5	3.8	14	22	18
KAB-RB13-321-190/1	49.7	50	49.8	4.3	4.3	4.3	13	19.8	16.4
KAB-RB13-321-190/2	49.3	51	50.2	3.7	5.7	4.7	8	22.5	15.3
KAB-RB13-326-207	49	50	49.5	3.3	4.3	3.8	12	33.9	22.9
KAB-RB13-329-163/1	49.7	50.7	50.2	4	3.7	3.8	5	28.3	16.7
KAB-RB13-329-167	51	51.3	51.2	4	5	4.5	6	29.3	17.6
KAB-RB13-329-172	52	50.7	51.3	4	4.3	4.2	7	30.4	18.7
KAB-RB13-333-223	51.3	51.3	51.3	4	5	4.5	7	23.3	15.1
KAB-RB13-334-130	49.3	50.7	50	3.3	3.7	3.5	7	23.4	15.2
KAB-RB13-334-137	49.3	52.7	51	3.3	4.3	3.8	9	28.7	18.8
KAB-RB13-364-212/2	49.3	51	50.2	2.7	3.7	3.2	10	29.3	19.6
KAB-RB13-399-219/1	51	52	51.5	3.7	4.3	4	5	28	16.5
KAB-RB13-403-153/1	50	52	51	4.7	5	4.8	9	26.8	17.9
SUB-OL-RB13-312-252	49	49.3	49.2	4	4.3	4.2	12	33.1	22.5
Check									
Nyeri	48.7	49.7	49.2	4.7	5.7	5.2	12	17.5	14.7
KIN 2	49.3	51.3	50.3	4	5	4.5	13	20.9	16.9

Continued: Duration to 50% flowering, vigour and number of racemes per plant of grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season

	50% DF			Vigour			No. of racemes $plant^{-1}$		
Genotype	**OJ[§]**	**KAB[§]**	**Mean**	**OJ**	**KAB**	**Mean**	**OJ**	**KAB**	**Mean**
OL-Dwarf 2	49.7	50.3	50	5.7	5.7	5.7	10	11.1	10.6
OL-Dwarf 3	50.7	49.7	50.2	6.3	5.7	6	6	6.6	6.3
Trial Mean	50.3	52.2	51.3	4	4.7	4.4	7	21.1	14.1
$LSD_{0.05}$ (G)	2.2	2.5	1.9	1.3	1.9	1.4	4.9	16	10.4
$LSD_{0.05}$ (S)			1.7			2.1			16.1
$LSD_{0.05}$ (G x S)			2.3			2			14.6
CV (%)	1.2	3		6.4	15.5		21.7	22.7	

DF-duration to flowering, LSD- least significant difference, CV-coefficient variation, [§]OJ- Ol Joro Orok, KAB-Kabete, G-genotype, S-site, G x S-Genotype x Site

Table 4. 2: Duration to 50% flowering, vigour and number of racemes per plant of advanced grain runner bean lines grown at Naivasha Vegpro farm under irrigation

Genotype	**50% DF**	**Vigour**	**No. of racemes plant^{-1}**
KAB-RB13-120-123/2	47	1	17
KAB-RB13-294-204/1	47	1	19
KAB-RB13-294-204/2	43	1	18
KAB-RB13-301-171/2	44	1	17
KAB-RB13-309-224/1	47	1	18
KAB-RB13-309-224/2	47	1	21
KAB-RB13-319-182/1	47	1	18
KAB-RB13-319-182/2	44	1	21
KAB-RB13-319-182/3	47	1	13
KAB-RB13-319-182/4	43	1	17
KAB-RB13-329-165	47	1	17
KAB-RB13-333-223/1	46	1	18
KAB-RB13-333-223/2	49	1	18
KAB-RB13-364-212/1	42	1	22
KAB-RB13-364-212/2	43	1	22
KAB-RB13-399-219/2	49	1	16
KAB-RB13-403-149	44	1	23
KAB-RB13-408-220/1	42	1	21
KAB-RB13-408-220/2	45	1	17
KAB-RB13-48-17	45	1	21
Check			
Nyeri	48	1	15
KIN 2	49	1	21
Mean	45.2	1.0	18.7
LSD $_{0.05}$	8.0	0.0	5.1
CV (%)	8.4	0.0	13.0

DF-duration to flowering, LSD- least significant difference, CV-coefficient variation,

4.3.5. Reaction of new lines to major diseases under field conditions

There were significant differences ($p<0.05$ and $p<0.01$) in reaction of the advanced lines to angular leaf spot, BCMV and CBB at Kabete and Ol Joro Orok (Tables 4.6 and 4.7). Sites varied significantly for angular leaf spot, BCMV, CBB and rust ($P<0.01$). Sites varied significantly for anthracnose ($P<0.05$) (Table 4.6). There was interaction between genotypes and sites for angular leaf spot, anthracnose, BCMV and powdery mildew. There was no interaction for CBB and rust. In Naivasha, there were no diseases because the trial was conducted during a dry spell which was not favourable for disease development. Angular leaf spot, anthracnose and BCMV were the most prevalent diseases in Ol Joro Orok while powdery mildew was the most prevalent in Kabete (Appendix 7). Forty four lines were rated resistant to the major diseases while seven lines had intermediate resistance. However, there were no lines which were susceptible to the major diseases. Most of the lines were comparable with some checks on disease reactions. Most of the new lines were resistant compared with checks (Dwarf 2 and Dwarf 3) which had intermediate resistance (Table 4.3). Incidence of rust and CBB was low among the new lines at both sites.

Table 4. 3: Reaction of new grain runner bean lines to six major diseases at Kabete and Ol Joro Orok during 2014 long rain season.

	Disease score									
	ALS		Anthracnose		BCMV		CBB		Powdery mildew	
Genotype	**OJ***	**KAB***	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**
KAB-OL-RB13-426-228	2	1	2	1	2	1	1	1	2	2
KAB-RB13-120-123/1	2	1	2	1	2	1	1	1	1	2
KAB-RB13-120-123/2	2	1	2	1	4	1	1	1	1	2
KAB-RB13-297-144/1	2	1	1	1	1	2	1	1	1	3
KAB-RB13-297-144/2	2	1	1	1	4	1	1	1	2	3
KAB-RB13-303-151	2	1	1	1	1	1	1	1	1	2
KAB-RB13-308-217	2	1	1	1	3	1	2	1	1	2
KAB-RB13-312-160	2	1	2	1	2	1	1	2	1	1
KAB-RB13-313-127/1	2	1	1	1	1	1	2	1	1	2
KAB-RB13-321-190/1	2	2	1	1	2	1	1	1	1	3
KAB-RB13-321-190/2	2	1	2	1	3	1	1	1	1	2
KAB-RB13-326-207	2	2	2	1	1	1	1	1	1	2
KAB-RB13-329-163/1	2	2	2	1	1	1	1	1	1	2
KAB-RB13-329-164	2	1	1	1	1	2	1	1	1	1
KAB-RB13-329-166	2	1	2	1	1	1	1	1	1	2
KAB-RB13-329-167	2	2	1	1	3	1	1	1	1	2
KAB-RB13-329-172	2	2	3	1	1	2	1	1	1	1
KAB-RB13-331-225	2	1	2	1	1	1	1	1	1	1
KAB-RB13-334-130	2	1	2	1	2	2	1	1	1	2
KAB-RB13-334-137	2	1	1	1	1	1	1	1	1	2
Check										
Nyeri	3	2	2	1	1	2	2	1	1	1
KIN 2	3	1	3	1	2	1	1	1	2	2

Continued: Reaction of new grain runner bean lines to six major diseases at Kabete and Ol Joro Orok during 2014 long rain season.

	Disease score									
	ALS		Anthracnose		BCMV		CBB		Powdery mildew	
Genotype	**OJ***	**KAB***	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**
OL-Dwarf 2	3	1	2	1	3	1	4	1	1	2
OL-Dwarf 3	4	3	1	1	1	1	3	1	2	2
Trial Mean	2.6	1.2	1.9	1	1.8	1.3	1.3	1.1	1.2	1.9
$LSD_{0.05}$ (G)	1.5	0.7	1.5	0.3	1.7	0.9	1.1	0.6	0.9	1.3
$LSD_{0.05}$ (S)	0.6		0.5		0.2		0.1		1.2	
$LSD_{0.05}$ (G x S)	1.2		1.1		1.3		0.8		1.3	
CV (%)	4.1	12.4	10.7	2.5	4.7	9.9	8.8	8.2	10.3	19.9

ALS-angular leaf spot, BCMV-bean common mosaic virus, CBB-common bacterial blight, LSD-least significant differences, CV-coefficient variation, *OJ-Ol Joro Orok, KAB-Kabete, G-genotype, S-site, G x S-Genotype x Site

4.3.6. Pods per plant

Advanced lines grown at Ol Joro Orok and Naivasha showed significant differences ($p<0.05$) for pods per plant (Tables 4.7 and 4.8). Sites varied significantly for pods per plant ($P<0.05$). There was no interaction between genotypes and sites. In Ol Joro Orok, pods per plant varied from 23 to 66 (KAB-RB13-46-19, SUB-OL-RB13-96-237 and KAB-RB13-301-171/2), compared to 14 to 30 pods plant-^{1} at Kabete and 2 to 31 at Naivasha (KAB-RB13-333-223/1 and KAB-RB13-294-204/1) (Table 4.4, 4.5 and Appendix 8). The highest number of pods per plant was recorded at Ol Joro Orok (35) while the lowest was recorded at Naivasha (15). Eleven lines in Ol Joro Orok, 24 lines in Kabete and six lines in Naivasha had higher number of pods per plant than the checks (Table 4.4, 4.5 and Appendix 8). KAB-RB13-108-125 and KAB-OL-RB13-426-228 were the outstanding lines in Ol Joro Orok, KAB-RB13-399-219/2, KAB-RB13-329-172 and KAB-RB13-333-223 in Kabete and KAB-RB13-294-204/2 and KAB-RB13-364-212/1 in Naivasha.

4.3.7. Grain yield

Advanced lines and local checks grown in all sites showed significant differences in yield potential. Sites varied significantly for grain yield ($P<0.05$). There was no interaction between genotypes and sites. The highest mean grain yields were recorded at Naivasha (7254 kg ha-^{1}) and lowest at Kabete (3034 kg ha-^{1}). In Ol Joro Orok, grain yield ranged from 2622 to 7414 kg ha^{-1}, compared to 1675 to 4104 kg ha^{-1} at Kabete, and 876 to 14,472 kg ha^{-1} at Naivasha (Tables 4.4, 4.5 and Appendix 8). The new lines had a yield advantage of 80% at Naivasha compared with the checks. However, the new lines yield advantage was 35% at Ol Joro Orok and 32% at Kabete. Sixteen lines had average yield of more than 3820 kg ha^{-1} for the two sites (Kabete and Ol Joro Orok) compared to the best check, Nyeri, (3808 kgha^{-1}). However, in Naivasha, all the lines apart from one had higher grain yield than the checks. The best lines in terms of average grain yield in Kabete and Ol Joro Orok were KAB-RB13-155-122 (5,017 kg ha^{-1}), KAB-OL-RB13-426-228 (4,686 kg ha^{-1}) and KAB-RB13-120-123/1(4611 kg ha^{-1}). The best lines in Naivasha were KAB-RB13-294-204/2, (14,472 kg ha^{-1}) KAB-RB13-364-212/1 (12,496 kgha^{-1}) and KAB-RB13-364-212/2 (10,923 kgha^{-1}) (Tables 4.4 and 4.5). Grain yield and pods per plant were highly positively correlated ($r= 0.9$, $P=0.01$).

4.3.8. Genetic diversity of grain runner bean lines for evaluation of agronomic performance

Cluster analysis of 48 grain runner bean lines and their parents revealed two clusters. The four check varieties (KIN 2, OL-DWARF 3, OL-DWARF 1 and NYERI) fell in the first cluster (Appendix 23). They are land races collected from farmers' fields in Nyandarua and Nyeri counties. All the bred lines fell into the second cluster. The first cluster flowered later with an average days to flowering of (51.9) compared to the second cluster with days to 50% flowering of 51.7. The genotypes in the first cluster had a vigour score of 5 compared to 3 in the second cluster. Genotypes in the first cluster had an average of 10.3 racemes per plant compared with 16.9 for the second. The genotypes in the first cluster had lower number of pods per plant (18) and grain yield (2217.6 kg ha^{-1}) compared with 19 pods per plan and 2511.3 kg ha^{-1} in the second.

Table 4. 4: Pods per plant and grain yield of advanced grain runner bean lines grown at Kabete and Ol Joro Orok during 2014 long rain season.

	Pod $plant^{-1}$			Grain yield (kg ha^{-1})		
Genotype	**OJ***	**KAB***	**Mean**	**OJ**	**KAB**	**Mean**
KAB-OL-RB13-426-228	55	16	36	7414	1958.5	4686.2
KAB-RB13-108-125	63	19	41	6351.5	2776.3	4563.9
KAB-RB13-120-123/1	51	24	37	6300.6	2921.7	4611.1
KAB-RB13-120-123/2	54	21	38	6035.2	2933.7	4484.4
KAB-RB13-155-122	40	32	36	5986.4	4048.4	5017.4
KAB-RB13-293-209	39	24	31	5310.6	3138.2	4224.4
KAB-RB13-297-144/1	41	26	34	5299.6	3726.8	4513.2
KAB-RB13-297-144/2	34	18	26	5294.7	2443	3868.9
KAB-RB13-301-171/1	32	23	27	5200.1	3452	4326
KAB-RB13-301-171/2	66	19	43	5198.1	2380	3789.1
KAB-RB13-308-217	35	19	27	5090.1	2565.3	3827.7
KAB-RB13-312-160	41	27	34	5042.8	3771	4406.9
KAB-RB13-313-127/1	38	21	30	4922.6	2951.5	3937.1
KAB-RB13-313-127/2	32	29	31	4821.7	3368.2	4095
KAB-RB13-321-185/2	52	19	36	4776	2639.4	3707.7
KAB-RB13-321-190/1	39	16	28	4775.3	2611.3	3693.3
KAB-RB13-321-190/2	38	28	33	4626.6	4032.3	4329.5
KAB-RB13-329-163/1	43	27	35	4422.6	3398.7	3910.7
KAB-RB13-329-172	35	30	32	4015	3695	3855
KAB-RB13-333-223	28	30	29	3643.4	4104.3	3873.9
Check						
Nyeri	40	20	30	4830.2	2785.7	3808

Continued: Pods per plant and grain yield of advanced grain runner bean lines grown at Kabete and Ol Joro Orok during 2014 long rain season.

	Pod plant^{-1}			Grain yield (kg ha^{-1})		
Genotype	**OJ***	**KAB***	**Mean**	**OJ**	**KAB**	**Mean**
KIN 2	33	22	28	3464.3	2249.4	2856.8
OL-Dwarf 2	32	13	23	2875.9	1895.1	2385.5
OL-Dwarf 3	22	15	18	1833.3	1834.6	1833.9
Trial Mean	35	23	29	4153	3034.6	3593.8
LSD$_{0.05}$ (G)	22	14	15.3	2904.8	2276.9	2101.9
LSD $_{0.05}$ (S)			9.7			1142.1
LSD $_{0.05}$ (G x S)			18			2461.7
CV (%)	5.2	7		2.4	10.1	

LSD- least significant difference, CV-coefficient variation, *OJ- Ol Joro Orok, KAB-Kabete, G-genotype, S-site, G x S-Genotype x Site

Table 4. 5: Pod per plant and grain yield of advanced grain runner bean lines grown at Naivasha Vegpro Farm during 2014 short rain season under irrigation

Genotype	**Pod plant^{-1}**	**Grain yield (kg ha^{-1})**
KAB-RB13-120-123/2	10	4239
KAB-RB13-294-204/1	17	7436
KAB-RB13-294-204/2	31	14472
KAB-RB13-301-171/2	15	4743
KAB-RB13-309-224/1	11	5584
KAB-RB13-309-224/2	16	6811
KAB-RB13-319-182/1	11	5826
KAB-RB13-319-182/2	13	7172
KAB-RB13-319-182/3	7	2944
KAB-RB13-319-182/4	16	8153
KAB-RB13-329-165	17	8866
KAB-RB13-333-223/1	2	876
KAB-RB13-333-223/2	10	4248
KAB-RB13-364-212/1	30	12496
KAB-RB13-364-212/2	21	10923
KAB-RB13-399-219/2	10	4224
KAB-RB13-403-149	19	9869
KAB-RB13-408-220/1	21	10580

Continued: Pod per plant and grain yield of advanced grain runner bean lines grown at Naivasha Vegpro Farm during 2014 short rain season under irrigation

Genotype	**Pod plant^{-1}**	**Grain yield (kg ha^{-1})**
KAB-RB13-408-220/2	22	10120
KAB-RB13-48-17	11	5496
Check		
Nyeri	16	2732
KIN 2	18	2944
Mean	15.4	7254.0
LSD $_{0.05}$	14.0	7293.6
CV%	13.1	12.8

LSD- least significant difference, CV-coefficient variation,

Table 4. 6: Mean squares of duration to flowering, vigour, number of racemes per plant, diseases, pods per plant and pod yield of grain runner bean lines grown at Kabete Field Station during 2014 long rain season

Source of variation	**df**	**Days to flowering**	**Vigour**	**No. of racemes plant^{-1}**	**Angular leaf spot**	**Anthracnose**	**BCMV**	**CBB**	**Powdery mildew**	**Rust**	**Pod plant^{-1}**	**Pod yield (kg ha^{-1})**
Replicates	2	5.91	68.621	2802	2.596	0.07627	2.0678	0.9915	17.5621	0	265.6	11106610
Genotype	117	6.083**	1.095^{ns}	103.55^{ns}	0.2416^{ns}	0.04078**	0.3529^{ns}	0.134^{ns}	2.9113**	0	84.89^{ns}	1593503^{ns}
Site	1	215*	48.5_{ns}	12363_{ns}	149.5**	55.8*	24.8**	2**	38.1_{ns}	12.3**	14548*	128809731*
G x S	115	2.7*	1_{ns}	55.2_{ns}	0.8*	0.7*	1.2**	0.4_{ns}	1.3**	0.2_{ns}	155.5_{ns}	2395556_{ns}
Error	234	2.374	1.431	96.8	0.1943	0.02499	0.3071	0.134	0.6533	0	74.87	2003381

*, ** and ns 0.05, 0.01 significance probability level and not significant respectively, df-degree of freedom, BCMV- bean common mosaic virus, CBB- common bacterial blight, G x S-Genotype x Site

Table 4. 7: Mean squares of duration to flowering, vigour, number of racemes per plant, diseases, pods per plant and pod yield of grain runner bean lines grown at KALRO Ol Joro Orok during 2014 long rain season

Source of variation	df	Days to flowering	Vigour	No. of racemes plant^{-1}	Angular leaf spot	Anthracnose	BCMV	CBB	Powdery mildew	Rust	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	2	19.377	3.4025	133.653	0.6101	2.1572	0.358	0.6478	0.8365	0.0818	179	538915
Genotype	52	3.935**	1.4265**	24**	1.4649**	1.1766^{ns}	2.104**	1.021**	0.4115^{ns}	0.4069^{ns}	295.8*	4069084^{ns}
Site	1	215*	48.5_{ns}	12363_{ns}	149.5**	55.8*	24.8**	2**	38.1_{ns}	12.3**	14548*	128809731*
G x S	115	2.7*	1_{ns}	55.2_{ns}	0.8*	0.7*	1.2**	0.4_{ns}	1.3**	0.2_{ns}	155.5_{ns}	2395556_{ns}
Error	104	1.82	0.6141	9.053	0.8216	0.8239	1.128	0.4619	0.3237	0.4087	184.2	3218486

*, ** and ns 0.05, 0.01 significance probability level and not significant respectively, df-degree of freedom, BCMV- bean common mosaic virus, CBB- common bacterial blight, G x S-Genotype x Site

Table 4. 8: Mean squares of duration to flowering, vigour, number of racemes per plant, pods per plant and pod yield of grain runner bean lines grown at Naivasha Vegpro farm during 2014 short rain season

Source of variation	df	Days to flowering	Vigour	No. of racemes plant^{-1}	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	3.6	0	19.881	81.51	17146331
Genotype	19	9.49^{ns}	0	12.188^{ns}	104.57*	23535242^{ns}
Error	19	14.55	0	5.926	44.96	12143351

* , **, ns 0.05, 0.01significance probability level and not significant, df-degree of freedom

Table 4. 9: Correlation matrix among agronomic traits of grain runner bean lines

	50% duration to flowering	Number of racemes plant^{-1}	Pods pant^{-1}	Vigour	Grain yield (kg ha^{-1})
50% duration to flowering	1				
Number of racemes plant^{-1}	-0.1725	1			
Pods pant^{-1}	0.0386	0.2783**	1		
Vigour	0.1339	-0.423**	-0.2424*	1	
Grain yield kg ha^{-1}	0.0348	0.317**	0.9001**	-0.2713**	1

4.4. DISCUSSION

4.4.1. 50% days to flowering

The significant differences for days to flowering in advanced lines in Kabete and Ol Joro Orok can be attributed to genetic differences among genotypes. In Naivasha, where higher temperatures were recorded, genotypes flowered earlier (Appendix 2). However, the genotypes flowered later at Kabete and Ol Joro Orok due to lower temperatures (Appendix 1). Grain type runner bean has received very little research attention. As a result there are very few runner bean improvement programs in the world, and virtually none in Eastern Africa (Kimani et al., 2009). Consequently there is little published data to facilitate comparison. However, there is considerable data on common bean, its close relative. According to Wallace et al, (1991) days to flowering of common beans is influenced by the temperature which alters the rate of vegetative development and cause faster flower development under higher temperatures. George (1988) found that under higher elevations with lower temperatures, duration to flowering in common bean and soybean crop tended to be longer. The duration to flowering ranged from 49 to 53 days and 50 to 55 days in Ol Joro Orok and Kabete respectively. This was in agreement with Kimani et al, (2014) who found the duration to flowering in runner bean lines ranging from 49 to 53 days at Ol Joro Orok and 46 to 54 days at Kabete. Duration to flowering in Naivasha ranged from 42 to 49 days. The results differed with Mulanya et al., (2014) and Kimani and Mulanya (2014) probably due to differences in environmental conditions. Some of the lines can be classified as early maturing due to shorter number of days to flowering while others classified as late maturing due to longer days to flowering. Maturity is important to producers because it determines the harvesting time of the crop. Early maturity enhances profitability of the crop because it is able to get to market before the late maturing crops hence avoiding glut. There were no differences in flowering between bush and climbing runner bean types.

4.4.2. Vigour

The new lines showed significant differences in plant vigour at Kabete and Ol Joro Orok. However, there were no significant differences in plant vigour among advanced lines grown in Naivasha. The crops were highly vigorous probably due to higher soil fertility through input application, wetter conditions and efficient crop protection which favour growth of runner beans. There was low vigour in both Kabete and Ol Joro Orok probably due to low fertility and scarcity of water during the growing season. Kabete received 472.6 mm of rainfall from planting to maturity; Ol Joro Orok received 625.3 mm while Naivasha received 348 mm. The low vigour in Kabete and Ol Joro Orok could be associated to dry spells that were experienced in both sites. Ol Joro Orok experienced dry spell for the first three months after planting while Kabete experienced intermittent dry spell (two months after one month from planting and the last three months before maturity) (Appendix 1). Negative correlation between vigour and number of racemes per plant, pods per plant and grain yield implies that when the crop is too vigorous tend to have high flower abortion reducing the number of racemes per plant, pods per plant and grain yield. This occurs probably due to lack of light penetration leading to flower abortion.

4.4.3. Number of racemes per plant

One of the objectives of the runner bean program at the University of Nairobi is to develop tropically adapted runner bean varieties that can flower and form pods without extended artificial lighting. Results of this study indicate that the new lines meet this objective. Virtually all the new study lines flowered normally at Ol Joro Orok, Kabete and Naivasha without any extended light. This implies that selection of short day plants from segregating populations derived from crosses between long day and short day parents was effective as evidenced by formation of racemes. Results showed that number of racemes formed was influenced by prevailing environmental conditions at each test site.

High number of racemes per plant in Kabete can be explained by cooler weather experienced at the beginning of the season. Low number of racemes per plant in Naivasha was as a result of flower abortion due to heat stress. Maximum temperature at Naivasha during flowering ranged from 28 to 32 ^{0}C compared to average temperature of 18.7 ^{0}C in Kabete and 15.1 ^{0}C in Ol Joro Orok. The results were in agreement with Mulanya et al., (2014) who found that number of racemes per plant of runner bean lines grown in Kabete was low due to water stress that was experienced during the trial period. Low number of racemes per plant in Ol Joro Orok can be explained by moisture stress experienced during the beginning of the season. These results disagreed with Mulanya et al., (2014) who found the number of racemes per plant in runner bean lines grown in Ol Joro Orok during 2013 were more than those in Kabete. The explanation was cooler climate with abundant rainfall which increases number of racemes and grain yield. Hadjichristodoulou, (1990) reported that runner beans are adapted to cooler climates and that in areas with high temperatures seed yields are low due to poor flowering. However, they give satisfactory yields when planted at cooler areas with low temperatures. Positive correlation between number of racemes per plant and grain yield implies that when there is low flower abortion the grain yield tend to increase.

4.4.4. Reaction of new lines to major diseases

Development of runner bean varieties with resistance to major diseases is a major objective of the runner bean breeding program at the University of Nairobi. Runner bean is known to be susceptible to seed borne bacterial disease (*Pseudomonas phaseolicola*), fusarium wilt (*Fusarium oxysporum*), bean rust (*Uromyces phaseoli*) and anthracnose (*Colletotrichum lindemuthianum*) (Kay, 1979). In Kenya, runner bean has been reported to be susceptible to rust, aschochyta, anthracnose, bean common mosaic virus and common bacterial blight (Kimani et al, 2008; Kimani and Mulanya, 2014). Results of this study showed that there are significant differences in reactions to infection by angular leaf spot, CBB, BCMV and powdery mildew. Test lines showed higher levels of resistance compared with checks. According to Blink, (2006) runner beans are known to have resistance to diseases and mostly used to improve common bean in disease resistance. This research was in agreement with Kimani et al, (2014) who found that earlier generations of these runner bean lines grown at Kabete were resistant to BCMV, CBB and rust.

4.4.5. Pods per plant

Pods per plant is major determinant of the productivity of most legume crops. Results of this study showed that there are significant differences in pods per plant among the new runner bean lines and test locations. Differences in pod load were most evident at Naivasha and Ol Joro Orok. Number of pods per plant varied from 23 to 63 in Ol Joro Orok and 2 to 30 in Naivasha. Pods per plant are influenced by the number of racemes per plant. However, the higher number of racemes per plant in Kabete was not reflected in pods per plant. This could be probably due to flower abortion because of water stress. In Naivasha, there was low number of racemes and pod per plant despite high levels of nutrients and enough soil moisture. This was probably due to high vegetative growth hindering access of enough sunlight. This was evidenced by observing high number of racemes on the upper side of the runner bean canopy facing the sunlight. Failure of the crop to obtain enough sunlight led to flower abortion and few pods. High positive correlation between pods per plant and grain yield is expected because the higher the number of pods per plant the higher the number of seeds hence the higher the grain yield.

4.4.6. Pod yield

Although runner bean has traditionally grown in Kenya, there has been no genetic improvement of the yield potential of local varieties. Several reports indicate the yield range of local runner bean varieties in Kenya is between 600 to 1300 kg ha-1 (Suttie, 1969; Kay, 1979; Kahuro, 1990). However, Kimani and Mulanya (2014) reported that yield of the new locally bred grain type runner bean lines were significantly higher compared to farmer's varieties. Results of this study seem to confirm previous reports. Yield of the new lines varied from 1,833.3 to 7,414 kg ha^{-1} at Ol Joro Orok, 1,674.5 to 4,104.3 kg ha^{-1} at Kabete and 876 to 14,472 kg ha^{-1} at Naivasha. The results indicated that the new lines had a yield advantage of 32 to 80% across sites. High number of pods per plant resulted to high grain yield in Ol Joro Orok and low number of pods per plant in Kabete resulted to low grain yield. However, number of pods per plant in Naivasha was low but resulted to high grain yield. According to Emmam et al, (2010) and Gebeyehu, (2006), effect of yield is due to adverse effects on yield components such as number of pods per plant, number of seeds per pod and seed mass. High grain yield despite low pod per plant in Naivasha could be due to high number of seeds per pod and high seed mass due to availability of enough soil moisture through irrigation. The average grain yield was in agreement with Kimani et al, (2014) who found the grain yield of runner bean lines grown in Kabete and Ol Joro Orok during 2013 to range from 8910 to 9908 kg ha^{-1}. Higher yield in Ol Joro Orok than at Kabete could be due to cooler and wetter climate experienced in the area. Mulanya and Kimani, (2014) reported that runner bean lines grown at Ol Joro Orok had higher racemes per plant and pod yield due to cooler climate and enough rainfall.

4.5. CONCLUSION

Agronomic performance of the grain runner bean genotypes revealed that they are adapted to the short day and that is why they were able to flower without additional light. This proves that selection for adaptation to short-day was effective. Runner beans have been reported to be affected by major diseases such as angular leaf spot, anthracnose, BCMV, CBB, powdery mildew, rust among others. Such diseases have hindered productivity due to increased cost of production. The new lines are resistant to most of the major diseases and this would improve productivity and adoption of the crop production by smallholders. The local varieties of runner bean are known to be low yielding especially the dwarf varieties. Low grain yield makes production of runner bean uneconomical to smallholders and therefore, low adoption. The new lines have proved to be high yielding and they will address food insecurity and poverty in the country.

Among the advanced grain runner bean lines, several lines which showed better yields than the local varieties have been identified. These lines include: KAB-RB13-294-204/2, KAB-RB13-364-212/1, KAB-RB13-364-212/2 (Naivasha), KAB-OL-RB13-426-228, KAB-RB13-108-125, KAB-RB13-120-123/1, KAB-RB13-120-123/2 and KAB-RB13-155-122 (Ol Joro Orok and Kabete). The check variety (Nyeri) was comparable to some of the new lines in Ol Joro Orok (KAB-RB13-313-127/1, KAB-RB13-312-160 and KAB-RB13-308-217) and Kabete (KAB-RB13-329-167, KAB-RB13-334-137 and KAB-RB13-341-134).

Selection of new lines on agronomic performance have aided in the identification of agronomically superior lines from the available germplasm. Considering the recorded variation in agronomic performance of these lines, evaluation of these lines for traits related to grain quality such as cooking time, water absorption, hard-shell defect and canning and sensory attributes, to identify bean lines that meet requirements of the producer and the consumers, would contribute to increasing the utilization and commercialization of the grain runner bean crop.

CHAPTER 5

POD YIELD, POD QUALITY AND DISEASE RESISTANCE OF NEW TROPICALLY ADAPTED VEGETABLE RUNNER BEAN LINES DEVELOPED IN KENYA

Abstract

Development of tropically adapted, high yielding, disease resistant vegetable runner bean (*Phaseolus coccineus* L) varieties can reduce production costs, facilitate local seed production and enhance the competiveness of Kenyan products in domestic and export markets. The objective of this study was to evaluate new locally developed short-day vegetable runner bean lines for pod quality, pod yield and resistance to diseases. Fifty new vegetable runner bean lines and one commercial variety were evaluated at Ol-Joro-Orok and Kabete Field Station during the long rain season of 2014 in a randomized complete block design with three replicates. Eighteen of the best lines from both sites were evaluated in an irrigated high input production system at Naivasha Vegpro farm. Ten pods per plot were randomly selected and evaluated for pod length, pod curvature, pod yield and resistance to rust, angular leaf spot, anthracnose and common bacterial blight. The pods were graded according to fresh produce standard commercial classes. Pod yield was determined as the cumulative weight from all the harvests. A disease score of 1 to 9, where 1-3 is resistant, 4-5 intermediate and 6-9 susceptible was used to determine the disease severity. The data was subjected to ANOVA and the means separated by Fishers Protected Least significant difference (LSD) test at $P<0.05$.

Results showed significant ($P<0.05$) differences among the test lines for pod yield, pod quality and disease resistance across the sites. All the test lines flowered and formed pods under short day conditions at the three locations. Duration to flowering varied from 43 to 48 days in Naivasha, 49 to 55 days in Kabete and 48 to 54 days in Ol Joro Orok. The crop was extremely vigorous at Naivasha due to adequate and regular supply of water, nutrients and efficient crop protection. In the low input system vigour varied from 2 to 3 at Ol Joro Orok and 4 to 7 at Kabete. The mean number of racemes per plant in Kabete was 6, 10 at Ol Joro Orok and eight at Naivasha. There were no diseases at Naivasha because the trial was conducted during dry spell (Sep 2014) which was not conducive for disease development. Major diseases recorded at Kabete and Ol Joro Orok were angular leaf spot, anthracnose, bean common mosaic virus (BCMV), common bacterial blight (CBB), powdery mildew and rust. Angular leaf spot was severe at Ol Joro Orok. However, there were no diseases which were severe in Kabete. Number of pods per plant varied from 3 to 11 in Naivasha, 5 to 23 in Ol Joro Orok and 1 to 20 in Kabete. Most of the new lines across the sites had higher pod yield compared with commercial variety, White Emergo. Outstanding lines included KAB-RB13-1-105/2 (18,354kg ha^{-1}) and KAB-RB13-1-105/3(10,114ha^{-1}) while White Emergo produced a cumulative pod yield of 896 kg ha^{-1}. KAB-RB13-1-105/3 had the highest percentage of grade I pods (93.9%). Twenty six new lines in Ol Joro Orok, 13 in Naivasha and sixty two in Kabete were comparable to White Emergo for pod curvature (straight) and met market pod length requirement of 18 cm. The new lines were resistant to major diseases such as angular leaf spot, rust, anthracnose, BCMV, CBB and powdery mildew while the commercial variety was susceptible to angular leaf spot, common bacterial blight and powdery mildew. KAB-RB13312-37 had the highest pod yield at Ol Joro Orok (16,884 kg ha^{-1}), where White Emergo produced 5,401.5 kg ha^{-1}. Pod length and diameter ranged from 18 to 22.7cm and 1.8 to 2.4cm respectively. High pod yield, pod quality and disease resistance of these lines can contribute to increased productivity, reduction in production costs and enhance competitiveness of local products in domestic and export markets.

Key words: Disease resistance, pod quality, pod yield, vegetable runner bean

5.1 INTRODUCTION

Runner beans have shown considerable promise as an export crop due to decline of the domestic production in Western Europe as a result of increasing costs of production. This creates an opportunity for Kenya to expand and take advantage of relatively low cost of production and favourable climatic conditions. However, the potential is hindered by photoperiod sensitivity because the imported varieties fail to flower and set pods under natural day length. This problem is probably due to selection of cultivars that are adapted to long days for summer production in United Kingdom (Kimani, 1999). The imported varieties meet the consumers demand like taste, shape, tenderness, physical appearance, cooking and eating qualities which are lacking in local varieties produced for grain type for domestic consumption. According to Kahuro (1990) the white seeded Kenyan cultivar flowers and sets pods at altitudes of 1860m and above but it’s produced mainly for dry seeds. Its pod quality is not suitable for vegetable export markets because the pods are stringy and curved.

No improved vegetable or grain type runner bean varieties have been developed in Kenya because of the limited breeding work. The two cultivars can only be reconciled through breeding due to their differences in various aspects i.e. local cultivars are well adapted to natural day length but not suitable for vegetable runner bean export markets. However, imported cultivars, though acceptable to consumers are poorly adapted to production under natural day length. Selection for short day adaptation and market preferred pod quality has been done in University of Nairobi (Mulanya et al., 2014). Most of the lines evaluated were highly resistant to prevalent diseases such as angular leaf spot, anthracnose, powdery mildew, common bacterial blight, bean common mosaic virus and rust among others. Most of the genotypes were high yielding with pod yield of more than 1000 kg ha^{-1} per harvest (Mulanya et al., 2014). Therefore, evaluation and selection for yield potential, pod quality and disease resistance becomes important to reduce the cost of production. This can improve production and competitiveness of the Kenyan products in the export markets while expanding the areas under runner bean production. Use of imported varieties and high cost of production has eliminated small scale growers from the market. Therefore, development of short-day high quality runner bean varieties which can be accessed by all farmers' country wide is critical.

The objective of this study was to evaluate new locally developed short-day vegetable runner bean lines for pod quality, pod yield and resistance to diseases.

5.2. MATERIALS AND METHODS

5.2.1. Plant Materials

One hundred and thirteen and 49 F_7 new vegetable runner bean lines selected at Kabete Field Station and Ol Joro Orok respectively during 2012/2013 season were used in this study. The materials (162 lines) were evaluated both at Kabete Field Station and KALRO-Ol Joro Orok. These lines originated from 1154 single plant selections which were selected from F_5 bulk populations grown at Ol Joro Orok, Subukia and Kabete Field Station during the 2009 long rain season. The best 20 lines from both sites were evaluated at Naivasha Vegpro farm in an irrigated high input production system. One check namely, White Emergo which is a commercial long-day imported variety was used for comparison.

5.2.2. Trial Sites

The site description was similar to 4.2.2 section

5.2.3. Experimental design, treatments and crop husbandry

Experimental design and crop management was carried out similar to 4.2.3 section.

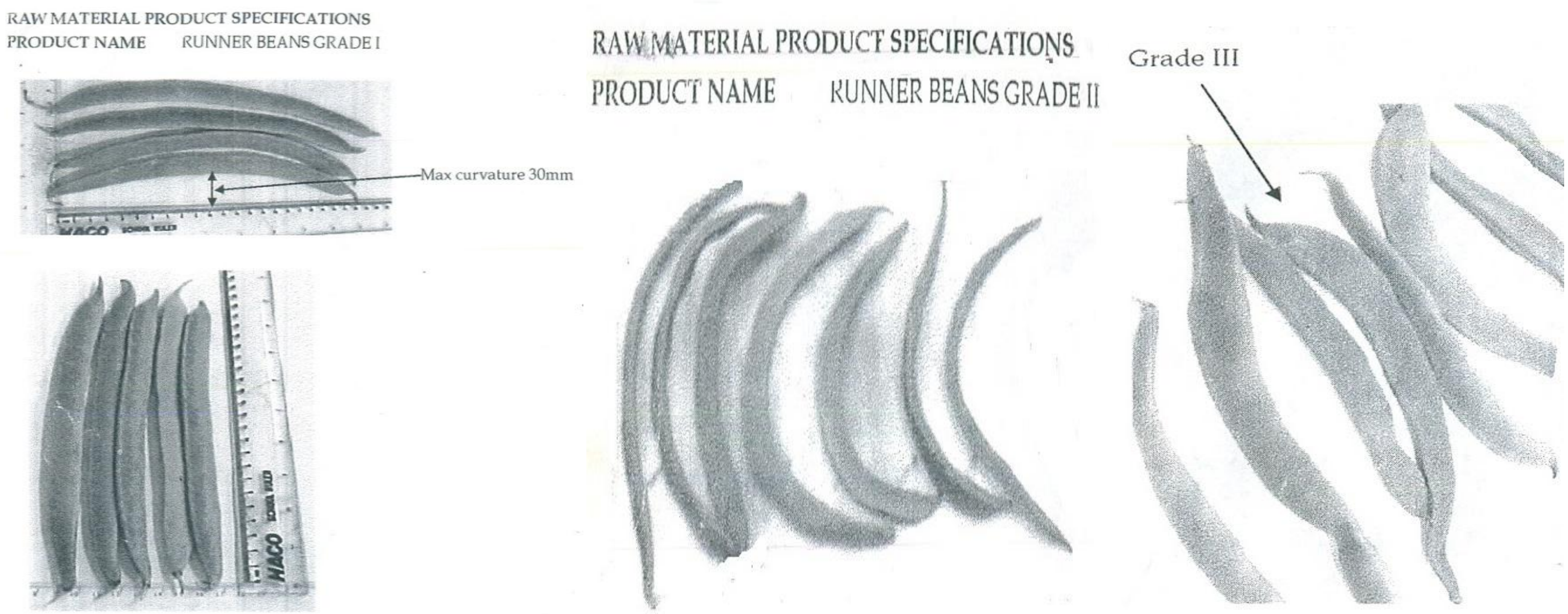
5.2.4. Data Collection

Data on duration to 50% flowering, plant vigour, number of racemes per plant and disease resistance were recorded using standard system for the evaluation of bean germplasm described by van Schoonhoven and Pastor-Corales, (1987). Vigour scoring was done from flowering to pod filling stages using a nine point hedonic scale (1-9), where a score of 1 to 3 was considered vigorous, 4 to 6 intermediate vigour, and 7 to 9 as poor vigour. The test lines were screened for natural epiphytotics of angular leaf spot, anthracnose, bean common mosaic virus (BCMV), common bacterial blight (CBB), powdery mildew and rust. A disease score of 1 to 9 was used to determine the disease severity according to Schoonhoven and Pastor (1987) where 1-3=resistant, 4-6=intermediate resistant, and 7-9=susceptible (Fig 5.1). The sites were chosen for disease screening because the environmental conditions provide conducive environment for development of diseases making them hotspots for the diseases. Days to flowering were recorded as number of days from planting to when approximately 50% plants in a plot had at least one opened flower. Harvesting was done twice per week at an interval of three days (Monday and Thursday).

The pods were graded according to fresh produce standard commercial classes (Fig 5.2). **Grade I** consisted of whole green and young tender pods, flat, very straight pods of length 18-27cm, easily broken by hand, free from pests, diseases, no seeds and maximum curvature of 30 mm; **Grade II** was young green tender pods, easily broken, flat, slightly curved, length of 18- 27 cm and free from pests and diseases, and **Grade III** =broken beans, beans have necks, seeded beans and those shorter than 18cm (Sunripe Company Manual, 2013). The harvested pods were weighed by use of top loading laboratory weighing balance (Delmer, Z-2 Budget, Vadodara, Gujarat, India) to determine pod yield per plant. Cumulative weight of pods per plant in each plot was used to estimate pod yield per ha.

Rating	Category	Description	Comments
1-3	Resistant	No visible symptoms or light symptoms (2% of the leaf)	Germplasm useful as a parent or commercial variety
4-6	Intermediate	Visible and conspicuous symptoms (2-5% of the leaf)resulting only in limited economic damage	Germplasm can be used as commercial variety or source of resistance to diseases
7-9	Susceptible	Severe to very severe symptoms (10-25% of the leaf) causing yield losses or plant death	Germplasm in most cases not useful as parent or commercial variety

Fig 5. 1: General scale used to evaluate the reaction of bean germplasm to fungal and diseases (van Schoonhoven and Pastor-Corrales, 1987).



GRADE I

GRADE II

GRADE III

Fig 5. 2: Pod grading according to Sun ripe Fresh Produce Company

5.2.5. Data Analysis

All data was subjected to analysis of variance in Genstat software (v. 15, VSN, UK, 2010) with replicates and genotypes as factors and the measurements as variables. Data from each site was analyzed separately. Fisher's Protected Least significant difference at 1 and 5% probability levels was used for mean separation.

5.3 RESULTS

5.3.1 Weather

Weather data during the experiment period is presented in section 4.3.1.

5.3.2 Duration to flowering

There were significant differences for 50% days to flowering among the new lines (Tables 5.12 to 5.14). Sites varied significantly for 50% days to flowering ($P<0.01$). There was interaction between genotypes and sites. The days to flowering varied from 49 to 55 days in Kabete, 48 to 54 days in Ol Joro Orok and 43 to 48 days in Naivasha (Tables 5.3, Appendix 9 and 10). The test lines took longer to flower in Kabete (52.6 days) compared to Ol Joro Orok (50 days) and Naivasha (45 days). The check variety, White Emergo flowered within 52 days in Kabete, 48 days in Ol Joro Orok and 36 days in Naivasha. However, White Emergo and Equator checks took 38 and 47 days to flower under extended light at Naivasha respectively (Table 5.3). Thirty five lines in Kabete flowered earlier than the check while three lines in Ol Joro Orok flowered as early as the check and thirteen lines in Naivasha flowered earlier than Equator check. White Emergo with light and without light were the earliest checks to flower in Naivasha (Table 5.3). KAB-RB13-302-100/1 line was the earliest to flower in Kabete, KAB-RB13-363-131 and KAB-RB13-363-54 in Ol Joro Orok and KAB-RB13-380-55/1 in Naivasha (Tables 5.1, 5.2 and 5.3). There was positive correlation between 50% duration to flowering and number of racemes per plant ($r= 0.3^{**}$) (Table 5.15).

5.3.3. Plant vigour

There were significant differences ($P<0.01$) for vigour among the test lines in Kabete and Ol Joro Orok (Tables 5.12 and 5.13). Site varied significantly but there was no interaction between genotypes and sites. However, there were no significant differences among advanced lines in Naivasha (Table 5.3). Plant vigour varied from 5 to 8 in Kabete and 2 to 3 in Ol Joro Orok. Kabete lines had slightly poorer vigour than Ol Joro Orok lines (Tables 5.1, 5.2, Appendix 9 and 10). At Naivasha, all the lines were rated vigorous with score of one (Table 5.3). It was a clear effect of good crop management practices was observed.

5.3.4. Number of racemes per plant

Number of racemes per plant varied significantly (P<0.01) among the new lines in all the sites (Tables 5.12 to 5.14). There were no significant differences between sites. In addition there was no interaction between genotypes and sites. In Kabete, the number of racemes per plant varied from 1 to 18 compared to 3 to 16 in Ol Joro Orok and 6 to 11 in Naivasha. The highest mean number of racemes per plant was recorded in Ol Joro Orok while the lowest was in Kabete (Tables 5.1, 5.2, Appendix 9 and 10). Most of the lines in all the sites had higher number of racemes per plant than the checks. White Emergo check had the highest number of racemes per plant (10) in Ol Joro Orok. KAB-RB13-327-48, KAB-RB13-294-24 and KAB-RB13-302-100/2 lines showed the most profuse flowering at Kabete and KAB-RB13-363-131, SUB-RB13-240-126/2 and SUB-RB13-271-78/2 lines in Ol Joro Orok and SUB-RB13-106-12/1A at Naivasha (Tables 5.1, 5.2 and 5.3).

Table 5. 1: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Days to flowering	Vigour	No. of racemes per plant
KAB-RB13-294-24	50	6.3	13
KAB-RB13-299-43/2	51.3	7	13
KAB-RB13-301-39	51.3	5.7	11
KAB-RB13-302-100/2	53.3	5	13
KAB-RB13-305-130/2	49.7	4.3	10
KAB-RB13-30-87	54.3	6.3	10
KAB-RB13-309-62	54.3	6.3	11
KAB-RB13-311-102/1	52.7	6.3	12
KAB-RB13-314-91	52.7	7	10
KAB-RB13-327-48	50.7	5.7	18
KAB-RB13-329-108/2	53.3	5.7	12
KAB-RB13-330-116/2	52.7	5.7	11
KAB-RB13-330-116/3	51.7	5	11
KAB-RB13-331-66/1	52	6.3	12
KAB-RB13-331-66/2	53.7	5.7	13
KAB-RB13-331-66/3	52.3	6.3	12
SUB-RB13-117-68	52	5.7	11
SUB-RB13-133-80/1	50.3	5.7	12
SUB-RB13-240-125/2	51.3	6.3	13

SUB-RB13-240-126/3	52.3	7	12
Check			
W. Emergo	52.3	6.3	5
Trial Mean	52.6	6.1	6
LSD $_{0.05}$ Genotype	1	0.6	2.7
CV (%)	3.5	16.9	18.7

LSD-least significant difference, CV-coefficient variation

Table 5. 2: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	**Days to flowering**	**Vigour**	**No. of racemes plant^{-1}**
KAB-RB13-1-105/1	49	3	12
KAB-RB13-299-43	49	2	10
KAB-RB13-301-39	48	3	15
KAB-RB13-312-37	49	3	14
KAB-RB13-318-34	49	3	11
KAB-RB13-320-104/3	50	2	11
KAB-RB13-320-104/4	50	2	14
KAB-RB13-331-66/1	49	3	11
KAB-RB13-331-66/2	49	3	11
KAB-RB13-363-131	48	3	15
KAB-RB13-363-54	48	3	13
KAB-RB13-364-97/1	49	2	14
KAB-RB13-470-72	49	3	11
KAB-RB13-471-117	49	3	12
KAB-RB13-85-18	49	3	13
OL-RB13-21-2/1	49	2	13
SUB-RB13-106-12/1	49	2	11
SUB-RB13-106-12/2	49	2	11
SUB-RB13-240-126/2	49	3	16
SUB-RB13-271-78/2	49	3	15
Check			
W. Emergo	48	4	10
Trial Mean	50	3	10
LSD $_{0.05}$ Genotype	1	1	3
CV (%)	2	3	9

LSD-least significant difference, CV-coefficient variation

Table 5. 3: Duration to flowering, vigour and number of racemes per plant of vegetable runner bean lines grown at Naivasha Vegpro farm during 2014 short rain season

Genotype	**Days to flowering**	**Vigour**	**No. of racemes plant^{-1}**
KAB-RB13-1-105/2	46	1	10
KAB-RB13-311-103/1	46	1	9
KAB-RB13-312-35/1	47	1	7
KAB-RB13-320-104/1	46	1	10
KAB-RB13-327-92/4	46	1	8
KAB-RB13-380-55/1	43	1	9
KAB-RB13-380-56/1	47	1	8
KAB-RB13-46-22/1	46	1	6
KAB-RB13-471-118/1	45	1	8
KAB-RB13-471-118/2	48	1	7
KAB-RB13-64-107/1	45	1	10
KAB-RB13-64-107/2	43	1	10
KAB-RB13-85-18/1	46	1	7
KAB-RB13-85-18/2	45	1	8
OL-RB13-21-2/3	48	1	10
SUB-RB13-106-12/1A	46	1	11
SUB-RB13-133-80/2	48	1	7
SUB-RB13-133-80/3	46	1	6
Check			
Equator	47	1	7
W. Emergo (with light)	38	1	6
W. Emergo (without light)	36	1	2
Trial Mean	45.0	0.0	7.9
LSD $_{0.05}$ Genotype	0.9	0.0	0.6
CV (%)	2.6	0.0	11.0

LSD-least significant difference, CV-coefficient variation

5.3.5. Reaction of new lines to major diseases

There were significant differences (P<0.01) in reaction of the advanced lines to angular leaf spot, anthracnose, BCMV, CBB, powdery mildew and rust in Kabete and Ol Joro Orok (Tables 5.4 and 5.5). Sites varied significantly for angular leaf spot, powdery mildew and rust (Table 5.12). However, there was no interaction between genotypes and sites for all the diseases. In Naivasha, there were no incidences of diseases because the trial was conducted during a dry spell (Sep 2014) which was not favourable for disease development. However, severity of diseases varies with seasons. All the lines across the sites had a disease score of 1 to 3 which means they were resistant to all the diseases. However, White Emergo check had intermediate resistance (4 to 6) for all the diseases in Kabete and Ol Joro Orok (Tables 5.4, 5.5, Appendices 11 and 12).

Table 5. 4: Reaction of vegetable runner bean lines to major diseases at Kabete Field Station during 2014 long rain season

	Disease score					
Genotype	**ALS**	**Anth**	**BCMV**	**CBB**	**Powdery mildew**	**Rust**
KAB-RB13-129-121/1	1	2	1	1	1	1
KAB-RB13-138-38	1	2	2	1	1	1
KAB-RB13-240-119	1	2	1	1	1	1
KAB-RB13-308-114	2	3	1	1	2	1
KAB-RB13-327-48	1	2	2	1	2	1
KAB-RB13-338-38	1	2	1	1	1	1
KAB-RB13-364-97/1	1	2	2	1	1	1
KAB-RB13-379-33	1	2	2	1	2	1
KAB-RB13-380-56/2	1	2	1	1	2	1
KAB-RB13-403-88/1	1	2	1	1	1	1
KAB-RB13-46-22/2	1	2	1	1	1	1
KAB-RB13-470-72	1	2	2	1	1	1
KAB-RB13-471-118/4	1	2	2	1	2	1
KAB-RB13-471-118/5	1	2	2	1	1	1
KAB-RB13-64-107/2	1	2	1	1	1	1
KAB-RB13-64-107/3	1	2	1	1	1	1
SUB-RB13-106-12/2	1	2	1	1	2	1
SUB-RB13-234-13/2	1	2	1	1	1	1
SUB-RB13-240-126/1	1	2	2	1	1	1
SUB-RB13-271-78	2	3	1	1	1	1
Check						
W. Emergo	4	4	5	4	5	4
Trial Mean	1.56	1.39	1.46	1.19	1.33	1

LSD $_{0.05}$ Genotype	1.38	0.31	0.33	0.23	0.21	0
CV %	45	41.3	42.2	35.7	29.2	0

LSD-least significant difference, CV-coefficient variation, Anth-anthracnose, ALS-angular leaf spot, BCMV-bean common mosaic virus, CBB-common bacterial blight

Table 5. 5: Reaction of vegetable runner bean lines to major diseases at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	ALS	Anth	BCMV	CBB	Powdery mildew	Rust
KAB-RB13-1-105/1	3	2	1	1	1	2
KAB-RB13-1-105/2	2	1	1	1	1	1
KAB-RB13-1-105/3	3	1	1	1	1	2
KAB-RB13-1-105/4	2	2	1	1	1	2
KAB-RB13-129-121	2	1	2	1	1	2
KAB-RB13-294-24	2	1	2	1	1	1
KAB-RB13-299-43	2	1	1	1	2	1
KAB-RB13-301-39	3	1	2	1	1	2
KAB-RB13-305-130/1	3	2	2	1	1	2
KAB-RB13-305-130/2	2	1	1	1	1	2
KAB-RB13-311-103	2	2	1	2	1	2
KAB-RB13-312-37	3	1	1	2	1	2
KAB-RB13-320-104/4	3	1	1	1	1	2
KAB-RB13-331-66/1	3	2	1	1	1	2
KAB-RB13-331-66/2	3	1	1	1	1	1
KAB-RB13-363-131	3	2	2	1	1	1
OL-RB13-21-2/1	3	1	1	1	1	3
SUB-RB13-106-12/2	3	1	1	1	2	2
SUB-RB13-133-80/1	3	2	1	1	1	2
SUB-RB13-234-13	3	2	2	1	1	2
Check						
W. Emergo	5	4	5	3	4	6
Trial Mean	2	1	2	1	1	2
LSD $_{0.05}$ Genotype	0.8	0.7	0.8	0.4	0.3	0.8
CV%	3.4	10.4	3.9	6.2	4.7	6

LSD-least significant difference, CV-coefficient variation, Anth-anthracnose, ALS-angular leaf spot, BCMV-bean common mosaic virus, CBB-common bacterial blight

5.3.6. Pod length, pod diameter and pod curvature

There were significant differences ($P<0.01$) in pod length and pod diameter among the new lines across the sites (Table 5.12 to 5.14). Sites varied significantly for pod length and pod diameter (P<0.01). Also there was interaction between genotypes and sites for the two traits (Table 5.12). Pod length varied from 16.6 to 21.3 cm with a mean of 20 cm in Kabete (Appendix 13). In Ol Joro Orok, pod length varied from 18.2 to 22.7 cm with a mean of 19.8cm (Appendix 14). However, pods in Naivasha had the shortest length among the three sites. They varied from 16.2 to 18.8 cm with a mean of 18.4 cm (Table 5.8). KAB-RB13-129-121/2 and KAB-RB13-1-105/3 lines had the longest pods in Kabete, SUB-RB13-133-80/1 and KAB-RB13-363-131 lines in Ol Joro Orok and SUB-RB13-133-80/2 and OL-RB13-21-2/3 lines in Naivasha (Tables 5.6, 5.7 and 5.8). Pod diameter varied from 2 to 2.5 cm with a mean of 2 cm in Kabete. In Ol Joro Orok, pod diameter varied from 1.8 to 2.2 cm with a mean of 2.1 cm. In Naivasha, pod length varied from 1.7 to 2.2 cm with a mean of 1.9 cm. Twenty eight lines in Kabete and 22 lines in Ol Joro Orok had longer pod length than the check (Appendices 13 and 14). However, two lines in Naivasha had longer pod length than White Emergo without light and Equator checks (Table 5.8). Pod curvature ranged from markedly curved to straight across the sites. More than 80 percent of the lines across the sites had as straight pods as the checks (Table 5.6, 5.7 and 5.8).

Table 5. 6: Pod quality of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-1-105/3	20.8	2.4	Straight
KAB-RB13-129-121/2	21.3	2	Markedly curved
KAB-RB13-296-111/1	19.9	2.5	Slightly curved
KAB-RB13-299-43/1	19.6	2.4	Straight
KAB-RB13-308-114	20.8	2.4	Straight
KAB-RB13-310-86	20.3	2	curved
KAB-RB13-311-103/2	19.9	2.5	Slightly curved
KAB-RB13-311-103/5	19.6	2.4	Straight
KAB-RB13-320-104/4	20.8	2.4	Straight
KAB-RB13-331-112	19.9	2.5	Slightly curved
KAB-RB133-312-37	19.6	2.4	Straight
KAB-RB13-339-95	20.8	2.4	Straight
KAB-RB13-363-131	20.3	2	Markedly curved
KAB-RB13-364-97/2	19.9	2.5	Slightly curved
KAB-RB13-380-55	19.6	2.4	Straight
KAB-RB13-446-5	20.8	2.4	Straight
KAB-RB13-471-118/3	19.9	2.5	Slightly curved
KAB-RB13-97-14	20.8	2.4	Straight

Continued: Pod quality of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
SUB-RB13-133-11	19.9	2.5	Slightly curved
SUB-RB13-240-126/3	20.8	2.4	Straight
Check			
W. Emergo	19.4	2.3	Straight
Trial Mean	20	2	
LSD $_{0.05}$ Genotype	0.3	1.4	
CV %	5.6	3.9	

LSD-least significant difference, CV-coefficient variation,

Table 5. 7: Pod quality of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-1-105/3	21.3	2	Straight
KAB-RB13-1-105/4	20.4	2	Slightly curved
KAB-RB13-305-130/1	21	2	Straight
KAB-RB13-309-62	21.6	2.1	Straight
KAB-RB13-312-35	20.9	2	Straight
KAB-RB13-331-66/2	20.4	2	Slightly curved
KAB-RB13-363-131	22.7	2.1	Straight
KAB-RB13-46-22/1	20.1	2.2	Straight
KAB-RB13-46-22/2	20.4	2.1	Straight
KAB-RB13-470-72	21	2.3	Slightly curved
KAB-RB13-471-118/2	21	2.2	Straight
KAB-RB13-471-118/4	20.2	2.2	Slightly curved
KAB-RB13-649-70	20.2	2	Straight
KAB-RB13-85-18	20.3	2	Slightly curved
OL-RB13-21-2/1	20.4	2	Straight
OL-RB13-21-2/2	21.1	2	Slightly curved
SUB-RB13-133-80/1	22.5	2.2	Slightly curved
SUB-RB13-133-80/2	20.3	2.2	Slightly curved
SUB-RB13-234-13	20.8	2.3	Straight
SUB-RB13-240-125/1	20.5	2.2	Straight
Check			
W. Emergo	20	2	Straight
Trial Mean	19.8	2	
LSD $_{0.05}$ Genotype	0.2	1.2	

CV (%)	5.2	3.8

LSD-least significant difference, CV-coefficient variation,

Table 5. 8: Pod quality of vegetable runner bean lines grown at Naivasha Vegpro farm during 2014 short rain season

Genotype	Pod length (cm)	Pod diameter (mm)	Pod curvature
KAB-RB13-1-105/2	18.0	2.0	Straight
KAB-RB13-311-103/1	17.2	1.9	Straight
KAB-RB13-312-35/1	17.5	2.0	Straight
KAB-RB13-320-104/1	17.6	1.9	Straight
KAB-RB13-327-92/4	16.7	1.9	Straight
KAB-RB13-380-55/1	16.9	2.2	Slightly curved
KAB-RB13-380-56/1	17.6	2.1	Straight
KAB-RB13-46-22/1	18.3	2.0	Straight
KAB-RB13-471-118/1	18.4	1.9	Slightly curved
KAB-RB13-471-118/2	17.4	1.7	Slightly curved
KAB-RB13-64-107/1	17.3	2.1	Slightly curved
KAB-RB13-64-107/2	16.9	1.9	Straight
KAB-RB13-85-18/1	18.5	1.9	Straight
KAB-RB13-85-18/2	16.2	1.9	Straight
OL-RB13-21-2/3	18.8	1.8	Straight
SUB-RB13-106-12/1A	17.8	1.9	Straight
SUB-RB13-133-80/2	18.9	1.8	Slightly curved
SUB-RB13-133-80/3	17.5	1.9	Straight
Check			
Equator	18.5	1.8	Straight
W. Emergo (with light)	19.2	2.0	Straight
W. Emergo (without light)	18.2	2.3	Straight
Trial Mean	18.4	1.9	
LSD $_{0.05}$ Genotype	0.5	0.1	
CV (%)	3.4	4.1	

LSD-least significant difference, CV-coefficient variation,

5.3.7. Pods per plant

Pods per plant varied significantly among the new lines in all the sites (Tables 5.12, 5.13 and 5.14). There were no significant differences between sites. There was interaction between genotypes and sites. Kabete lines had the least mean pods per plant across the sites (3.7) (Appendix 15). The highest mean pods per plant were recorded in Ol Joro Orok (9). The mean pods per plant in Naivasha were 6.5. KAB-RB13-1-105/2 and KAB-RB13-379-33 lines were among those with the highest number of pods per plant in Kabete, KAB-RB13-312-35, KAB-RB13-312-37 and KAB-RB13-46-22/1 lines in Ol Joro Orok and KAB-RB13-380-56/1 and KAB-RB13-311-103/1 lines in Naivasha (Tables 5.9, 5.10 and 5.11). In Kabete, only 11 lines had lower number of pods per plant than the check while 24 lines in Ol Joro Orok had higher number of pods per plant than the check. Six lines in Naivasha had higher pods per plant than White Emergo without light check (Tables 5.11, Appendix 15 and 16).

5.3.8. Pod yield

There were significant differences ($P<0.01$) for pod yield among the new lines across the sites (Tables 5.12, 5.13 and 5.14). Sites varied significantly for pod yield ($P<0.05$). There was interaction between genotypes and sites for pod yield (Table 5.12). The new vegetable runner bean lines were far much better in terms of yield than the check, White Emergo at Kabete. KAB-RB13-1-105/2 and KAB-RB13-1-105/3 were among the high yielder with pod yield of 18,353 and 10,114 kg ha^{-1} respectively (Table 5.9). The yield for the new lines in Kabete varied from 474.2 to 18,353 kg ha^{-1} (Appendix 15). Some new lines had high yields across the sites e.g. KAB-RB13-1-105/2 and KAB-RB13-1-105/3 (Tables 5.9 and 5.10). Pod yield in Ol Joro Orok varied from 1818 kg ha^{-1} (KAB-RB13-320-104/1) to 16884 kg ha^{-1} (KAB-RB13-312-37) (Appendix 16). Pod yield in Naivasha varied from 2443.1 kg ha^{-1} (KAB-RB13-64-107/2) to 8678.7 kg ha^{-1} (OL-RB13-21-2/3) (Table 5.11). Grade I and grade II market classes are the marketable classes. Most of the new lines have high percentage of grade II as opposed to grade I. Some of the new lines were comparable to check on percentage distribution of the pod yield. Some of the new lines had very high percentage of grade I e.g. KAB-RB13-1-105/3 and SUB-RB13-133-80/2 had percentage pod yield distribution of 93.9% and 81.5% respectively (Table 5.9). The highest mean pod yield was recorded in Ol Joro Orok (6,174 kg ha^{-1}) (Table 5.10). However, Naivasha had mean pod yield of 5,085 kg ha^{-1} while Kabete had 3,535 kg ha^{-1}. Ninety two lines at Kabete and thirty four lines at Ol Joro Orok had higher yield than the check (Appendix 15 and 16). However, only seven lines at Naivasha out yielded White Emergo without light check. Equator check was comparable to one of the new lines in terms of yield. White Emergo with light check had higher pod yield (10632.6 kg ha^{-1}) than the new lines in Naivasha (Table 5.11). There was positive correlation between pods per plant and pod yield (r= 0.61**) (Table 5.15).

5.3.9. Genetic diversity of vegetable runner bean lines

Cluster analysis of 43 vegetable runner bean lines and White Emergo, check revealed three clusters. The check, White Emergo was obtained from Vegpro farm in Naivasha, a company which does commercial production of vegetable runner bean for export market. The first cluster had the longest days to 50% flowering (53.2) compared to second (52) and third (52.5). Also the first cluster was the least vigorous (7) among the three clusters. Number of racemes per plant was lowest in the first cluster (4). Pod length and pod diameter were comparable among the three clusters. They most differed in pods per plant and pod yield with the first cluster having the least (Appendix 24).

Table 5. 9: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-1-105/1	10.8	9705.9	33.9	66.1
KAB-RB13-1-105/2	19.6	18353.7	21.3	78.7
KAB-RB13-1-105/3	4.7	10114.1	93.9	6.1
KAB-RB13-129-121/2	10.3	8667.3	43.8	56.2
KAB-RB13-30-87	0.6	5654.4	19.3	80.7
KAB-RB13-311-103/1	10.9	9027.2	21.6	78.4
KAB-RB13-320-104/4	5.8	6075.2	45	55
KAB-RB13-331-113	6.8	5452.1	62.6	37.4
KAB-RB13-331-66/2	2	9455.6	20.9	79.1
KAB-RB13-379-33	15.3	17162.8	27.8	72.2
KAB-RB13-46-22/2	2.8	7959.7	58.8	41.2
KAB-RB13-470-72	8.4	5693.8	57.2	42.8
KAB-RB13-471-118/3	4.9	6454.6	32.4	67.6
KAB-RB13-471-118/4	7.3	7960	44	56
SUB-RB13-106-12/2	7.4	6567.8	33.6	66.4
SUB-RB13-133-80/1	8	7428.9	59.7	40.3
SUB-RB13-133-80/2	6.4	7763.8	81.5	18.5
SUB-RB13-234-13/1	9.5	8936.1	11	89
SUB-RB13-240-125/1	7.3	6664.1	9.2	90.8

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
SUB-RB13-240-126/1	6	6231.6	52	48
Check				
W. Emergo	1	895.6	50	50
Trial Mean	3.7	3535.9		
LSD $_{0.05}$ Genotype	0.2	146.1		
CV (%)	10.3	9.6		

LSD-least significant difference, CV-coefficient variation,

Table 5. 10: Pods per plant and pod yield of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	Pod plant $^{-1}$	Total pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-1-105/2	18	10809	25.4	74.6
KAB-RB13-1-105/3	18	12919.5	31.4	68.6
KAB-RB13-1-105/4	9	7956	50.9	49.1
KAB-RB13-129-121	14	8217	44.6	55.4
KAB-RB13-299-43	14	9625.5	37.3	62.7
KAB-RB13-301-39	18	8302.5	35.3	64.7
KAB-RB13-305-130/2	18	12627	9.2	90.8
KAB-RB13-309-62	18	10381.5	55.1	44.9
KAB-RB13-312-35	23	10260	50	50
KAB-RB13-312-37	23	16884	57.2	42.8
KAB-RB13-363-131	14	9355.5	34.5	65.5
KAB-RB13-364-97/1	14	9459	6	94
KAB-RB13-46-22/1	23	15462	23.5	76.5
KAB-RB13-471-118/2	14	10458	33.1	66.9
KAB-RB13-85-18	9	7965	36.4	63.6
SUB-RB13-106-12/1	14	14391	32.3	67.7
SUB-RB13-106-12/2	14	9090	20.8	79.2
SUB-RB13-133-80/2	9	8914.5	41.6	58.4
SUB-RB13-234-13	14	9999	35.1	64.9
SUB-RB13-240-126/2	14	12298.5	53.8	46.2
Check				
W. Emergo	9	5401.5	37	63
Trial Mean	9	6174		
LSD $_{0.05}$ Genotype	14	1187.6		
CV (%)	26	25.4		

LSD-least significant difference, CV-coefficient variation,

Table 5. 11: Pods per plant and pod yield of vegetable runner bean lines grown at Naivasha Vegpro farm during 2014 short rain season

Genotype	Pod plant^{-1}	Pod yield (kg ha^{-1})	% grade distribution Grade I	Grade II	Grade III
KAB-RB13-1-105/2	7.1	5245.1	53.2	31.0	15.7
KAB-RB13-311-103/1	10.4	7733.5	40.3	31.7	28.0
KAB-RB13-312-35/1	6.1	4184.7	57.9	28.9	13.2
KAB-RB13-320-104/1	8.6	5981	42.1	32.6	25.3
KAB-RB13-327-92/4	4.6	3188.6	54.6	28.7	16.7
KAB-RB13-380-55/1	5.4	3878.7	37.9	30.6	31.5
KAB-RB13-380-56/1	10.6	6436.4	56.2	25.6	18.2
KAB-RB13-46-22/1	8.7	5655.4	58.0	31.2	10.8
KAB-RB13-471-118/1	4	3708.2	63.8	19.6	16.6
KAB-RB13-471-118/2	6	4036.9	56.0	27.2	16.7
KAB-RB13-64-107/1	5.2	3800.1	38.0	45.0	17.0
KAB-RB13-64-107/2	3.2	2443.1	52.9	31.7	15.4
KAB-RB13-85-18/1	3.5	2588.2	50.8	32.0	17.2
KAB-RB13-85-18/2	4.3	3240.4	47.1	23.7	29.2
OL-RB13-21-2/3	12	8678.7	64.3	19.2	16.4
SUB-RB13-106-12/1A	10.3	6964.9	47.1	33.6	19.3
SUB-RB13-133-80/2	3.7	3010.9	60.0	25.2	14.8
SUB-RB13-133-80/3	4.4	3310.6	51.9	29.1	19.1
Check					
Equator	11.5	7646.4	67.6	20.2	12.2
W. Emergo (with light)	17.6	10632.6	33.2	45.0	21.8
W. Emergo (without light)	8.5	4427.2	39.5	26.4	34.1
Trial Mean	6.5	5085.3			
LSD $_{0.05}$ Genotype	1.2	874.4			
CV (%)	17.7	14.7			

LSD-least significant difference, CV-coefficient variation,

Table 5. 12: Mean squares of duration to flowering, vigour, number of plants per plant, pod length, pod diameter, diseases, pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Source of variation	**df**	**Days to flowering**	**Vigour**	**No. of racemes plant^{-1}**	**Pod length (cm)**	**Pod diameter (mm)**	**Angular leaf spot**	**Anthracnose**	**BCMV**	**CBB**	**Powdery mildew**	**Rust**	**Pod plant $^{-1}$**	**Pod yield (kg ha^{-1})**
Replicates	2	136.357	60.417	4710.53	0.7524	0.1523	4.4087	4.4609	1.487	6.7565	5.713	0	0.39581	343400.00
Genotype	114	55.198**	13.168**	313.14**	150.263**	0.1235**	4.8613**	5.3295**	4.978**	2.9991**	2.2892**	0^{ns}	3.36083**	3240000**
Site	1	564.4**	773.8**	995.4_{ns}	29.2**	3.9**	29.3**	0.01_{ns}	1.4_{ns}	0.24_{ns}	4.4*	29.3*	2290.5_{ns}	6626000000*
G x S	114	4.4*	0.74_{ns}	29.6_{ns}	2.16**	0.04**	0.8_{ns}	0.4_{ns}	0.5_{ns}	0.16_{ns}	0.13_{ns}	0.29_{ns}	82.2**	1434000000**
Error	228	4.864	1.567	25.36	0.4521	0.0125	0.495	0.3303	0.3805	0.1822	0.1508	0	0.09642	74900.00

*, ** and ns 0.05, 0.01 significance probability level and not significant respectively, df-degree of freedom, BCMV- bean common mosaic virus, CBB- common bacterial blight, G-genotype, S-site

Table 5. 13 Mean squares of duration to flowering, vigour, number of plants per plant, pod length, pod diameter, diseases, pods per plant and pod yield of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Source of variation	df	Days to flowering	Vigour	No. of racemes plant^{-1}	Pod length (cm)	Pod diameter (mm)	Angular leaf spot	Anthracnose	BCMV	CBB	Powdery mildew	Rust	Pod plant $^{-1}$	Pod yield (kg ha^{-1})
Replicates	2	5.91	0.4133	88.91	0.4837	0.00693	0.5833	0.07627	0.3733	0.4933	0.28	1.0133	0.6297	931421
Genotype	49	6.083**	1.0256**	53.49**	3.3194**	0.04407**	1.4836**	0.04078**	1.5249**	0.378**	0.45605**	1.2378**	1.897**	2556592**
Site	1	564.4**	773.8**	995.4_{ns}	29.2**	3.9**	29.3**	0.01_{ns}	1.4_{ns}	0.24_{ns}	4.4*	29.3*	2290.5_{ns}	6626000000*
G x S	114	4.4*	0.74_{ns}	29.6_{ns}	2.16**	0.04**	0.8_{ns}	0.4_{ns}	0.5_{ns}	0.16_{ns}	0.13_{ns}	0.29_{ns}	82.2**	1434000000**
Error	98	2.374	0.3291	7.449	0.5793	0.01134	0.5298	0.02499	0.4996	0.1514	0.08558	0.4454	0.8167	1087826

*, ** and ns 0.05, 0.01 significance probability level and not significant respectively, df-degree of freedom, BCMV- bean common mosaic virus, CBB- common bacterial blight, G-genotype, S-site

Table 5. 14: Mean squares of duration to flowering, vigour, number of plants per plant, pod length, pod diameter, pods per plant and pod yield of vegetable runner bean lines grown at Naivasha Vegpro farm during 2014 short rain season

Source of variation	**df**	**Days to flowering**	**Vigour**	**No. of racemes plant^{-1}**	**Pod length (cm)**	**Pod diameter (mm)**	**Pod plant $^{-1}$**	**Pod yield (kg ha^{-1})**
Replicates	1	0.167	0	19.44	1.1793	0.147267	2.1944	495497
Genotype	20	124.417**	0	58.088**	304.4078**	0.245367**	24.917**	21920658**
Error	20	1.376	0	0.7624	0.4317	0.00635	0.3012	183084

*, ** and ns 0.05, 0.01 significance probability level and not significant, df-degree of freedom

Table 5. 15: Correlation matrix among agronomic traits of grain runner bean lines

	50% duration to flowering	Number of racemes plant^{-1}	Pod diameter (cm)	Pod length (cm)	Pod yield (kg ha^{-1})	Pods plant^{-1}	Vigour
50% duration to flowering	1.00						
Number of racemes plant^{-1}	-0.30**	1.00					
Pod diameter (cm)	-0.09	0.04	1.00				
Pod length (cm)	-0.02	-0.09	-0.02	1.00			
Pod yield (kg ha^{-1})	0.13	-0.06	0.02	0.07	1.00		
Pods plant^{-1}	0.10	-0.06	-0.07	0.09	0.61**	1.00	
Vigour	0.11	-0.16	0.14	-0.02	0.12	-0.04	1.00

5.4 DISCUSSION

5.4.1. Duration to flowering

The significant differences for duration to 50% flowering in all sites can be attributed to genetic differences among genotypes. The number of days to 50% flowering determines the maturity of the plant. Early flowering was recorded in Naivasha where the mean temperatures were high (Appendix 2). However, late flowering was recorded in Kabete and Ol Joro Orok where mean temperatures were low. The new lines had more flowers than the check. White Emergo had few flowers which were probably the result of cross pollination. The cross pollination effect was evident when the colour of seed harvested differed from the normal white seed of White Emergo. Vegetable runner bean has received very little research attention. As a result there are very few runner bean improvement programs in the world, and virtually none in Eastern Africa (Kimani et al., 2009). Consequently, there is little published data to facilitate comparison. However, there is considerable data on common bean which its close relative. Wallace et al., (1991) found that, days to flowering of common beans is influenced by the temperature which alters the rate of vegetative development and cause faster flower development under high temperatures. In addition, George (1988) found that under high elevations with lower temperatures, common bean and soybean crops duration to flowering tend to prolong. This study was in agreement with the above findings whereby the duration to flowering ranged from 48 to 55 days in Kabete and Ol Joro Orok where altitude is high and temperatures are low compared to 43 to 48 days at Naivasha where elevation is low and temperatures are high. Mulanya et al., (2014) found the duration to flowering varying from 50 to 52 days in Kabete and Ol Joro Orok. Some of the lines can be classified as early maturing due to shorter number of days to flowering while others classified as late maturing due to longer days to flowering. Maturity is important to producers because it determines the harvesting time of the crop. Early maturity enhances profitability of the crop because it is able to get to market before the late maturing crops hence avoiding glut.

5.4.2. Plant vigour

The new lines showed significant differences in plant vigour at all sites. The low vigour for the new lines at Kabete was as result of water stress experienced during flowering. This was in agreement with Mulanya et al (2014) who found that the vigour and number of racemes were low due to water stress. However, there were no significant differences in plant vigour among advanced lines grown in Naivasha. The crops were highly vigorous probably due to more fertility in the soil and wetter conditions which favour growth of runner beans.

5.4.3. Number of racemes per plant

One of the objectives of the runner bean program at the University of Nairobi is to develop tropically adapted runner bean varieties that can flower and form pods without extended artificial lighting. Results of this study indicate that the new lines meet this objective. Virtually all the new study lines flowered normally at Ol Joro Orok, Kabete and Naivasha without any extended light. This implies that selection of short day plants from segregating populations derived from crosses between long day and short day parents was effective as evidenced by formation of racemes. Results showed that number of racemes formed was influenced by prevailing environmental conditions at each test site. Low number of racemes per plant in Kabete and Ol Joro Orok can be explained by dry spells experienced in both sites. Low number of racemes per plant in Naivasha was as a result of flower abortion due to heat stress. The results were in agreement with Mulanya et al (2014) who found that number of racemes per plant of runner bean lines grown in Kabete was low due to water stress that was experienced during the trial period. Mulanya et al (2014) found the number of racemes per plant of runner bean lines grown at Ol Joro Orok during 2013 season were more than those at Kabete. The results were contrary to this study and the explanation was cooler climate with abundant rainfall which increases number of racemes and pod yield.

5.4.4. Reaction of new lines to major diseases

Development of runner bean varieties with resistance to major diseases is a major objective of the runner bean breeding program at the University of Nairobi. Runner bean is known to be susceptible to seed borne bacterial disease (*Pseudomonas phaseolicola*), fusarium wilt (*Fusarium oxysporum*), bean rust (*Uromyces phaseoli*) and anthracnose (*Colletotrichum lindemuthianum*) (Kay, 1979). In Kenya, runner bean has been reported to be susceptible to rust, aschochyta, anthracnose, bean common mosaic virus and common bacterial blight (Kimani et al, 2008; Kimani and Mulanya, 2014). Results of this study showed that there are significant differences in reactions to infection by angular leaf spot, CBB, BCMV and powdery mildew. Test lines showed higher levels of resistance compared with checks. According to Blink, (2006) runner beans are known to have resistance to diseases and mostly used to improve common bean in disease resistance. This study was in agreement with

Mulanya et al., who found the resistance of new runner bean lines to rust, BCMV and CBB at Ol Joro Orok and Kabete to vary from 1 to 4 (resistant to intermediate resistance).

5.4.5. Pod quality

Development of vegetable runner bean lines with acceptable pod quality is one of the objectives of the runner bean breeding program at the University of Nairobi. There were significant differences for pod length and pod diameter among new runner bean lines across the sites. The pod length, pod diameter and pod curvature determine the acceptance of the runner bean by consumers. The minimum required pod length by fresh market is 18cm and most of the new lines were above that length. Pod straightness is important in processing green beans because straight beans make a neater cut or whole pack product and also they flow through the processing equipment more rapidly (Myers and Baggett, 1999). Slightly curved pods are not a quality problem, however the more the pods are curved the less uniform they appear.

5.4.6. Pods per plant

Pods per plant is major determinant of the productivity of most legume crops. Results of this study showed that there were significant differences in pods per plant among the new runner bean lines and test locations. Differences in pods per plant were most evident at Kabete and Ol Joro Orok. Pods per plant is expected to be highly positively correlated to number of racemes per plant. The pods per plant and number of racemes per plant were high at Ol Joro Orok. This could be probably due to availability of moisture during flowering and pods development. In Naivasha, there was low number of racemes and pod per plant despite high levels of nutrients and enough soil moisture. This was probably due to high vegetative growth hindering access of enough sunlight. This was evidenced by observing high number of racemes on the upper side of the runner bean canopy facing the sunlight. Failure of the crop to obtain enough sunlight led to flower abortion and few pods.

5.4.7. Pod yield

Despite runner beans showing considerable promise as an export crop in Kenya, there has been no genetic improvement of the yield potential of local varieties. Several reports indicate that the pod yield of green pods of runner beans vary from 8.75 to 13.75 t ha^{-1} (Kay, 1979). However, Brink (2006) reported a yield of 10 t ha^{-1}. Mulanya et al., (2014) reported that yield of the new locally bred vegetable runner bean lines were significantly higher compared to commercial variety. The new runner bean lines yield at Kabete varied from 474.2 to 18,353 kg ha^{-1}, 1818 kg ha^{-1} to 16884 kg ha^{-1} at Ol Joro Orok and 2443.1 kg ha^{-1} to 7733.5 kg ha^{-1} at Naivasha. This study was in agreement with Mulanya et al (2014) who found the pod yield of new runner bean lines at Kabete and Ol Joro Orok to vary from 3,249 to 7,735 kg ha^{-1}. The best new line had a yield advantage of 58% over the best performing check, Equator.

Most of the lines had high percentage of grade II as opposed to grade I. Grade I is more marketable than grade II therefore, the lines with high percentage of grade I are preferred than those with grade II e.g. KAB-RB13-1-105/3 and SUB-RB13-133-80/2 had 93% and 81% grade I respectively. High yield comes as a result of better flowering and pod formation (Mulanya et al., 2014). The new lines with high yield could be used to increase production while promoting the competitiveness of the product both locally and globally.

5.5 CONCLUSION

Agronomic performance of the grain runner bean genotypes revealed that they are adapted to the short day and that is why they are able to flower without additional light. This proves that adaption to short day is heritable and can be transferred to the progeny through crosses between difference day length plants. The new lines were resistant to most of the major diseases and this would improve productivity and adoption of the crop production by smallholders. The new lines have proved to be high yielding under natural conditions with no additional light.

Evaluation of vegetable runner bean for pod yield, pod quality and disease resistance is not only beneficial to our economy but also increases productivity and reduces food insecurity in the country. Availability of public commercial varieties will increase access to seed by smallholder farmers. New varieties are likely to lower production cost due to reliance on short day length to flower and pod setting. Development of disease resistant varieties will reduce use of chemicals in production, lowering the cost of production while promoting the competitiveness of the product globally due to the issues of maximum residual levels (MRLs).

CHAPTER 6

POD YIELD, POD QUALITY AND DISEASE RESISTANCE OF NEW LOCALLY BRED SNAP BEAN LINES

Abstract

Snap bean (*Phaseolus vulgaris* L.) also commonly known as 'French bean' is probably the most important high value bean grown in East and Central Africa. They are mostly grown for export markets but the domestic markets especially in urban areas are growing rapidly. However, most of the available varieties for the snap bean are low yielding and susceptible to diseases such as rust, angular leaf spot, anthracnose and common bacterial blight. Due to demand for high quality, smallholder farmers use toxic chemicals to reduce production cost and post harvest losses associated with pests and diseases. Use of fungicides increases cost of production, reduces profitability and competitiveness of snap bean in domestic and export markets, increases the risk of rejection of their produce due to maximum residual levels in export markets. The objective of this study was to evaluate locally bred new snap bean lines for yield potential, pod quality and disease resistance. One hundred and seven lines and three checks were grown at Kabete Field Station and Mwea, and evaluated for pod length, pod shape, pod curvature, pod yield, disease reaction and market class distribution. Disease resistance and vigour were scored on 1 to 9 scale (1 to 3 (resistance/ vigorous), 4 to 6 (intermediate) and 7 to 9 (susceptible/ poor vigour)). Pod length and pod diameter were determined using Royal Sluis grading ruler. Pod yield was the cumulative weight of all harvests. The data was subjected to analysis of variance and means separated by Fisher's protected least significance difference (LSD) at $P<0.05$. Results showed that there are significant differences among snap bean lines for pod yield, pod length, pod diameter, pod per plant and disease resistance. Fifty eight new lines were higher yielding than the checks. For example, KSB15-02 (10,835.4 kg ha^{-1}), KSB15-01 (12, 847.2 kg ha^{-1}), KSB13-11 (9,559.7 kg ha^{-1}) compared to Serengeti (6988.4 kg ha^{-1}) and Samantha (6396.6 kg ha^{-1}). Seventy six lines had round, straight pods with required standards for pod quality and more than 80% of premium grades. For example, KSB15-01 and KSB15-07 produced 100% extra fine and fine pods and zero bobby. The new lines showed resistant reactions to angular leaf spot, common bacterial blight and rust diseases. The highest disease reaction was intermediate susceptibility. Only two lines showed intermediate reaction to rust while the rest were resistant. All the lines were resistant to angular leaf spot and common bacterial blight.

Fifty one bush and seven climbing lines showed a combination of high yield potential, pod quality and disease resistance. Utilisation of these lines as commercial varieties will not only increase productivity, reduced cost of production and increased profitability but also increase competitiveness of Kenyan produce in regional and international markets.

Key words: Snap bean, disease resistance, pod quality, pod yield

6.1. INTRODUCTION

Snap bean (*Phaseolus vulgaris L*.) is a major vegetable export in Kenya. In eastern Africa, snap beans are also produced in Uganda, Tanzania, Rwanda, Zambia, Zimbabwe and Burundi. It is an important export crop in those countries and over 90% of the crop is exported to regional and global markets (CIAT, 2004). Snap bean production in East Africa is dominated by small scale farmers although large commercial companies also grow for export to overseas supermarkets and for the canning industries (Gitta and Kata, 2012). It is an important vegetable crop in Kenya employing over 500,000 small scale farmers, and more than 1 million people along its value chain (Odero et al., 2013). In 2013, the commercial snap bean production in Kenya was 31,974 t valued at 9.9 billion (www.hcda.or.ke accessed 10 May 2014). The area, yield and value of snap bean have increased by 7.1%, 14.6% and 43.3% respectively since 2011 (HCDA, 2013). However, the total production of snap bean by smallholder farmers in 2014 was 112,409 t valued at Kshs 5.04 billion (HCD, 2014).

Snap beans are highly perishable and thus have an inherent short shelf-life. They remain in saleable condition at 0^0C and 95 to 100% relative humidity (RH) for 7 to 9 days. Exposure to 20^0C for 30 min each day can reduce the shelf life by half (Hardenburg *et al*., 1986; Varoquarux *et al*., 1996). This rapid quality loss at relatively modest temperatures emphasizes the critical need for immediate cooling of vegetable pulse (Thompson *et al*., 1998) especially in the humid tropics of Sub-Saharan Africa. Evaluating snap beans for productivity, pod quality and disease resistance is critical in development of new varieties. It contributes to reduction of food losses, improves overall food quality and safety, and increases profits for growers and marketers. Colour, firmness, stringiness, pod shape, size and turgidity have high influence on acceptability of snap bean pods to consumer (Hedwig et al., 2012). The above characteristics are affected by snap bean variety, timeliness in harvesting, handling techniques and storage period time. Hence postharvest characteristics and productivity need to be evaluated.

Snap bean production in Eastern Africa is threatened by high cost of quality seeds (Chemining'wa et al., 2012). Most of the commercial varieties are developed by multinational companies such as Monsanto, Syngenta and Royal Sluis. No informal seed production is allowed because the varieties are protected by legislation. The seed produced is exported for processing and later re-imported for sale to farmers (Chemining'wa et al., 2012). However, due to high cost of seed, the farmers end up planting the seed saved from the previous season (Lenne et al., 2005). This phenomenon leads to low yield and quality deterioration.

Snap bean varieties produced in Kenya include Teresa, Amy, Paulista, Julia, Serengeti, Samantha, Star 2053, among others. They are produced for different pod attributes which include; extra fine, fine and bobby beans for fresh produce markets, and for frozen and canned products (Chemining'wa et al., 2012). Varieties grown in Kenya for fresh market include Amy, Pekera, Teresa, Paulista, Rexas, Samantha and Cupvert. Julia, Vernadon and Sasa are grown for processing (Ndegwa et al., 2010; HCDA, 2012).

Production of snap beans in Kenya has faced challenges which range from lack of high yielding varieties that are resistant to pests and diseases to lack of high quality seeds (Kimani et al., 2004). According to Kimani (2006), many of the commercial varieties have succumbed to diseases necessitating evaluation and selection for pod yield, pod quality and disease resistance in order to enhance competitiveness in regional and international markets. Yield of snap beans in smallholder farms varies from 2 to 8 t ha^{-1} compared with large scale production attaining over 14 t ha^{-1} (CIAT, 2004). Smallholder production is constrained by diseases like rust, angular leaf spot, root rot, bean common mosaic virus and pests like stem maggots, thrips and nematodes (Kimani, 2006). Pod quality requirements in snap beans vary from region to region. Characteristics related to pod shape, length, pod quality (pod fiber content, pod smoothness and straightness, pod colour and flavour) determine the degree to which snap beans are accepted by consumers and processors (Mullins and Coffey, 1990).

The principal quality determining factors for snap beans are low fiber content in pod walls and absence of string in the suture. Characteristics like pod shape, color, curvature and pod length are qualities taken into account by consumers where snap beans are usually consumed fresh (Myers and Baggett, 1999). Commercial varieties which are susceptible to diseases fail to achieve the desired pod quality, become uncompetitive in the export markets.

Development of high quality and high yielding disease resistant varieties is very fundamental. These characteristics would contribute to acceptability of the products in the market and by consumers. Use of resistant varieties reduce reliance on pesticides and is one of the ways of enhancing growers' capacity to comply with the stipulated stringent EUREP-GAP regulation for horticultural export produce. The goal of snap breeding is to promote competitiveness of Kenya's snap bean sub- sector through development and dissemination of new high yielding snap bean varieties with multiple disease resistance, marketable pod traits and efficient local seed production. Snap bean improvement in Kenya started in 1998 at Kenya Agricultural and Livestock Research Organisation (KALRO)-Thika with support from the Center for Tropical Agriculture (CIAT) and the Eastern and Central Africa Bean Research Network (ECABREN) as a regional activity (Chemining'wa et al., 2012). These efforts led to development of Kutuless (J12) by KALRO-Thika in 2000 (KEPHIS, 2009). In 2001, a regional snap bean programme, initially supported by CIAT and ECABREN and from 2006 by ASARECA, was initiated to develop improved snap bean varieties with high yield potential, resistant to biotic stresses, and high pod quality for smallholder producers (CIAT, 2006). Snap bean breeding has been going on at the University of Nairobi to identify snap bean lines with multiple disease resistance to angular leaf spot, anthracnose and rust (Wahome at al., 2011). However, breeding snap bean lines for pod quality and pod yield is also carried out to produce snap bean varieties with desirable quality and able to compete in export market (Wahome et al., 2013). At the University of Nairobi activities focused on identification and evaluation of marketable snap bean lines, development of segregating populations and evaluation of advanced bush and climbing beans. More than 44 bush and 15 climbing snap bean lines including fresh market and canning types, were identified but their reaction to diseases, pod quality and yield potential is not yet known. The objective of this study was to evaluate these snap bean lines for reaction to multiple diseases, pod quality and yield potential.

6.2. MATERIALS AND METHODS

6.2.1. Plant Materials

One hundred and seven advanced snap bean lines and three local commercial varieties were used in this study (Table 6.1). The advanced lines were obtained from the University of Nairobi Bean Research Program. They originated from populations developed by the University of Nairobi Bean Research Program (Kimani et al, 2013). The lines were selected based on their performance in different environments including Embu, Mwea and Kabete in 2012 and 2013. Large number of lines was chosen to broaden genetic base of the study materials and increase chances of capturing the combination of the desired traits. Julia, Samantha and Serengeti were used as check varieties.

Table 6. 1: List of advanced snap bean lines used in the study

Line code	Growth habit	Number of entries	Description
KSB15	Bush	23	A nursery constituted in 2015 and evaluated at Embu and Mwea
KSB14	Bush	28	A nursery constituted in 2014 and evaluated at Embu and Kabete Field Station
KSB13	Bush	46	A nursery constituted in 2013 and evaluated at Kabete Field Station and Mwea
KSV14	Climbing	10	A climbing snap bean nursery constituted in 2014 and evaluated at Kabete Field Station and Mwea
Checks			
Serengeti	Bush		
Samantha	Bush		
Julia	Bush		
Total		107	

6.2.2. Trial sites

Experiments were conducted in Kabete Field Station during 2014 long and short rain season and KALRO Mwea Kirogo research station during the 2014 short rain season.

6.2.2.1. Kabete Field Station

Kabete Field Station of the University of Nairobi lies at an altitude of 1737 m above sea level and on latitude 1^0 15’ S and longitude 36^0 44’ E (Mburu, 1996). It falls under agro-ecological zone UM (Upper Midland). The area has a bimodal rainfall pattern with peaks in April and November. The annual rainfall is around 1000 mm which is received during long rains (March to May) and short rains (October to December) season every year. The site has maximum and minimum mean temperatures of 24.3^0 and 13.7^0C respectively. The soils are Nitisols which are very deep, well-drained, dark reddish, deep friable clay type resistant to erosion (Jaetzold et al., 2006). The experiments were conducted during 2014 short rain season (October to December) and 2015 long rain season (March to May).

6.2.2.2. Kirogo Research Station, KARLO-Mwea

Kirogo Research Station is located at $32^0 20'$ East and $0^0 41'$ South at an elevation of about 1159m above sea level. It experiences bimodal rainfall of 973 mm with long rains occurring between March and May. Short rains occur between October and December with a mean of 71 mm and 50 mm per month respectively. The mean annual maximum and minimum temperatures at long rain season are 27.8^0 C and 15.6^0 C during short rain season (Ndungu et al., 2004). The experiments were conducted between November and January (2014/2015) with supplemental irrigation.

6.2.3. Experimental design, treatments and crop husbandry

The field experiments were laid out in a randomized complete block design with two replicates. Plants were spaced at 10 cm within rows and 50 cm between rows at KALRO-Mwea and Kabete Field Station. A plot consisted two rows each with 30 plants leading to a plant density of 20 plant m^{-1}. Rows were 3 m. Land was prepared by mechanical ploughing and harrowing so as to achieve a moderate tilth in the seed-bed. Di-ammonium phosphate (18-46-0) fertilizer was applied at a rate of 200 kg ha^{-1} and thoroughly mixed with soil. During flowering, the plants were top dressed with calcium ammonium nitrate at a rate of 100 kg ha^{-1}. The fields were kept relatively clean of weeds throughout the growing seasons. There were no pest control measures at Kabete Field Station since there were no pests prevalent. However, pest control was undertaken at Mwea due to dry weather with high prevalence of aphids, thrips and white flies. Several chemicals were applied to control the above pests. Thiamethoxam (Apron Star 42WS, Syngenta, Switzerland) was applied at 0.3 kg $ha-^1$ once per week to control white flies. Thiamethoxam (Actara 25WG, Syngenta, Switzerland) at 0.15 kg $ha-^1$ rate was applied once in every two weeks to control aphids, thrips and white flies. Pymetrozine (Chess 50WG, Syngenta, Switzerland), was applied at 0.3 kg ha-1 rate every two weeks to control aphids, thrips and white flies. The season (Oct, Nov and Dec) was dry and hence the need for supplemental irrigation (Appendix 3). The crop was irrigated by sprinklers at a rate of 600 litres per hectare during the first two weeks after planting and later by flooding during the subsequent growing stages. Irrigation was done twice per week and the soil was flooded to field capacity.

6.2.4. Data collection

Data was recorded on duration to 50% flowering, plant vigour, disease resistance using the standard system for the evaluation of bean germplasm (van Schoonhoven and Pastor-Corrales, 1987). Days to flowering were recorded as number of days from planting to when approximately 50% plants in a plot had at least one opened flower.

Plant vigour was done at vegetative stage by hedonic scale (1 to 9), where a score of 1 =excellent, 3 =good, 5 =intermediate, 7 =poor and 9 =very poor (van Schoonhoven and Pastor-Corrales, 1987). Disease scoring was done from flowering to final pod harvesting stages using a nine point severity scale (1-9), where a score of 1 to 3 was considered resistant, 4 to 6 intermediate resistance and 7 to 9 as susceptible. The test lines were scored for reaction to infection by angular leaf spot, common bacterial blight (CBB) and rust using hedonic scale according to Van Schoonhoven and Pastor-Corrales, (1987). Pod yield was determined as the cumulative weight from all harvests until physiological maturity was reached. Harvesting started when at least one plant per plot had attained the required premium standards. Harvesting was done thrice per week (Mon, Wed and Fri) at one day interval and continued for six weeks. The pods were graded into three standard categories defined by their pod diameter and length based on Royal Sluis standard ruler as extra fine (6 mm), fine (6-8mm) and bobby (>8 9 mm) and length of the pods above 10 cm (HCDA, 2009). Weight for each grade category was obtained at each harvest, and the cumulative total weight obtained at the end of the harvest period. The pod yield was averaged to give pod yield per plant which was then multiplied by the number of plants in one hectare to obtain pod yield per hectare.

The number of pods per plant was determined by taking the total number of pods in a plot and dividing by the number of plants in that plot. Pod length and pod diameter were measured by a standard ruler (Royal Sluis) with holes of 6 mm, 8 mm and 12 mm diameters for extra fine, fine and bobby pods respectively.

Fig 6. 1: Ruler used for measuring pod length and pod diameter of snap bean pods

6.2.5. Data analysis

Quantitative data collected from the experiment was subjected to combined analysis of variance (ANOVA) using the GenStat software (v. 15, VSN, UK, 2010). Differences among the treatment means were separated using the Fisher's protected LSD test at 5% probability level.

6.3. RESULTS

6.3.1. Weather

Weather data was obtained from Kabete weather station and KALRO-Mwea Kirogo weather station. Kabete received a total of about 411 mm during long rain and 348 mm during short rain season while Mwea received a total of about 239 mm during short rain season (Appendices 3, 4 and 5). The mean temperature during short rain at Kabete was 18.5 ^{0}C and during long rain was 19.1 ^{0}C. However, mean temperature at Mwea during short rain season was 22.2 ^{0}C (Appendices 3, 4 and 5). The highest rainfall was received at Kabete during long rain season while lowest rainfall was received at Mwea during short rain season. Low rainfall at Mwea, it necessitated use of supplemental irrigation. The mean rainfall in Kabete was too low as compared to rainfall description of Jaetzold et al., (2006). The mean temperature was almost the same as that of Jaetzold et al (2006). The mean rainfall in Mwea was lower compared to 297 mm reported by Ndung'u et al., (2004). However, the mean temperature in Mwea during short rain was slightly higher (22.2 ^{0}C) compared to Jaetzold et al (2006) (21.5 ^{0}C).

6.3.2. Days to 50% flowering

Days to 50% flowering varied significantly (p<0.01) among advanced lines of the four groups in both sites (Tables 6.14 to 6.22). Sites varied significantly (P<0.05) for duration to 50% flowering only in KSVI4 climbing snap bean lines (Tables 6.14, 6.17, 6.19 and 6.21). All the lines flowered earlier in Mwea than at Kabete. Among KSB13 group, early flowering lines in Kabete long rain season were KSB13-50, KSB13-51 and KSB13-31 (26.9, 35 and 35 days respectively). The latest lines were KSB13-52, KSB13-18 and KSB13-37 (39, 39.7 and 39.7 days respectively). Samantha flowered in 39.7 days in Kabete during long rain season. The duration to 50% flowering at Kabete during short rain season ranged from 36.5 to 40 days while in Mwea during the same season it varied from 31.5 to 35 days. Serengeti, which was the earliest check variety, flowered in 38.5 days at Kabete and in 33.5 days at Mwea during the short rain season (Table 6.2).The KSB 13 lines flowered in 33.6 to 38.2 days (Appendix 17). Among KSB14 group, early flowering lines in Kabete were KSB14-21, KSB14-15, KSB14-24 and KSB14-02 (38 days) (Appendix 18). The latest lines were KSB14-23 and KSB14-14 (41 days). The earliest lines in Mwea during the same season were KSB14-21, KSB14-15, KSB14-24 and KSB14-02 (33 days). The latest were KSB14-23 and KSB14-14 (36 days) (Table 6.3). The average duration to 50% flowering of the KSB 14 lines varied from 35 to 38 days. The earliest check variety was Serengeti (37 days). Among KSB15 group, the earliest lines across the sites were KSB15-05, KSB15-16, KAB15-04 and KSB15-10. The latest lines flowered within 41 days at Kabete and 36 days at Mwea. The earliest checks were Samantha and Serengeti which flowered within an average of 38 days. The average duration to flowering of the KSB15 lines varied from 37 to 39 days (Table 6.4). Among KSV14 group, the earliest lines across the sites were KSV14-05, KSV14-03, KSV14-10 and KSV14-09.They flowered in 40 days. Among the check varieties, Serengeti was the earliest. It flowered in 35 days. The new lines flowered within 37 to 42 days (Table 6.5). Duration to 50% flowering correlated positively with days to first harvest (r= 0.77**), days to last harvest (r= 0.73**) and vigour (r= 0.55**) and negatively correlated with pods per plant (r= -0.51**) and pod yield (r= -0.4**) (Table 6.23).

6.3.3. Plant vigour

There were significant differences (p<0.01) in plant vigour among the advanced lines in all groups in both sites (Tables 6.14 to 6.22). Sites varied significantly (P<0.05) for vigour only in KSB13 snap bean lines (Tables 6.14, 6.17, 6.19 and 6.21). All the lines showed better

vigour in Mwea than at Kabete. Among KSB13 group, the average vigour across the sites and seasons ranged from 2.2 to 4.4. The check with the best vigour was Serengeti (2.8). The lines with the best vigour were KSB13-50, KSB13-46 and KSB13-22 (2.2 to 2.3). The lines with poor vigour were KSB13-23, KSB13-41, KSB13-26 and KSB13-40 (4.2 to 4.4) (Table 6.2 and Appendix 17). Among KSB14 group, average vigour ranged from 2 to 4. All the lines were vigorous in Mwea. Ten lines had intermediate vigour in Kabete while the rest were vigorous (Table 6.3 and Appendix 18). The best check (Serengeti) had an average vigour of 3. Twelve lines had better vigour than the best check. Among KSB15 group, average vigour ranged from 2 to 4. The best check (Serengeti) had an average vigour of 3. All the lines in Mwea were vigorous as opposed to Kabete lines which had intermediate vigour (Table 6.4).
Among the KSV14 (climbers), the average vigour ranged from 2 to 3. The best check (Serengeti) had an average vigour of 2. All the lines were vigorous across the sites. Most of the lines were comparable to all the checks in term of vigour (Table 6.5). Vigour positively correlated with 50% duration to flowering (r= 0.55**), days to first harvest (r= 0.49**) and days to last harvest (r= 0.48**) and negatively with pods per plant and pod yield (r= -0.42) (Table 6.23).

Table 6. 2: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

	50% DF				Vigour				Days							
									First harvest				Last harvest			
	[ʃ]LR	[ʃ]SR			LR	SR			LR	SR			LR	SR		
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**
KSB13-11	35.3	38.5	33.5	35.8	3.7	3	1	2.6	50	47	44.5	47.2	75.3	68	65	69.4
KSB13-12	36.7	37	32	35.2	5	5	1.5	3.8	51	47	42	46.7	79	70	65	71.3
KSB13-14	37.3	37	32	35.4	5	4	2	3.7	51.3	47	42	46.8	75.3	71	63	69.8
KSB13-23	36.3	37.5	32.5	35.4	5.7	5	2	4.2	50.7	47	42	46.6	74	70	65	69.7
KSB13-24	36.7	38.5	33.5	36.2	4.3	4	1.5	3.3	51.3	47	43	47.1	77.7	67	63	69.2
KSB13-26	35.7	38	33	35.6	5	4	3.5	4.2	50	47	43	46.7	72.3	70	64	68.8
KSB13-28	36	37	32	35	5	3	1	3	50	47	43	46.7	82	71	65	72.7
KSB13-29	35.7	37.5	32.5	35.2	4.3	3	2.5	3.3	50	47	44.5	47.2	82	71	65	72.7
KSB13-30	35	37	32	34.7	3.7	3	1.5	2.7	50	47	42	46.3	78.3	71	63	70.8
KSB13-36	35.7	39	34	36.2	4.3	2	1	2.4	50	47	44	47	76.7	71	63	70.2
KSB13-38	36	37.5	32.5	35.3	5	4	1	3.3	50.7	47	42	46.6	80	68	65	71
KSB13-40	37.3	36.5	31.5	35.1	6.3	4	3	4.4	52	47	42	47	74.7	71	65	70.2
KSB13-41	35.7	37.5	32.5	35.2	5	4	4	4.3	50	47	43	46.7	74	68	63	68.3
KSB13-42	35.3	36.5	31.5	34.4	3.7	3	1	2.6	50	47	43	46.7	78.3	71	64	71.1
KSB13-43	36	39	34	36.3	3	4	2	3	50.7	47	43	46.9	80	67	63	70
KSB13-44	35.7	37.5	32.5	35.2	4.3	3	1.5	2.9	50	47	44	47	80.7	70	61	70.6
KSB13-46	36.3	39	34	36.4	3	3	1	2.3	50.7	47	42	46.6	78	68	65	70.3
KSB13-47	37	38.5	33.5	36.3	4.3	5	2	3.8	52	47	42	47	75.6	68	62	68.5
KSB13-48	37.7	38	33	36.2	4.3	5	2.5	3.9	51.3	47	43	47.1	80	68	64	70.7
KSB13-54	36.7	39	34	36.6	4.3	5	3	4.1	51	48	43	47.3	75	68	65	69.3
Checks																
Julia		40	35	37.5		4	2.5	3.3		51	51.5	51.3		71	65	68

Continued: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

	50% DF				Vigour				Days							
									First harvest				Last harvest			
	[ʃ]LR	[ʃ]SR			LR	SR			LR	SR			LR	SR		
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**
Samantha	39.7	40	35	38.2	6.3	5	1.5	4.3	54.3	50	47	50.4	79	71	65	71.7
Serengeti		38.5	33.5	36		3	2.5	2.8		48	45.5	46.8		68	65	66.5
Trial Mean	37	38.4	33.4	35.9	4.3	3.5	1.8	2.6	51.6	48	43.9	46	77.4	70	64	67
$LSD_{0.05}$ Genotype	0.4	0.8	0.8		0.4	0.8	0.4		0.5	1.1	1.3		1.2	1.2	1	
$LSD_{0.05}$ Site				0				5.6				5.2				5.7
$LSD_{0.05}$ G x S				2.3				2.1				3.6				3.4
CV (%)	2.8	0.8	1		20.7	9	17		2.1	0.1	1.2		3.7	0.9	0	

DF-duration to flowering, LSD-least significant difference, CV-coefficient variation, [ʃ]SR= short rain, LR= long rain, G x S-Genotype x Site

Table 6. 3: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB14 snap bean lines grown at Kabete Field station and Mwea during 2014 short rain season

	50% DF			Vigour			Days					
							First harvest			Last harvest		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSB14-01	39	34	37	3	2	2	48	47	48	71	65	68
KSB14-02	38	33	36	5	2	3	47	43	45	71	63	67
KSB14-03	39	34	36	2	1	2	47	42	45	71	63	67
KSB14-04	39	34	36	3	2	3	47	43	45	71	63	67
KSB14-05	40	35	37	2	2	2	47	43	45	61	63	62
KSB14-06	39	34	36	3	1	2	47	44	46	71	65	68
KSB14-08	39	34	36	3	1	2	47	46	46	71	63	67
KSB14-10	40	35	37	3	2	2	47	49	48	71	65	68

Continued: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB14 snap bean lines grown at Kabete Field station and Mwea during 2014 short rain season

							Days					
	50% DF			Vigour			First harvest			Last harvest		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSB14-11	40	35	37	5	2	3	47	44	46	70	63	67
KSB14-12	39	34	37	2	1	2	47	46	46	71	65	68
KSB14-13	39	34	36	3	2	3	47	43	45	71	64	68
KSB14-15	38	33	35	6	2	4	47	45	46	71	65	68
KSB14-16	40	35	37	5	3	4	47	47	47	61	65	63
KSB14-17	39	34	37	4	2	3	48	45	46	71	65	68
KSB14-18	40	35	37	3	3	3	47	46	46	71	63	67
KSB14-19	40	35	37	2	2	2	47	43	45	68	65	67
KSB14-20	40	35	37	2	2	2	47	47	47	71	65	68
KSB14-21	38	33	36	4	2	3	47	45	46	71	63	67
KSB14-24	38	33	35	4	2	3	47	44	46	66	63	65
KSB14-27	40	35	37	2	3	2	47	46	46	70	65	68
Checks												
Julia	41	36	39	5	4	5	50	47	49	71	65	68
Samantha	40	35	38	7	3	5	50	48	49	66	65	66
Serengeti	40	35	37	4	2	3	47	43	45	71	65	68
Trial Mean	39.3	34.3	36.8	3.6	1.8	2.7	47	45.5	46	70	64.3	67
$LSD_{0.05}$ Genotype	0.4	0.4	0.93	0.9	0.6	1.6	0.7	1.1	2.1	2.6	1	4.2
$LSD_{0.05}$ Site			0			1.8			1.2			18
$LSD_{0.05}$ G x S			1.3			2.3			2.9			6.8
CV (%)	0.9	1.1		1.3	14		0	0.3		2	0.9	

DF-duration to flowering, LSD-least significant difference, CV-coefficient variation, G x S-Genotype x Site

Table 6. 4: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB15 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							Days					
	50% DF			Vigour			First harvest			Last harvest		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSB15-24	41	36	38	4	2	3	47	48	48	70	65	68
KSB15-08	41	36	38	2	2	2	47	47	47	68	65	67
KSB15-17	40	35	37	5	2	4	47	47	47	70	65	68
KSB15-01	41	36	38	3	2	3	47	46	46	67	63	65
KSB15-18	40	35	37	4	3	4	47	44	46	68	63	66
KSB15-06	40	35	38	4	2	3	47	48	47	67	63	65
KSB15-19	41	36	39	3	2	3	48	51	49	68	65	67
KSB15-10	39	36	38	2	2	2	48	52	50	71	65	68
KSB15-02	41	34	38	4	2	3	47	46	46	71	65	68
KSB15-22	41	36	39	4	2	3	50	52	51	70	65	68
KSB15-12	40	35	37	4	2	3	47	46	46	71	64	68
KSB15-04	39	34	37	2	3	2	47	47	47	71	64	68
KSB15-15	41	36	38	3	1	2	47	46	46	67	65	66
KSB15-11	40	35	38	4	3	3	48	47	48	68	64	66
KSB15-21	41	36	39	5	3	4	51	48	50	71	65	68
KSB15-07	40	35	37	3	1	2	48	46	47	71	64	68

Continued: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB15 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							Days					
	50% DF			**Vigour**			**First harvest**			**Last harvest**		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSB15-13	41	36	38	2	2	2	47	49	48	71	64	68
KSB15-09	40	35	38	3	3	3	50	47	49	71	65	68
KSB15-16	39	34	37	4	2	3	47	48	47	70	65	68
KSB15-05	38	33	36	2	2	2	47	44	46	70	63	67
KSB15-03	41	36	39	4	2	3	48	46	47	68	63	66
KSB15-23	41	36	39	5	2	4	50	47	48	71	65	68
KSB15-20	40	35	38	4	2	3	47	48	48	71	65	68
Checks												
Julia	41	36	39	4	4	4	50	61	56	71	65	68
Samantha	41	36	38	6	2	4	47	48	48	67	65	66
Serengeti	41	36	38	3	3	3	48	47	48	70	64	67
Trial Mean	40.2	35.1	37.6	3.6	2.1	2.8	48.0	47.7	48	70.0	64.3	67
$LSD_{0.05}$ Genotype	0.6	0.6	1.4	0.7	0.6	1.4	0.7	1.7	2.6	1.2	1.0	2.3
$LSD_{0.05}$ Site			0			4.5			17.2			3.5
$LSD_{0.05}$ G x S			1.9			2.1			5.3			3.2
CV (%)	0.6	0.9		1.3	34.6		0.9	3.6		0.3	0.7	

DF-duration to flowering, LSD-least significant difference, CV-coefficient variation, G x S-Genotype x Site

Table 6. 5: Duration to 50% flowering, plant vigour and days to first and last harvest of KSV14 climbing snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

	50% DF			Vigour			Days					
							First harvest			Last harvest		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSV14-01	44	39	41	3	2	3	53	53	53	78	65	71
KSV14-07	43	38	40	4	3	3	54	52	53	75	61	68
KSV14-02	44	39	41	3	2	3	54	52	53	75	65	70
KSV14-05	39	34	37	3	2	3	53	43	48	71	63	67
KSV14-03	42	37	40	4	2	3	54	49	52	77	65	71
KSV14-10	42	37	39	5	2	3	52	46	49	72	63	67
KSV14-08	44	39	42	4	2	3	53	52	52	76	65	71
KSV14-09	42	37	40	3	3	3	52	45	48	74	61	68
KSV14-04	43	38	40	3	1	2	54	47	50	76	65	70
KSV14-06	43	38	40	3	2	2	55	53	54	74	65	70
Checks												
Julia	39	34	36	4	2	3	49	48	49	72	65	68
Samantha	40	35	38	4	2	3	54	47	51	73	64	68
Serengeti	38	33	35	3	2	2	53	44	49	72	65	69
Trial Mean	41.5	37.1	39	3.6	2.3	2.7	52.8	49.9	50.5	74.0	63.9	69
$LSD_{0.05}$ Genotype	1.5	1.1	1.2	0.9	0.6	1.2	1.5	2.1	3.9	1.2	1.1	2

$LSD_{0.05}$ Site			0.2			3.9			1			4.4
$LSD_{0.05}$ G x S			1.7			1.8			5.3			2.8
CV (%)	1.3	2.4		14.8	3.3		0.9	0.5		0.2	0.3	

DF-duration to flowering, LSD-least significant difference, CV-coefficient variation, G x S-Genotype x Site

6.3.4. Days to first and last harvest

There were significant differences ($p<0.01$) among advanced lines for duration to first and last harvest on both sites (Tables 6.14 to 6.22). Sites varied significantly for days to first harvest in KSB 14 and KSV14 snap bean lines. Additionally, Sites varied significantly for days to last harvest in KSV14 snap bean lines (Tables 6.14 to 6.21). There was interaction between genotypes and sites for days to first and last harvests in all the four snap bean groups. Among all groups, days to first and last harvest were longer at Kabete than at Mwea. Among KSB13 group, duration to first harvest varied from 46.3 to 50 days on average with KSB13-30, KSB13-23, KSB13-46 and KSB13-38 being among the earliest lines to reach the first harvest date (46.3 to 46.6 days on average) (Appendix 19). The earliest check, Serengeti, was first harvested after 46.8 days and to the last harvest in 66.5 days. Duration to last harvest varied from 68.3 to 72.7 days for the KSB 13 lines. KSB13-28, KSB13-35 and KSB13-29 were among the lines with the longest harvesting duration (72 to 72.7 days in average) (Table 6.2 and Appendix 19). KSB14 group reached the first harvest after 45 to 48 days. However, days to last harvest varied from 62 to 68 days. The earliest check, Serengeti, had an average of 45 days to first harvest and 68 days to last harvest (Table 6.3 and Appendix 20). Among KSB15 group, days to first harvest ranged from 46 to 51 days with KSB15-01, KSB15-18, KSB15-12 and KSB15-05 being the earliest lines. Days to last harvest ranged from 65 to 68 days on average. The earliest check, Serengeti, had 48 days to first harvest and 68 days to last harvest in average (Table 6.4). The KSV14 group, which are climbers, had the longest duration to first harvest (48 to 54 days on average). Apart from KSV14-04 and KSV14-05 lines, the rest had longer days to first harvest than the earliest checks (Julia and Serengeti). Days to last harvest ranged from 67 to 71 days on average. This was comparable to the three KSB 13 lines with the longest harvest duration (KSB13-28, KSB13-35 and KSB13-29). Most of the climbing bean lines had longer harvesting duration than the bush check varieties (Table 6.5).

Duration to last harvest was higher at Kabete than at Mwea. Mean duration to last harvest of bush snap bean lines at Kabete was 70 days while at Mwea was 64 days. However, mean duration to last harvest at Kabete was 74 days while at Mwea was still 64 days (Tables 6.2 to 6.5). The new lines are expected to reach first harvest under warm and wet climatic conditions. Snap bean lines at Kabete are expected to have longer harvest duration. Days to first harvest positively correlated with days to lat harvest ($r= 0.64^{**}$) and vigour ($r= 0.49^{**}$) and negatively correlated with pods per plant ($r= -0.51^{**}$) and pod yield ($r= -0.46^{**}$). Days to last harvest positively correlated with vigour (r= 0.48**) and negatively correlated with pods per plant (r= -0.36**) (Table 6.23).

6.3.5. Pod length and pod diameter

Pod length and pod diameter of the genotypes in all the groups varied significantly ($p<0.01$) across the sites (Tables 6.14 to 6.22). Sites varied significantly for pod length in KSV 14 and pod diameter in KSB 13 and KSV14 lines (Tables 6.14, 6.17, 6.19 and 6.21). There was interaction between genotypes and sites in KSB 14 and KSB 15 lines. Among KSB13 group, pod length ranged from 7.3 to 14.4 cm on average. KSB13-28, KSB13-11 and KSB13-36 were among the lines with the longest pods (13.7 to 14.4 cm). The lines with the shortest pod length were KSB13-40 and KSB13-53. Pods of Samantha, which had the longest pods among the check varieties, were 11.2 cm on average. Nine KSB 13 lines had longer pods than Samantha. Most of the KSB 13 lines had comparable pod length with the checks (Table 6.6 and Appendix 19). Among KSB14 group, pod length varied from 8 to 15 cm (KSB14-15 and KSB14-12). The check variety with the longest pod was Julia (14 cm).Seven lines were comparable to the check with the longest pod length. Pod diameter ranged from 6 to 7 mm which was comparable to all the checks (Table 6.7 and Appendix 20). Among KSB15 group, pod length ranged from 10 to 14 cm (KSB15-19 and KSB15-12, KSB15-16). Eight lines had longer pod length than the longest check variety, Serengeti (12 cm). Most of the lines were comparable with the checks in terms of pod length. Twenty three KSB 13 lines met the minimum pod length of 10 cm compared to 27 lines for KSB 14, 23 lines for KSB 15 and nine lines in KSV 14 group (Tables 6.6 to 6.9, Appendices 19 and 20). The KSV 14 climbing lines had shorter pod length compared with bush lines.

Pod diameter ranged from 5.7 to 9.3 mm (KSB13-17 and KSB13-14) among KSB 13 group. The check variety with the smallest pod diameter was Julia (4.9 mm) (Appendix 19). Pod diameter varied from 5 to 7 mm among KSB 15 group. The check variety with the largest pod diameter was Serengeti (6 mm) which was comparable to most of the lines (Table 6.8). KSV14 group had the smallest pod length among the four groups (9 to 12 cm). KSV14-07, KSV14-10 and KSV14-09 were among the lines with the shortest pod length. Pod diameter ranged from 5 to 9 mm. Two lines had comparable pod diameter with the check with the largest pod diameter (Serengeti, 6 mm) (Table 6.9). The processors and consumers prefer thin pods with pod diameter of 4 to 6 mm (extra fine) and 6 to 8 (fine). KSV 14 lines had wider pods than the bush lines. Forty three lines met the market criteria for pod diameter in KSB

13, twenty eight lines in KSB 14 group, twenty three lines in KSB 15 group and eight lines in KSV 14 group (Tables 6.6 to 6.9, Appendices 19 and 20). Six lines had better pod diameter (<6 mm) than the checks (Samantha and Serengeti) while fifty eight lines had as good pod length as the checks (6 mm). Pod diameter weakly correlated with pod yield (r= 0.32*). There was no correlation between pod length and other traits (Table 6.23).

6.3.6. Pod shape and pod curvature

Pod shape and pod curvature varied across the sites. Among KSB13 group, KSB13-50, KSB13-41, KSB13-12, KSB13-26, KSB13-29 and KSB13-53 were among 27 lines with round pod shape across the sites. The above lines were comparable with the check varieties in terms of pod shape. Twenty three lines had straight pod across the sites (Table 6.6 and Appendix 19). Among KSB14 group, ten lines had round pod shape across the sites. Twenty one lines had straight pods across the sites. Check varieties had flat pods in Kabete (Table 6.7 and Appendix 20). Among KSB15 group, 13 lines had round pod shape across the sites. Pod curvature of the lines across sites was comparable with the checks whereby 17 lines had straight pods across the sites. KSB15-17, KSB15-19, KSB15-02, KSB15-22 and KSB15-12 were among lines with round and straight pods across the sites (Table 6.8). KSV14 group had consistent lines for pod shape across the sites apart from KSV14-09 which had round pods in Kabete and flat pods in Mwea. All the pods were straight across the sites apart from KSV14-08 and KSV14-10 (Table 6.9). Twenty four lines met the market requirement for straight round pods in KSB 13 group, 23 lines in KSB 14 group, 23 lines in KSB 15 group and seven lines in KSV 14 group. Thirty two lines were better than the commercial varieties for these aspects. Twenty seven lines across the groups did not meet the market criteria for straight round pods (Tables 6.6 to 6.9, Appendices 19 and 20).

6.3.7. Reaction of the advanced lines to major diseases under field conditions

The advanced lines grown in Kabete and Mwea during long and short season of 2014 showed significant differences (p<0.01) in reaction to angular leaf spot, rust and common bacterial blight (Tables 6.14, 6.15, 6.17, 6.19 and 6.21). Diseases were more prevalent during long rain than short rain. Angular leaf spot, rust and CBB occurred at Kabete among KSB 13 group during long rain while rust and angular leaf spot occurred among other groups during short rain season (Table 6.6 to 6.9, Appendices 19 and 20). Rust had the highest incidence in KSB13 group whereby five lines had intermediate resistance. Thirty nine lines were resistant to rust. The check varieties had intermediate resistance apart from Serengeti which was rated resistant (2) (Appendix 19). All KSB14 lines except KSB14-23 were resistant to rust (1-3) (Table 6.7). All KSB15 and KSV14 lines were resistant to rust on average (Table 6.8 and 6.9). The check varieties in plots planted with KSB13 and KSB14 lines showed intermediate resistance (4 to 6). All the lines in the four groups showed resistance to common bacterial blight and angular leaf spot (1-3) (Tables 6.6, 6.7, 6.8 and 6.9). They were comparable to check varieties.

Table 6. 6: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB13 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain seasons.

											Diseases								
	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Rust			ALS[§]			CBB[§]		
					[ʃ]SR						[ʃ]LR	SR	Mean	LR	SR	mean	LR	SR	Mean
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**				**Kabete**					
KSB13-11	13.1	15.4	14.3	6.9	6.5	6.7	Flat	Flat	Straight	Straight	1.7	1	1.3	2.7	1	1.8	2	1.3	1.7
KSB13-14	12.3	11	11.6	9.3	9.3	9.3	Flat	Flat	Straight	Curved	3.3	1	2.2	2.3	1	1.7	2	1.3	1.7
KSB13-16	12.1	11.7	11.9	6.6	6.4	6.5	Flat	Flat	Straight	Curved	1.7	1	1.3	2	1	1.5	3	2.3	2.7
KSB13-18	10.2	10.6	10.4	6.4	6.2	6.3	Flat	Round	Straight	Straight	2.3	1	1.7	2.3	1	1.7	2	1.3	1.7
KSB13-19	10.7	10.6	10.7	8.1	9.9	9	Flat	Round	Straight	Straight	3	1	2	2.3	2	2.2	2	1.3	1.7
KSB13-20	10.7	9.7	10.2	6.2	6.3	6.2	Flat	Round	Straight	Curved	3	2	2.5	2	1	1.5	2.3	1.6	2
KSB13-21	11.6	11.2	11.4	6.3	8.5	7.4	Flat	Flat	Straight	Straight	1	1	1	2.3	1	1.7	2	1.3	1.7
KSB13-23	11.4	10.6	11	7.4	6.4	6.9	Flat	Flat	Straight	Curved	2.3	1	1.7	2	1	1.5	2.3	1.6	2
KSB13-24	11.4	10.6	11	6.3	6.4	6.3	Flat	Round	Straight	Straight	2.3	3	2.7	2	1	1.5	2.3	1.6	2
KSB13-27	10.2	10.9	10.5	6.9	6.9	6.9	Flat	Flat	Straight	Curved	2.3	1	1.7	2	1	1.5	2.3	1.6	2
KSB13-28	14.9	13.8	14.4	6.7	5.7	6.2	Flat	Flat	Curved	Curved	2.7	3	2.8	2.3	1	1.7	2.3	1.6	2
KSB13-34	11.2	10.8	11	6.3	6.6	6.4	Flat	Round	Straight	Straight	3.3	1	2.2	2	1	1.5	2	1.3	1.7
KSB13-35	12	11.4	11.7	6.7	6.4	6.5	Flat	Round	Straight	Straight	1.7	4	2.8	2.7	1	1.8	2.3	1.6	2
KSB13-36	11.9	15.5	13.7	6.5	5.7	6.1	Flat	Round	Straight	Curved	3.3	1	2.2	2.3	1	1.7	2	1.3	1.7
KSB13-44	14.2	9.1	11.6	5.7	6.3	6	Flat	Round	Straight	Curved	1.7	4	2.8	2	1	1.5	3.3	2.6	3
KSB13-45	10.2	11.3	10.8	6.5	8.1	7.3	Flat	Round	Straight	Curved	1.7	1	1.3	2	1	1.5	2	1.3	1.7
KSB13-46	10.4	10.4	10.4	6.3	6	6.2	Flat	Flat	Straight	Straight	1	2	1.5	2	1	1.5	2.3	1.6	2
KSB13-50	10.9	10.3	10.6	6.2	5.9	6.1	Round	Round	Curved	Curved	3	1	2	2.3	1	1.7	2.3	1.6	2
KSB13-51	11.7	14	12.8	5.8	6.2	6	Flat	Round	Straight	Straight	3	4	3.5	2	1	1.5	3	2.3	2.7
KSB13-55	10.8	10.3	10.6	6.3	7.3	6.8	Flat	Flat	Straight	Curved	2.3	1	1.7	2.7	1	1.8	2.7	2	2.3
Checks																			
Julia	10.1	9.4	9.8	5.3	4.5	4.9	Round	Round	Straight	Straight		6	6		2	2		4	4

Continued: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB13 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain seasons.

											Diseases								
	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Rust			ALS§			CBB§		
						∫SR					∫LR	SR	Mean	LR	SR	mean	LR	SR	Mean
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**				Kabete					
Samantha	11.7	10.6	11.2	5.9	5.2	5.6	Round	Round	Straight	Straight	2.7	6	4.4	2.3	3	2.7	2	5	3.5
Serengeti	12.1	9.5	10.8	5.9	4.4	5.2	Round	Round	Straight	Straight		2	2		1	1		3	3
Trial Mean	10.3	9.9	10.1	6.5	6.6	6.6					2.6	2.1		2.1	1.2		2.3	1.1	
$LSD_{0.05}$ (G) §	0.7	1.2	2.04	0.3	0.6	1.04					1.3	0.8		0.5	0.3		0.8	0.2	
$LSD_{0.05}$ Site			0.59			0.02													
$LSD_{0.05}$ G x S			2.86			1.45													
CV (%)	1.7	1.1		0.5	0.4						31.8	15.9		15.4	2.4		21.1	2.1	

LSD-least significant difference, CV-coefficient variation, ∫ LR= long rain, SR, short rain seasons; §G= Genotype, ALS= angular leaf spot, CBB= common bacterial blight, G x S-Genotype x Site

Table 6. 7: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB14 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

											Diseases	
	Pod length (cm)			Pod diameter			Pod shape		Pod curvature		Rust	ALS§
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	
KSB14-01	13	13	13	6	6	6	Round	Round	Straight	Straight	2	1
KSB14-02	15	13	14	7	7	7	Round	Round	Straight	Straight	2	2
KSB14-03	13	12	13	6	6	6	Flat	Round	Straight	Straight	3	2
KSB14-04	16	12	14	7	6	6	Flat	Round	Straight	Curved	3	1
KSB14-06	14	13	13	6	6	6	Flat	Round	Straight	Straight	2	2
KSB14-07	15	11	13	6	6	6	Flat	Round	Straight	Straight	1	1
KSB14-08	15	13	14	7	7	7	Flat	Round	Straight	Straight	2	1
KSB14-09	14	12	13	6	6	6	Round	Round	Straight	Straight	3	2
KSB14-12	14	16	15	7	7	7	Flat	Round	Straight	Curved	3	3
KSB14-13	15	11	13	7	6	6	Flat	Round	Straight	Straight	2	1
KSB14-16	15	14	14	7	7	7	Flat	Flat	Straight	Curved	2	2
KSB14-17	12	14	13	6	7	7	Round	Round	Straight	Straight	2	1
KSB14-18	14	13	14	7	6	6	Flat	Round	Straight	Straight	2	2
KSB14-19	14	12	13	6	6	6	Flat	Round	Straight	Straight	3	3
KSB14-20	13	12	13	7	6	6	Flat	Round	Straight	Curved	1	2
KSB14-21	15	12	14	7	6	6	Flat	Round	Straight	Straight	2	3
KSB14-22	11	12	12	6	6	6	Round	Flat	Straight	Curved	2	1
KSB14-25	12	12	12	6	6	6	Round	Round	Straight	Straight	1	1
KSB14-26	12	13	13	6	6	6	Round	Round	Straight	Straight	1	1
KSB14-27	13	11	12	6	6	6	Round	Round	Straight	Straight	2	2
Checks												
Julia	11	17	14	6	8	7	Flat	Flat	Straight	Straight	6	1

Continued: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB14 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

											Diseases	
	Pod length (cm)			Pod diameter			Pod shape		Pod curvature		Rust	ALS[§]
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	
Samantha	11	8	10	6	5	6	Flat	Round	Straight	Straight	5	3
Serengeti	12	12	12	6	6	6	Flat	Round	Straight	Straight	2	1
Trial Mean	12.9	11.8	12.3	6.3	6	6.1					2.3	1.6
$LSD_{0.05}$ (G)[§]	0.6	0.9	1.6	0.2	0.3	0.54					0.6	0.4
$LSD_{0.05}$ Site			3.34			2						
$LSD_{0.05}$ G x S			2.29			0.84						
CV %	1.5	4.8		2.8	0.8						20.2	0.9

LSD-least significant difference, CV-coefficient variation, [§]G= Genotype, ALS= angular leaf spot, G x S-Genotype x Site

Table 6. 8: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB15 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Disease score	
											Rust	ALS§
Genotype	Kabete	Mwea	Mean	Kabete	Mwea	Mean	Kabete	Mwea	Kabete	Mwea	Kabete	
KSB15-24	13	9	11	6	4	5	Flat	Round	Straight	Straight	1	1
KSB15-08	14	13	13	6	5	6	Flat	Round	Straight	Straight	3	1
KSB15-17	11	12	11	7	6	6	Round	Round	Straight	Straight	1	1
KSB15-01	14	10	12	7	5	6	Flat	Round	Straight	Curved	2	1
KSB15-18	16	9	12	7	6	7	Round	Round	Straight	Curved	1	2
KSB15-06	14	12	13	6	6	6	Flat	Round	Straight	Straight	2	2
KSB15-19	12	9	10	6	5	5	Round	Round	Straight	Straight	1	2
KSB15-10	14	9	11	7	5	6	Round	Round	Straight	Straight	2	1
KSB15-02	12	10	11	7	8	7	Round	Round	Straight	Straight	2	1
KSB15-22	12	12	12	6	6	6	Round	Round	Straight	Straight	1	2
KSB15-12	15	12	14	7	6	6	Round	Round	Straight	Straight	2	2
KSB15-04	15	11	13	7	6	6	Flat	Round	Straight	Straight	3	1
KSB15-15	14	11	13	7	6	6	Round	Round	Straight	Straight	3	2
KSB15-11	15	11	13	7	6	6	Round	Round	Straight	Curved	2	1
KSB15-21	11	12	11	6	6	6	Round	Flat	Straight	Curved	1	2
KSB15-07	14	12	13	7	6	6	Round	Round	Straight	Straight	1	1

Continued: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB15 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

											Disease score	
	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Rust	ALS§
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	
KSB15-13	12	11	11	6	6	6	Round	Round	Straight	Curved	2	2
KSB15-09	12	11	11	6	6	6	Round	Round	Straight	Straight	2	1
KSB15-16	15	13	14	7	6	6	Round	Flat	Straight	Straight	2	1
KSB15-05	15	10	12	7	6	7	Round	Round	Straight	Straight	2	2
KSB15-03	15	9	12	6	6	6	Flat	Round	Straight	Straight	1	1
KSB15-23	12	11	11	8	7	7	Round	Round	Straight	Curved	1	1
KSB15-20	13	12	12	7	6	6	Flat	Round	Straight	Straight	1	1
Checks												
Julia	11	9	10	6	4	5	Round	Round	Straight	Curved	3	2
Samantha	10	10	10	6	5	5	Round	Round	Straight	Straight	3	2
Serengeti	13	12	12	6	6	6	Round	Round	Straight	Straight	2	1
Trial Mean	13.1	10.8	12	6.5	5.6	6					1.8	1.4
LSD $_{0.05}$ (G) §	0.8	1.4	2.41	0.3	0.5	0.89					1.0	0.6
LSD$_{0.05}$ Site			4.5			2.19						
LSD$_{0.05}$ G x S			3.4			1.29						
CV %	1.5	0.5		2.1	2.5						7.7	3.4

LSD-least significant difference, CV-coefficient variation, §G= Genotype, ALS= angular leaf spot, G x S-Genotype x Site

Table 6. 9: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSV14 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Disease score	
											Rust	ALS§
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	
KSV14-01	11	10	11	7	7	7	Round	Round	Straight	Straight	1	1
KSV14-07	10	7	9	6	5	6	Round	Round	Straight	Straight	1	1
KSV14-02	12	9	11	8	6	7	Round	Round	Straight	Straight	3	1
KSV14-05	13	12	12	10	9	9	Flat	Flat	Straight	Straight	1	1
KSV14-03	12	11	11	10	8	9	Round	Round	Straight	Straight	2	1
KSV14-10	11	9	10	7	7	7	Flat	Flat	Curved	Straight	1	1
KSV14-08	13	10	11	8	6	7	Flat	Round	Curved	Straight	3	1
KSV14-09	11	9	10	7	7	7	Round	Flat	Straight	Straight	1	1
KSV14-04	11	10	11	7	6	6	Round	Round	Straight	Straight	3	1
KSV14-06	13	10	11	9	6	7	Flat	Flat	Straight	Straight	1	1
Checks												
Julia	12	8	10	6	4	5	Round	Round	Straight	Straight	4	2
Samantha	13	8	11	6	5	6	Round	Round	Straight	Straight	4	2
Serengeti	15	11	13	6	6	6	Round	Round	Straight	Straight	3	1
Trial Mean	12.1	8.9	10.9	7.4	6.2	6.8					2.1	1.2
$LSD_{0.05}$ (G) §	0.6	0.8	0.75	0.2	0.7	1.13					1.3	0.4

$LSD_{0.05}$ Site			0.22			0.2		
$LSD_{0.05}$ G x S			1.04			1.5		
CV %	0.4	3.3		2.4	0.9		5.9	18.9

LSD-least significant difference, CV-coefficient variation, [§]G= Genotype, ALS= angular leaf spot, G x S-Genotype x Site

6.3.8. Pods per plant

Advanced lines from the four groups and commercial varieties grown during 2014 long and short rain seasons showed significant differences in yield potential and pods per plant ($P<0.01$) (Tables 6.14 to 6.22). There was no interaction between genotypes and harvesting dates apart from KSB13 lines. Sites varied significantly for pods per plant in KSB 15 and KSV14 lines (Tables 6.14, 6.17, 6.19 and 6.21). There was interaction between genotypes and sites for pods per plant in all groups of snap bean. Pods per plant was highest in Kabete long rain season (Tables 6.10 to 6.13). Pods per plant ranged from 19 to 37 (KSB13-40 and KSB13-21). Most of the lines had higher pods per plant than the best check. Pods per plant was higher in Mwea than in Kabete during short rain season. However, the average pods per plant ranged from 6.8 (KSB14-28) to 22.5 (KSB14-15) (Appendices 21 and 22). Most of the lines had more pods per plant on average than Julia (7). Nine lines were comparable to Samantha in terms of pod per plant. The average pods per plant among KSB15 group ranged from 8 to 20 (Table 6.12). Most of the lines were comparable to Julia variety in terms of pods per plant. Pods per plant were also higher in Kabete than in Mwea. The average pods per plant ranged from 17 to 28 (Tables 6.12, 6.13, Appendices 21 and 22). Pods per plant highly positively correlated with pod yield ($r= 0.93$) and negatively correlated with 50% duration to flowering ($r= -0.51^{**}$), days to first harvest ($r= -0.51^{**}$), days to last harvest ($r= -0.36^{**}$) and vigour ($r= -0.42^{**}$) (Table 6.23).

6.3.9. Pod yield

Sites varied significantly ($P<0.05$) only in KSV14 lines (Tables 6.14, 6.17, 6.19 and 6.21). There was interaction between genotypes ad sites for pod yield in all groups of the snap bean. Among KSB13 lines, mean pod yield at Kabete during the long rain season was higher than for short rain season, and also at Mwea. The average pod yield varied from 4243.9 kg ha^{-1} (KSB13-56) to 9559.7 kg ha^{-1} (KSB13-11). The best line had yield advantage of 44% over the best check variety (Samantha, 5351.5 kg ha^{-1}). Thirty five lines had better yield than the best check variety (Table 6.10 and Appendix 21). KSB13-14, KSB13-15, KSB13-13, KSB13-11 and KSB13-12 were among the lines with the highest pod yield. The poor performing lines included KSB13-56, KSB13-55 and KSB13-54. These lines had low pod yields. Among KSB14 lines, Kabete site performed better than Mwea in terms of pod yield. The average pod yield varied from 3,260.7 kg ha^{-1} (KSB14-28) to 8,582.4 kg ha^{-1} (KSB14-01). The best check variety was Serengeti (6,853.1 kg ha^{-1}). Four lines had better pod yield than the best check variety. Most of the lines had comparable pod yield with other checks (Julia and Samantha) (Table 6.11 and Appendix 22). Among KSB15 lines, Kabete site had higher pod yield than Mwea. The average pod yield varied from 4,525.3 kg ha^{-1} (KSB15-24) to 12,847.2 kg ha^{-1} (KSB15-01). Eleven lines had higher yield than the best check variety (Serengeti, 6,988.4 kg ha^{-1}). KSB15-01, KSB15-02 and KSB15-03 were among the lines with high pod yield. All the lines had higher pod yield than Julia check (Table 6.12). Climbing snap bean lines (KSV 14) had the highest pod yield. Pod yield of these lines varied from 8,288.1 kg ha^{-1} (KSV14-10) to 20,695.1 kg ha^{-1} (KSV14-01). Pod yield at Kabete was higher than at Mwea. Four new lines had higher pod yield than the best check variety (Serengeti, 13, 258.7 kg ha^{-1}) (Table 6.13). On average, climbing lines out yielded bush lines. The best yielder in climbing bean lines produced 20,695.1 kg ha^{-1} while the best yielder in bush lines produced 12,847.2 kg ha^{-1}. Climbing snap bean lines had a yield advantage of 40% over bush snap bean lines. Pod yield negatively correlated with 50% duration to flowering (r= -0.4**), days to first harvest (r= -0.46**) and vigour (r= -0.42**) and highly positively correlated with pods per plant (r= 0.93**) (Table 6.23).

6.3.10. Grade distribution

KSB13-47, KSB13-18, KSB13-41, KSB13-12 and KSB13-17 were among the lines in KSB 13 group with the lowest grade of bobby market class across the sites because most of their pods were of extra fine and fine grades. These lines are comparable with the checks which constitute high percentages of extra fine and fine market classes (Table 6.10 and Appendix 21). Most of the lines in KSB 14 group had high percentages of extra fine and fine which are the marketable classes. Six lines had no bobby market class, and produced only extra fine and fine beans. These lines were comparable with check varieties which have high percentage grade distribution of extra fine and fine market classes (Table 6.11 and Appendix 22). Among KSB 15 lines, extra fine and fine grade distributions were high across the sites. Most of the lines had grade distributions which are comparable to the check varieties. Ten lines produced only extra fine and fine pods and no bobby market class across the sites (Table 6.12). These lines were comparable with check varieties (Julia and Serengeti). Five lines were better than Serengeti check. Grade distribution of climbing bean lines contrasted sharply with that of bush lines. In general, the climbing bean lines (KSV14) lines had a larger proportion of bobby market class compared to bush lines. For example, the proportion of bobby beans varied from 0 to 42.7 % at Kabete, and from 0 to 15.2% at Mwea. In contrast, the proportion of bobby among the bush KSB 13 lines varied from 0 to 14.6 % at Kabete, and from 0 to 20.4 % at Mwea, KSB14 lines varied from 0 to 7.8% at Kabete, and from 0 to 0.7 % at Mwea and KSB15 lines varied from 0 to 16.8 % at Kabete and 0 to 2 % at Mwea. Seven climbing bean lines had a higher proportion of bobby market class than the check variety with the highest bobby market class (Samantha, 13.3 %). KSV14-10, KSV14-08 and KSV-09 were among the lines with the highest percentages of extra fine and fine grade distribution and low bobby market class (Table 6.13).

6.3.11. Genetic diversity of snap bean lines

Cluster analysis of 46 snap bean lines and three checks revealed seven clusters. The three checks namely Serengeti, Julia and Samantha are commercial varieties grown by farmers for both local and export market. The first cluster was the latest to flower (38 days). However, it had better vigour than the second cluster. Pod length, pod diameter, days to first and last harvest were comparable among the clusters. However, they differed in pods per plant and pod yield. The third cluster had better vigour (1), higher pods per plant (18.5) and increased yield potential (7568.4 kg ha-1). KNSB88-4R1 had high pods per plant (24.4) and pod yield of 10,184.8 kg ha-1. KNSB88-2R1/2 had the highest days to 50% flowering, lowest pods per plant (2.2) and pod yield (563.5 kg ha-1) hence becoming distantly related to other lines (Appendix 25)

Table 6. 10: Pod yield, pod per plant and grade distribution of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

	Pod yield (kg ha-1)				Pods plant-1				% Grade distribution: Extra-fine			% Grade distribution: Fine			% Grade distribution: Bobby		
	∫LR	∫SR			LR	SR			LR	SR		LR	SR		LR	SR	
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**
KSB13-11	7511.3	8199.2	12968.7	9559.7	40.7	18	21	26	50.1	37.3	23.8	48.3	61	69.3	1.6	1.7	6.9
KSB13-12	9450.8	4474.3	14338.9	9421.3	56.4	12	35	34	42.2	55.3	40.3	56.8	44.7	59.7	0.9	0	0
KSB13-13	8132.3	7515.6	11236.4	8961.4	42.8	18	25	29	57.6	37.1	29.9	42.4	54.7	69.5	0	8.2	0.6
KSB13-14	6721	6053.4	13273.2	8682.5	38.3	14	32	28	47.8	30.4	32.7	49.3	69.6	60.5	3	0	6.8
KSB13-15	7686	2634.1	14360.7	8226.9	48.4	5	32	29	35.2	39.8	26.4	59.6	60.2	71.5	5.1	0	2.1
KSB13-16	7894.5	6922.5	9740	8185.7	44.7	17	23	28	50.7	53.9	58.1	47.6	45.9	41.8	1.7	0.2	0.1
KSB13-17	8650.8	3741.8	11626.7	8006.4	42.8	13	31	29	41.8	84.2	54.7	57.7	15.8	45.3	0.5	0	0
KSB13-18	10736.7	4385.8	8421.7	7848	67.6	13	26	35	54.1	50.1	61	45.7	49.9	39	0.2	0	0
KSB13-19	7554	5729.7	10226.5	7836.7	47.1	11	18	25	55	30.5	25.6	42.1	54.9	61.7	2.9	14.6	12.7
KSB13-20	8711	4585.6	9848.3	7715	38.7	12	19	23	63.5	62.5	30.8	35.9	31.4	68.2	0.6	6.1	1
KSB13-21	8808.8	4946.8	8878.3	7544.6	74.6	12	23	37	56.6	54.7	39.4	42.2	43.2	58.6	1.3	2.1	2
KSB13-22	8268.9	7703.5	6430	7467.5	47.7	18	18	28	44.8	40.6	43.8	53.4	57	54.7	1.7	2.4	1.4
KSB13-23	7542.1	5585.9	8537.5	7221.8	52.2	14	25	30	54.4	44.9	41.1	44.2	50.6	58.9	1.4	4.5	0
KSB13-24	2865.7	7647.7	11126.7	7213.4	20.3	19	24	21	62.4	45.9	47	37.6	53.3	44.9	0	0.8	8.1
KSB13-25	8282.6	4780.8	8144.5	7069.3	51.8	15	20	29	42.4	50.2	39.7	57	47.7	60.3	0.5	2.1	0
KSB13-26	8151.9	4958.6	7823.8	6978.1	44.1	12	23	27	43.4	40.6	51.2	46.8	58.9	48.8	9.8	0.5	0
KSB13-27	9073	4021	7830.4	6974.8	54.9	11	21	29	42.1	33.5	48.7	57.4	64.2	51.3	0.5	2.3	0
KSB13-28	10895.3	5833.5	4100	6943	60.3	11	9	27	53.1	40	47.9	38.8	59.3	52.1	8.1	0.7	0
KSB13-29	8844	4664.3	6928.4	6812.2	50.8	10	22	27	35.2	35.9	50	62.3	61.4	49	2.5	2.8	1.1
KSB13-30	3427.7	6740.7	10239.3	6802.5	25.9	16	26	23	47.8	42.3	33.5	52.2	56.4	63.9	0	1.3	2.6
Checks																	
Julia		1434.4	3271.4	2352.9		6	15	11		96.1	100		3.9	0		0	0

Continued: Pod yield, pod per plant and grade distribution of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

									% Grade distribution								
	Pod yield (kg ha^{-1})				**Pods plant^{-1}**				**Extra-fine**			**Fine**			**Bobby**		
	∫LR	**∫SR**			**LR**	**SR**			**LR**	**SR**		**LR**	**SR**		**LR**	**SR**	
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**
Samantha	7419.4	3490.3	5144.7	5351.5	34.3	9	15	20	60.1	84.9	88.7	36.2	13.9	11.3	3.6	1.2	0
Serengeti		4340	4160.2	4250.1		14	12	13		90.9	84.3		9.1	15.7		0	0
Trial Mean	7272	4535.9	6580.1	5558.4	48	14	24	15.3									
LSD $_{0.05}$ (G) §				0.43				0.6									
LSD$_{0.05}$ Site				5.6				1.58									
LSD$_{0.05}$ (G x S) §				2.1				0.88									
CV (%)	22.7	1.9	12		19.7	0.4	8.6										

LSD-least significant difference, CV-coefficient variation, §G= Genotype, G x S= Genotype x Site

Table 6. 11: Pod yield, pod per plant and grade distribution of KSB14 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							% Grade distribution					
	Pod yield (kg ha^{-1})			**Pod plant^{-1}**			**Extra fine**		**Fine**		**Bobby**	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSB14-01	12922	4242.9	8582.4	14	9.6	11.7	61.9	57.3	37.2	42.7	0.9	0
KSB14-02	10624.5	5944.5	8284.5	19	12.1	15.6	48.8	33.6	51.2	66.4	0	0
KSB14-03	6266.1	9698.2	7982.1	10	18	14.1	40.3	36.9	54.7	63.1	5	0
KSB14-04	7452.5	6319.6	6886	10	14.7	12.5	33.4	55.7	58.8	44.3	7.8	0
KSB14-05	7592.7	6081.5	6837.1	16	21.1	18.7	51.5	68.7	45.5	31.3	3	0
KSB14-06	7737.6	5613.5	6675.5	13	12.5	12.6	47.1	46.1	52.4	53.9	0.5	0
KSB14-07	5597.3	7690	6643.7	12	20.8	16.3	49	66.7	51	33.3	0	0

Continued: Pod yield, pod per plant and grade distribution of KSB14 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							% Grade distribution					
	Pod yield (kg ha^{-1})			Pod plant^{-1}			Extra fine		Fine		Bobby	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSB14-08	7753.7	5520.3	6637	10	12.8	11.2	39.1	51.9	60.2	48.1	0.7	0
KSB14-09	8294.6	4800.9	6547.8	13	9.9	11.5	46.2	62.5	51.8	37.5	2	0
KSB14-10	8419.9	4554.6	6487.2	14	11.9	13.1	42.3	56.2	53.2	43.8	4.5	0
KSB14-21	7755.5	4770.9	6263.2	10	13.4	11.9	43.6	59.4	52.5	39.9	3.9	0.7
KSB14-12	3954	8527.8	6240.9	7	17.6	12.1	49	53.7	48.9	46.3	2	0
KSB14-13	5638	6710.8	6174.4	9	14.3	11.6	35.2	46.4	59.6	53.6	5.2	0
KSB14-14	10715.8	1620.9	6168.4	21	5	12.9	49.5	69.3	47.8	30.7	2.6	0
KSB14-15	4014.1	7602.8	5808.4	13	32	22.4	60.5	69.4	34	30.6	5.4	0
KSB14-16	5971.4	5343.3	5657.4	10	11.2	10.6	40.4	57	58.2	43	1.4	0
KSB14-17	5101.4	5941.7	5521.5	8	15.3	11.6	45.3	49.8	48.9	50.2	5.8	0
KSB14-18	4706.8	6166.7	5436.7	9	12.3	10.4	43.1	52.6	56.5	47.4	0.4	0
KSB14-19	6551.1	4140.3	5345.7	10	10.2	10.2	47.7	44.1	51.3	55.9	0.9	0
KSB14-20	6956.5	3335.7	5146.1	13	7.7	10.3	42.6	66.8	55.4	33.2	2	0
Checks												
Julia	3834.5	1400	2617.2	11	2.8	7	87	40.7	13	59.3	0	0
Samantha	5180.2	3638.6	4409.4	12	13.2	12.6	63.1	97.8	36.9	2.2	0	0
Serengeti	7961.7	5744.4	6853.1	16	13.8	14.7	67	70.6	31.5	29.4	1.4	0
Trial Mean	6163.9	4643.6	5403.6	11.7	12.7	11.7						
LSD $_{0.05}$ (G) §			0.5			0.47						
LSD$_{0.05}$ Site			1.8			0.83						
LSD$_{0.05}$ (G x S) §			0.8			0.66						
CV (%)	3.1	15.2		7	13.1							

LSD-least significant difference, CV-coefficient variation, §G= Genotype, G x S= Genotype x Site

Table 6. 12: Pod yield, pod per plant and grade distribution of KSB15 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							% Grade distribution					
	Pod yield (kg ha^{-1})			Pod plant^{-1}			Extra fine		Fine		Bobby	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSB15-24	6104.3	2946.2	4525.3	9	6	8	45.7	43.3	54.3	56.7	0.0	0.0
KSB15-08	9284.7	6397.2	7841.0	14	14	14	51.4	73.6	46.9	24.5	1.7	2.0
KSB15-17	9064.5	2356.2	5710.4	18	5	11	29.0	75.1	60.2	24.9	10.7	0.0
KSB15-01	19981.5	5712.8	12847.2	27	12	20	43.0	64.7	57.0	35.3	0.0	0.0
KSB15-18	7137.8	4278.6	5708.2	12	13	13	40.4	53.8	59.6	45.8	0.0	0.3
KSB15-06	10972.9	5779.2	8376.0	14	13	14	31.9	44.1	63.3	55.9	4.8	0.0
KSB15-19	9006.5	2188.9	5597.7	17	6	12	46.3	63.1	53.7	36.9	0.0	0.0
KSB15-10	10825.5	3372.2	7098.9	21	9	15	45.2	58.6	53.2	41.4	1.6	0.0
KSB15-02	6446.6	15224.3	10835.4	11	30	20	44.9	37.6	51.5	62.4	3.5	0.0
KSB15-22	5412.6	4368.2	4890.4	12	10	11	62.7	54.9	37.3	45.1	0.0	0.0
KSB15-12	8946.3	4854.2	6900.2	15	13	14	39.6	75.2	60.4	24.8	0.0	0.0
KSB15-04	15287.3	2043.5	8665.4	18	5	11	34.0	61.4	49.2	38.6	16.8	0.0
KSB15-15	10234.9	2124.8	6179.8	17	5	11	43.7	49.8	56.3	50.2	0.0	0.0
KSB15-11	11914.8	2107.1	7011.0	17	6	12	44.4	68.5	54.3	31.5	1.3	0.0
KSB15-21	7432.8	2998.6	5215.7	16	8	12	57.6	51.8	42.4	48.2	0.0	0.0
KSB15-07	9037.7	7050.0	8043.9	17	15	16	43.3	66.4	56.7	33.6	0.0	0.0

Continued: Pod yield, pod per plant and grade distribution of KSB15 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							% Grade distribution					
	Pod yield (kg ha^{-1})			Pod $plant^{-1}$			Extra fine		Fine		Bobby	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSB15-13	10122.0	3621.4	6871.7	22	9	15	50.1	87.0	49.9	13.0	0.0	0.0
KSB15-09	9606.5	5261.1	7433.8	18	13	15	44.7	74.2	53.4	25.8	1.8	0.0
KSB15-16	5429.9	6523.7	5976.8	10	13	11	49.4	35.1	50.0	64.9	0.7	0.0
KSB15-05	10484.4	6724.5	8604.4	16	15	15	46.1	47.0	53.1	53.0	0.8	0.0
KSB15-03	13390.5	5419.2	9404.9	21	9	15	53.1	44.2	46.3	55.8	0.5	0.0
KSB15-23	3777.2	5285.5	4531.3	9	11	10	46.9	54.9	53.1	44.8	0.0	0.4
KSB15-20	6678.0	4416.4	5547.2	11	12	11	43.4	45.0	56.0	55.0	0.6	0.0
Checks												
Julia	7409.5	341.2	3875.3	22	2	12	93.7	100.0	6.3	0.0	0.0	0.0
Samantha	4595.9	8197.2	6396.6	13	24	19	85.8	85.1	13.0	14.9	1.1	0.0
Serengeti	9455.3	4521.6	6988.4	22	13	17	75.0	77.3	25.0	22.7	0.0	0.0
Trial Mean	8420.8	4072.2	6352.2	17.2	10.8	14.4						
$LSD_{0.05}$ (G) §			0.45			1.1						
$LSD_{0.05}$ Site			4.47			0.42						
$LSD_{0.05}$ (G x S) §			1.42			1.53						
CV (%)	2.5	13.7		5.0	12.5							

LSD-least significant difference, CV-coefficient variation, §G= Genotype, G x S= Genotype x Site

Table 6. 13: Pod yield, pod per plant and grade distribution of KSV14 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

	Pod yield (kg ha^{-1})			Pod $plant^{-1}$			% Grade distribution					
							Extra fine		Fine		Bobby	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSV14-01	37170.1	4220.0	20695.1	48	8	28	24.5	45.7	54.8	40.0	20.7	14.2
KSV14-07	15321.3	5250.0	10285.7	21	14	18	23.8	73.3	54.6	26.7	21.7	0.0
KSV14-02	36739.4	4608.4	20673.9	40	11	25	24.9	35.8	51.9	49.0	23.2	15.2
KSV14-05	14639.5	10933.4	12786.5	20	20	20	19.5	29.6	56.1	59.6	24.4	10.8
KSV14-03	25680.3	5352.5	15516.4	37	14	25	11.9	39.1	45.4	53.3	42.7	7.6
KSV14-10	11242.7	5333.4	8288.1	24	11	17	37.8	22.9	62.2	77.1	0.0	0.0
KSV14-08	14173.0	4671.4	9422.2	25	10	18	32.9	51.9	62.6	48.1	4.5	0.0
KSV14-09	14557.4	3084.6	8821.0	21	8	14	20.8	44.0	62.6	56.0	16.6	0.0
KSV14-04	21476.1	6550.0	14013.1	26	13	19	26.4	32.8	41.9	67.2	31.7	0.0
KSV14-06	14540.6	6657.1	10598.9	22	14	18	24.6	41.4	66.7	43.6	8.8	15.0
Checks												
Julia	10559.4	2740.4	6649.9	25	11	18	77.7	95.1	9.1	4.9	13.3	0.0
Samantha	12784.2	5673.0	9228.6	24	21	22	56.5	98.7	36.6	1.3	6.9	0.0
Serengeti	20008.9	6508.5	13258.7	37	16	26	68.8	84.4	29.8	15.6	1.4	0.0
Trial Mean	17025.0	6211.9	15381	28.3	13.8	28.8						

LSD $_{0.05}$ (G) [§]			0.53			1.23
LSD$_{0.05}$ Site			4.72			0.43
LSD$_{0.05}$ (G x S) [§]			1.48			1.67
CV (%)	2.3	7.9		6.8	7.5	

LSD-least significant difference, CV-coefficient variation, [§]G= Genotype, G x S= Genotype x Site

Table 6. 14: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, diseases, pods per plant and pod yield of KSB 13 snap bean lines grown at Kabete Field Station during 2014 long rain season

Source of variation	**df**	**Duration to flowering**	**Plant vigour**	**Days to first harvest**	**Days to last harvest**	**Rust**	**Angular leaf spot**	**Common bacterial blight**	**Pod plant^{-1}**	**Pod yield (kg ha^{-1})**
Replicates	2	104.7	158.8	30.028	1774.92	0.96	0.0267	4.6067	255.366	81080000
Genotype	49	65.431**	30.4082**	104.923**	345.805**	2.3325**	0.1361*	0.2988*	26.404**	6262000**
Error	98	1.038	0.7836	1.193	8.381	0.6607	0.1083	0.2461	16.327	5469000

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 15: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, diseases, pods per plant and pod yield of KSB 13 snap bean lines grown at Kabete Field Station during 2014 short rain season

Source of variation	df	Duration to flowering	Plant vigour	Days to first harvest	Days to last harvest	Pod length	Pod diameter	Rust	Angular leaf spot	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	44.449	44.449	0.827	194.327	13.714	0.405	50.957	0.3673	0.0116	410.16
Site	1	1225_{ns}	145.7_{ns}	1033_{ns}	1704*	8.7_{ns}	0.5**			255.5_{ns}	22750000_{ns}
Error (a)	1	0	9.4	8.1	9.8	0.1	0			6.8	1334000
Genotype	49	24.237**	15.842**	62.219**	39.184**	43.672**	8.1829**	59.25**	5.7551**	2.4897**	572106**
Genotype x Site	48	0_{ns}	0.93_{ns}	6.1**	3.7_{ns}	2_{ns}	0.56_{ns}			5.3**	975300**
Error (b)	96	1.3	0.85	3.2	2.7	2.1	0.54			1.68	280500

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 16: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, pods per plant and pod yield of KSB 13 snap bean lines grown at Mwea during 2014 short rain season

Source of variation	df	Duration to flowering	Plant vigour	Days to first harvest	Days to last harvest	Pod length	Pod diameter	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	44.449	40.5	125.724	0.367	5.417	0.3528	14.399	3370397
Genotype	49	24.237**	8.0625**	62.958**	29.25**	62.478**	20.2030**	8.989*8	1782244**
Error	98	1.314	0.3542	3.699	2.124	3.202	0.875	2.456	405046

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 17: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, diseases, pods per plant and pod yield of KSB 14 snap bean lines grown at Kabete Field Station during 2014 short rain season

Source of variation	df	Duration to flowering	Plant vigour	Days to first harvest	Days to last harvest	Pod length	Pod diameter	Rust	Angular leaf spot	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	37.1613	0.581	0.145	558	10.0968	8.74126	58.0645	20.9032	2.3812	126974
Site	1	775_{ns}	102*	90.61*	921.3_{ns}	35.24_{ns}	1.71_{ns}			3.73_{ns}	7961133_{ns}
Error (a)	1	0	0.65	0.29	62.4	2.14	0.77			1.18	451357
Genotype	30	13.7323**	29.613**	21.765**	130.15**	49.0440**	2.14692**	31.4613**	8.9129**	2.5462**	1047703**
Genotype x Site	30	0_{ns}	1.54_{ns}	4.4**	7.71_{ns}	4.32**	0.55**			5.29**	987236**
Error (b)	60	0.43_{ns}	1.34	2.14	8.94	1.28	0.15			1.02	255724

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 18: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, pods per plant and pod yield of KSB 14 snap bean lines grown at Mwea during 2014 short rain season

Source of variation	df	Duration to flowering	Plant vigour	Days to first harvest	Days to last harvest	Pod length	Pod diameter	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	37.1613	17.5645	3.629	98.129	88.132	0.5806	9.494	1706803
Genotype	30	13.7323**	7.1323**	73.481**	16.065**	76.448**	8.2915**	7.031**	590211**
Error	60	0.429	0.7516	3.003	2.37	1.771	0.2335	1.368	192015

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 19: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, diseases, pods per plant and pod yield of KSB 15 snap bean lines grown at Kabete Field Station during 2014 short rain season

Source of variation	df	Duration to flowering	Plant vigour	Days to first harvest	Days to last harvest	Pod length	Pod diameter	Rust	Angular leaf spot	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	18.15	0.6	54.15	15	10.267	5.046	5.4	0.6	2.447	144781
Site	1	675$_{ns}$	63.79$_{ns}$	2.7$_{ns}$	720.5$_{ns}$	144.2$_{ns}$	15.04$_{ns}$			118.9*	53371397$_{ns}$
Error (a)	1	0	3.34	49.3	2.08	3.4	0.8			0.26	1114956
Genotype	26	11.8397**	19.469**	26.529**	37.531**	43.313**	4.3353**	11.276**	4.3241**	16.921**	2572376**
Genotype x Site	26	0.3$_{ns}$	1.19$_{ns}$	8.6**	1.96$_{ns}$	3.95$_{ns}$	0.43$_{ns}$			14.32**	1993496**
Error (b)	52	0.9	0.98	3.4	2.57	2.87	0.4			5.63	482390

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 20: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, pods per plant and pod yield of KSB 15 snap bean lines grown at Mwea during 2014 short rain season

Source of variation	df	Duration to flowering	Plant vigour	Days to first harvest	Days to last harvest	Pod length	Pod diameter	Pod plant^{-1}	Pod yield (kg ha^{-1})
Replicates	1	31.6406	153.1406	855.562	56.25	0.936	5.76	6.475	1102661
Genotype	29	12.5156**	10.3745**	186.315**	15.097**	29.599**	316.7044**	7.306**	1063640**
Error	58	0.9027	0.8866	6.417	2.121	4.532	0.63	1.483	286708

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 21: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, diseases, pods per plant and pod yield of KSV 14 climbing snap bean lines grown at Kabete Field Station during 2014 short rain season

Source of variation	**df**	**Duration to flowering**	**Plant vigour**	**Days to first harvest**	**Days to last harvest**	**Pod length**	**Pod diameter**	**Rust**	**Angular leaf spot**	**Pod plant^{-1}**	**Pod yield (kg ha^{-1})**
Replicates	1	23.077	21.564	18.692	2.077	0.1869	2.51308	1.256	3.6923	8.155	331900.00
Site	1	325*	40.69^{ns}	267.75**	1290.02*	86.33*	17.08**			760.07**	397300000*
Error (a)	1	0.31	1.23	0.08	1.56	0.65	0			0.09	1281000
Genotype	12	51.231**	5.077**	26.269**	53.731**	20.9593**	22.43269**	17.436**	1.6923**	26.758**	20080000**
Genotype x Site	12	0$_{ns}$	0.65$_{ns}$	10.69$_{ns}$	5.14*	1.71$_{ns}$	1.04$_{ns}$			23.87**	13330000**
Error (b)	24	3.03	0.69	7.08	1.82	1.12	0.6			4.63	2046000

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 22: Mean squares of duration to flowering, vigour, days to first harvest and last harvest, pod length, pod diameter, pods per plant and pod yield of KSV 14 climbing snap bean lines grown at Mwea during 2014 short rain season

Source of variation	**df**	**Duration to flowering**	**Plant vigour**	**Days to first harvest**	**Days to last harvest**	**Pod length**	**Pod diameter**	**Pod plant^{-1}**	**Pod yield (kg ha^{-1})**
Replicates	1	136421	0	11.605	8.526	14.632	0.533	2.2411	508100
Genotype	12	77.447**	0	343.921**	33.789**	76.306**	26.139**	16.5027**	7518000**
Error	24	2.769	0	9.956	2.725	1.53	1.144	0.776	164500

*, ** and ns 0.05, 0.01 significance probability level and not significant, df -degree of freedom

Table 6. 23: Correlation matrix among agronomic traits of snap bean lines

	50% duration to flowering	Days to first harvest	Days to last harvest	Pod diameter (mm)	Pod length (cm)	Pod plant^{-1}	Pod yield (kg ha^{-1})	Vigour
50% duration to flowering	1.00							
Days to first harvest	0.77**	1.00						
Days to last harvest	0.73**	0.64**	1.00					
Pod diameter (mm)	-0.09	-0.21	-0.08	1.00				
Pod length (cm)	0.07	0.08	0.18	0.06	1.00			
Pod plant^{-1}	-0.51**	-0.51**	-0.36**	0.24	-0.03	1.00		
Pod yield (kg ha^{-1})	-0.40**	-0.46**	-0.23	0.32*	0.14	0.93**	1.00	
Vigour	0.55**	0.49**	0.48**	-0.12	-0.12	-0.42**	-0.42**	1.00

6.4 DISCUSSION

6.4.1. Days to flowering

The significant differences for days to flowering in advanced lines of snap bean in Kabete and Mwea can be attributed to genetic differences among genotypes. There was early flowering in Mwea where higher temperatures were recorded. However, duration to flowering was later in Kabete during long and short rain season. This was due to lower temperatures recorded in Kabete compared with Mwea. The results showed that duration to flowering ranged from 31 to 39 days among KSB lines which are bush snap bean. They flowered almost at the same time. However, KSV lines which are climbing snap bean were late flowering, which delayed early pod set and harvesting. According to Wahome et al., (2013) who evaluated populations, parent varieties, KSB group of snap bean lines and climbing snap bean lines in Thika and Mwea found that populations and parent varieties flowered almost the same time. Their duration to flowering ranged from 36.3 to 40.1 days. KSB group and climbing lines were late flowering. The duration to flowering ranged from 39.9 to 44.2 days for the KSB lines and from 40.8 to 43.6 days for the climbing lines. This was in agreement with Ndegwa et al., (2011) who worked with determinate snap bean lines and found the duration to flowering ranging from 39- 43 days.

6.4.2. Plant vigour and days to first and last harvest

High plant vigour in Mwea can be explained by high fertility of the soil because it was a virgin land and supplemental furrow irrigation. Kabete materials were faced by drought stress due to scarcity of rainfall. Days to first harvest were lower in Mwea than in Kabete due to high temperatures which shortened the duration to flowering. However, both sites had the same number of harvesting (9). It shows that at Mwea the test lines reached days to first and last harvest earlier compared with Kabete. The climbing lines had longer duration to flowering and they were expected to have longer days to last harvest. However, they had almost the same days to last harvest as the bush lines. This could be due to water stress experienced during pod formation stage in Kabete and white fly infestation that occurred in Mwea. According to Wahome et al., (2013) climbing beans are known to mature late because they do not set their flowers in single flush as bush bean. This characteristic makes climbing snap beans to be of interests to farmers because it allows prolonged harvesting duration. Most of the KSB bush and KSV climbing snap bean lines had pods that could meet the export standards.

6.4.3. Pod length and pod diameter

The KSB13 lines had the shortest pod length which ranged from 7.3 to 14.4 cm. KSB14 and KSB15 lines pod length ranged from 10 to 15 cm. KSV14 lines pod length ranged from 9 to 12 cm. The longest check variety, Serengeti had 13 cm. Pods of other commercial varieties was slightly shorter than the standard pod length. Also the pod length of the advanced lines varied significantly across the sites. According to Wahome et al., (2013), these variations were associated to conditions in the experimental sites such as long period of moisture stress, low soil fertility and fertilizer application rates. Mwea lines pod length could have been influenced by infestation of white flies during flowering and pod formation. Ndegwa et al., (2011), reported pod length of 11 to 18 cm among climbing snap bean lines. This research was in agreement with Wahome et al., (2013) who found the pod length of KSB snap bean lines ranging from 9.7 to 11.7 cm while climbing snap bean lines ranging from 10.5 to 11.4 cm. Myers and Baggett, (1999) reported that pod length of between 10 to 16 cm are highly demanded by the processor industries especially for canning. KSB13 and KSV14 lines had the largest pod diameter which ranged from 6 to 8mm. KSB14 and KSB15 lines pod length ranged from 6 to 7 mm. Pod length and pod diameter determines the grade distribution of the pod according to the market classes (extra fine 6mm, fine 6-8 mm and bobby >8 mm) and pod length of above 10 cm (HCDA, 2009). Wahome et al., (2013) reported pod diameter of between 6 to 7 mm among KSB snap bean lines and between 10 to 11 mm among climbing lines. Ndegwa et al., (2011) reported pod diameter of climbing lines ranging from 4 to 9 mm. Length, cross-sectional shape, diameter and length of the spur and pedicel affect pod shape (Myers and Baggett, 1999).

6.4.4. Pod shape and pod curvature

Characteristics such as pod shape, colour, pod curvature and pod length are qualities taken into account by consumers where snap beans are usually consumed fresh (Myers and Baggett, 1999). Most of the lines achieved the standards for pod length, pod diameter, pod shape and pod curvature and therefore, they are competitive in both local and international markets.

6.4.5. Reaction of new lines to major diseases

Appearance of significant differences for the diseases severity among the snap bean lines shows that variability for resistance existed among the genotypes for rust, angular leaf spot and common bacterial blight. Climbing snap bean lines showed higher resistance to rust and angular leaf spot compared with KSB bush lines. According to Wahome et al., (2011) nine lines reduced severity of angular leaf spot by 17%, anthracnose by 16% and rust by 36%. Such genotypes that posses multiple resistances are useful since the commercial varieties are exposed to various diseases that contribute to yield loss. Ndegwa, (2010) found ten climbing snap bean lines resistant to rust. Seven lines compared well with check, J12 which was highly resistant.

6.4.6. Pods per plant and pod yield

Pod per plant was positively related to pod yield across the sites. However, some lines had low pods per plant but high yield. This could be due to heavy pods increasing pod yield. Serengeti was the best yielding check variety. This was probably because it was recently released as opposed to other check varieties. Tian et al., (2010) working with soybean found that there had been a progressive increase in yield with release of new varieties over a period of fifty six years. Wahome et al., (2013) reported that Star2053 check variety produced higher yield than other check varieties because it was recently released. Ndegwa et al., (2009) reported that commercial varieties concentrated their pod yield on extra fine and fine market classes. Wahome et al., (2013) reported that pod yield for KSB snap bean lines ranged from 3833.3 to 8666.7 kg ha^{-1}. KSV14 lines had the highest pod yield (8,288 to 20,695 kg ha^{-1}). This could be due to setting of flowers in multiple flushes and heavy weight of the pods. Wahome et al., (2013) found that climbing snap bean lines having thicker pods which could lead to high pod yield. The new snap bean lines have the potential to address low yielding problem in snap bean production because they have shown tremendous improvement in yield compared to previous research.

6.4.7. Grade distribution

Most of the new lines concentrated their pod yield on extra fine and fine and they were comparable to check varieties. Most of the new lines met 1:1 ratio of extra fine to fine grade pods which is recommended for growing in order to meet the specifications of export markets (Muchui et al., 2001).

6.5. CONCLUSION

Evaluation of snap beans for pod yield, pod quality and disease resistance is not only beneficial to our economy but also increases productivity and reduces food insecurity in the country. Commercial varieties have been reported to be low yielding due to susceptibility to diseases and also lack of adaption to tropical conditions. The new lines especially the climbing snap bean lines will address low yield problem increasing profitability and adoption of snap production by smallholders. Climbing snap beans had yield advantage of 40% over bush snap beans. However, they require sticks for staking to offer support and they are late maturing compared to bush snap beans. Availability of public commercial varieties will increase access to seed by smallholder farmers. Commercial varieties are known to be susceptible to diseases especially rust and angular leaf spot. New varieties are likely to lower production costs due to reduced reliance on fungicides and pesticides. Most importantly, reduced reliance on pesticides will assist farmers to meet the stringent export requirements for residue levels, essential if this crop is to continue providing incomes and employment in rural areas (Kimani, 2006). New varieties with disease resistance, good pod yield and pod quality will promote our market competitiveness both locally and internationally. There is potential of increasing yield of snap bean in East and Central Africa by developing climbing varieties that are well adapted in the region. Rigorous evaluation of climbing snap bean lines for pod quality is required. Advanced varieties such as KSB15-12, KSB15-02, KSB14-02 and KSV14-01 are among 18 bush snap bean lines and five climbing snap bean lines that met agronomic and quality traits in all groups. They will be very important in addressing the issues of maximum residual levels, production constraints, poor pod quality and low productivity due to their improved characteristics. In addition, they can be advanced to the next breeding stages such as national performance trial (NPT) and distinctive uniform and stability (DUS).

CHAPTER 7

CANNING QUALITY AND SENSORY ANALYSIS OF NEW GRAIN RUNNER BEAN LINES

Abstract

Canned beans are becoming a major form of dry bean consumption especially in urban areas for its convenience and distinctive flavor while providing excellent consumer value. Grain quality traits related to end-user preferences are of utmost importance for success of new grain runner bean varieties. In Kenya, processing industry depends on white seeded local unimproved farmers' variety. Several grain runner bean lines with different seed colour and superior agronomic traits were recently developed at the University of Nairobi. However, their potential for use by the processing industry is not known. The objective of the study was to evaluate the canning quality of the new breeding lines and to identify the lines that combine most of the canning quality traits. Forty three advanced lines, three checks and one reference variety (TruFood RB) grown at Ol-Joro-Orok and Kabete Field Station, were evaluated for canning quality and sensory properties. Grain runner beans were soaked, blanched, canned in brine and incubated for seven days, and subsequently evaluated for canning quality attributes including hydration coefficient (HC), washed drained weight (WDWT) and percentage washed drained weight (PWDWT). Physical properties (size, shape, uniformity) and visual appearance properties (splits, clumping and brine clarity) were determined subjectively using seven point hedonic scale. Results showed significant ($P<0.05$, 0.01) differences in all traits evaluated. Thirty five lines met the industrial canning standards. Among the best performers at Kabete were KAB-RB13-327-92/1, KAB-RB13-326-207/1B and KAB-RB13-326-207/1B. Lines that showed poor canning quality attributes such as low HC included KAB-RB13-471-117/2, KAB-RB13-341-143/A, KAB-RB13-312-160/5 and KAB-OL-RB13-440-232/2. Lines with low PWDWT included KAB-RB13-408-220/5 and the industry reference variety, TruFood RB. The best performers among lines grown at Ol-Joro-Orok lines were KAB-RB13-471-117/1, SUB-OL-RB13-275-248/3 and KAB-RB13-310-161/5. KAB-RB13-338-41/1 had the highest proportion of clumps (3). The reference variety had low PWDWT and brine pH before and after incubation (57%, 58% and 5.66, 5.68 respectively). These new lines of grain runner bean will provide the bean processing industry with better raw materials that meet consumer's preferences while increasing production of processed products.

Key words: Canning quality, runner bean, hydration coefficient, PWDWT

7.1 INTRODUCTION

The Grain Legume Research Program of the University of Nairobi is mandated to develop new runner bean varieties for the processing industries. The processing industry is constrained by inadequate and erratic supply of runner beans. Due to low local production, the industry does not meet the consumption demand in the market. This has also led to seasonal processing of runner beans and importation to meet the deficit. Low productivity of runner bean is associated to lack of high yielding varieties with resistance to diseases. The farmers rely on unimproved local varieties such as Nyeri, Kinangop 1, Kinangop 2, Dwarf 1and Dwarf 2. These varieties are lower yielding and susceptible to diseases compared with the new varieties developed by University of Nairobi Bean Program (Kimani et al., 2014). The low yields disease susceptibility and lack of certified seed have led to low adoption of the crop by farmers despite high demand in the market. Apart from South Africa country which has reports on bean canning, the rest of the countries in Africa have minimal information suggesting that very little has been done to develop improved canning bean varieties in Kenya and eastern Africa in general.

Due to changing consumer's preferences, urbanization and changing eating habits, demand of canned runner bean products is growing. The Legume Research Program is not only improving runner bean varieties which are acceptable to farmers, but also to a wide range of consumers and processors' preferences. No improved grain type runner bean varieties are available to farmers in Kenya. The canning runner bean project was initiated with objective of identifying new varieties combining high yield, disease resistance and desirable canning quality. To ensure the end products are acceptable to processing industries, it was necessary to collaborate with bean canning firms and farmers. The initial stages of the breeding activities involved evaluation of locally developed segregating populations for yield potential, disease resistance and other agronomic traits (Kimani et al., 2013a). Between 2009 and 2012, selected lines were evaluated for farmer preferences in participatory variety selection (PVS) on-farm trials and for adaptation across diverse agro-ecological zones. The objective of the study was to evaluate the canning quality of the new breeding lines and to identify the lines that combine most of the canning quality traits.

7.2 MATERIALS AND METHODS

7.2.1 Planting Materials

Samples of 47 advanced runner bean lines were evaluated for canning quality at Njoro Canning Factory, Nakuru County between 5th and 6th March 2015. Of the 47 lines, 29 were white seeded and 18 were purple speckled. They were grown at Kabete Field Station and KARLO- Ol Jorok Orok Research Station. Local farmer's varieties, Nyeri 1, Dwarf 1, Dwarf 2, and TruFood variety, were included for comparison with the new advanced lines. The local varieties were obtained from farmers around Nakuru and Nyandarua counties. TruFood variety was obtained from TruFood Company.

7.2.2 Location of production site and canning factory

The grain type runner beans for canning were grown at Kabete Field Station and KALRO-Ol Joro Orok research station. Kabete Field Station is located within Nairobi County at University of Nairobi, College of Agriculture and Veterinary Sciences farm. However, KALRO-Ol Joro Orok is located in Nyandarua County. Njoro Canning Factory is located in Nakuru County near Egerton University.

7.2.3 Canning process

7.2.3.1 Sample preparation

Njoro Canning Factory was created in 1938 produces a wide range of food products such as frozen vegetables, canned vegetables, dehydrated vegetables, pickles and relishes, jams and marmalades, sauces, spices and desserts (www.njorocanning.co.ke).

Evaluation for canning quality was planned at Njoro Canning Factory. The lines were tested for water uptake and cooking time. Lines with more than 95% water uptake after soaking for 16 hrs and cooked within the specified 2 hrs were evaluated for canning quality.

7.2.3.2 Soaking and Blanching

Grain samples equivalent to 100g of bean solids were transferred into a coded nylon mesh bags for soaking. Before the soaking, samples were separated into colour groups to avoid colour distortion during soaking process. Samples were soaked for 16 hours in cold water (25°C) followed by blanching for 15 minutes in hot water (90° C). The blanched samples were drained, weighted and transferred into M1 cans (73x110 mm). Then seeds were covered with hot brine (90°C) with concentration of 1.9% NaCl (TruFood, 2014) and sealed with automatic can sealer (Angelus Sanitary Can Machine Co., Los Angeles, CA, USA). The sealed cans were heat sterilized in an automatic retort (Barriquand Steriflow, Roanne, France) at 122° C for 60 minutes followed by instant cooling (Njoro Canning, 2014). *Each sample was replicated two times.*

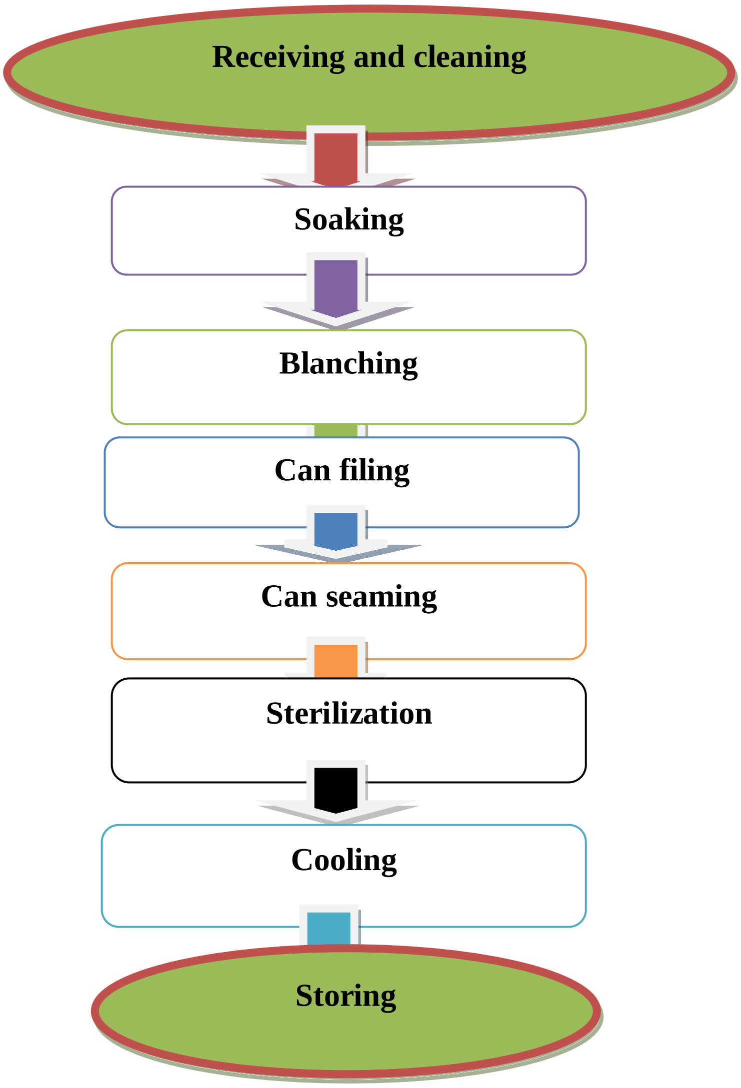


Fig 7. 1: Flow chart of runner bean canning process.


a
b
c


d
e
f

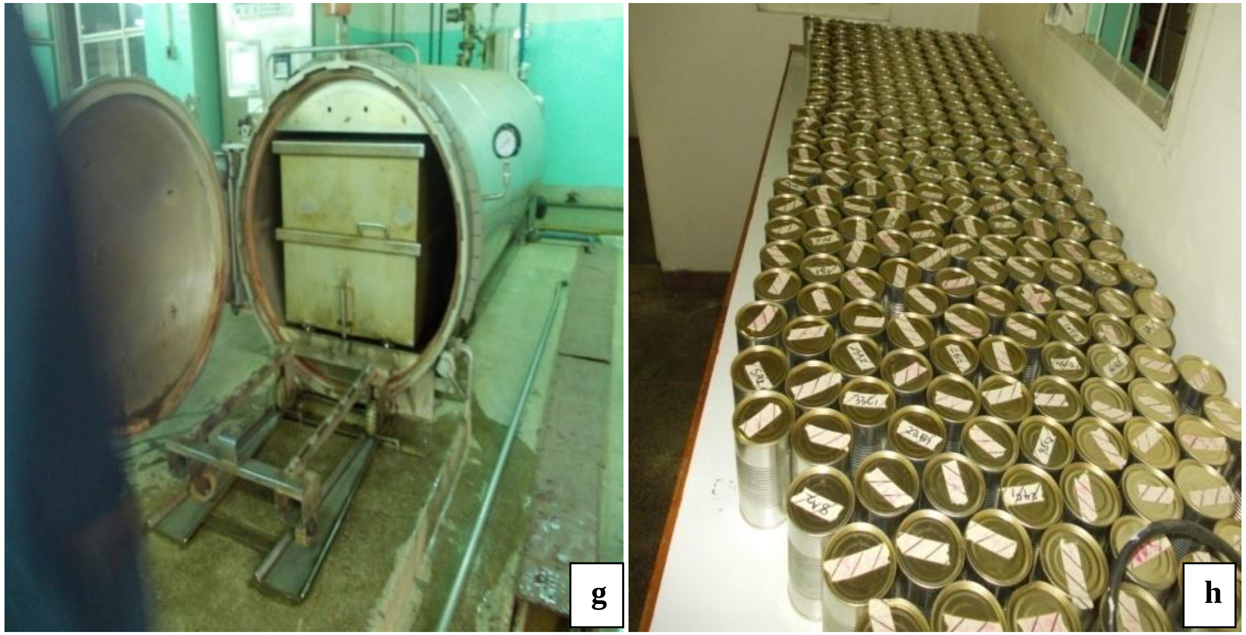


Fig 7. 2: Grain runner bean canning process at Njoro Canning Factory; a) soaking, b) blanching, c) can filling and brining, d) can sealing, e) can cooling after sealing, f) retorting, g) can removal from retort and h) storage

7.2.4. Post-canning evaluation-physical properties

After seven days of incubation at 38^0 C, the canned beans were opened using manual can-opener and canning quality and sensory attributes of the beans were studied. Canning quality was determined following procedures used by Njoro Canning Factory Ltd (Nakuru) and TruFoods Ltd, Nairobi (2014). Canning quality attributes which were determined included fresh weight to yield required solids, hydration coefficient (HC), washed drained weight (WDWT), percent washed drained weight (PWDWT), physical properties (size, shape and uniformity), and visual appearance (splits, degree of clumping and brine clarity).

(i) Hydration coefficient (HC): The amount of water imbibed by the seeds during soaking and blanching is quantified by the HC (Balasubramanian et al., 2000). HC is important in bean canning, because a larger quantity of beans is necessary to fill a certain can volume, when the HC ratio is low. A high HC would therefore improve canning yield (Ghaderi et al., 1984). A HC of 1.8 to 2 is considered optimum by the industry and gives an indication of well soaked beans (Nordstrom and Sistrunk, 1979; Hosfield, 1991). The processors desire a high HC of 1.8 and above. The hydration coefficient was calculated as:

$$\text{HC} = \frac{\textit{Mass of soaked beans}}{\textit{Mass of dry beans}}$$

(ii) Washed drained weight (WDWT) and percentage washed drained weight (PW) DWT): The WDWT refers to the mass of rinsed beans drained for 2 min on a 0.239 cm screen positioned at a 15 ° angle (Hosfield et al., 1984a). Drained weight of dry beans relates to "processors yield", as it would require fewer beans with a high WDWT to fill a can than in the case of beans with low WDWT. A high WDWT indicates large swelling capacity. According to Balasubramanian et al., (2000), the PWDWT of dry beans should be at least 60 %. Percentage washed drained weight was calculated as follows (van Loggerenberg, 2004):

$$\text{PWDWT} = \frac{\text{WDWT (g)}}{\text{Weight of can contents (g)}} \times 100$$

(iii) Texture: Texture was determined on 100g of washed processed beans by using a texture shear press system (Model TA-XT Plus, Stable Micro Systems, Surrey, UK) fitted with a standard multiblade shear compression cell. Force was applied until the blades passed through the bean sample. The texture data include the peak of the curve, which indicates the shear resistance peak, and the total shear resistance, which is calculated from the total area beneath the curve. Data were stored electronically at 0.1s interval for 12s. Compression force (kg $100g^{-1}12s^{-1}$) was determined by calculating the surface area beneath the texture curve for the 12s (De Lange and Labuschagne, 2000).

(iv) Size and shape: The size of beans selected for canning purposes is an important consideration in terms of quality (van Loggerenberg, 2004). This is determined subjectively using a scale 1 to 7 (Hosfield and Uebersax, 1996). For the size, the value 1 =very small, 2 = moderately small, 3 =slightly small, 4 =neither large nor small, 5 =slightly large, 6 =moderately large and 7 =very large. For the shape, the value 1 =very elongated, 2 =moderately elongated, 3 =slightly elongated, 4 =neither round nor elongated, 5 =slightly round, 6 =moderately round and 7 =very round.

(v) Uniformity: Uniformity in size, shape and color is considered among important canning quality atributes (van Loggerenberg, 2004). This is determined subjectively using 1-7 scale, where a value of 1 =very uniform, 2 =moderately uniform, 3 =slightly uniform, 4 =neither varied nor uniform, 5 =slightly varied, 6 =moderately varied and 7 =very varied (Uebersax and Hosfield, 1996).

(vi) Splits: Splitting of cooked beans is one of the factors that determine the intactness of cooked beans, and is determined subjectively. Beans with splits are evaluated on scale from 1-7 (Uebersax and Hosfield, 1996). On this scale, a score of 1 =very broken, 2 =moderately broken, 3 =slightly broken, 4 =neither intact nor broken, 5 =slightly intact, 6 =moderately intact and 7 =very intact.

(vii) Degree of clumping: The degree of packing indicates the degree of clumping that would occur after processing, which might lead to cultivar rejection by the processor. The degree of clumping was determined subjectively using 1-7 scale, where a value of 1 =high degree of clumping, 2 =moderate degree of clumping, 3 =slight degree of clumping, 4 =neither few clumps nor high degree of clumping, 5 =slight few clumps, 6 =moderately few clumps, and 7 =very few clumps (Uebersax and Hosfield, 1996).

(viii) Brine clarity: The canned beans undergo loss of colour and solids to the canning medium. This is determined subjectively using 1-7 scale (Uebersax and Hosfield, 1996), where the value 1 =very cloudy, 2 =moderately cloudy, 3 =slightly cloudy, 4 =neither clear nor cloudy, 5 =slightly clear, 6 =moderately clear and 7 =very clear brine.

7.2.5. Sensory analysis

Sensory evaluation was done by panel of ten judges from Njoro Canning Factory on 5th March 2013. The panel was asked to identify bean varieties which are suitable for the canning industry based on their color, size, appearance, taste, mouth-feel, flavor, wholesomeness and overall acceptability of the beans. Judges were served with baked beans, which had been stored at room temperature for seven days in white plastic containers. Distilled drinking water was provided to panellists to rinse their mouth after each tasting. Sensory evaluation was done using seven point hedonic scale. On this scale, a score of 7= like very much, 6= like moderately, 5= like slightly, 4= neither like nor dislike, 3= dislike slightly, 2= dislike moderately, and 1= dislike very much.

7.2.6. Data analysis

To determine if there were significant genotypic differences, analysis of variance was performed using GenStat software (v.14, VSN, UK, 2010). Significant differences between means were determined using Fisher's Least Significant difference (LSD) test at the $P<0.05$ level. Relationship between canning quality variable was determined by correlation analysis. Significance of correlation coefficients was determined at 5 and 1% probability levels.

7.3. RESULTS

7.3.1 Moisture content and water absorption

Analysis of variance showed that there were highly significance ($P<0.01$) differences in moisture content of the grain before soaking and water absorption capacity during soaking among advanced lines of grain runner bean except for water absorption capacity during blanching (Table 7.8). The values for moisture content and water absorption are presented in Table 7.1 and 7.2.

Few lines were same as TruFood variety for water uptake after soaking for 16 h. However, several new lines had far better WU after blanching. This was due to differences in size of the new grain type runner bean lines. Results indicated that grain moisture concentration was influenced by the location where the genotype was grown. The moisture content of advanced lines grown at Kabete, varied from 9.8 to 12.7%. KAB-RB13-319-194/1 and KAB-RB13-321-185/1 had the highest moisture content (11.7%) among purple speckled lines grown at Kabete. KAB-RB13-326-207/1) had the lowest moisture concentration (9.8%) Among white seeded lines grown at Kabete, KAB-RB13-308-222/1, had the highest moisture content (12.7%), while KAB-RB13-471-117/2 had the lowest (10%) (Table 7.1). The local varieties in Kabete (Dwarf 1 and Nyeri) had moisture content of 11 and 11.3% respectively. TruFood RB variety, the industry reference variety, had the lowest moisture content of 10.4% (Table 7.1). The moisture content the genotypes grown at Ol Joro Orok lines was lower than when grown at Kabete lines regardless the seed colour. The moisture content at Ol Joro Orok ranged from 8.8% (KAB-RB13-310-162/1) to 11.1% (SUB-OL-RB13-326-251/4). The highest moisture content among purple speckled lines at Ol Joro Orok site was 11% while the lowest was 8.8%. Among white-seeded lines at Ol Joro Orok, the highest moisture content was 11.1% while the lowest was 9.2% (Table 7.2). The local variety in Ol Joro Orok had moisture concentration of 10.2%.

Advanced lines in both sites showed rapid water absorption behaviour both during soaking and blanching. Among Kabete lines, the water absorption capacity during soaking ranged from 55% (KAB-RB13-341-143/A) to 115% (KAB-RB13-294-204/1) (Table 7.1), while Ol Joro Orok lines ranged from 70% (KAB-RB13-379-148/1) to 125% (KAB-RB13-85-18A/4) (Tables 7.1 and 7.2). In both sites, most of the lines achieved more than 80% weight increase after 16 hours. Among Kabete lines, 21 lines had achieved 100% and above water absorption capacity after 16 hours (Table 7.1). However, only seven lines managed to achieve 100% and above water absorption capacity after 16 h at Ol Joro Orok (Table 7.2). The local varieties grown at Kabete (Dwarf 1 and Nyeri) had 95 and 90% water absorption capacity while Dwarf 3 at Ol Joro Orok had 115 %. The TruFood variety achieved 115% water absorption capacity after 16 h of soaking (Table 7.1 and 7.2).

Apart from two lines from Kabete, most test lines across site including checks had over 95% water absorption capacity after blanching. Among lines at Kabete, the weight increase after blanching ranged from 95% (KAB-RB13-471-117/2) to 174% (KAB-RB13-327-92/1) (Table 7.1). The highest weight increase after blanching at Ol Joro Orok was 187% (KAB-RB13-85-18A/4) while the lowest was 111% (KAB-RB13-338-41/1) (Table 7.2). The weight increase after blanching among the checks across the sites ranged from 121% (Dwarf 1) to 156% (Dwarf 3). The TruFood reference variety had 131% weight increases after 15 min of blanching. Two lines had better water uptake after soaking than the TruFood check. However, 29 lines had better water uptake after blanching than the TruFood check. Thirty one lines qualified for canning based on water uptake after soaking and blanching.

Table 7. 1: Percent moisture content and water holding capacity after soaking and blanching of grain runner bean lines grown at Kabete Field Station during long rain 2014

Genotype	Seed colour	% §MC	% WU§ after soaking (16 h)	% WU after blanching (15min)
KAB-OL-RB13-440-232/2	Purple speckled	10.2	75	108
KAB-RB13-294-204/1	White	10.9	115	137
KAB-RB13-303-146/1	White	10.6	105	150
KAB-RB13-308-222/1	White	12.7	100	140
KAB-RB13-310-161/2	Purple speckled	9.9	95	121
KAB-RB13-312-160/5	Purple speckled	10.9	85	112
KAB-RB13-314-192/1	Purple speckled	10.0	105	147
KAB-RB13-319-182/1	White	11.9	105	153
KAB-RB13-319-182/4	White	10.6	90	123
KAB-RB13-319-194/1	Purple speckled	11.7	115	153
KAB-RB13-321-185/1	Purple speckled	11.7	90	133
KAB-RB13-326-207/1B	Purple speckled	9.8	80	136
KAB-RB13-327-48/1	White	12.5	115	143
KAB-RB13-327-92/1	White	10.1	110	174
KAB-RB13-329-164/2	White	10.9	100	134
KAB-RB13-329-165/1	White	11.6	95	126
KAB-RB13-329-165/3	White	10.9	100	146
KAB-RB13-341-143/A	Purple speckled	10.4	55	97
KAB-RB13-343-189/5A	White	11.2	110	139
KAB-RB13-379-147/3	White	11.0	100	139
KAB-RB13-399-219/4B	White	11.6	105	162
KAB-RB13-403-150/2	White	10.1	95	152
KAB-RB13-403-150/4B	White	11.6	110	139
KAB-RB13-408-220/5	Purple speckled	10.1	105	165
KAB-RB13-46-124/1	White	11.5	110	144
KAB-RB13-46-124/3A	White	10.1	100	127
KAB-RB13-471-117/2	White	10.0	85	95
KAB-RB13-471-117/3	White	10.5	100	131

Continued: Percent moisture content and water holding capacity after soaking and blanching of grain runner bean lines grown at Kabete Field Station during long rain 2014

Genotype	Seed colour	% §MC	% WU§ after soaking (16 h)	% WU after blanching (15min)
KAB-RB13-62-9/2	White	10.9	100	133
SUB-OL-RB13-177-3/5	White	10.4	100	137
SUB-OL-RB13-178-239/4	White	10.7	110	138
SUB-OL-RB13-269-129/3B	Purple speckled	11.0	85	149
Checks				
Dwarf 1	Purple speckled	11.0	95	121
Nyeri	Purple speckled	11.3	90	144
TruFood RB variety	White	10.4	115	131
Mean		10.6	99	138
LSD $_{0.05}$ Genotype		0.2	24.1	41.6
CV (%)		3.3	12.1	15

LSD-least significant difference, CV-coefficient variation, §**MC**= moisture content, **WU**=water uptake

Table 7. 2: Percent moisture content and water holding capacity after soaking and blanching of grain runner bean lines grown at Ol-Joro-Orok during long rain 2014

Genotype	Seed colour	% MC§	% WU§ after soaking (16hrs)	% WU after blanching (15min)
KAB-RB13-297-144/2	Black	9.0	100	152
KAB-RB13-310-161/5	Purple speckled	9.7	100	125
KAB-RB13-310-162/1	Purple speckled	8.8	90	123
KAB-RB13-326-207/1	Purple speckled	9.8	80	123
KAB-RB13-338-41/1	White	9.7	100	111
KAB-RB13-379-148/1	Purple speckled	9.3	70	135
KAB-RB13-471-117/1	White	9.3	120	160
KAB-RB13-85-18A/4	White	9.6	125	187
SUB-OL-RB13-226-251/4	White	9.2	105	124

Continued: Percent moisture content and water holding capacity after soaking and blanching of grain runner bean lines grown at Ol-Joro-Orok during long rain 2014

Genotype	Seed colour	% MC§	% WU§ after soaking (16hrs)	% WU after blanching (15min)
SUB-OL-RB13-275-248/3	Purple speckled	11.0	100	145
SUB-OL-RB13-326-251/4	White	11.1	90	164
Checks				
Dwarf 3	White	10.2	115	156
TruFood RB variety	White	10.4	115	131
Mean		10.6	99	138
LSD $_{0.05}$ Genotype		0.2	24.1	41.6
CV (%)		3.3	12.1	15

LSD-least significant difference, CV-coefficient variation, §**MC**= moisture content, **WU**=water uptake

7.3.2. Post-canning evaluation

7.3.2.1. Hydration coefficient

The canning quality attributes of advanced grain runner bean lines are presented in Tables 7.3 and 7.4. All the genotypes from the two sites are reported separately for better comparison and interpretation of the results. Among genotypes of both sites, analysis of variance showed significance differences (P<0.05) for all canning quality traits studied apart from hydration coefficient (HC) (Table 7.9). The hydration coefficient (HC) ranged from 1.7 (KAB-RB13-471-117/2) to 2.7 (KAB-RB13-408-220/5 and KAB-RB13-327-92/1). A hydration coefficient of 1.8 to 2 is considered optimal for canning beans (Sastry et al., 1985). Twenty five lines had higher HC compared to TruFood RB variety, standard variety, which had a value of 2.3. Dwarf 1 and Nyeri (local varieties) had HC of 2.2 and 2.4 respectively. There were significant differences for all canning qualities apart from HC for genotypes grown at Ol Joro Orok (Table 7.4). KAB-RB13-85-18A/4 had the maximum hydration coefficient of 2.9 and KAB-RB13-338-41/1 had the minimum value of 2.1. Dwarf 3 local variety had HC of 2.6 while TruFood RB variety had 2.3 (Table 7.4).

7.3.2.2. Fresh weight to yield solid required

The fresh weight to yield solid required ranged from 110.9 g (KAB-RB13-326-207/1B) to 114.5 g (KAB-RB13-308-222/1) (Table 7.3). All the genotypes from Kabete including the checks had higher fresh weight to yield solid than the reference variety, TruFood RB (110.3 g). This meant that more dry seeds of new lines are required to fill a can. However, the differences were small (0.3 to 4.2 g per can). Fresh weight to yield solid required at Ol Joro Orok varied from 109.9g to 112.4g. KAB-RB13-297-144/2 had the lowest fresh weight to yield solid, while SUB-OL-RB13-326-251/4 had the highest.

7.3.2.3. Brine pH

The brine pH before incubation ranged from 5.86 to 6.02. KAB-RB13-312-160/5 had the lowest brine pH before incubation and KAB-RB13-62-9/2 had the highest. All the Kabete genotypes had higher brine pH than the reference variety (5.66). However, the brine pH before and after incubation were not significantly different. The lowest brine pH after incubation was 5.81 and the highest was 6.01. Generally, the brine pH before incubation is higher than after incubation (Table 7.3). At Ol Joro Orok, KB-RB13-310-161/5 had the highest brine pH before (6.00) and after incubation, (6.08). SUB-OL-RB13-326-251/4 had the lowest pH before (6.00) and after incubation (5.96). The reference variety had brine pH of 5.66 before incubation and 5.68, after incubation (Table 7.4).

7.3.2.4. Washed drained weight (WDWT) and percent washed drained weight (PWDWT)

A PWDWT of 60% is considered optimal by dry bean canning industry (Balasubramanian et al., 1999). KAB-RB13-46-124/1 had the highest washed drained weight (WDWT) and percentage washed drained weight (PWDWT) before and after incubation which was 300g, 298g and 69%, 68% respectively (Table 7.3). The lowest WDWT and PWDWT before and after incubation were recorded in KAB-RB13-319-194/1 which was 253g, 257g and 59%, 59% respectively (Table 7.3). At Ol Joro Orok, KAB-RB13-297-144/2 had the lowest WDWT before and after incubation (256 g) and PWDWT of 57% before and after incubation. KAB-RB13-338-41/1 had the highest WDWT and PWDWT. The reference variety achieved WDWT of 264 g before incubation and 269 g after incubation and PWDWT of 57% before incubation and 58% after incubation. About 80% of genotypes grown at Ol Joro Orok and 85% of those grown at Kabete met minimum standards for WDWT and PWDWT required for processing industry (Table 7.4).

7.3.2.5. Texture

Texture (firmness) ranged from 9.37 to 21.94 kg 100 g^{-1} across the sites (Tables 7.3 and 7.4). Among Kabete lines, KAB-RB13-46-124/1 (white seeded) had the lowest texture (9.37 kg 100 g^{-1}) while KAB-RB13-314-192/1 (purple speckled) had the highest texture (19.44 kg 100 g^{-1}). Value of 72 kg 100 g^{-1} is considered optimum for navy beans in United States of America (Hosfield and Uebersax, 1980). However, among Ol Joro Orok lines, texture ranged from 10.19 kg 100 g^{-1} (KAB-RB13-338-41/1-white seeded) to 21.94 kg 100 g^{-1} (KAB-RB13-310-162/1-purple speckled). White seeded lines had lower texture than purple speckled lines across the sites. The reference variety texture was comparable with some of the new white seeded lines across the sites. All the new purple speckled lines across the sites had higher texture than the reference variety (12.5 kg 100 g^{-1}) (Tables 7.3 and 7.4).

7.3.2.5. Physical characteristics

7.3.2.5.1. Seed size

Size, shape and uniformity are physical characteristics of seeds related to canning quality. High values for the traits are the desired by the processing industry (van Loggerenberg, 2004). Evaluation of these parameters was conducted subjectively on a scale of 1 to 7. Size ranged from 4 to 7 which mean beans were within range of the regular sizes (5.72 to 6.89). KAB-OL-RB13-440-232/2 had the highest score while KAB-RB13-294-204/1 and KAB-RB13-343-189/5A had the lowest score. All the new lines were comparable to TruFood check variety in terms of seed size. All the genotypes at Ol Joro Orok had size score of five (slightly large) and above. The highest score was 7 (very large seeds) (KAB-RB13-297-144/2, KAB-RB13-310-161/5 and KAB-RB13-471-117/1) and the rest genotypes had size score of 5 (slightly large) (Tables 7.3 and 7.4). The processors have preference on large seeds, elongated and uniform seeds to maximise their yield per and can enhance acceptability of the products by the consumers.

7.3.2.5.2. Seed uniformity

Beans should be uniform in size for canning purposes, as indicated by Uebersax et al., (1991). Uniformity ranged from 1 (very uniform) to 3 (slightly uniform). The TruFood check variety was moderately uniform (Tables 7.3 and 7.4). Uniformity of the all the test lines was within the accepted limit by the processors (1 to3 (very uniform to slightly uniform)).

7.3.2.5.3. Seed shape

Shape ranged from 1 (very elongated) to 5 (slightly round). TruFood RB variety was moderately elongated (2). Twenty one lines were comparable to check variety in terms of shape. Large seeded beans tend to be elongated and that is why 31 elite lines were moderately to very much elongated (Tables 7.3 and 7.4). The processors prefer elongated seeds because they maximize their yield per can increasing their profit.

7.3.2.6. Visual appearance

7.3.2.6.1. Splitting

Visual appearance parameters such as splitting, clumping and brine clarity were evaluated subjectively on a scale of 1 to 7. Splitting varied from 3 (slightly broken) to 7 (very intact). The split values for the reference standards of choice (Teebus) and standard grade (Helderberg) beans were 9.67 and 9.56 on 1 to 10 scale (van Loggerenberg, 2004). Canned product from five lines were the most intact with the highest splits score of 7. This meant that most of the beans had no cracks, splits or loose skins after canning. KAB-RB13-46-124/1, with a score of 3 was the least intact. SUB-OL-RB13-275-248/3 had the highest score of splits. This meant that this variety had very intact canned beans (Tables 7.3 and 7.4).

7.3.2.6.2. Degree of clumping

Degree of clumping varied from 3 (slight high degree of clumping) to 7 (very few clumps). High clumping values are the desired traits. Twenty two lines had fewer clumps than the TruFood check variety (6). SUB-OL-RB13-275-248/3 had the highest score of clumps (7). This meant that this variety had very few clumps (Tables 7.3 and 7.4). Consumers prefer seeds with few clumps due to good presentation during eating.

7.3.2.6.3. Brine clarity

Brine clarity varied from 2 (moderately cloudy) to 7 (very clear). Five lines had clearer brine than the check variety (6). The brine clarity of all purple speckled genotypes ranged from 2 to 3 while the white seeded genotypes ranged from 5 to 7. This meant that the speckled genotypes did not lose colour during soaking and blanching while white seeded genotypes maintained their clear brine since they were white. The white seeded genotype, KAB-RB13-471-117/2 showed high values for all visual appearances. SUB-OL-RB13-275-248/3 had moderately cloudy brine (score of 2). This indicated that the beans did not lose colour during soaking and blanching. The best performing lines at the two sites differed suggesting a strong genotype x environment interaction for canning traits (Tables 7.3 and 7.4).

7.3.3. Correlation between traits

There were significant correlations ($P<0.05$ and 0.01) between some attributes of the advanced grain runner bean lines (Table 7.5). Brine pH had no correlation with other canning traits. It is probably influenced by other factors such as environment and genetic makeup. Brine clarity was negatively correlated with clumping (r= -0.34*), degree of splitting (r= -0.43**), seed size (r= -0.35*), texture (r= -0.88**) and total resistance (r= -0.88**). This meant that beans with clear brine are likely to have more clumps, high degree of splitting, small size and low texture. In addition, brine clarity was positively correlated to PWDWT (r= 0.52**) and WDWT (r= 0.56**). This suggests that beans with clear brine are likely to imbibe more water during canning. However, there was no correlation between HC and fresh weight to solid yield required with other canning traits. This may imply that water imbibition during soaking and blanching may not be influenced by other traits. WDWT and PWDWT had a strong positive correlation (r= 0.95**) suggesting that the higher the WDWT the higher the PWDWT. PWDWT was negatively correlated to texture (r= -0.61**), degree of splitting (r= -0.48**) and total resistance (r= -0.63**). This implied that when beans imbibe more water during canning they are likely to have low texture and very broken. Seed size was positively correlated to texture (r= 0.35*), splitting (r= 0.42**) and total resistance (r= 0.36*). Large seeded beans will have better texture and very intact. Texture was positively correlated to splitting (r= 0.48**) and total resistance (r= 0.97**), but negatively correlated to WDWT (r= -0.64**). Beans with high texture are likely to be intact and imbibe less water during canning. Degree of splitting was negatively correlated with WDWT (r= -0.51**) and PWDWT (r= -0.48**). This meant that very intact beans have low WDWT and PWDWT (Table 7.5).

Table 7. 3: Canning quality characteristics of grain runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Seed colour	Fresh wt to yield solid (g)	Hydration coefficient (HC)	Brine PH		Brine clarity		WDWT (g)		PWDWT (%)		Texture 1(kg 100g^{-1}12s^{-1})	Texture 2 (kg s^{-1})	Seed size	Shape	Uniformity	Splits	Clumping
				AI	BI	AI	BI	AI	BI	AI	BI							
KAB-OL-RB13-440-232/2	Purple speckled	111.4	2.1	5.91	5.93	3	2	259	259	59	61	17.78	108.43	7	2	2	6	7
KAB-RB13-294-204/1	White	112.2	2.4	5.96	6	7	6	270	268	61	63	11.08	67.18	4	2	3	6	6
KAB-RB13-303-146/1	White	111.9	2.5	5.85	5.83	7	6	268	265	62	61	12.18	73.0	5	3	3	5	6
KAB-RB13-308-222/1	White	114.5	2.4	6.01	6.01	7	6	278	286	64	66	10.25	60.4	5	3	1	5	6
KAB-RB13-310-161/2	Purple speckled	111	2.2	5.9	5.89	2	2	260	258	61	60	19.44	112.17	6	2	2	6	6
KAB-RB13-312-160/5	Purple speckled	112.3	2.1	5.81	5.86	2	2	258	262	59	60	19.04	111.49	6	2	1	7	7
KAB-RB13-314-192/1	Purple speckled	111.1	2.5	5.84	5.89	2	2	261	264	61	60	19.55	112.31	5	2	2	7	7
KAB-RB13-319-182/1	White	113.5	2.5	5.92	5.92	6	5	270	270	63	62	10.92	62.77	5	3	2	6	6
KAB-RB13-319-182/4	White	111.8	2.2	5.94	5.95	6	5	269	272	62	64	12.79	76.58	6	2	1	6	6
KAB-RB13-319-194/1	Purple speckled	113.2	2.5	5.85	5.88	3	2	257	253	59	59	18.43	107.59	6	2	2	6	6
KAB-RB13-321-185/1	Purple speckled	113.3	2.3	5.89	5.9	2	2	261	260	59	60	18.27	109.49	6	2	2	6	7
KAB-RB13-326-207/1B	Purple speckled	110.9	2.4	5.93	5.94	2	2	260	262	60	61	17.75	103.46	5	3	1	6	7
KAB-RB13-327-48/1	White	114.3	2.4	5.94	6.01	6	5	283	277	66	63	10.08	60.93	6	2	3	6	6
KAB-RB13-327-92/1	White	111.2	2.7	5.93	5.93	5	6	264	270	61	63	11.98	73.89	5	3	3	6	6
KAB-RB13-329-164/2	White	112.3	2.3	5.91	5.88	6	6	272	270	63	62	12.19	62.8	6	2	2	6	7
KAB-RB13-329-165/1	White	113.1	2.3	5.95	5.99	6	5	272	274	64	64	14.51	80.66	6	2	3	6	7
KAB-RB13-329-165/3	White	112.3	2.5	5.92	5.9	5	6	268	266	64	61	14.07	85.05	6	3	2	6	6
KAB-RB13-341-143/A	Purple speckled	111.6	2	5.93	5.93	2	2	267	264	63	61	19.08	107.05	6	2	1	7	7
KAB-RB13-343-189/5A	White	112.6	2.4	5.93	5.87	7	6	265	266	62	61	13.82	66.67	4	4	3	6	6

Continued: Canning quality characteristics of grain runner bean lines grown at Kabete Field Station during 2014 long rain season.

		Fresh wt to yield solid	Hydration coefficient	Brine PH		Brine clarity		WDWT (g)		PWDWT (%)		Texture 1(kg 100g^{-1}12s^{-1})	Texture 2 (kg s^{-1})	Seed				
Genotype	**Seed colour**	**(g)**	**(HC)**	**AI**	**BI**	**AI**	**BI**	**AI**	**BI**	**AI**	**BI**			**size**	**Shape**	**Uniformity**	**Splits**	**Clumping**
KAB-RB13-379-147/3	White	112.4	2.4	5.94	5.88	6	5	268	271	61	64	10.64	64.83	5	3	1	6	7
KAB-RB13-399-219/4B	White	113.1	2.6	5.82	5.87	6	6	274	272	62	62	10.39	60.53	5	2	1	6	7
KAB-RB13-403-150/2	White	111.2	2.5	5.95	5.94	7	6	272	270	63	62	1136	65.3	6	3	1	6	6
KAB-RB13-403-150/4B	White	113.1	2.4	6	5.99	6	5	282	286	65	66	11.02	61.17	6	2	2	5	6
KAB-RB13-408-220/5	Purple speckled	111.2	2.7	5.87	5.92	2	2	259	258	58	59	16.17	97.44	6	2	1	6	7
KAB-RB13-46-124/1	White	113	2.4	5.95	6.01	6	5	298	300	68	69	9.37	53.85	3	1	2	3	6
KAB-RB13-46-124/3A	White	111.2	2.3	5.98	6.01	6	5	278	280	65	63	9.9	60.38	6	2	2	6	6
KAB-RB13-471-117/2	White	111.1	1.7	5.94	5.98	6	6	262	270	60	63	10.37	60.93	6	2	1	7	7
KAB-RB13-471-117/3	White	111.7	2.3	5.99	5.98	6	6	275	274	64	63	10.56	61.72	6	2	2	6	6
KAB-RB13-62-9/2	White	112.3	2.3	5.96	6.02	6	6	284	274	65	63	10.16	58.57	6	2	2	5	6
SUB-OL-RB13-177-3/5	White	111.6	2.4	5.91	5.93	6	6	272	270	62	62	10.0	59.58	5	2	2	6	6
SUB-OL-RB13-178-239/4	White	112	2.4	5.94	5.96	6	6	271	270	64	62	11.31	63.02	5	3	2	6	6
SUB-OL-RB13-269-129/3B	Purple speckled	112.4	2.5	5.93	5.92	2	2	255	260	60	61	18.76	114.66	6	2	1	7	7
Checks																		
Dwarf 1	Purple speckled	112.3	2.2	5.97	5.98	2	2	261	256	60	58	16.92	100.19	6	2	2	6	5
Nyeri	Purple speckled	112.7	2.4	5.96	6	2	2	263	262	62	61	16.78	101.89	5	3	3	4	6
TruFood RB variety	White	110.3	2.3	5.68	5.66	6	5	259	264	58	57	12.5	75.02	4	2	2	6	6
Mean		111.8	2.4	5.93	5.96	5	4	269	269	6.2	62	14.23	81.77	6	2	2	6	6
LSD (0.05)		0.09	0.5	0.04	0.47	0.7	1	5.5	9.9	2	3	16.4	144.6	0.7	0.5	0.5	0.8	0.5

CV%		0.4	9.5	0.3	0.4	7.4	7	1	1.8	1.6	2.4	5.9	8.8	6	10.1	12.7	6.9	3.9

LSD-least significant difference, CV-coefficient variation, AI-after incubation, BI-before incubation, WDWT-washed drained weight, PWDWT-percent washed weight.

Table 7. 4: Canning quality characteristics of grain runner bean lines grown at Ol-Joro-orok during long rain 2014

Genotype	**Seed colour**	**Fresh wt to yield solid (g)**	**Hydration coefficient (HC)**	**Brine PH**		**Brine clarity**		**WDWT (g)**		**PWDWT (%)**		**Texture 1 (kg 100g^{-1}12s^{-1})**	**Texture 2 (kg s^{-1})**	**Seed size**	**Shape**	**Uniformity**	**Splits**	**Clumping**
				AI	**BI**	**AI**	**BI**	**AI**	**BI**	**AI**	**BI**							
KAB-RB13-297-144/2	Black	109.9	2.5	6.01	5.97	2	2	256	256	59	59	18.62	101.92	7	1	3	6	7
KAB-RB13-310-161/5	Purple speckled	110.7	2.3	6.08	6	3	2	258	254	59	58	20.84	113.46	7	1	1	6	7
KAB-RB13-310-162/1	Purple speckled	109.7	2.2	5.93	6.08	2	2	261	264	60	62	21.94	1244	6	2	3	6	7
KAB-RB13-326-207/1	Purple speckled	110.9	2.2	6.01	6.05	3	2	256	260	60	61	19.13	97.85	5	2	3	6	7
KAB-RB13-338-41/1	White	110.7	2.1	5.98	6.06	6	6	312	304	73	70	10.19	57.49	6	2	2	5	3
KAB-RB13-379-148/1	Purple speckled	110.2	2.4	5.97	6	3	2	259	260	59	61	18.7	101.55	6	2	3	6	7
KAB-RB13-471-117/1	White	110.3	2.6	5.99	6.05	5	6	274	276	64	65	10.49	55.79	7	1	1	6	7
KAB-RB13-85-18A/4	White	110.7	2.9	5.93	6.04	6	5	306	300	71	68	12.12	66.62	5	3	2	5	6
SUB-OL-RB13-226-251/4	White	110.1	2.2	5.98	6.05	6	6	288	284	66	66	10.65	54.81	5	5	2	6	7
SUB-OL-RB13-275-248/3	Purple speckled	112.3	2.5	5.99	6.05	2	2	262	258	60	60	20.76	120.31	6	2	2	7	7
SUB-OL-RB13-326-251/4	White	112.4	2.6	5.96	6	6	5	262	268	62	63	11.89	67.7	5	2	2	6	7
Checks																		
Dwarf 3	White	111.3	2.6	5.93	5.99	7	6	268	270	63	62	12.31	73.51	6	2	2	4	6
TruFood RB variety	White	110.3	2.3	5.68	5.66	6	5	259	264	58	57	125	75.02	4	2	2	6	6
Mean		111.8	2.4	5.93	5.96	5	4	269	269	6.2	62	14.23	81.77	6	2	2	6	6

LSD (0.05)	0.09	0.5	0.04	47	0.7	1	5.5	9.9	2	3	16.4	144.6	0.7	0.5	0.5	0.8	0.5
CV%	0.4	9.5	0.3	0.4	7.4	7	1	1.8	1.6	2.4	5.9	8.8	6	10.1	12.7	6.9	3.9

LSD-least significant difference, CV-coefficient variation, AI-after incubation, BI-before incubation, WDWT-washed drained weight, PWDWT-percent washed weight.

Table 7. 5: Correlation matrix among canning quality parameters

	Brine pH	Brine clarity	Clumping	Fresh weight to yield required (g)	Hydration coefficient (HC)	PWDWT	Seed size	Shape	Shear force(N $100g^{-1}$)	Splits	Uniformity	WDWT (g)	Work of shearing (N S^{-1})
Brine pH	1												
Brine clarity	0.05	1											
Clumping	-0.11	-0.34*	1										
Fresh weight to yield required (g)	-0.02	0.24	-0.10	1									
Hydration coefficient (HC)	-0.06	0.10	-0.01	0.08	1								
PWDWT	0.27	0.52**	-0.57**	0.09	0.08	1							
Seed size	0.18	-0.35*	0.13	-0.22	-0.18	-0.23	1						
Shape	-0.09	0.34*	-0.10	0.06	0.09	0.15	-0.24	1					
Shear force(N $100g^{-1}$)	-0.04	-0.88**	0.39**	-0.25	-0.13	-0.61**	0.35*	-0.24	1				
Splits	-0.19	-0.43**	0.52**	-0.10	-0.20	-0.48**	0.42**	-0.05	0.48**	1			
Uniformity	0.11	0.02	-0.14	0.01	0.12	0.04	-0.16	0.11	0.07	-0.20	1		
WDWT (g)	0.21	0.56**	-0.55**	0.09	0.08	0.95**	-0.29*	0.14	-0.64**	-0.51**	0.00	1	
Work of shearing (N S^{-1})	-0.10	-0.88**	0.35*	-0.19	-0.10	-0.63**	0.36*	-0.24	0.97**	0.47**	0.04	-0.66**	1

*,**Correlation coefficient significant at 0.05 and 0.01 probability levels, respectively. HC= hydration coefficient, PWDWT= percent washed drained weight and WDWT= washed drained weight

7.3.4. Sensory quality evaluation

7.3.4.1. Seed colour

Analysis of variance (ANOVA) revealed highly significant differences ($p<0.05$) in sensory quality attributes among grain runner bean lines grown at the two locations (Table 7.10) The sensory qualities were subjectively evaluated on 1 to 7 hedonic scale. At both locations, the score for colour ranged from 4 to 6. Only four genotypes were neither liked nor disliked for colour while the rest were either liked slightly or liked moderately. TruFood check variety was slightly liked for colour (5) (Tables 7.6 and 7.7). Genotypes from both sites consisted of two distinctive colour (white and purple speckled) but there was no indication that the panelist discriminated particular seed colour

7.3.4.2. Flavour

Seed favour influences consumers' preferences. The score for flavor varied from 4 (neither like nor dislike) to 6 (like moderately). Forty one lines across the sites had better flavor than the check variety (4). Eight lines had the same flavor as the check variety (Tables 7.6 and 7.7).

7.3.4.3. Visual appearance

The score for visual appearance varied from 4 to 6. Thirty eight lines had better appearance than the check variety (4). Five lines were comparable to the check variety in terms of appearance (Tables 7.6 and 7.7). High values are the desired traits because they indicate intact beans, with skin still attached and a clear and shiny surface colour, with colour uniformity (De Lange and Labuschagne, 2000).

7.3.4.4. Mouth feel

The score for mouth feel varied from 5 (like slightly) to 6 (like moderately). Nine lines had better mouth feel than the check variety, while 28 lines were comparable to the check variety (Tables 7.6 and 7.7).

7.3.4.5. Seed size

The score for seed size varied from 5 to 7. KAB-RB13-471-117/3 line was much liked for seed size (7). However, twenty three lines across the sites had better seed size than the check variety (5) (Tables 7.6 and 7.7).

7.3.4.6. Taste

The taste score varied from 4 to 6. Taste is one of the traits that influence consumers' preferences. Fifteen lines had better taste than the check variety (5). However, 25 lines across the sites were comparable to check variety (Tables 7.6 and 7.7)

7.3.4.7. Wholesomeness

Wholesomeness score varied from 4 to 6. Thirty three lines had better score for wholesomeness than the check (4). Wholesomeness is a trait that ensures that the beans are intact without splits. Eleven lines were comparable with the check variety (Tables 7.6 and 7.7).

7.3.4.8. Overall acceptability

The check variety was neither accepted nor rejected (4). However, seven lines across the sites were moderately accepted during sensory analysis. The most acceptable lines were KAB-RB13-343-189/5A, SUB-OL-RB13-177-3/5 and SUB-OL-RB13-269-129/3B while the least acceptable were KAB-RB13-294-204/1, KAB-RB13-319-194/1, KAB-RB13-327-92/1, KAB-RB13-46-124/1, KAB-RB13-46-124/3A and SUB-OL-RB13-178-239/4. At Kabete, both Dwarf 1 and Nyeri checks had an overall acceptability of 5 while the reference variety, TruFood RB achieved an acceptability of 4 (Table 7.6). At Ol Joro Orok, SUB-OL-RB13-226-251/4 had the lowest score for overall acceptability (4) while KAB-RB13-297-144/2, KAB-RB13-310-161/5 and KAB-RB13-326-207/1 scored the highest for overall acceptability (6) (Table 7.7). Dwarf 3 check variety had an overall acceptability of 5 (slightly acceptable). KAB-RB13-321-185/1 and SUB-OL-RB13-178-239/4 obtained low scores for most of sensory quality traits. However, KAB-RB13-312-160/5 obtained the highest scores for most of the sensory quality traits.

7.3.5. Genetic diversity of grain runner bean lines for canning quality analysis

Cluster analysis of 40 grain runner bean lines and four check varieties revealed seven clusters. Dwarf 1 and Nyeri are closely related but distantly related to other lines. Dwarf 3 check variety is related to most of the lines in the second cluster. The first cluster had the lowest fresh weight to yield required solids (111 g) compared with the second (111.9 g). However, the cluster also had low washed drained weight (260 g) and percent washed drained weight (60) compared to second cluster which had 270 g washed drained weight and

62 percent washed drained weight (Appendix 26). KAB-RB13-46-124/1 line which is dissimilar from the rest of the lines had a mean of 112.7g of fresh weight to yield required solid, 304g of washed drained weight and 71 percent washed drained weight. The reference variety, TruFood RB variety is distantly related to the two clusters because of low percent washed drained weight (57) (Appendix 26).

Table 7. 6: Means of hedonic scores for sensory quality parameters of grain runner bean lines grown at Kabete field station during long rain 2014

Genotype	Seed colour	Colour	Flavor	Appearance	Mouth feel	Size	Taste	Whole-someness	Overall acceptability
KAB-OL-RB13-440-232/2	Purple speckled	5	5	6	6	6	5	5	5
KAB-RB13-294-204/1	White	6	4	5	4	5	4	4	4
KAB-RB13-303-146/1	White	5	5	5	5	5	6	5	5
KAB-RB13-308-222/1	White	5	5	5	5	6	6	5	5
KAB-RB13-310-161/2	Purple speckled	5	4	5	5	5	5	5	5
KAB-RB13-312-160/5	Purple speckled	6	5	6	5	6	5	5	6
KAB-RB13-314-192/1	Purple speckled	5	5	5	5	5	5	6	5
KAB-RB13-319-182/1	White	5	6	5	5	6	5	5	5
KAB-RB13-319-182/4	White	5	5	5	5	6	6	5	5
KAB-RB13-319-194/1	Purple speckled	5	4	5	5	5	5	4	4
KAB-RB13-321-185/1	Purple speckled	4	4	5	4	5	5	4	5
KAB-RB13-326-207/1B	Purple speckled	5	5	5	4	6	5	5	5
KAB-RB13-327-48/1	White	6	4	5	5	5	4	5	5
KAB-RB13-327-92/1	White	5	5	5	5	6	5	5	4
KAB-RB13-329-164/2	White	6	5	5	5	6	6	5	5
KAB-RB13-329-165/1	White	5	5	6	5	6	6	5	5
KAB-RB13-329-165/3	White	5	6	6	5	6	5	5	5

Continued: Means of hedonic scores for sensory quality parameters of grain runner bean lines grown at Kabete field station during long rain 2014

Genotype	Seed colour	Colour	Flavor	Appearance	Mouth feel	Size	Taste	Whole-someness	Overall acceptability
KAB-RB13-341-143/A	Purple speckled	5	5	4	4	5	5	5	5
KAB-RB13-343-189/5A	White	6	5	5	5	6	6	5	6
KAB-RB13-379-147/3	White	5	5	5	5	6	5	5	5
KAB-RB13-399-219/4B	White	5	5	5	6	6	6	5	5
KAB-RB13-403-150/2	White	5	5	6	5	5	6	4	5
KAB-RB13-403-150/4B	White	4	5	5	5	6	6	4	5
KAB-RB13-408-220/5	Purple speckled	5	5	5	5	6	5	5	5
KAB-RB13-46-124/1	White	5	6	4	6	5	5	4	4
KAB-RB13-46-124/3A	White	5	4	5	5	6	5	4	4
KAB-RB13-471-117/2	White	5	5	5	5	6	5	6	5
KAB-RB13-471-117/3	White	6	6	5	6	7	5	5	5
KAB-RB13-62-9/2	White	5	4	5	4	5	5	4	5
SUB-OL-RB13-177-3/5	White	6	5	5	5	5	6	6	6
SUB-OL-RB13-178-239/4	White	5	4	6	4	5	4	4	4
SUB-OL-RB13-269-129/3B	Purple speckled	6	6	6	6	6	6	6	6
Checks									
Dwarf 1	Purple speckled	6	5	5	5	5	5	5	5

Nyeri	Purple speckled	5	5	5	5	5	4	4	5
TruFood RB variety	White	5	4	4	5	5	5	4	4
Mean		5	5	5	5	5	5	5	5
LSD $_{0.05}$		0.7	1	0.8	0.9	0.9	1.1	1	0.9
CV (%)		7.1	0.4	8	8.9	8.3	10.1	10.2	9

LSD-Least significant difference, CV-Coefficient variation, Sensory evaluation was based on 1-7 hedonic scale where 7=Like very much, 6= like moderately, 5= like slightly, 4= neither like nor dislike, 3= dislike slightly, 2= dislike moderately and 1= dislike very much

Table 7. 7: Means of hedonic scores for sensory quality parameters of grain runner bean lines grown at Ol-joro-orok during long rain 2014

Genotype	Seed colour	Colour	Flavor	Appearance	Mouth feel	Size	Taste	Whole-someness	Overall acceptability
KAB-RB13-297-144/2	Black	4	6	4	6	5	6	5	6
KAB-RB13-310-161/5	Purple speckled	5	5	5	6	5	5	6	6
KAB-RB13-310-162/1	Purple speckled	4	5	5	5	6	5	5	5
KAB-RB13-326-207/1	Purple speckled	6	5	5	5	6	6	5	6
KAB-RB13-338-41/1	White	5	5	4	6	5	5	4	5
KAB-RB13-379-148/1	Purple speckled	5	5	6	5	6	5	5	5
KAB-RB13-471-117/1	White	5	5	6	5	6	6	5	5
KAB-RB13-85-18A/4	White	5	5	5	6	5	6	5	5
SUB-OL-RB13-226-251/4	White	5	5	4	5	5	5	4	4
SUB-OL-RB13-275-248/3	Purple speckled	5	5	5	5	5	5	5	5
SUB-OL-RB13-326-251/4	White	5	5	5	5	5	5	5	5
Checks									
Dwarf 3	White	5	5	5	5	5	5	5	5
TruFood RB variety	White	5	4	4	5	5	5	4	4
Mean		5	5	5	5	5	5	5	5
LSD $_{0.05}$		0.7	1	0.8	0.9	0.9	1.1	1	0.9
CV (%)		7.1	0.4	8	8.9	8.3	10.1	10.2	9

LSD-least significant difference, CV-coefficient variation. Sensory evaluation was based on 1-7 hedonic scale where 7=Like very much, 6= like moderately, 5= like slightly, 4= neither like nor dislike, 3= dislike slightly, 2= dislike moderately and 1= dislike very much

Table 7. 8: Mean squares of percent moisture content and water uptake after soaking and blanching grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season for canning quality.

		%		
Source of variation	**df**	**Moisture content**	**Water uptake after blanching**	**Water uptake after soaking**
Replicates	1	5.83	78.70	0.00
Genotypes	46	1.552**	679.6^{ns}	363.4**
Error	46	0.00	428.00	143.50

*, ** and ns Significance at 0.05, 0.01 probability level and not significant, df =degree of freedom

Table 7. 9: Mean squares of fresh weight to yield required, hydration coefficient, brine pH, brine clarity, percent washed drained weight, washed drained weight, texture, clumping, seed size, shape, splits and uniformity of grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season for canning quality.

				Before incubation				After incubation								
Source of variation	**df**	**Fresh weight to yield required (g)**	**Hydration coefficient**	**Brine pH**	**Brine clarity**	**Percent washed drained weight**	**Washed drained weight**	**Brine pH**	**Brine clarity**	**Percent washed drained weight**	**Washed drained weight**	**Texture (kg 100g^{-1}12s^{-1})**	**Texture (kg s^{-1})**	**Clumping**	**Seed size**	**Shape**
Replicates	1	8.93	0.02	0	0.38	0.71	37.03	0	0.1	0.3	2.72	4.38	120.6	0.17	0.52	0.01
Genotypes	46	2.54**	0.08^{ns}	0.01**	6.09**	14.33**	264.91**	0.01**	6.97**	18.68**	315.15**	308.648**	10239.6**	1.19**	1.83**	1.08**
Error	46	0	0.05	0	0.08	2.23	24.14	0	0.12	1.03	7.44	7.071	515.2	0.06	0.11	0.05

*, ** and ns Significance at 0.05, 0.01 probability level and not significant, df =degree of freedom

Table 7. 10: Mean squares of colour, flavor, appearance, mouth feel, size, taste, wholesomeness and overall acceptability of grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season for sensory analysis.

Source of variation	**df**	**Colour**	**Flavor**	**Appearance**	**Mouth feel**	**Overall acceptability**	**Size**	**Taste**	**Wholesome-ness**
Replicates	1	5.4118	0.1159	0.0129	0.2877	0.1303	0.266	0.0239	0.4634
Genotypes	46	0.4601**	0.5988**	0.4648**	0.4582**	0.5414**	0.5415**	0.64**	0.6969**
Error	46	0.1339	0.268	0.1614	0.2055	0.196	0.199	0.2759	0.2425

*, ** and ns Significance at 0.05, 0.01 probability level and not significant, df =degree of freedom

7.4 DISCUSSION

This study is an attempt to provide this information and to identify new lines which meet requirements of the canning industry. Hosfield and Uebersax (1996) developed physical and chemical composition tests for dry bean that provide a basis for differentiating and selecting breeding lines for canning quality. These canning quality traits relate to those that have economic impact for the processing industry and those that affect appeal and palatability of the canned product (Khanal et al, 2015).

One of the current objectives of bean breeding programs in eastern Africa is to develop improved varieties which are not only agronomically superior in farmers' fields, but also have acceptable canning quality desired by the processing industry. Recently, new agronomically superior dry bean lines that meet industry criteria were developed and released in Kenya (Warsame and Kimani, 2014). However, runner bean varieties suitable for canning have received little research attention in eastern Africa. There is minimal research done on canning quality of grain runner bean, therefore limiting availability of literature on the same.

The moisture content ranged from 8.8 to 12.7% which is comparable to results reported by other researchers. Uebersax et al (1991) found the suitable moisture content of dry beans for canning purposes to be 12 to 16%. According to van Loggerenberg (2004), moisture content (MC) is one of the physical properties of the dry beans. A moisture concentration of 9 to 13% is considered optimum by local industries (TruFood Company Manual, 2014) and is necessary to ensure good, stable canning quality within the same variety and to eliminate the affect of differential initial moisture content values on cotyledon tenderization during soaking and cooking (Hosfield and Uebersax, 1980). Hsieh et al. (1992) reported that moisture content can be a useful indicator of maturity of canning beans. The moisture content was 13.1 to 15.3% for two types of immature beans, 9.7 to 10.8% for mature beans, and 7.4 to 8.7% for over-mature seeds. Moisture content of all the test lines, local varieties and reference variety in study were within the mature range. According to Nordstrom and Sistrunk (1979), too low moisture content at time of processing could lead to water imbibition problems and affect the rate of water uptake (Hosfield and Uebersax, 1979) if the initial moisture content of beans is too low, it lead to brittle seed coats with consequential cracking, thereby delivering a poor quality canned products (Nordstrom and Sistrunk, 1979).

Water uptake (WU) is a key factor to consider during canning process. The purpose of soaking and blanching prior to autoclaving is to ensure uniform and complete WU in order to prevent further expansion of beans in the can. In addition, soaking prevents the presence of hard seeds in the canned products (Priestly, 1978). Water uptake is an important parameter for the canning industry. The WU of the study lines ranged from 55 to 115% after soaking. Most of the lines from Kabete had weight increase of 90% and above. This was in agreement with Heinen and Van Tisk (1976) who worked with 18 small white bean samples from breeding trials and only seven were able to pick more than 90% water. Those beans that are unable to take up at least 90% water are rejected for canning purposes. Hosfield (1991) found the optimum WU of beans for canning process is 80%. Temperature is known to influence the rate of WU in soybeans, with higher temperatures increasing the rate (Hsu et al., 1983), but Thanos (1998) found only temperatures above 40^0 C were efficient in decreasing the time necessary for maximum WU. This agrees with increase in weight after blanching at 90^0 C for 15 minutes. The weight increased after blanching ranged from 95 to 174%. This implies that the new lines have the potential to maximise processors' yield and profitability. The high weight after blanching indicates that the processors will use less seeds to produce more processed products.

Fresh weight to yield required is an important factor in canning quality traits because it determines the seed solids required to be soaked and blanched. The fresh weight solids for elite lines used in this study varied 110 to 114 g and were therefore within the optimum range. On the basis of the laboratory canning protocol developed by Michigan State University (MSU) (Hosfield and Uebersax, 1980; Uebersax and Bedford, 1980), a fresh-mass equivalent of 100 to 115 g solids is required for 15 oz (303 x 406mm) cans for soaking and blanching in water containing 50 to 100 mg Ca kg^{-1}.

Among canning quality traits, hydration coefficient (HC) is considered as very vital trait in bean canning industry as it indicates the amount of seeds need to fill the can after soaking and blanching (van Loggerenberg, 2004). An HC of 1.8 to 2.0 is considered optimum by the industry and gives an indication of well-soaked beans (Balasubramanian at al., 2000). Hosfield and Uebersax (1980) found the HC of seven types of white dry beans to range from 1.82 to 1.94. In a study of three navy bean cultivars, Balasubramanian et al. (1999) found the same order of HC ranges (1.84 to 1.96). The HC is important in bean canning, as a larger quantity of beans is necessary to fill a certain can volume, when the HC ratio is low. A higher HC would therefore improve canning yield (Ghaderi et al., 1984). Hydration coefficient of the elite lines used in this study varied from 1.7 to 2.9. The results of this study were not comparable to the above results probably due to genetic factors of runner bean and seed size (large seeded).

The Canadian Agriculture Products Standards Act (1978) stated that PWDWT of canned beans should be no less than 60%. In South Africa, a standard of WDWT of 272 was reported by van Loggerenberg (2004). Sixteen elite lines met these above standards for both WDWT and PWDWT. However, only eight lines across the sites failed to meet the standard for PWDWT. According to van Loggerenberg (2004), the PWDWT after incubation (7 days) was higher than PWDWT before incubation (24 hours). In the present study, differences in PWDWT between cultivars were more pronounced after incubation. This could be due to the water uptake that takes place inside the can during the first seven days after canning (Bolles et al., 1982). Seventeen lines were in agreement with that research while the rest were contrary. PWDWT of 60% was comparable with results found by other researchers. Van Loggerenberg (2004) found both laboratory and industrial canning of Teebus variety were close to the 60% standard set by Canadian government regulations (Balasubramanian et al., 1999). Kabete line KAB-RB13-471-117/2 with the lowest HC (1.7) achieved PWDWT comparable with SUB-OL-RB13-269-129/3B which had HC of 2.5. This suggests that beans undergo more weight increase due to equilibration of beans and brine in the can. van Loggerenberg (2004) suggested that WDWT is a function of the equilibrium of beans and brine in the can, and is highly dependent on the moisture content of the beans after soaking, the fill weight and the brine fill. There were no significant differences in HC among the genotypes. This could be due to the fact that the genotypes were all large seeded. According to Warsame (2013) there were significant differences in HC among large and small seeded genotypes across seven market classes of beans. This may be attributed to differences in factors inherent in seeds. The white seeded genotypes had higher water uptake and HC than purple speckled genotypes. This was in agreement with Del Valle et al., (1992) who found that seed coats of white beans are preferentially permeable to water when compared with those of black and red beans. In this study, there was an average WU of 98% after soaking. There were no significant differences in HC among genotypes. These results confirmed absence of significant correlation between seed size and HC. This was probably due to use of elite lines which were large seeded. Khanal et al. (2015) reported negative correlation between HC and PWDWT ($r= -0.62$ $P>0.001$).

Texture is used as an indication of the degree of consumer acceptance of canned beans (Ghaderi et al., 1984; Hosfield, 1991) as it affects the perceived stimulus of chewing (Ghaderi et al., 1984). Consumers usually rate texture of beans from “too soft” or “mushy” to “too firm / tough” or “hard” (Hosfield, 1991). The white seeded varieties from both sites had lower texture than purple speckled varieties. This indicates that seed colour influences the texture quality. This was in agreement with van Loggerenberg, 2004 who was working with four small white bean cultivars and found that there was a negative correlation between texture and a_L-value colour of seeds (red to green). Texture, which is measured by a shear press, is an indication of the firmness of the beans (Ghaderi et al., 1984) and is measured as kg force required to shear 100 g of beans (Hosfield and Uebersax, 1980). The shear press curve is used to indicate maximum shear force by means of maximum peak height. A higher maximum peak height indicates firmer beans (Bolles et al., 1990). In this research texture correlated negatively with PWDWT (r= -0.61**). However, according to Loggerenberg, 2004 research on four small white bean cultivars, texture was found to correlate negatively with PWDWT (r= -0.57**). The latter correlation was also indicated in the literature (Ghaderi et al., 1984; Balasubramanian et al., 1999). In addition, Khanal et al.2015 found correlation between texture and PWDWT (r= -0.37 P>0.01). However, Walters et al, (1995) identified significant correlations between the HC and texture. In the present study, no significant correlations (Table 7.5) between texture and HC were found, which agrees with findings of He et al, (1989) and van Loggerenberg, (2004). Texture ranged from 9.37 to 21.94 kg $100g^{-1}$ $12s^{-1}$ across the sites. In addition, the total texture which is the area under curve ranged from 53.85 to 124.4 kg s^{-1}. This texture was too low compared with findings of van Loggerenberg, (2004) texture for the reference standards of choice (Teebus) and standard grade (Helderberg) beans being 70.21 and 75.26 kg $100g^{-1}.12s^{-1}$ respectively. This indicates that runner beans have quite softer texture than common bean. The mean texture value did not agree with the USA guidelines of 72 kg $100g^{-1}$ in bean cultivars. This could be probably due to genetic variation in both common bean and runner bean.

Size and shape of canned beans are important for the canning industry due to consumer's preferences. Beans destined for canning purposes should be uniform in size with regular shape. Uniformity is a key factor considered by the processing industries.

Visual appearance of canned beans is an evaluation of the general suitability of beans for commercial processing (Hosfield and Uebersax, 1980). Canned beans are evaluated for splits, free seed coats, clumping and brine clarity (Hosfield and Uebersax, 1980). Several workers have reported that bean genotypes that have high PWDWT tend to split (van Loggerenberg, 2004; Balasubramanian et al., 2000; Mekonnen, 2012). Results for this study confirmed this finding. Results showed that there was significant negative correlation (P<0.01) between splits, PWDWT and WDWT. However, according to Van Buren et al., 1986 the incidence of bean splits after canning is lower in beans with low PWDWT values. According to Warsame 2013, the lowest scores for splits was recorded on small navy and large red kidney bean genotypes which had the highest and second highest PWDWT among small and large seeded types respectively. Larger sized beans have fewer splits, due to larger volume-to-surface ratio (Faris and Smith, 1964). van Loggerenberg (2004) found larger seeds had fewer splits. Result of the present study showed a significant positive correlation ($P>0.01$) between seed size and splits.

Sensory evaluation results showed that the panelists had clear preferences for certain grain runner bean genotypes across the sites on their colour, size, appearance, taste, mouth-feel, flavor, wholesomeness and overall acceptability. According to Calvo et al. (1999), Casanas et al. (2002), Mkanda (2007), Makonnen (2012) trained panel of judges detected differences in sensory quality attributes among different cooked dry bean varieties.

With regard to colour, panelist showed significant different preferences for colour across the sites. Preference for colour was significantly different ($p<0.05$) among all the genotypes across the sites. There was no discrimination against the seed colour. According to Bressani and Elias (1980) consumers normally prefer light coloured seeds to dark coloured seeds possibly because of good taste as dark coloured beans (black, red, bronze seed coats) have been reported to contain considerable amounts of poyphenols, and have thus been associated with astringent and bitter tastes. van Loggerenberg (2004) reported that intact navy beans gave brighter colour compared to broken beans.

In general, results of this study did not indicate preference for particular seed colour because genotypes from both white and purple speckled types were rated high. There was no discrimination on basis of seed size. This was probably because they were all large seeded. In contrast to these findings, in South Africa, Mkanda (2007) found that consumers rated low a cooked variety for its small seed size compared to large seeded speckled sugar varieties. Liebenberg et al. (2003) reported discrimination against small seeded varieties of beans on South Africa market.

Appearance scores were significantly different ($p<0.05$) among the genotypes. Low appearance scores may be due to undesirable colour or splits or both because they are the components of appearance (van Loggerenberg, 2004). KAB-RB13-338-41/1 (OJ white) andSUB-OL-RB13-226-251/4 (OJ white) had not only the lowest appearance score values but also the lowest and second lowest scores for wholesomeness and colour respectively.

Taste is the most important sensory quality from the consumers' point of view and product purchase criterion (Kihlberg, 2004). In cooked beans, sweet taste is due to breakdown of complex sugars into simple sugars such as glucose and fructose. Soft texture and flavor of cooked beans has been found to be the major reasons for rating a cooked bean variety high by consumers while bitter taste, soapy and metallic mouth-feel and hard texture contributed to consumers' dislike of certain bean varieties (Mkanda, 2007). Martin-Cebrejas et al., (1997) reported that fast cooking beans also have good cooked aroma and flavor. Good flavors probably mean fully developed bean flavour and relative sweetness. According to Mkanda, (2007) for the less preferred beans, hardness, appearance and flavor dominated the consumers' reasons for their negative opinions. Light coloured beans seem to have a bland (not strong) flavor compared to dark coloured beans (black, red and bronze seed coats), which have been reported to contain considerable amounts of polyphenols (Bressani and Elias, 1980), which may lead to intense flavor and bitterness. In this study, the sensory panel was heard recommending the good flavor in purple speckled genotypes as opposed to white seeded genotypes (Njoro Canning, personal communication). Seven lines received the highest score value for overall acceptance (KAB-RB13-312-160/5, KAB-RB13-343-189/5A, SUB-OL-RB13-177-3/5, SUB-OL-RB13-269-129/3B, KAB-RB13-310-161/5, KAB-RB13-297-144/2 and KAB-RB13-326-207/1). This observation could be attributed to their good sensory qualities including colour, size, appearance, taste, mouth-feel, flavor and wholesomeness. According to Shivachi et al. (2012), among 13 dolichos genotypes, the highest overall acceptability was recorded on the genotypes with the highest values for appearance, texture and taste. SUB-OL-RB13269-129/3B was among the genotypes with the highest score for overall acceptance and also highest scores for other sensory quality attributes.

TruFood RB is the canning industry reference variety. Much of the best canning quality attributes and sensory parameters were expected from the variety but it did not reveal that superiority. However, 36 elite lines were better than the TruFood check variety in both canning quality and sensory analysis. This is an indication that these lines can be used to produce even better products. This may suggest the need for comparing the most outstanding lines identified in this study and TruFood RB under different locations, seasons and including tomato sauce as canning media.

7.5 CONCLUSION

The 43 grain runner bean genotypes evaluated showed significant differences for canning qualities which are probably due to genetic factors inherent in the genotypes. Results showed that purple speckled SUB-OL-RB13-269-129/3B, KAB-RB13-341-143/A and KAB-OL-RB13-440-232/2 (Kabete) and KAB-RB13-310-161/5 and KAB-RB13-471-117/1 (Ol-Joro-Orok) had superior canning quality attributes. TruFood variety, reference variety was among the lines with low PWDWT. Result show that lines SUB-OL-RB13-269-129/3B, KAB-RB13-341-143/A, KAB-OL-RB13-440-232/2 (Kabete) and KAB-RB13-310-161/5 and KAB-RB13-471-117/1(Ol-Joro-Orok) had superior canning quality and sensory attributes compared to existing canning grain runner bean variety, TruFood RB variety. Good sensory attributes influence consumers' and processors' preferences. Most of the new runner bean lines had better sensory and canning qualities than the reference variety, TruFood RB. These lines were also superior for agronomic traits compared to local varieties. The results of the study suggest that the new grain runner bean varieties developed by University of Nairobi will have major implications in bean canning industry in Kenya and probably eastern Africa region. It is certain that in the future the manufacturing industry will expand depending on development of new products and technologies and adoption of grain runner bean production by smallholders. The good sensory attributes with the new lines will improve acceptance of the products by consumers while expanding production by manufacturing industry.

CHAPTER 8

CANNING QUALITY OF NEW LOCALLY BRED SNAP BEAN LINES

Abstract

Canned snap beans are becoming a major form of vegetable consumption especially in urban areas for its convenience and distinctive flavor while providing excellence consumer value. Vegetable quality traits related to end-user preferences are of utmost importance for success of new snap bean varieties. Breeding snap bean varieties suitable for processing industry has received very limited research attention in eastern Africa. In Kenya, processing industry depends on low yielding and disease susceptible commercial varieties. Several snap bean lines with superior agronomic traits were recently developed at the University of Nairobi. However, their potential for use by the processing industry is not known. The objective of this study was to evaluate the canning quality of the new breeding lines and to identify the lines that combine most of the canning quality traits. Twenty seven advanced lines, and one canning check variety, Julia were grown at KALRO Mwea Kirogo research site, and evaluated for canning quality. At early pod formation, pods were harvested, cleaned soaked, snipped, sorted, blanched, canned in brine and incubated for seven days, and subsequently evaluated for canning quality attributes including hydration coefficient (HC), washed drained weight (WDWT) and percentage washed drained weight (PWDWT), fiber content, water uptake after soaking and blanching, and percent waste after sorting. Results showed significant ($p<0.05$, 0.01) differences in all traits evaluated apart from HC and fiber content. Twenty lines met the industrial canning standards. Among the best performers were KSB22-147-2M/1, KSB22-147-2M/2 and KSB52-2M. Lines that showed poor canning quality attributes such as low HC and WDWT included KSB69-1-1MR1, KSB14-1-1MR1 and KNSB79-1R1/1. The reference variety, Julia had low HC (1.1) and high fiber content (20%). These new lines of snap bean will provide the bean processing industry with raw materials that meet consumer’s preferences while increasing production of processed products.

Key words: Canning quality, snap bean, hydration coefficient, PWDWT

8.1 INTRODUCTION

Development of snap beans suitable for processing has received hardly any research attention in eastern Africa. Indeed this is pioneering work, probably the first of its kind in east, central and west Africa region. The processing industry is constrained by inadequate and erratic supply of snap beans. Due to low local production, the industry does not meet the consumption demand in the market. This has also led to seasonal processing of snap beans. Low production of snap beans is associated to lack of high yielding varieties with resistance to diseases. The farmers rely on commercial varieties of snap beans such as Amy, Monel, Samantha and Paulista for fresh market and Julia variety for processing. These varieties are low yielding and susceptible to diseases compared to the new varieties developed by University of Nairobi Bean Program (Wahome et al., 2013). The low yielding and disease susceptibility aspects have led to low production and high production costs of the crop by farmers despite high demand in the market.

Due to changing consumer's preferences, urbanization and changing eating habits, demand of canned snap beans is growing. The Grain Legume Research Program of the University of Nairobi is mandated to develop new snap bean varieties for the processing industries. The bean program is not only developing improved snap bean varieties which are acceptable to farmers but also to a wide range of consumers and processors' preferences. The snap bean breeding project was initiated with objective of identifying new varieties combining high yield, disease resistance and desirable canning quality. To ensure the end products are acceptable to processing industries, it was necessary to collaborate with bean canning firms and farmers. The initial stages of the breeding activities involved evaluation of germplasm for yield potential, disease resistance and other agronomic traits (Kimani et al., 2013a). The selected lines were evaluated participatory variety selection (PVS) on-farm trials and for adaptation across diverse agro-ecological zones.

Evaluation for canning quality was conducted in partnership with Njoro Canning Factory in Nakuru County. The factory started operation in 1938 and now produces a wide range of food products such as frozen vegetables, canned vegetables, dehydrated vegetables, pickles and relishes, jams and marmalades, sauces, spices and desserts (www.njorocanning.co.ke accessed on 23rd March 2015). Canned snap beans are important production line in the factory. Consumption of canned food is gaining popularity due to urbanization and reduced cost on energy. Snap beans are consumed in larger quantities in developed countries, where there is greater flexibility in foods available, compared to developing countries (Myers and

Baggett, 1999). On a daily utilisation basis, developed countries consumed 3.1 g day^{-1} compared to 1.1 g day^{-1} in developing countries (Rubatzky and Yamaguchi, 1997). Relative to other vegetable crops, snap bean consumption is moderate in the United States. In 1995, per capita consumption of snap beans was 3.4 kg compared to 2.3 kg for broccoli, 5 kg for cabbage, 5.1 kg for carrot, 12.7 kg for sweet corn, 1.7 kg for green pea, 2.8 kg for bell pepper and 42.8 kg for tomato (Maynard and Hochmuth, 1997).

Pod traits are perhaps the most important aspect of snap bean cultivars. Traits of importance include colour, pod shape, length, cross-sectional shape, straightness, smoothness, fibre content, rate of seed development, and point of detachment (Silbernagel, 1986). Nearly all bean for fresh market and processing have pods with some shade of green (Myers and Baggett, 1999). Fresh market cultivars traditionally had lighter green colours compared to the processing types, but the gap in colour differences is narrowing. While not true in every case, many processors would prefer dark green pods for canning and freezing. Lighter pods are much more acceptable for freezing than canning, indicating that colour has been less critical in freezing than in canning (Myers and Baggett, 1999). Length, cross-sectional shape, diameter and length of the spur and pedicel affect pod shape. Pods of beans for processing are about 10 to 16 cm in length. Pod lengths greater than 16 cm are too long for existing processing equipment (Myers and Baggett, 1999). Processors prefer a round pod because round pods are fleshier and because there is a close relationship between sieve size, quality and maturity when the round pods are sorted in a sieve grader. The spur, or remnant of the style, can vary in length with some cultivars possessing a long tapered spur and others having a short broad-based spur. Processors prefer spurs that are short and straight because they are easier to remove during preparation of pods for packing (Myers and Baggett, 1999).

Sieve size is probably the single most important factor in processed beans. After harvest, unsorted pods are brought into the plant where equipment is used to separate the pods into different sizes based mainly on pod diameter (Table 8.0). Pod straightness is important in processing green beans because straight beans make a neater cut or whole pack product and also they flow through the processing equipment more rapidly (Myers and Baggett, 1999). Straightness and fiber content are interrelated qualities. Fresh market beans, which have greater fiber content than do beans used for processing, are also straighter (Silbernagel, 1986). The challenge for breeding processing cultivars is to select for straight pods while maintaining low fiber content. Pod detachment force is a trait of considerable interest to both fresh market and processing industries. Fresh market producers consider breakage at the pod neck a disadvantage because such breakage increases pod discoloration and decay during shipping (Lien and Baggett, 1998). At the processing plant, one of the first procedures to undertake is to snip both ends of the pod to remove the spur and pedicel. Sometimes is difficult to snip off the pedicels and therefore, the processors prefer cultivars with easy picking traits (Lien and Baggett, 1998).

Yield and quality are traits that are considered by both growers and processors. Yield is more complex in a vegetable crop such as snap bean, compared to a seed crop (Myers and Baggett, 1999). Snap bean yield is a moving target in that growers attempt to harvest at the highest yield possible while maintaining quality. Yield and quality have an inverse relationship (Mullins and Coffey, 1990). To a grower or processor, quality is defined in terms of sieve size, percent seed by weight of total pod weight, pod fibre content, pod smoothness and straightness, pod colour and flavour (Myers and Baggett, 1999). A contemporary trend in the canning industry is an increased demand for small-sieve beans. Full-sieve cultivars produce substantial quantities of five and six-sieve beans, which are used in a cut bean pack. Currently, some processors consider that an optimum harvest should produce 60% 1 to 4-sieve beans.

Growing of beans for canning is an important industry in Eastern Africa with Ethiopia taking the lead where the industry has grown tremendously to be a major export earner.

Agro processing, packaging, canned and frozen beans and quality standards in the domestic, regional and international market are not fully developed. Deliberate efforts should be made towards investing in these areas to increase the produce shelf life, reduce post-harvest losses and improve consumer acceptance both in domestic and international market (Duiker, 2012). The canning industries have been relying on Julia commercial variety of snap bean for canning products. However, the variety has succumbed to diseases such as rust, angular leaf spot, anthracnose and common bacterial blight among others leading to low yield and poor pod quality. The farmers have abandoned growing the variety due to low yield and susceptibility to diseases. This has led to unavailability of raw materials to processing industries leading to low production despite the growing demand for processed products especially in urban areas. The predicament with processors necessitates evaluation of new snap bean lines for canning quality to address not only the problem of raw material scarcity but also poverty. The new snap bean lines will promote production of processed products, enhance competitiveness of Kenyan processed products and boost the country economy.

8.2 MATERIALS AND METHODS

8.2.1 Canning process

Pod samples of 27advanced snap bean lines and a check variety, Julia were evaluated for canning quality at Njoro Canning Factory, Nakuru, Kenya between 22nd and 23rd April 2015. The 27 elite lines were selected based on good pod quality (straight, round and green), high pod yield and resistant to diseases. Julia variety was used to compare with the new advanced lines. Julia is one of three varieties grown in Kenya for the processing industry (Tito, 2012). The other two are Vernadon and Sasa.

Snap bean samples were separated by genotype/varieties and soaked in plastic boxes for 45 minutes in cold water (25^{o} C). End of the soaked samples were snipped by hand followed by sorting. The samples were sorted based on blemishes, insect bites, flat pods, deformed and out of size. Pod diameter was determined by a ruler with different sieve sizes. Canners' grade 1, sieve size 2 and pod diameter of 5.5 to 6.5 mm was used (Table 8.1). Pod length of between 6 to 8 cm is preferred for canning snap beans (Njoro Canning, 2014). The standard pod length of 6 to 8 cm and pod diameter of 5.5 to 6.5 mm was for export canned products. The sorted samples were blanched for 3 minutes in hot water (90° C). The blanched samples were drained, weighted and transferred into M1 cans (73x110 mm one piece cans and 73 mm ends). Then pods were covered with hot brine (90°C) with a concentration of 1.5% NaCL (TruFood, 2014) and sealed with an automatic can sealer (Angelus Sanitary Can Machine Co., Los Angleles, CA, USA). The sealed cans were heat sterilized in an automatic retort (Barriquand steriflow, Roanne, France) at 122° C for 40 minutes followed by instant cooling (Njoro Canning, 2014). Two experts from quality control department and five technicians from production line at Factory 5 provided technical support during the canning process. Each sample was replicated two times.

Table 8. 1: Grade, sieve size and pod cross-section thickness used for sorting snap beans pods for canning

Canner's grade	Sieve Size	Pod cross-section thickness (mm)
1	1	<5.8
1	2	5.8 – 7.5
1	3	7.5 – 8.5
2	4	8.5 – 9.7
3	5	9.7 – 10.9
4	6	10.9
Cull	7 and over	>10.9

(After Duncan et al., 1960)

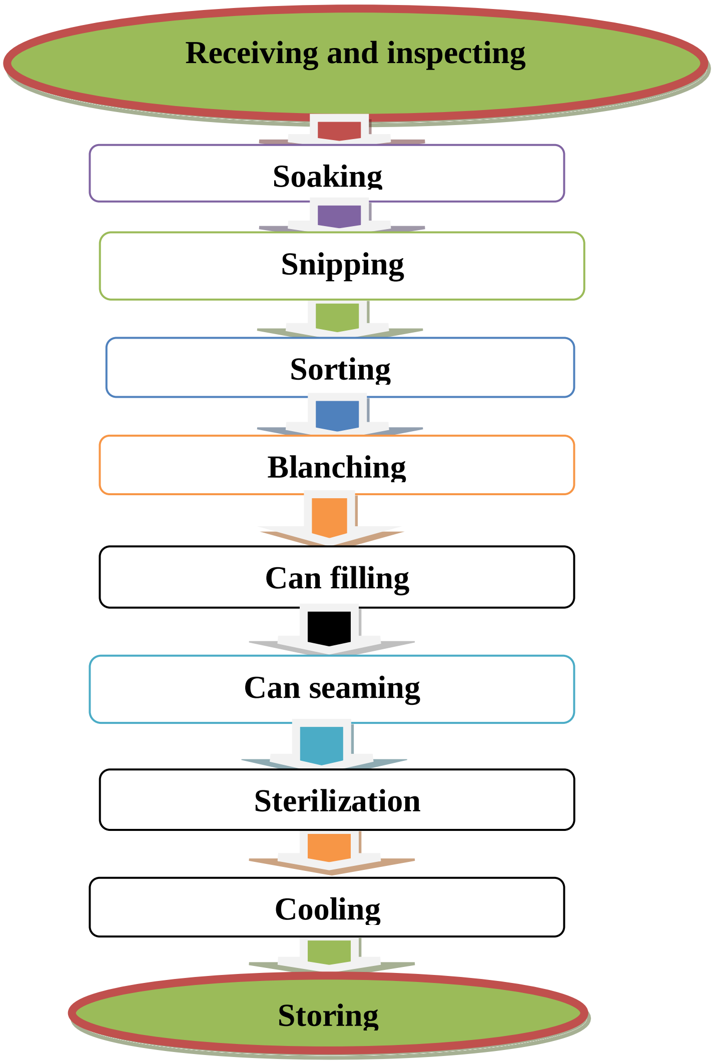


Fig 8. 1: Flow chart of snap bean canning process


a
b
c

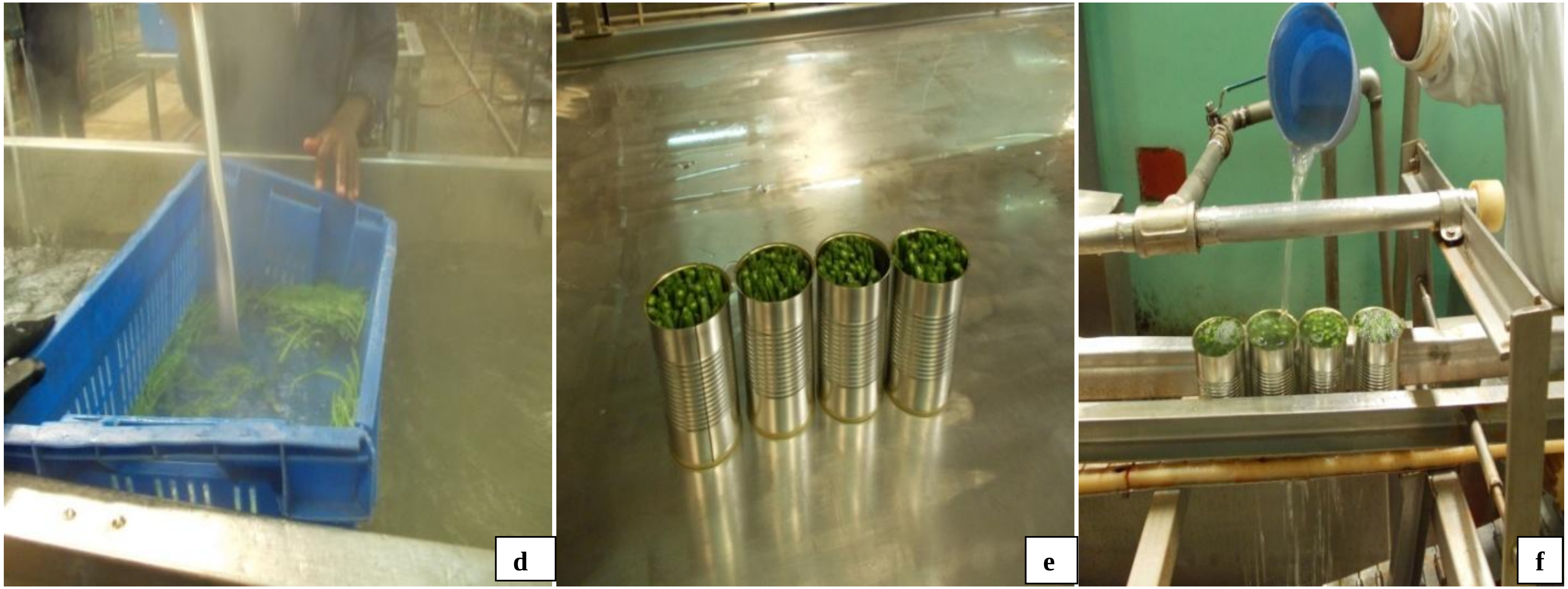

d
e
f

Fig 8. 2: Snap bean canning process at Njoro Canning Factory a)Soaking, b)Snipping, c)Sorting, d)Blanching, e)Can filling, f)Brining, g)Can sealing and h) Can storage

8.2.2 Post-canning evaluation

After seven days of incubation at 55^0 C, the canned beans were opened using manual can-opener and canning quality and sensory attributes of the beans were studied. Canning quality of the canned runner beans was determined using procedures described by Njoro Canning Factory and TruFood Company, 2014. Data collected include: hydration coefficient (HC), washed drained weight (WDWT), percent washed drained weight (PWDWT) and fiber content.

(i) Hydration coefficient (HC): The amount of water imbibed during soaking and blanching is quantified by the HC (Balasubramanian et al., 2000) and is important in bean canning, as a larger quantity of beans is necessary to fill a certain can volume, when the HC ratio is low. A high HC would therefore improve canning yield (Ghaderi et al., 1984). According to (Nordstrom and Sistrunk, 1979; Hosfield, 1991) an HC of 1.8 to 2 is considered optimum by the industry and gives an indication of well soaked beans. The processors desire a high HC of 1.8 and above. The following formula was used to calculate HC (van Loggerenberg, 2004): HC= mass of soaked beans / mass of non-soaked beans**.**

(ii) Washed drained weight (WDWT) and percentage washed drained weight (PWDWT): The WDWT refers to the mass of rinsed beans drained for 2 min on a 0.239 cm screen positioned at a 15 ° angle (Hosfield et al., 1984a). Drained weight of beans relates to "processors yield", as it would require fewer beans with a high WDWT to fill a can than in the case of beans with low WDWT. A high WDWT indicates large swelling capacity. According to (Balasubramanian et al., 2000) the PWDWT of dry beans should be at least 60 %. Percentage washed drained weight is calculated as follows (van Loggerenberg, 2004):

$$\textbf{PWDWT}=\frac{WDWT\ (g)}{Weight\ of\ can\ contents\ \ (g)}\text{x } 100$$

(iii) Fiber content: Ten pods were randomly selected after canning and were mashed between hands. The pods with fiber of more than 2 cm were considered with fiber. The number was converted into percentage.

$$\textbf{Fiber content}\ \% = \frac{\textbf{No.of pods with fiber}}{\textbf{Total No.of pods}}\text{ x } 100$$

8.2.3 Sensory Analysis

Sensory evaluation was done by panel of ten judges from Njoro Canning Factory on 23rd April 2015. The panel was asked to identify bean varieties which are suitable for the canning industry based on their colour, size, appearance, taste, mouth-feel, flavor, wholesomeness and overall acceptability of the beans. Judges were served with canned beans in plastic containers. Distilled drinking water was provided to panellists to rinse their mouth after each tasting. Sensory evaluation was done using seven point hedonic scale (7= like very much, 6= like moderately, 5= like slightly, 4= neither like nor dislike, 3= dislike slightly, 2= dislike moderately and 1= dislike very much).

8.2.4 Data analysis

Analysis of variance was performed using GenStat software (v.14, VSN, UK, 2010). Significance of differences between means were determined using Fisher's least significance difference (LSD) test at 5% probability level.

Significance of correlation coefficients (r) was determined by use of Gen Stat software (v.14, VSN, UK, 2010) and statistical table depending on degree of freedom was used to establish relationships between canning variables. Both the significant ($p<0.05$ and $p<0.01$) correlation coefficients with either a strong or weak degree of association were considered.

8.3 RESULTS

8.3.1 Water uptake during soaking and blanching

Analysis of variance showed that there were highly significance ($P<0.01$) differences in water uptake during soaking and blanching among the test lines (Table 8.6). The values for water absorption are presented in Table 8.2. Water absorption during soaking ranged from 2.5 to 9.2% (KSB69-1-1MRI, KSB27-2-2M and KSB22-147-2M/1 respectively). Fourteen lines had water absorption of more than 5% during soaking. Apart from two lines, the rest absorbed more water than the check (Julia, 2.8%) during soaking (Table 8.2). There were significant increases in weight after blanching which was as a result of further water absorption. Water absorption during blanching ranged from 2.3 (KNSB79-1R1/1, KSB14-1-1MR1) to 9.4% (KSB06-1-1-2M). Eighteen lines had higher water absorption than the check (Julia, 3.8%) during blanching (Table 8.2). High water uptake during blanching is important because it indicates that the new lines have the potential to maximise processors' yield and profit. The high weight with the new lines after blanching indicates that the processors will use fewer vegetables to produce more processed products. Waste after sorting ranged from 10% (KKSB27-2-2M) to 46% (KNSB90-59-R1). Twelve lines had less waste materials than the check (Julia, 29%). There were significant differences in fibre content among the test lines (Table 8.5). Pod fiber content varied from 0 to 35%. Twenty lines had lower fiber content than the check (Julia, 20%). Only four lines had more than 20% fiber content (KSB13-23-248/2, KSB20-146-2-1-4MR1/2, KSB22-3-1T and KSB33-1-2M) (Table 8.2).

Table 8. 2: Percentage water uptake after soaking and blanching, waste after sorting and fiber content of snap bean lines grown at Mwea during long rain 2015

Genotype	Water uptake after soaking (%)	Water uptake after blanching (%)	Waste after sorting (%)	Fibre content (%)
KNSB13-90-188	5.1	6.7	28.0	5.0
KNSB79-1R1/1	3.7	2.3	43.0	0.0
KNSB90-59-R1	3.9	4.7	46.0	0.0
KSB06-1-1-2M	4.6	9.4	29.5	5.0
KSB13-14-218/2	4.2	6.3	20.5	15.0
KSB13-20-208	6.1	8.7	30.5	5.0
KSB13-23-239/1	5.8	3.7	31.0	20.0
KSB13-23-248/2	6.2	3.4	20.0	25.0
KSB13-30-26	4.3	3.8	19.0	5.0
KSB13-30-27/1	3.5	6.7	20.0	5.0
KSB13-30-27/2	7.7	9.6	39.0	10.0
KSB13-39-121	3.4	8.2	35.5	10.0
KSB13-39-169/1	2.9	4.4	29.5	15.0
KSB14-1-1MR1	4.7	2.3	37.5	5.0
KSB20-146-2-1-4MR1/1	5.9	9.2	38.5	20.0
KSB20-146-2-1-4MR1/2	4.0	3.5	35.5	25.0
KSB22-147-2M/1	9.2	7.7	17.5	0.0
KSB22-147-2M/2	7.6	6.6	22.0	20.0

Continued: Percentage water uptake after soaking and blanching, waste after sorting and fiber content of snap bean lines grown at Mwea during long rain 2015

Genotype	**Water uptake after soaking (%)**	**Water uptake after blanching (%)**	**Waste after sorting (%)**	**Fibre content (%)**
KSB22-3-1T	5.7	7.8	41.0	35.0
KSB23-66-2-2M/A	4.1	4.9	23.5	0.0
KSB27-2-2M	2.5	8.5	10.0	10.0
KSB33-1-2M	5.2	5.2	37.0	25.0
KSB33-3-1M	5.6	8.9	24.5	15.0
KSB39-1-4M	5.8	3.0	30.5	15.0
KSB39-3M	6.1	3.1	33.5	5.0
KSB52-2M	5.4	4.0	21.5	15.0
KSB69-1-1MRI	2.5	3.2	17.0	10.0
Check				
Julia	2.8	3.8	29.0	20.0
Mean	4.9	5.7	28.9	12.1
LSD $_{0.05}$	0.3	2.9	8.9	20.0
CV (%)	2.5	8.4	15.0	8.3

LSD-least significant difference, CV-coefficient variation

8.3.2 Canning quality evaluation

The canning quality values of advanced snap bean lines are presented in Table 8.3. Analysis of variance showed significant differences ($p<0.01$) for all canning quality traits studied apart from hydration coefficient (HC) (Table 8.6) The HC ranged from 1.1 to 1.2. Most of the lines were comparable to check variety, Julia, which had HC 1.1. Brine pH ranged from 5.3 to 5.6. The check variety had the highest brine pH (5.6) (Table 8.3). Brine salt concentration ranged from 0.8 to 1. Two lines (KSB14-1-1MRI and KSB20-146-2-1-4MR1/2) had as high brine salt concentration as the check variety Julia, with a brine pH of 1. KSB52-2M had the highest WDWT (238 g) and PWDWT (60%). KSB14-1-1MR1 had the lowest WDWT (223 g) and

PWDWT (54%). Julia had WDWT of 228.5 g and a PWDT of 57%. Five lines had higher WDWT and PWDWT than the check variety Julia).

8.3.3. Correlation analysis

Correlation analysis between canning quality attributes of the advanced snap bean lines showed three traits were positively correlated, and two were negatively correlated (Table 8.4). Brine pH was negatively correlated with water uptake after blanching (r= -0.39*). This indicates that the higher the water uptake after blanching the lower the brine pH. HC was positively correlated with water uptake after blanching (r= 0.385**) and water uptake after soaking (r= 0.39*). However, HC was negatively correlated with waste after sorting (r= -0.45**). WDWT and PWDWT showed a high positive correlation (r= 0.78**) as expected (Table 8.4).

Table 8. 3: Canning quality characteristics of snap bean lines grown at Mwea during 2015 long rain season.

Genotype	HC	Brine pH	Salt concentration (%)	PWDWT (%)	WDWT (g)
KNSB13-90-188	1.2	5.3	0.8	58.0	233.0
KNSB79-1R1/1	1.1	5.5	0.8	57.0	223.5
KNSB90-59-R1	1.1	5.5	0.8	56.0	225.5
KSB06-1-1-2M	1.2	5.3	0.9	58.0	231.0
KSB13-14-218/2	1.2	5.3	0.9	57.0	228.0
KSB13-20-208	1.2	5.3	0.9	55.0	223.5
KSB13-23-239/1	1.1	5.4	0.8	56.0	230.5
KSB13-23-248/2	1.1	5.3	0.8	57.0	231.0
KSB13-30-26	1.1	5.4	0.9	57.0	229.0
KSB13-30-27/1	1.2	5.4	0.9	56.0	227.5
KSB13-30-27/2	1.2	5.4	0.9	55.0	228.5
KSB13-39-121	1.2	5.3	0.8	59.0	234.0
KSB13-39-169/1	1.1	5.4	0.8	58.0	228.0
KSB14-1-1MR1	1.1	5.4	1.0	54.0	223.0
KSB20-146-2-1-4MR1/1	1.2	5.4	0.8	57.0	226.0
KSB20-146-2-1-4MR1/2	1.1	5.4	1.0	57.0	225.0

Continued: Canning quality characteristics of snap bean lines grown at Mwea during 2015 long rain season.

Genotype	HC	Brine pH	Salt concentration (%)	PWDWT (%)	WDWT (g)
KSB22-147-2M/1	1.2	5.4	0.9	55.0	228.0
KSB22-147-2M/2	1.2	5.4	0.8	57.0	231.0
KSB22-3-1T	1.2	5.4	0.8	56.0	224.0
KSB23-66-2-2M/A	1.1	5.5	0.8	55.0	226.0
KSB27-2-2M	1.2	5.4	0.9	55.0	219.0
KSB33-1-2M	1.2	5.3	0.8	56.0	225.0
KSB33-3-1M	1.2	5.4	0.8	56.0	224.0
KSB39-1-4M	1.1	5.4	0.8	57.0	226.5
KSB39-3M	1.1	5.4	0.8	57.0	227.5
KSB52-2M	1.1	5.5	0.9	60.0	238.0
KSB69-1-1MRI	1.1	5.5	0.8	55.0	224.0
Check					
Julia	1.1	5.6	1.0	57.0	228.5
Mean	1.2	5.4	0.9	56.0	227.5
LSD $_{0.05}$	0.0	0.1	0.0	1.4	4.1
CV (%)	6.1	0.5	2.5	1.2	0.9

LSD-least significant difference, CV-coefficient variation, HC-hydration coefficient, WDWT-washed drained weight, PWDWT-percent washed drained weight

Table 8. 4: Correlation matrix between canning quality parameters of snap bean genotypes

	Brine pH	HC	Fiber content (%)	PWDWT	Salt concentration	WDWT (g)	WU after blanching (%)	WU after soaking (%)	Waste after sorting (%)
Brine PH	-								
HC	-0.26	-							
Fiber content (%)	-0.12	0.05	-						
PWDWT	-0.01	0.00	0.11	-					
Salt concentration	0.18	0.06	0.05	-0.27	-				
WDWT (g)	-0.03	0.09	0.03	0.78**	-0.07	-			
WU after blanching (%)	-0.39*	0.39*	0.02	-0.13	0.06	-0.05	-		
WU after soaking (%)	-0.31	0.39*	0.07	-0.09	-0.05	0.23	0.27	-	
Waste after sorting (%)	0.02	-0.45s**	0.05	-0.05	-0.14	-0.15	0.03	0.05	-

*,**Correlation coefficient significant at 0.05 and 0.01 probability levels, respectively. HC- hydration coefficient, PWDWT-percent washed drained weight and WDWT-washed drained weight, WU-water uptake

8.3.4. Sensory quality evaluation

Analysis of variance revealed highly significant differences ($p<0.05$) in sensory quality attributes among snap bean lines apart from mouth feel, size and taste (Table 8.7). The sensory qualities were subjectively evaluated by 1 to 7 hedonic scale.

The score for appearance ranged from 4 (neither like nor dislike) to 6 (like moderately). Only KNSB13-90-188 and check, Julia were neither liked nor disliked for appearance. All the other lines were either liked slightly or liked moderately for appearance. The pod colour scale varied from 5 to 7 (Table 8.5). Most of the lines were liked moderately for colour including the check, Julia. The colour ranged from light green to dark green. However, there were five purple podded lines. Light green and purple podded lines were more preferred than the dark green lines. Fifteen lines met the colour criteria preferred by processors. Flavor (aroma) score ranged from 5 to 6 with Julia scoring 5 (slightly liked) (Table 8.5). Mouth-feel (texture) score ranged from 4 to 6. Only two lines were neither liked nor disliked (KSB13-23-248/2 and KSB22-3-1T). Taste score ranged from 4 to 6. The check, Julia was among the lines that were neither liked nor disliked for taste. The size score ranged from 5 to 6. Wholesomeness score ranged from 4 to 6. Most of the lines remained whole after canning hence moderately liked (Table 8.5). Overall acceptability score ranged from 4 to 6. KSB06-1-1-2M was neither accepted nor rejected for overall acceptability. The rest of the other lines were either slightly accepted or moderately accepted including the check, Julia (5) (Table 8.5). KSB14-1-1MR1, KSB33-1-2M, KSB23-66-2-2M/1, KSB20-146-2-1-4MR1/2 and KNSB90-59-R1 were the new lines that were overall accepted due to high quality sensory traits.

8.3.5. Genetic diversity of snap bean lines for canning quality analysis

Cluster analysis of 26 snap bean lines and one check, Julia revealed a single cluster. Julia, the reference variety, was distantly related to the other lines. It had low water uptake after soaking (2.9%), water uptake after blanching (3.8%) and high brine pH (5.56). KSB52-2M line is an outlier because it is dissimilar from the other lines. It had the highest washed drained weight (241g) and percent washed drained weight (61) (Appendix 27).

Table 8. 5: Means of hedonic scores for sensory quality parameters of snap bean lines grown at Mwea during long rain 2015

Genotype	**Appearance**	**Colour**	**Mouth feel (Texture)**	**Flavor (Aroma)**	**Taste**	**Size**	**Whole-someness**	**Overall acceptability**
KNSB13-90-188	4	5	5	5	5	5	4	5
KNSB79-1R1/1	5	6	5	6	5	5	6	6
KNSB90-59-R1	5	6	6	6	6	5	6	6
KSB06-1-1-2M	5	5	5	5	5	5	4	4
KSB13-14-218/2	5	5	5	5	4	5	5	5
KSB13-20-208	5	5	5	5	4	5	5	5
KSB13-23-239/1	6	6	5	5	6	5	5	5
KSB13-23-248/2	6	5	4	5	5	6	6	5
KSB13-30-26	6	5	5	6	5	5	5	6
KSB13-30-27/1	5	5	5	5	6	5	5	5
KSB13-30-27/2	5	6	5	5	5	6	6	5
KSB13-39-121	5	6	5	5	5	5	5	5
KSB13-39-169/1	6	5	5	5	5	5	6	6
KSB14-1-1MR1	6	7	5	6	6	6	6	6
KSB20-146-2-1-4MR1/1	5	6	5	6	5	5	5	5
KSB20-146-2-1-4MR1/2	6	6	5	6	5	6	6	6
KSB22-147-2M/1	5	6	5	5	6	5	5	6

Continued: Means of hedonic scores for sensory quality parameters of snap bean lines grown at Mwea during long rain 2015

Genotype	**Appearance**	**Colour**	**Mouth feel (Texture)**	**Flavor (Aroma)**	**Taste**	**Size**	**Whole-someness**	**Overall acceptability**
KSB22-147-2M/2	6	6	5	5	5	6	6	5
KSB22-3-1T	5	5	4	5	5	5	4	5
KSB23-66-2-2M/A	5	6	6	6	6	6	6	6
KSB27-2-2M	5	6	5	5	5	5	5	5
KSB33-1-2M	6	6	6	6	6	6	6	6
KSB33-3-1M	5	6	5	5	5	6	5	5
KSB39-1-4M	6	5	5	5	6	6	6	6
KSB39-3M	6	6	5	5	5	6	5	6
KSB52-2M	5	5	5	5	5	5	5	5
KSB69-1-1MRI	5	6	5	6	5	5	6	6
Check								
Julia	4	6	5	5	4	5	5	5
Mean	5.2	5.5	5.0	5.4	5.1	5.3	5.3	5.4
LSD $_{0.05}$	1.1	0.8	1.0	0.9	1.4	1.0	1.0	7.3
CV (%)	10.4	7.4	10.0	8.3	13.7	9.2	9.4	6.6

LSD-least significant difference, CV-coefficient variation. Sensory evaluation was based on 1-7 hedonic scale where 7=Like very much, 6= like moderately, 5= like slightly, 4= neither like nor dislike, 3= dislike slightly, 2= dislike moderately and 1= dislike very much

Table 8. 6: Mean squares of water uptake after soaking and blanching, waste after sorting, fiber content, percent washed drained weight, washed drained weight, brine pH, hydration coefficient, and salt concentration of canning quality traits of snap bean lines grown at KALRO-Mwea during 2014 short rain season for canning quality.

		Percent (%)								
Source of variation	**df**	**Water uptake after blanching**	**Water uptake after soaking**	**Waste after sorting**	**Fiber content**	**PWDWT**	**Brine pH**	**Hydration coefficient**	**Salt concentration**	**WDWT (g)**
Replicates	1	6.512	0.0061	2162.57	28.57	2.6368	0.0003	0.14	0.0001	13.018
Genotype	27	11.726**	5.306**	162.77**	168.25*	2.9641**	0.0105**	0.003^{ns}	0.005**	30.864**
Error	27	1.924	0.0159	18.83	95.24	0.4622	0.0006	0	0.0004	3.907

*, **, ns significant at 0.05, 0.01 probability levels and not significant respectively, df= degree of freedom, PWDWT= percent washed drained weight and WDWT= washed drained weight

Table 8. 7: Mean squares of appearance, colour, flavor, mouth feel, size, taste, wholesomeness and overall acceptability of sensory quality traits of snap bean lines grown at KALRO-Mwea during 2014 short rain season for sensory analysis.

Source of variation	df	Appearance	Colour	Flavor	Mouth feel	Overall acceptability	Size	Taste	Wholesomeness
Replicates	1	0.0579	0.2857	0.7314	0.035	0.0579	0.9257	0.56	0.0029
Genotype	27	0.5444*	0.4011*	0.4747*	0.2852^{ns}	0.3971**	0.3344^{ns}	0.448^{ns}	0.6356**
Error	27	0.286	0.1687	0.1966	0.2557	0.126	0.2353	0.4993	0.2503

*, **, ns significant at 0.05, 0.01 probability levels and not significant respectively, df= degree of freedom

8.4 DISCUSSION

Water uptake (WU) is a key factor to consider during canning process. The purpose of soaking and blanching prior to autoclaving is to ensure uniform and complete WU in order to prevent further expansion of beans in the can. The WU of the new lines after soaking ranged from 2.5 to 9.2% while WU after blanching ranged from 2.3 to 9.6%. Low water absorption was due to succulent state of the snap bean vegetables as opposed to dry beans. Hosfield (1991) found the optimum WU of dry beans for canning process is 80%.

The new lines showed considerable variation in proportion of waste, which is the proportion of pods harvested that is not suitable for canning. It varied from 10 to 46%. Waste was the result of snipping, overgrown pods, blemishes, insect bites, fiber and short pods. The high waste component was as a result of two weeks storage in cold room prior to processing. Processing should be done immediately after harvesting to reduce the level of waste component. High fiber content and oversize pods contributed most to the waste content. According to Leakey (1988) three major genes control the switch from the highly fibrous dry bean type pod to a relatively fibre free pod of the typical snap bean. Within snap beans, fibre content appears to be quantitatively inherited, with reported values from 0.02% to 20% of pod fresh weight (Silbernagel and Drake, 1978). According to Myers and Baggett (1999) fresh market and over-mature beans exhibit the highest percentages of fiber content. Fiber content also increases with sieve size and maturity. More than half of the lines had higher waste content than the check, Julia. However, some of the lines had no fiber content despite high waste component (KNSB79-1R1/1 and KNSB90-59-R1) (Table 8.1). Low waste and low fiber content was also common in some of the lines (KSB22-147-2M/1 and KSB27-2-2M). According to Baggett and Varseveld (1982) fiber content is influenced by soil water potential. Low soil water potential increases snap bean fiber content. Canning snap bean for export markets should be Canner's grade 1, sieve size 2 and pod cross-section thickness of 6 to 6.5 mm which is the requirement for processed snap bean for canning. Due to two weeks storage in cold room at 4^0 C, most of the pods were above sieve size 2 and 6.5 mm diameter hence contributing to high waste materials after sorting.

Among canning quality traits, hydration coefficient (HC) is considered as very vital trait in bean canning industry as it indicates the amount of seeds need to fill the can after soaking and blanching (van Loggerenberg, 2004). An HC of 1.8 to 2.0 is considered optimum by the industry and gives an indication of well-soaked beans (Balasubramanian et al., 2000). Hosfield and Uebersax (1980) found the HC of seven types of white dry beans to range from 1.82 to 1.94 and significant differences ($p<0.01$) between bean types were found for HC. Balasubramanian et al. (1999) found the same order of HC ranges (1.84 to 1.96) and significant differences ($p<0.05$) in HC values for three navy bean cultivars. The HC is important in bean canning, as a larger quantity of beans is necessary to fill a certain can volume, when the HC ratio is low. A higher HC would therefore improve canning yield (Ghaderi et al., 1984). Most of the HC values reported are for dry beans. In contrast, the HC for snap bean are lower compared to that of dry beans. In this study HC varied from 1.1 to 1.2 compared to 1.8 to 2.0 for dry beans. However, HC of snap bean lines was not significant. This was due to low amount of water absorbed during soaking and blanching. By nature snap bean are succulent with high water content, therefore, limited uptake. Snap beans have higher moisture concentration of about 88% compared to 70% for cooked dry beans (Myers and Baggett, 1999) and 12 to 16% of dry bean for canning purposes (Uebersax et al., 1991). The Canadian Agriculture Products Standards Act (1978) stated that PWDWT of canned beans should be no less than 60%. In South Africa, a standard of WDWT of 272 was reported by van Loggerenberg (2004). However, WDWT of snap bean lines was lower than that of dry beans. The highest WDWT was 238 g. According to Njoro Canning (2014), the standard for WDWT is 225g. High WDWT is considered better than low WDWT because fewer products are required to fill the can. All the snap bean lines, apart from KSB52-2M had a lower PWDWT than the standard for dry bean (60%). Low WDWT indicates that the snap beans absorb little water inside the cans during the first seven days after canning. Some of the lines had low HC but high WDWT and PWDWT (KSB52-2M). This suggests that beans undergo more weight increase due to equilibration of beans and brine in the can.

Brine pH is considered important trait for canning snap beans. Standard snap bean brine pH varies from 5.2 to 5.9 (Njoro Canning, 2014). Snap bean lines either < 5.2 or > 5.9 are rejected. The brine pH ranged from 5.3 to 5.6 implying they are within the accepted range. The check, Julia had the highest brine pH (5.6). Salt concentration determines the taste of the products. Snap bean salt concentration ranges from 0.8 to 1.25 (Njoro Canning, 2014). Salt concentration of the study lines ranged from 0.8 to 1.0. They were all within the required ranges of salt concentration.

Sensory evaluation results showed that the panelist had clear preferences for certain snap bean genotypes based on their colour, size, appearance, taste, mouth-feel, flavor, wholesomeness and overall acceptability. According to Calvo et al., (1999), Casanas et al., (2002), Mkanda (2007), Makonnen (2012) trained panel of judges detected differences in sensory quality attributes among different cooked dry bean varieties.

With regard to colour, panellists showed significant different preferences for colour. Results showed that they were significant differences (P<0.05) for colour in preferences among all the genotypes. According to Silbernagel (1986), colour (relative internal and external colour and uniformity of colour) is among the traits of importance in snap beans. Nearly all beans for fresh market and processing have pods with some shade of green. Fresh market cultivars have traditionally had lighter green colour compared to the processing types, but the gap in colour differences is narrowing (Myers and Baggett, 1999). Many processors would prefer a dark green pod for canning and freezing. Lighter pods are much more acceptable for freezing than in canning (Myers and Baggett, 1999). Pods generally darken with blanching and a bean that has light coloured pods may blanch to an acceptable dark green colour.

Appearance scores were significantly different (P<0.05) among the genotypes. Low appearance scores may be due to undesirable colour or splits or both because they are the components of appearance (van Loggerenberg, 2004). KNSB13-90-188 had not only the lowest appearance score value but also the lowest for colour and wholesomeness meaning it had poor sensory qualities. Snap bean appearance is related to presentation. Curved pods are considered to be of poor presentation. Very straight pods have good presentation in the can (Njoro Canning, 2014).

Taste is the most important sensory quality from the consumers' point of view and product purchase criterion (Kihlberg, 2004). In cooked beans, sweet taste is due to breakdown of complex sugars into simple sugars such as glucose and fructose. Soft texture and flavor of cooked beans has been found to be the major reasons for rating a cooked bean variety high by consumers, while bitter taste, soapy and metallic mouth-feel and hard texture contributed to consumers' dislike of certain bean varieties (Mkanda, 2007). There were no significant differences among the genotypes on taste and texture. They generally had good taste and texture. However, there were significant differences (P<0.05) in flavor (aroma) among the test lines. Eight lines had better score for flavor than Julia and it means they had better flavor. The other lines had the same flavor as the check. There were no significant differences in size. This was probably because the pods were trimmed to uniform size during can filling. Wholesomeness and overall acceptability were highly significant (P<0.01). The snap bean lines differed in levels of intactness and splits after canning. Most of the lines were better scored for wholesomeness than the check (5, slightly liked). In addition, most of the lines were better accepted, in relation to other sensory qualities than the check. According to Shivachi et al., (2012), among 13 dolichos genotypes, the highest overall acceptability was recorded on the genotypes with the highest values for appearance, texture and taste. KSB14-1-1MR1 and KSB33-1-2M were among the lines moderately accepted and also moderately liked for other sensory parameters (Table 8.4).

Julia is the canning industry reference variety. Much of the best canning quality attributes and sensory parameters were expected from the variety but it did not reveal that superiority. This may suggest the need for comparing the most outstanding lines identified in this study and Julia under different locations, seasons and including tomato sauce as canning media.

8.5 CONCLUSION

The 27 snap bean lines evaluated showed significant differences for most of the canning qualities. This was probably due to genetic factors inherent in the genotypes. Results showed that KSB22-147-2M/1, KAB06-1-1-2M and KNSB13-90-188 had superior canning quality attributes compared with current industry referred variety, Julia. KSB33-1-2M and KSB14-1-1-1MR1 had superior sensory qualities. These lines were also superior for agronomic traits compared to commercial variety. Good sensory and canning qualities influence consumers' and processors preferences. The results of the study indicate that the new snap bean lines developed by University of Nairobi will have major implications in bean canning industry in Kenya and probably Eastern Africa region. It is certain that in the future, manufacturing industries will expand which will depend on development of new products and technologies. The manufacturing industry will undertake production throughout the year due to availability of raw materials hence meeting the consumers demand. The good canning and sensory attributes of the new lines will enhance competitiveness of the products both in local and international market.

CHAPTER 9

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

The results showed great potential of developing local runner and snap bean varieties from the evaluated advanced lines. Parent-offspring regression revealed that duration to flowering, pod length, pod diameter, pods per plant and pod yield traits are highly heritable. All the traits showed moderate to high heritability which varied across the populations. The lowest heritability was recorded in pod length (0.42) while the highest was recorded in pods per plant (0.94). The cross between Morelli x HAV 130, Serengeti x HAV 132, Samantha x HAV 132 and Vernandon x HAV 134 were most variable for these traits. The results indicated that duration to flowering, pod length, pod diameter, pods per plant and pod yield are highly heritable and could be transferred to the commercial snap bean varieties via phenotypic selection with good genetic gain. Agronomic performance of grain runner bean genotypes revealed that local varieties are low yielding and susceptible to diseases as opposed to the advanced lines. Evaluation of advanced grain runner beans, resulted in identification of 21 lines across the three sites which had higher grain yield and resistant to diseases than the existing local landraces. These selected genotypes can be used in national trails for breeding improved grain runner beans. The outstanding high yielding grain runner bean lines identified in this study should also be evaluated in other bean growing regions in Kenya to widen end users participation in research, capture the broader perceptions and views on grain runner beans and determine their performance under different agro-ecological conditions. The results indicated that new high yielding grain runner bean lines with resistance to major diseases and tropical adaptation can be used to address food insecurity and poverty alleviation in the country.

From the results of runner bean lines evaluated for vegetable pods flowered easily under the short-photoperiod had abundant number of flowers and promising high pod yield. Based on these performances at two locations, 49 lines were selected. These lines show promising ability of being developed into local vegetable runner beans and hence should be advanced to national trials. High pod yield, pod quality and disease resistance of these lines can contribute to increased productivity, reduction in production costs and enhance competitiveness of local products in domestic and export markets.

The concept of multiple disease resistance, desirable pod quality and high pod yield was found to be achievable in this study among the evaluated snap bean lines. The results showed that 51 bush and seven climbing lines exhibited multiple disease resistance to rust, anthracnose and angular leaf spot, had good pod quality and high pod yield with high percentage of marketable classes (extra-fine and fine). Therefore, these lines can further be evaluated on national performance trials under optimal conditions that enhance disease development and infection. Utilization of these lines as commercial varieties will not only increase productivity, reduce cost of production and increased profitability but also increase competitiveness of Kenyan produce in regional and international markets.

Canning quality and sensory evaluation of grain runner and snap bean lines revealed that the existing canning runner and snap bean had inferior qualities compared to the new lines. Thirty five grain runner bean and twenty snap bean lines met the industrial canning standards. Among the best performers of runner bean lines were KAB-RB13-327-92/1, KAB-RB13-326-207/1B, KAB-RB13-326-207/1B, KAB-RB13-471-117/1, SUB-OL-RB13-275-248/3 and KAB-RB13-310-161/5. KSB22-147-2M/1, KSB22-147-2M/2 and KSB52-2M were among the best performing lines of snap bean. These new lines of runner and snap bean will provide the bean processing industry with raw materials that meet consumer's preferences while increasing production of processed products.

Recommendations

1-This study informed on the heritability of different traits namely duration to flowering, pod length and diameter and pods per plant and yield. Such information should be considered in developing breeding strategies in snap beans to produce varieties with the required marketable traits.

2-Further analysis is recommended on heritability of the genes involved in control of the studied traits in snap beans to validate these results.

3-Traits such as cooking time and hard-shell defect should be involved in selection criteria of grain runner bean for canning industry.

4-Further research is needed on canning runner beans with tomato sauce to be compared with the results obtained when canning was done by use of brine.

5-Marker assisted selection is recommended to find the location of the genes controlling the traits.

6-The new lines should be evaluated for canning quality under different canning procedure.

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APPENDICES

Appendix 1: Monthly mean of rainfall and temperature in Kabete and Ol Joro Orok during 2014 long rain season

	Rainfall (mm)		Average Temperature (^{0}C)	
Month	**Kabete**	**Ol Joro Orok**	**Kabete**	**Ol Joro Orok**
March	154.7	76.5	19.3	15.8
April	81.7	41.3	19.3	22.8
May	72.8	69.0	19.0	23.4
June	101.6	109.2	18.8	15.6
July	10.0	109.4	17.7	14.6
August	28.9	183.1	18.9	7.6
September	22.9	36.8	17.8	5.9
Mean	**472.6**	**625.3**	**18.7**	**15.1**

Source: KALRO-Ol Joro Orok

Appendix 2: Monthly means of rainfall and temperature in Naivasha during the 2014/2015 short rain season

Month	**Rainfall (mm)**	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**	**Average Temperature (^{0}C)**
October	34	28	9	18.5
November	39	29	9	19
December	77	31	7	19
January	28	33	6	19.5
February	20	32	8	20
March	3	32	6	19
April	147	29	9	19
Mean	**348**	**31**	**8**	**19**

Source: Naivasha Vegpro farm weather station

Appendix 3: Monthly means of rainfall and temperature in Mwea during the 2014 short rain season

Month	**Rainfall (mm)**	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**	**Average Temperature (^{0}C)**
September	0.0	26.9	15.6	21.3
October	21.1	28.4	17.3	22.9
November	178.3	27.4	17.3	22.3
December	40.0	27.7	16.6	22.2
Mean	**239.3**	**27.6**	**16.7**	**22.2**

Source: KALRO-Mwea weather station

Appendix 4: Monthly means of rainfall and temperature in Kabete during the 2014 short rain season

Month	**Rainfall (mm)**	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**	**Average Temperature (^{0}C)**
October	136.2	23.4	16.3	19.8
November	95.5	23.6	15.1	19.4
December	88.6	21.5	14.1	17.8
January	27.7	21.6	12.9	17.2
Mean	**348.0**	**22.5**	**14.6**	**18.5**

Source: Kabete Field Station weather department

Appendix 5: Monthly means of rainfall and temperatures in Kabete during the 2014 long rain season

Month	**Rainfall (mm)**	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**	**Average Temperature (^{0}C)**
March	154.7	24.3	14.2	19.3
April	81.7	23.0	15.6	19.3
May	72.8	23.5	14.6	19.0
June	101.6	22.3	15.2	18.8
Mean	**410.8**	**23.3**	**14.9**	**19.1**

Source: Kabete Field Station weather department

Appendix 6: Duration to flowering, vigour and number of racemes per plant of grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season

Genotype	50% DF			Vigour			No. of racemes plant^{-1}		
	OJ§	KAB§	Mean	OJ	KAB	Mean	OJ	KAB	Mean
KAB-OL-RB13-426-228	49.7	51.0	50.3	3.7	5.7	4.7	7.0	21.5	14.2
KAB-RB13-108-125	50.3	52.3	51.3	4.7	4.3	4.5	5.0	16.9	11.0
KAB-RB13-120-123/1	50.3	54.3	52.3	3.7	4.3	4.0	4.0	18.9	11.4
KAB-RB13-120-123/2	52.7	53.7	53.2	4.3	5.0	4.7	5.0	15.4	10.2
KAB-RB13-155-122	49.7	51.0	50.3	4.3	5.0	4.7	8.0	11.7	9.9
KAB-RB13-293-209	50.3	53.3	51.8	3.0	5.7	4.3	9.0	11.9	10.5
KAB-RB13-297-144/1	52.3	52.7	52.5	3.7	4.3	4.0	4.0	16.5	10.2
KAB-RB13-297-144/2	50.7	52.3	51.5	4.3	4.3	4.3	8.0	22.7	15.3
KAB-RB13-301-171/1	49.0	53.3	51.2	4.0	5.0	4.5	10.0	13.1	11.5
KAB-RB13-301-171/2	52.3	51.0	51.7	4.3	5.0	4.7	8.0	14.0	11.0
KAB-RB13-301-174	49.3	50.3	49.8	4.7	5.0	4.8	6.0	15.0	10.5
KAB-RB13-303-151	53.0	55.7	54.3	3.3	5.0	4.2	5.0	13.0	9.0
KAB-RB13-308-217	50.3	51.0	50.7	3.7	4.3	4.0	6.0	26.5	16.3
KAB-RB13-312-160	50.7	53.0	51.8	3.7	4.3	4.0	7.0	24.9	15.9
KAB-RB13-313-127/1	49.0	50.7	49.8	3.3	5.0	4.2	9.0	26.9	18.0
KAB-RB13-313-127/2	50.0	51.7	50.8	4.0	4.3	4.2	10.0	25.2	17.6
KAB-RB13-321-185/1	48.7	52.0	50.3	4.3	5.0	4.7	11.0	18.8	14.9
KAB-RB13-321-185/2	49.7	52.0	50.8	2.7	5.0	3.8	14.0	22.0	18.0
KAB-RB13-321-190/1	49.7	50.0	49.8	4.3	4.3	4.3	13.0	19.8	16.4
KAB-RB13-321-190/2	49.3	51.0	50.2	3.7	5.7	4.7	8.0	22.5	15.3
KAB-RB13-326-207	49.0	50.0	49.5	3.3	4.3	3.8	12.0	33.9	22.9
KAB-RB13-329-163/1	49.7	50.7	50.2	4.0	3.7	3.8	5.0	28.3	16.7
KAB-RB13-329-163/2	50.0	54.3	52.2	3.7	5.7	4.7	6.0	13.1	9.6
KAB-RB13-329-164	49.3	51.3	50.3	4.0	5.0	4.5	7.0	14.1	10.5
KAB-RB13-329-166	50.3	52.3	51.3	3.3	3.0	3.2	6.0	22.1	14.0
KAB-RB13-329-167	51.0	51.3	51.2	4.0	5.0	4.5	6.0	29.3	17.6
KAB-RB13-329-172	52.0	50.7	51.3	4.0	4.3	4.2	7.0	30.4	18.7

Continued: Duration to flowering, vigour and number of racemes per plant of grain runner bean lines grown at Kabete Field Station and KALRO-Ol Joro Orok during 2014 long rain season

Genotype	50% DF			Vigour			No. of racemes plant^{-1}		
	OJ[§]	KAB[§]	Mean	OJ	KAB	Mean	OJ	KAB	Mean
KAB-RB13-331-225	50.0	53.0	51.5	4.0	5.0	4.5	7.0	17.6	12.3
KAB-RB13-333-223	51.3	51.3	51.3	4.0	5.0	4.5	7.0	23.3	15.1
KAB-RB13-334-130	49.3	50.7	50.0	3.3	3.7	3.5	7.0	23.4	15.2
KAB-RB13-334-137	49.3	52.7	51.0	3.3	4.3	3.8	9.0	28.7	18.8
KAB-RB13-336-132	50.7	53.7	52.2	4.0	4.3	4.2	5.0	23.9	14.5
KAB-RB13-341-134	50.3	52.3	51.3	4.0	4.3	4.2	5.0	15.9	10.4
KAB-RB13-343-188	50.3	52.0	51.2	3.7	5.7	4.7	7.0	17.3	12.2
KAB-RB13-364-212/1	48.7	50.7	49.7	3.7	5.0	4.3	11.0	16.1	13.6
KAB-RB13-364-212/2	49.3	51.0	50.2	2.7	3.7	3.2	10.0	29.3	19.6
KAB-RB13-396-210	52.0	54.0	53.0	5.7	4.3	5.0	2.0	20.2	11.1
KAB-RB13-399-219/1	51.0	52.0	51.5	3.7	4.3	4.0	5.0	28.0	16.5
KAB-RB13-399-219/2	49.7	54.3	52.0	3.3	5.0	4.2	5.0	18.2	11.6
KAB-RB13-403-153/1	50.0	52.0	51.0	4.7	5.0	4.8	9.0	26.8	17.9
KAB-RB13-403-153/2	50.3	51.3	50.8	3.7	5.7	4.7	9.0	20.5	14.8
KAB-RB13-46-19	50.0	53.3	51.7	5.3	4.3	4.8	6.0	19.2	12.6
OL-OL-RB13-21-240	53.0	54.3	53.7	3.7	5.0	4.3	1.0	11.1	6.1
SUB-OL-RB13-231-226	52.0	55.0	53.5	4.0	4.3	4.2	7.0	19.3	13.1
SUB-OL-RB13-238-238/1	50.7	51.3	51.0	3.7	5.0	4.3	4.0	14.9	9.5
SUB-OL-RB13-238-238/2	51.7	51.7	51.7	4.0	5.0	4.5	3.0	14.1	8.6
SUB-OL-RB13-312-252	49.0	49.3	49.2	4.0	4.3	4.2	12.0	33.1	22.5
SUB-OL-RB13-96-237	50.0	51.7	50.8	4.0	5.0	4.5	8.0	13.0	10.5
Check									
Nyeri	48.7	49.7	49.2	4.7	5.7	5.2	12.0	17.5	14.7
KIN 2	49.3	51.3	50.3	4.0	5.0	4.5	13.0	20.9	16.9
OL-Dwarf 2	49.7	50.3	50.0	5.7	5.7	5.7	10.0	11.1	10.6
OL-Dwarf 3	50.7	49.7	50.2	6.3	5.7	6.0	6.0	6.6	6.3
Mean	50.3	52.2	51.3	4.0	4.7	4.4	7.0	21.1	14.1

$LSD_{0.05}$	2.2	2.5	1.3	1.9	4.9	16.0
CV (%)	1.2	3.0	6.4	15.5	21.7	22.7

§OJ- Ol Joro Orok, KAB-Kabete

Appendix 7: Reaction of new grain runner bean lines to six major diseases at Kabete and Ol Joro Orok during 2014 long rain season.

	Disease score											
	ALS		**Anthracnose**		**BCMV**		**CBB**		**Powdery mildew**		**Rust**	
Genotype	**OJ***	**KAB***	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**
KAB-OL-RB13-426-228	2	1	2	1	2	1	1	1	2	2	1	1
KAB-RB13-108-125	3	1	2	1	2	1	1	1	2	2	1	1
KAB-RB13-120-123/1	2	1	2	1	2	1	1	1	1	2	2	1
KAB-RB13-120-123/2	2	1	2	1	4	1	1	1	1	2	1	1
KAB-RB13-155-122	3	1	3	1	3	1	1	1	1	1	2	1
KAB-RB13-293-209	3	1	2	1	1	1	1	1	2	1	1	1
KAB-RB13-297-144/1	2	1	1	1	1	2	1	1	1	3	1	1
KAB-RB13-297-144/2	2	1	1	1	4	1	1	1	2	3	1	1
KAB-RB13-301-171/1	4	1	2	1	1	1	1	1	1	2	1	1
KAB-RB13-301-171/2	3	1	2	1	2	1	2	1	1	1	2	1
KAB-RB13-301-174	4	2	2	1	2	1	1	2	1	1	2	1
KAB-RB13-303-151	2	1	1	1	1	1	1	1	1	2	1	1
KAB-RB13-308-217	2	1	1	1	3	1	2	1	1	2	1	1
KAB-RB13-312-160	2	1	2	1	2	1	1	2	1	1	2	1
KAB-RB13-313-127/1	2	1	1	1	1	1	2	1	1	2	1	1
KAB-RB13-313-127/2	3	1	2	1	2	1	1	1	1	2	1	1
KAB-RB13-321-185/1	3	1	2	1	2	1	3	1	1	2	1	1
KAB-RB13-321-185/2	3	1	1	1	2	1	1	1	1	2	1	1
KAB-RB13-321-190/1	2	2	1	1	2	1	1	1	1	3	1	1
KAB-RB13-321-190/2	2	1	2	1	3	1	1	1	1	2	1	1
KAB-RB13-326-207	2	2	2	1	1	1	1	1	1	2	1	1
KAB-RB13-329-163/1	2	2	2	1	1	1	1	1	1	2	2	1

Continued: Reaction of new grain runner bean lines to six major diseases at Kabete and Ol Joro Orok during 2014 long rain season.

Genotype	Disease score											
	ALS		Anthracnose		BCMV		CBB		Powdery mildew		Rust	
	OJ*	**KAB***	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**	**OJ**	**KAB**
KAB-RB13-329-163/2	3	1	2	1	2	1	1	1	1	2	1	1
KAB-RB13-329-164	2	1	1	1	1	2	1	1	1	1	1	1
KAB-RB13-329-166	2	1	2	1	1	1	1	1	1	2	1	1
KAB-RB13-329-167	2	2	1	1	3	1	1	1	1	2	1	1
KAB-RB13-329-172	2	2	3	1	1	2	1	1	1	1	1	1
KAB-RB13-331-225	2	1	2	1	1	1	1	1	1	1	1	1
KAB-RB13-333-223	3	1	2	1	1	1	2	1	1	1	1	1
KAB-RB13-334-130	2	1	2	1	2	2	1	1	1	2	1	1
KAB-RB13-334-137	2	1	1	1	1	1	1	1	1	2	2	1
KAB-RB13-336-132	3	2	1	1	3	2	1	1	1	4	2	1
KAB-RB13-341-134	2	1	1	1	2	1	1	1	2	2	1	1
KAB-RB13-343-188	3	1	2	1	2	1	1	1	1	2	2	1
KAB-RB13-364-212/1	3	1	1	1	1	1	2	1	1	2	2	1
KAB-RB13-364-212/2	2	1	2	1	1	1	1	1	1	1	1	1
KAB-RB13-396-210	3	1	2	1	2	2	1	1	1	1	1	1
KAB-RB13-399-219/1	2	1	1	1	1	1	1	1	2	2	2	1
KAB-RB13-399-219/2	2	1	2	1	2	1	1	1	2	2	2	1
KAB-RB13-403-153/1	3	1	3	1	2	1	1	1	1	2	1	1
KAB-RB13-403-153/2	2	1	2	1	1	1	1	1	1	1	1	1
KAB-RB13-46-19	5	1	4	1	1	1	1	1	1	5	1	1
OL-OL-RB13-21-240	2	1	2	1	1	1	1	1	1	1	1	1
SUB-OL-RB13-231-226	3	1	1	1	2	1	1	1	2	6	2	1
SUB-OL-RB13-238-238/1	2	2	2	1	1	1	1	1	1	1	1	1
SUB-OL-RB13-238-238/2	2	1	2	1	1	1	1	1	1	2	1	1
SUB-OL-RB13-312-252	3	1	2	1	2	2	1	1	1	1	1	1

Continued: Reaction of new grain runner bean lines to six major diseases at Kabete and Ol Joro Orok during 2014 long rain season.

	Disease score											
	ALS		Anthracnose		BCMV		CBB		Powdery mildew		Rust	
Genotype	OJ*	KAB*	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB
SUB-OL-RB13-96-237	4	1	3	1	1	1	1	1	1	1	1	1
Check												
Nyeri	3	2	2	1	1	2	2	1	1	1	1	1
KIN 2	3	1	3	1	2	1	1	1	2	2	1	1
OL-Dwarf 2	3	1	2	1	3	1	4	1	1	2	2	1
OL-Dwarf 3	4	3	1	1	1	1	3	1	2	2	1	1
Mean	2.6	1.2	1.9	1.0	1.8	1.3	1.3	1.1	1.2	1.9	1.4	1.0
$LSD_{0.05}$	1.5	0.7	1.5	0.3	1.7	0.9	1.1	0.6	0.9	1.3	1.0	0.0
CV (%)	4.1	12.4	10.7	2.5	4.7	9.9	8.8	8.2	10.3	19.9	2.8	0.0

*OJ-Ol Joro Orok, KAB-Kabete, LSD-Least significant difference, CV-Coefficient variation

Appendix 8: Pods per plant and grain yield of advanced grain runner bean lines grown at Kabete and Ol Joro Orok during 2014 long rain season.

	Pod $plant^{-1}$			Grain yield (kg ha^{-1})		
Genotype	OJ*	KAB*	Mean	OJ	KAB	Mean
KAB-OL-RB13-426-228	55	16	36	7414.0	1958.5	4686.2
KAB-RB13-108-125	63	19	41	6351.5	2776.3	4563.9
KAB-RB13-120-123/1	51	24	37	6300.6	2921.7	4611.1
KAB-RB13-120-123/2	54	21	38	6035.2	2933.7	4484.4
KAB-RB13-155-122	40	32	36	5986.4	4048.4	5017.4
KAB-RB13-293-209	39	24	31	5310.6	3138.2	4224.4
KAB-RB13-297-144/1	41	26	34	5299.6	3726.8	4513.2
KAB-RB13-297-144/2	34	18	26	5294.7	2443.0	3868.9
KAB-RB13-301-171/1	32	23	27	5200.1	3452.0	4326.0

Continued: Pods per plant and grain yield of advanced grain runner bean lines grown at Kabete and Ol Joro Orok during 2014 long rain season.

	Pod plant^{-1}			Grain yield (kg ha^{-1})		
Genotype	**OJ***	**KAB***	**Mean**	**OJ**	**KAB**	**Mean**
KAB-RB13-301-171/2	66	19	43	5198.1	2380.0	3789.1
KAB-RB13-301-174	39	14	26	5101.1	1922.1	3511.6
KAB-RB13-303-151	42	14	28	5098.1	1938.6	3518.3
KAB-RB13-308-217	35	19	27	5090.1	2565.3	3827.7
KAB-RB13-312-160	41	27	34	5042.8	3771.0	4406.9
KAB-RB13-313-127/1	38	21	30	4922.6	2951.5	3937.1
KAB-RB13-313-127/2	32	29	31	4821.7	3368.2	4095.0
KAB-RB13-321-185/1	32	23	28	4792.3	2374.8	3583.6
KAB-RB13-321-185/2	52	19	36	4776.0	2639.4	3707.7
KAB-RB13-321-190/1	39	16	28	4775.3	2611.3	3693.3
KAB-RB13-321-190/2	38	28	33	4626.6	4032.3	4329.5
KAB-RB13-326-207	36	17	27	4426.7	2210.9	3318.8
KAB-RB13-329-163/1	43	27	35	4422.6	3398.7	3910.7
KAB-RB13-329-163/2	26	23	25	4388.3	2483.0	3435.7
KAB-RB13-329-164	36	19	27	4338.4	2368.3	3353.4
KAB-RB13-329-166	32	19	26	4219.4	2963.2	3591.3
KAB-RB13-329-167	36	22	29	4103.7	3051.2	3577.4
KAB-RB13-329-172	35	30	32	4015.0	3695.0	3855.0
KAB-RB13-331-225	39	23	31	3848.8	2401.6	3125.2
KAB-RB13-333-223	28	30	29	3643.4	4104.3	3873.9
KAB-RB13-334-130	23	24	23	3484.6	3235.1	3359.8
KAB-RB13-334-137	25	23	24	3461.3	3357.8	3409.5
KAB-RB13-336-132	41	25	33	3439.3	3540.1	3489.7
KAB-RB13-341-134	33	27	30	3338.8	3390.6	3364.7
KAB-RB13-343-188	25	16	20	3312.2	2039.4	2675.8
KAB-RB13-364-212/1	31	17	24	3309.8	2144.2	2727.0
KAB-RB13-364-212/2	32	18	25	3286.5	2949.6	3118.0

Continued: Pods per plant and grain yield of advanced grain runner bean lines grown at Kabete and Ol Joro Orok during 2014 long rain season.

	Pod plant^{-1}			Grain yield (kg ha^{-1})		
Genotype	**OJ***	**KAB***	**Mean**	**OJ**	**KAB**	**Mean**
KAB-RB13-396-210	34	17	25	3245.7	2352.4	2799.1
KAB-RB13-399-219/1	30	16	23	3188.1	2269.7	2728.9
KAB-RB13-399-219/2	37	30	33	3121.6	3900.0	3510.8
KAB-RB13-403-153/1	23	14	18	3047.0	1674.5	2360.7
KAB-RB13-403-153/2	23	15	19	3038.9	1887.6	2463.3
KAB-RB13-46-19	24	23	23	3012.8	2758.3	2885.5
OL-OL-RB13-21-240	28	29	28	2988.8	3758.5	3373.6
SUB-OL-RB13-231-226	25	26	26	2858.5	3033.7	2946.1
SUB-OL-RB13-238-238/1	28	16	22	2841.2	1910.4	2375.8
SUB-OL-RB13-238-238/2	26	22	24	2805.4	2604.9	2705.1
SUB-OL-RB13-312-252	29	23	26	2635.6	3472.9	3054.3
SUB-OL-RB13-96-237	23	24	23	2621.7	3529.1	3075.4
Check						
Nyeri	40	20	30	4830.2	2785.7	3808.0
KIN 2	33	22	28	3464.3	2249.4	2856.8
OL-Dwarf 2	32	13	23	2875.9	1895.1	2385.5
OL-Dwarf 3	22	15	18	1833.3	1834.6	1833.9
Mean	35	23	29	4153	3034.6	3593.8
$LSD_{0.05}$	22	14		2904.8	2276.9	
CV%	5.2	7		2.4	10.1	

*OJ-Ol Joro Orok, KAB-Kabete, LSD-Least significant difference, CV-Coefficient variation

Appendix 9: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Days to flowering	Vigour	No. of racemes per plant
KAB-RB13-1-105/1	52.7	5.7	5.0
KAB-RB13-1-105/2	52.7	6.3	1.0
KAB-RB13-1-105/3	53.7	5.7	3.0
KAB-RB13-1-105/4	51.3	6.3	7.0
KAB-RB13-129-121/1	52.0	6.3	5.0
KAB-RB13-129-121/2	55.0	5.7	4.0
KAB-RB13-138-38	53.0	5.7	2.0
KAB-RB13-240-119	53.7	6.3	2.0
KAB-RB13-294-24	50.0	6.3	13.0
KAB-RB13-296-111/1	53.3	5.7	9.0
KAB-RB13-296-111/2	51.3	6.3	9.0
KAB-RB13-299-43/1	52.0	5.7	4.0
KAB-RB13-299-43/2	51.3	7.0	13.0
KAB-RB13-301-39	51.3	5.7	11.0
KAB-RB13-301-46	54.0	6.3	1.0
KAB-RB13-302-100/1	49.0	6.3	7.0
KAB-RB13-302-100/2	53.3	5.0	13.0
KAB-RB13-302-90	52.7	7.0	2.0
KAB-RB13-303-32	53.7	5.7	3.0
KAB-RB13-305-130/1	54.3	5.0	5.0
KAB-RB13-305-130/2	49.7	4.3	10.0
KAB-RB13-308-114	50.3	5.7	1.0
KAB-RB13-30-87	54.3	6.3	10.0
KAB-RB13-309-62	54.3	6.3	11.0
KAB-RB13-310-86	52.7	5.7	5.0
KAB-RB13-311-102/1	52.7	6.3	12.0

Continued: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Days to flowering	Vigour	No. of racemes per plant
KAB-RB13-311-102/2	53.3	6.3	4.0
KAB-RB13-311-102/3	53.3	5.0	8.0
KAB-RB13-311-103/1	52.0	5.7	7.0
KAB-RB13-311-103/2	52.7	7.0	7.0
KAB-RB13-311-103/3	52.7	7.0	2.0
KAB-RB13-311-103/4	52.7	7.0	7.0
KAB-RB13-311-103/5	52.7	5.0	2.0
KAB-RB13-312-35	54.0	5.7	7.0
KAB-RB13-314-91	52.7	7.0	10.0
KAB-RB13-318-34/1	51.7	5.7	8.0
KAB-RB13-318-34/2	50.3	4.3	7.0
KAB-RB13-320-104/1	54.3	6.3	5.0
KAB-RB13-320-104/2	53.7	5.0	3.0
KAB-RB13-320-104/3	52.0	5.7	4.0
KAB-RB13-320-104/4	52.7	6.3	4.0
KAB-RB13-320-104/5	53.0	5.0	6.0
KAB-RB13-327-48	50.7	5.7	18.0
KAB-RB13-327-92	55.3	5.7	8.0
KAB-RB13-329-108/1	51.3	7.7	10.0
KAB-RB13-329-108/2	53.3	5.7	12.0
KAB-RB13-329-108/3	52.3	7.7	7.0
KAB-RB13-330-116/1	54.3	7.7	1.0
KAB-RB13-330-116/2	52.7	5.7	11.0
KAB-RB13-330-116/3	51.7	5.0	11.0
KAB-RB13-331-112	51.0	7.7	2.0
KAB-RB13-331-113	51.3	7.0	5.0

Continued: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Days to flowering	Vigour	No. of racemes per plant
KAB-RB133-312-37	51.3	5.7	8.0
KAB-RB13-331-66/1	52.0	6.3	12.0
KAB-RB13-331-66/2	53.7	5.7	13.0
KAB-RB13-331-66/3	52.3	6.3	12.0
KAB-RB13-331-66/4	51.3	7.0	8.0
KAB-RB13-331-66/5	54.3	7.0	9.0
KAB-RB13-336-63	51.7	5.7	6.0
KAB-RB13-338-38	54.0	5.0	6.0
KAB-RB13-339-89	50.3	5.7	3.0
KAB-RB13-339-95	53.0	6.3	4.0
KAB-RB13-341-94/1	54.7	7.7	6.0
KAB-RB13-341-94/2	54.0	6.3	8.0
KAB-RB13-363-131	53.3	6.3	4.0
KAB-RB13-363-54	54.0	5.7	5.0
KAB-RB13-364-97/1	52.7	7.0	4.0
KAB-RB13-364-97/2	53.0	5.7	2.0
KAB-RB13-379-33	53.3	7.0	2.0
KAB-RB13-380-55	52.7	7.0	3.0
KAB-RB13-380-56/1	55.3	6.3	4.0
KAB-RB13-380-56/2	54.7	6.3	3.0
KAB-RB13-380-56/3	53.7	5.7	7.0
KAB-RB13-396-53	50.3	6.3	8.0
KAB-RB13-403-88/1	52.7	6.3	3.0
KAB-RB13-403-88/2	52.7	5.7	6.0
KAB-RB13-426-84A	53.7	7.0	3.0

Continued: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	Days to flowering	Vigour	No. of racemes per plant
KAB-RB13-446-4	54.0	6.3	4.0
KAB-RB13-446-5	53.7	7.0	7.0
KAB-RB13-46-22/1	50.7	5.0	7.0
KAB-RB13-46-22/2	51.3	6.3	6.0
KAB-RB13-470-72	53.7	7.0	3.0
KAB-RB13-471-118/1	53.3	5.7	3.0
KAB-RB13-471-118/2	55.0	6.3	3.0
KAB-RB13-471-118/3	51.0	5.0	7.0
KAB-RB13-471-118/4	51.7	6.3	8.0
KAB-RB13-471-118/5	52.3	6.3	5.0
KAB-RB13-50-15	54.3	6.3	1.0
KAB-RB13-64-107/1	49.7	6.3	6.0
KAB-RB13-64-107/2	51.3	5.7	8.0
KAB-RB13-64-107/3	54.3	7.0	6.0
KAB-RB13-64-107/4	53.0	6.3	6.0
KAB-RB13-85-20	50.7	6.3	6.0
KAB-RB13-96-115	50.0	6.3	7.0
KAB-RB13-97-14	53.3	6.3	9.0
OL-RB13-21-2/1	52.7	5.7	6.0
OL-RB13-21-2/2	55.0	6.3	9.0
SUB-RB13-106-12/1	54.7	7.0	2.0
SUB-RB13-106-12/2	50.7	6.3	7.0
SUB-RB13-117-68	52.0	5.7	11.0
SUB-RB13-133-11	51.7	5.7	9.0
SUB-RB13-133-80/1	50.3	5.7	12.0

Continued: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season

Genotype	**Days to flowering**	**Vigour**	**No. of racemes per plant**
SUB-RB13-133-80/2	52.7	6.3	8.0
SUB-RB13-221-128	51.3	6.3	4.0
SUB-RB13-234-13/1	53.0	6.3	4.0
SUB-RB13-234-13/2	52.3	7.0	4.0
SUB-RB13-240-125/1	50.7	5.7	7.0
SUB-RB13-240-125/2	51.3	6.3	13.0
SUB-RB13-240-126/1	52.0	7.0	3.0
SUB-RB13-240-126/2	54.3	5.7	5.0
SUB-RB13-240-126/3	52.3	7.0	12.0
SUB-RB13-271-78	55.0	5.7	3.0
SUB-RB13-305-76	50.3	6.3	8.0
Check			
W. Emergo	52.3	6.3	5.0
Mean	52.6	6.1	6.0
LSD $_{0.05}$ Genotype	1.0	0.6	2.7
CV %	3.5	16.9	18.7

LSD-Least significant difference, CV-Coefficient variation

Appendix 10: Duration to flowering , vigour and number of racemes per plant of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	**Days to flowering**	**Vigour**	**No. of racemes plant^{-1}**
KAB-RB13-1-105/1	49	3	12
KAB-RB13-1-105/2	49	2	7
KAB-RB13-1-105/3	49	2	8
KAB-RB13-1-105/4	49	3	8
KAB-RB13-129-121	51	3	8
KAB-RB13-294-24	51	3	9
KAB-RB13-299-43	49	2	10
KAB-RB13-301-39	48	3	15
KAB-RB13-305-130/1	52	3	5
KAB-RB13-305-130/2	50	2	7
KAB-RB13-309-62	53	3	8
KAB-RB13-311-103	50	3	9
KAB-RB13-312-35	50	3	8
KAB-RB13-312-37	49	3	14
KAB-RB13-318-34	49	3	11
KAB-RB13-320-104/1	50	3	8
KAB-RB13-320-104/2	51	3	7
KAB-RB13-320-104/3	50	2	11
KAB-RB13-320-104/4	50	2	14
KAB-RB13-331-66/1	49	3	11
KAB-RB13-331-66/2	49	3	11
KAB-RB13-363-131	48	3	15
KAB-RB13-363-54	48	3	13
KAB-RB13-364-97/1	49	2	14
KAB-RB13-364-97/2	49	2	10
KAB-RB13-446-5	50	3	6

Continued: Duration to flowering, vigour and number of racemes per plant of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	Days to flowering	Vigour	No. of racemes $plant^{-1}$
KAB-RB13-46-22/1	49	2	9
KAB-RB13-46-22/2	50	3	8
KAB-RB13-470-72	49	3	11
KAB-RB13-471-117	49	3	12
KAB-RB13-471-118/1	50	3	8
KAB-RB13-471-118/2	50	3	9
KAB-RB13-471-118/3	50	3	8
KAB-RB13-471-118/4	50	3	8
KAB-RB13-649-70	51	2	5
KAB-RB13-85-18	49	3	13
OL-RB13-21-2/1	49	2	13
OL-RB13-21-2/2	54	3	3
SUB-RB13-106-12/1	49	2	11
SUB-RB13-106-12/2	49	2	11
SUB-RB13-133-80/1	51	2	8
SUB-RB13-133-80/2	50	2	9
SUB-RB13-234-13	49	3	10
SUB-RB13-240-125/1	49	3	10
SUB-RB13-240-125/2	49	2	9
SUB-RB13-240-126/1	49	3	10
SUB-RB13-240-126/2	49	3	16
SUB-RB13-271-78/1	49	2	9
SUB-RB13-271-78/2	49	3	15
Check			
W. Emergo	48	4	10
Mean	50	3	10

LSD $_{0.05}$	1	1	3
CV%	2	3	9

LSD-Least significant difference, CV-Coefficient variation

Appendix 11: Reaction of vegetable runner bean lines to major diseases at Kabete Field Station during 2014 long rain season.

	Disease score					
Genotype	**ALS**	**ANTH**	**BCMV**	**CBB**	**Powdery mildew**	**Rust**
KAB-RB13-296-111/2	1	1	1	1	1	1
KAB-RB13-299-43/2	1	1	2	1	1	1
KAB-RB13-305-130/2	1	1	1	1	1	1
KAB-RB13-311-103/1	1	1	1	2	1	1
KAB-RB13-314-91	1	1	2	1	1	1
KAB-RB13-320-104/1	1	1	2	1	2	1
KAB-RB13-320-104/4	1	1	1	1	1	1
KAB-RB13-327-48	1	2	2	1	2	1
KAB-RB13-329-108/2	1	1	1	1	1	1
KAB-RB13-330-116/2	1	1	2	1	1	1
KAB-RB13-331-66/1	1	1	1	2	1	1
KAB-RB13-331-66/4	1	1	1	1	1	1
KAB-RB13-338-38	1	2	1	1	1	1
KAB-RB13-380-56/2	1	2	1	1	2	1
KAB-RB13-446-4	1	1	1	1	2	1
KAB-RB13-46-22/1	1	1	2	1	2	1
KAB-RB13-471-118/2	1	1	1	1	1	1
KAB-RB13-471-118/4	1	2	2	1	2	1
KAB-RB13-471-118/5	1	2	2	1	1	1
KAB-RB13-64-107/2	1	2	1	1	1	1
OL-RB13-21-2/2	1	1	2	1	1	1
SUB-RB13-133-80/1	1	1	1	1	1	1
SUB-RB13-221-128	1	1	1	1	2	1

Continued: Reaction of vegetable runner bean lines to major diseases at Kabete Field Station during 2014 long rain season.

	Disease score					
Genotype	**ALS**	**ANTH**	**BCMV**	**CBB**	**Powdery mildew**	**Rust**
SUB-RB13-234-13/2	1	2	1	1	1	1
SUB-RB13-240-126/1	1	2	2	1	1	1
SUB-RB13-305-76	1	1	2	1	1	1
KAB-RB13-1-105/1	1	1	1	1	1	1
KAB-RB13-129-121/1	1	2	1	1	1	1
KAB-RB13-138-38	1	2	2	1	1	1
KAB-RB13-240-119	1	2	1	1	1	1
KAB-RB13-294-24	1	1	2	1	1	1
KAB-RB13-302-90	1	1	2	1	1	1
KAB-RB13-309-62	1	1	1	1	1	1
KAB-RB13-311-102/1	1	1	1	1	2	1
KAB-RB13-311-103/3	1	1	1	1	1	1
KAB-RB13-311-103/5	1	1	1	1	1	1
KAB-RB13-312-35	1	1	1	1	2	1
KAB-RB13-318-34/2	1	1	2	1	1	1
KAB-RB13-320-104/2	1	1	1	1	2	1
KAB-RB13-320-104/5	1	1	1	1	1	1
KAB-RB13-341-94/1	1	1	1	1	2	1
KAB-RB13-364-97/1	1	2	2	1	1	1
KAB-RB13-379-33	1	2	2	1	2	1
KAB-RB13-403-88/1	1	2	1	1	1	1
KAB-RB13-403-88/2	1	1	1	2	1	1
KAB-RB13-46-22/2	1	2	1	1	1	1
KAB-RB13-470-72	1	2	2	1	1	1
KAB-RB13-64-107/3	1	2	1	1	1	1
KAB-RB133-312-37	1	1	2	1	1	1

Continued: Reaction of vegetable runner bean lines to major diseases at Kabete Field Station during 2014 long rain season.

	Disease score					
Genotype	ALS	ANTH	BCMV	CBB	Powdery mildew	Rust
SUB-RB13-106-12/2	1	2	1	1	2	1
SUB-RB13-234-13/1	1	1	1	1	1	1
KAB-RB13-1-105/3	2	1	2	1	2	1
KAB-RB13-1-105/4	2	1	2	1	1	1
KAB-RB13-299-43/1	2	2	2	1	2	1
KAB-RB13-301-39	2	2	2	1	2	1
KAB-RB13-302-100/1	2	2	2	1	2	1
KAB-RB13-302-100/2	2	1	1	1	2	1
KAB-RB13-303-32	2	1	2	1	1	1
KAB-RB13-305-130/1	2	1	2	1	2	1
KAB-RB13-308-114	2	3	1	1	2	1
KAB-RB13-310-86	2	1	2	1	1	1
KAB-RB13-311-102/3	2	2	1	1	1	1
KAB-RB13-311-103/2	2	1	2	1	1	1
KAB-RB13-311-103/4	2	1	2	1	1	1
KAB-RB13-318-34/1	2	1	1	1	1	1
KAB-RB13-320-104/3	2	1	2	1	2	1
KAB-RB13-329-108/3	2	1	1	1	1	1
KAB-RB13-330-116/1	2	1	1	2	1	1
KAB-RB13-331-66/2	2	2	1	2	1	1
KAB-RB13-339-95	2	1	1	2	1	1
KAB-RB13-363-131	2	2	1	1	1	1
KAB-RB13-364-97/2	2	1	1	2	2	1
KAB-RB13-380-56/3	2	1	2	2	1	1
KAB-RB13-396-53	2	1	2	2	2	1
KAB-RB13-426-84A	2	1	1	1	1	1

Continued: Reaction of vegetable runner bean lines to major diseases at Kabete Field Station during 2014 long rain season.

Genotype	Disease score					
	ALS	ANTH	BCMV	CBB	Powdery mildew	Rust
KAB-RB13-471-118/1	2	2	1	1	2	1
KAB-RB13-50-15	2	1	2	1	1	1
KAB-RB13-64-107/1	2	1	1	1	1	1
KAB-RB13-64-107/4	2	1	1	1	1	1
KAB-RB13-97-14	2	2	1	2	1	1
OL-RB13-21-2/1	2	1	2	1	1	1
SUB-RB13-117-68	2	2	1	1	2	1
SUB-RB13-240-125/1	2	2	1	1	1	1
SUB-RB13-240-126/2	2	1	2	1	1	1
SUB-RB13-271-78	2	3	1	1	1	1
W.EMERGO/1	2	2	2	1	1	1
KAB-RB13-1-105/2	2	2	1	1	1	1
KAB-RB13-30-87	2	2	2	1	2	1
KAB-RB13-301-46	2	1	2	2	1	1
KAB-RB13-311-102/2	2	1	2	1	2	1
KAB-RB13-327-92	2	2	1	1	2	1
KAB-RB13-331-112	2	2	2	1	1	1
KAB-RB13-331-113	2	1	2	1	2	1
KAB-RB13-331-66/5	2	1	2	1	1	1
KAB-RB13-336-63	2	1	1	1	1	1
KAB-RB13-339-89	2	2	2	1	1	1
KAB-RB13-341-94/2	2	2	2	1	1	1
KAB-RB13-380-55	2	2	1	1	1	1
KAB-RB13-446-5	2	1	1	1	1	1
KAB-RB13-96-115	2	1	3	1	1	1
SUB-RB13-240-126/3	2	1	2	1	2	1

Continued: Reaction of vegetable runner bean lines to major diseases at Kabete Field Station during 2014 long rain season.

	Disease score					
Genotype	**ALS**	**ANTH**	**BCMV**	**CBB**	**Powdery mildew**	**Rust**
KAB-RB13-129-121/2	2	2	1	1	1	1
KAB-RB13-296-111/1	2	2	1	1	1	1
KAB-RB13-329-108/1	2	1	2	3	1	1
KAB-RB13-330-116/3	2	1	1	1	1	1
KAB-RB13-331-66/3	2	2	1	1	2	1
KAB-RB13-363-54	2	2	1	1	2	1
KAB-RB13-380-56/1	2	1	1	1	1	1
KAB-RB13-471-118/3	2	1	2	1	1	1
KAB-RB13-85-20	2	1	2	1	1	1
SUB-RB13-106-12/1	2	1	2	2	2	1
SUB-RB13-133-11	2	1	1	1	1	1
SUB-RB13-133-80/2	2	2	2	1	1	1
SUB-RB13-240-125/2	2	2	2	1	2	1
Check						
W. Emergo	4	4	5	4	5	4
Mean	1.56	1.39	1.46	1.19	1.33	1
LSD $_{0.05}$ Genotype	1.38	0.31	0.33	0.23	0.21	0
CV %	45	41.3	42.2	35.7	29.2	0

LSD-Least significant difference, CV-Coefficient variation, ALS-Angular leaf spot, ANTH-Anthracnose, BCMV-Bean common mosaic virus, CBB-Common bacterial blight

Appendix 12: Reaction of vegetable runner bean lines to major diseases at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	ALS	Anth	BCMV	CBB	Powdery mildew	Rust
KAB-RB13-1-105/1	3	2	1	1	1	2
KAB-RB13-1-105/2	2	1	1	1	1	1
KAB-RB13-1-105/3	3	1	1	1	1	2
KAB-RB13-1-105/4	2	2	1	1	1	2
KAB-RB13-129-121	2	1	2	1	1	2
KAB-RB13-294-24	2	1	2	1	1	1
KAB-RB13-299-43	2	1	1	1	2	1
KAB-RB13-301-39	3	1	2	1	1	2
KAB-RB13-305-130/1	3	2	2	1	1	2
KAB-RB13-305-130/2	2	1	1	1	1	2
KAB-RB13-309-62	1	1	2	1	1	1
KAB-RB13-311-103	2	2	1	2	1	2
KAB-RB13-312-35	2	1	2	1	2	2
KAB-RB13-312-37	3	1	1	2	1	2
KAB-RB13-318-34	2	2	1	1	1	2
KAB-RB13-320-104/1	2	1	1	1	1	1
KAB-RB13-320-104/2	2	2	1	1	1	1
KAB-RB13-320-104/3	2	2	1	1	1	2
KAB-RB13-320-104/4	3	1	1	1	1	2
KAB-RB13-331-66/1	3	2	1	1	1	2
KAB-RB13-331-66/2	3	1	1	1	1	1
KAB-RB13-363-131	3	2	2	1	1	1
KAB-RB13-363-54	2	2	2	1	1	1
KAB-RB13-364-97/1	2	1	1	1	1	2
KAB-RB13-364-97/2	2	1	1	1	1	1
KAB-RB13-446-5	2	1	1	1	1	1
KAB-RB13-46-22/1	2	1	2	1	1	2

Continued: Reaction of vegetable runner bean lines to major diseases at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	ALS	Anth	BCMV	CBB	Powdery mildew	Rust
KAB-RB13-46-22/2	2	1	2	1	1	2
KAB-RB13-470-72	2	1	1	1	1	2
KAB-RB13-471-117	2	1	2	2	1	1
KAB-RB13-471-118/1	2	1	1	1	1	1
KAB-RB13-471-118/2	2	1	2	1	1	1
KAB-RB13-471-118/3	2	1	2	1	1	2
KAB-RB13-471-118/4	2	1	2	1	1	2
KAB-RB13-649-70	2	1	2	1	1	2
KAB-RB13-85-18	2	1	2	1	1	2
OL-RB13-21-2/1	3	1	1	1	1	3
OL-RB13-21-2/2	2	2	2	1	1	2
SUB-RB13-106-12/1	2	1	2	1	2	2
SUB-RB13-106-12/2	3	1	1	1	2	2
SUB-RB13-133-80/1	3	2	1	1	1	2
SUB-RB13-133-80/2	1	1	2	1	1	1
SUB-RB13-234-13	3	2	2	1	1	2
SUB-RB13-240-125/1	1	1	3	1	1	1
SUB-RB13-240-125/2	2	1	2	1	1	2
SUB-RB13-240-126/1	2	1	1	1	1	1
SUB-RB13-240-126/2	1	2	2	1	1	1
SUB-RB13-271-78/1	2	1	1	1	1	1
SUB-RB13-271-78/2	2	1	1	1	1	1
Check						
W. Emergo	5	4	5	3	4	6
Mean	2	1	2	1	1	2
LSD $_{0.05}$	0.8	0.7	0.8	0.4	0.3	0.8
CV%	3.4	10.4	3.9	6.2	4.7	6

LSD-Least significant difference, CV-Coefficient variation, ALS-Angular leaf spot, ANTH-Anthracnose, BCMV-Bean common mosaic virus, CBB-Common bacterial blight

Appendix 13: Pod quality of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-1-105/1	19.0	2.1	Slightly curved
KAB-RB13-1-105/2	19.5	2.0	Straight
KAB-RB13-1-105/3	20.8	2.4	Straight
KAB-RB13-1-105/4	19.4	2.3	Straight
KAB-RB13-129-121/1	18.0	2.2	Straight
KAB-RB13-129-121/2	21.3	2.0	Markedly curved
KAB-RB13-138-38	18.7	2.3	Straight
KAB-RB13-240-119	18.6	2.2	Slightly curved
KAB-RB13-296-111/1	19.9	2.5	Slightly curved
KAB-RB13-296-111/2	19.3	2.4	Straight
KAB-RB13-299-43/1	19.6	2.4	Straight
KAB-RB13-299-43/2	18.3	2.1	Straight
KAB-RB13-301-39	19.1	2.2	Straight
KAB-RB13-301-46	18.2	2.0	Slightly curved
KAB-RB13-302-100/1	16.6	2.4	Slightly curved
KAB-RB13-302-90	18.6	2.4	Straight
KAB-RB13-303-32	19.0	2.1	Slightly curved
KAB-RB13-305-130/2	19.5	2.0	Straight
KAB-RB13-308-114	20.8	2.4	Straight
KAB-RB13-30-87	19.4	2.3	Straight
KAB-RB13-309-62	18.0	2.2	Straight
KAB-RB13-310-86	20.3	2.0	curved
KAB-RB13-311-102/3	18.7	2.3	Straight
KAB-RB13-311-103/1	18.6	2.2	Slightly curved

Continued: Pod quality of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-311-103/2	19.9	2.5	Slightly curved
KAB-RB13-311-103/3	19.3	2.4	Straight
KAB-RB13-311-103/5	19.6	2.4	Straight
KAB-RB13-312-35	18.3	2.1	Straight
KAB-RB13-314-91	19.1	2.2	Straight
KAB-RB13-318-34/1	18.2	2.0	Slightly curved
KAB-RB13-318-34/2	16.6	2.4	Slightly curved
KAB-RB13-320-104/1	18.6	2.4	Straight
KAB-RB13-320-104/2	19.0	2.1	Slightly curved
KAB-RB13-320-104/3	19.5	2.0	Straight
KAB-RB13-320-104/4	20.8	2.4	Straight
KAB-RB13-327-48	19.4	2.3	Straight
KAB-RB13-327-92	18.0	2.2	Straight
KAB-RB13-330-116/1	19.3	2.0	Slightly curved
KAB-RB13-330-116/2	18.7	2.3	Straight
KAB-RB13-330-116/3	18.6	2.2	Slightly curved
KAB-RB13-331-112	19.9	2.5	Slightly curved
KAB-RB13-331-113	19.3	2.4	Straight
KAB-RB133-312-37	19.6	2.4	Straight
KAB-RB13-331-66/1	18.3	2.1	Straight
KAB-RB13-331-66/2	19.1	2.2	Straight
KAB-RB13-331-66/3	18.2	2.0	Slightly curved
KAB-RB13-331-66/4	16.6	2.4	Slightly curved
KAB-RB13-331-66/5	18.6	2.4	Straight
KAB-RB13-336-63	19.0	2.1	Slightly curved
KAB-RB13-338-38	19.5	2.0	Straight

Continued: Pod quality of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-339-95	20.8	2.4	Straight
KAB-RB13-341-94/1	19.4	2.3	Straight
KAB-RB13-341-94/2	18.0	2.2	Straight
KAB-RB13-363-131	20.3	2.0	Markedly curved
KAB-RB13-363-54	18.7	2.3	Straight
KAB-RB13-364-97/1	18.6	2.2	Slightly curved
KAB-RB13-364-97/2	19.9	2.5	Slightly curved
KAB-RB13-379-33	19.3	2.4	Straight
KAB-RB13-380-55	19.6	2.4	Straight
KAB-RB13-380-56/2	18.3	2.1	Straight
KAB-RB13-380-56/3	19.1	2.2	Straight
KAB-RB13-396-53	18.2	2.0	Slightly curved
KAB-RB13-403-88/1	16.6	2.4	Slightly curved
KAB-RB13-403-88/2	18.6	2.4	Straight
KAB-RB13-426-84A	19.0	2.1	Slightly curved
KAB-RB13-446-4	19.5	2.0	Straight
KAB-RB13-446-5	20.8	2.4	Straight
KAB-RB13-46-22/1	19.4	2.3	Straight
KAB-RB13-46-22/2	18.0	2.2	Straight
KAB-RB13-470-72	19.3	2.0	Straight
KAB-RB13-471-118/1	18.7	2.3	Straight
KAB-RB13-471-118/2	18.6	2.2	Slightly curved
KAB-RB13-471-118/3	19.9	2.5	Slightly curved
KAB-RB13-471-118/4	19.3	2.4	Straight
KAB-RB13-471-118/5	19.6	2.4	Straight
KAB-RB13-50-15	18.3	2.1	Straight

Continued: Pod quality of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-64-107/1	19.1	2.2	Straight
KAB-RB13-64-107/2	18.2	2.0	Slightly curved
KAB-RB13-64-107/3	16.6	2.4	Slightly curved
KAB-RB13-64-107/4	18.6	2.4	Straight
KAB-RB13-85-20	19.0	2.1	Slightly curved
KAB-RB13-96-115	19.5	2.0	Straight
KAB-RB13-97-14	20.8	2.4	Straight
OL-RB13-21-2/1	19.4	2.3	Straight
OL-RB13-21-2/2	18.0	2.2	Straight
SUB-RB13-106-12/1	18.3	2.0	Slightly curved
SUB-RB13-106-12/2	18.7	2.3	Straight
SUB-RB13-117-68	18.6	2.2	Slightly curved
SUB-RB13-133-11	19.9	2.5	Slightly curved
SUB-RB13-133-80/1	19.3	2.4	Straight
SUB-RB13-133-80/2	19.6	2.4	Straight
SUB-RB13-221-128	18.3	2.1	Straight
SUB-RB13-234-13/1	19.1	2.2	Straight
SUB-RB13-234-13/2	18.2	2.0	Slightly curved
SUB-RB13-240-125/1	16.6	2.4	Slightly curved
SUB-RB13-240-125/2	18.6	2.4	Straight
SUB-RB13-240-126/1	19.0	2.1	Slightly curved
SUB-RB13-240-126/2	19.5	2.0	Straight
SUB-RB13-240-126/3	20.8	2.4	Straight
SUB-RB13-271-78	19.4	2.3	Straight
SUB-RB13-305-76	18.0	2.2	Straight
Check			

W. Emergo	19.4	2.3	Straight
Mean	20.0	2.0	
LSD $_{0.05}$ Genotype	0.3	1.4	
CV %	5.6	3.9	

LSD-Least significant difference, CV-Coefficient variation

Appendix 14: Pod quality of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	**Pod length (cm)**	**Pod diameter (cm)**	**Pod curvature**
KAB-RB13-1-105/1	19.6	1.8	Curved
KAB-RB13-1-105/2	19.7	2.0	Curved
KAB-RB13-1-105/3	21.3	2.0	Straight
KAB-RB13-1-105/4	20.4	2.0	Slightly curved
KAB-RB13-129-121	19.0	2.0	Straight
KAB-RB13-294-24	18.0	2.0	Straight
KAB-RB13-299-43	19.2	2.0	Straight
KAB-RB13-301-39	19.5	2.0	Slightly curved
KAB-RB13-305-130/1	21.0	2.0	Straight
KAB-RB13-305-130/2	19.1	2.0	Curved
KAB-RB13-309-62	21.6	2.1	Straight
KAB-RB13-311-103	19.4	2.1	Straight
KAB-RB13-312-35	20.9	2.0	Straight
KAB-RB13-312-37	19.1	2.0	Slightly curved
KAB-RB13-318-34	19.6	2.0	Slightly curved
KAB-RB13-320-104/1	18.5	1.9	Straight
KAB-RB13-320-104/2	18.5	1.9	Straight
KAB-RB13-320-104/3	18.3	2.2	Slightly curved
KAB-RB13-320-104/4	18.2	2.0	Straight
KAB-RB13-331-66/1	19.0	1.9	Straight
KAB-RB13-331-66/2	20.4	2.0	Slightly curved

Continued: Pod quality of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
KAB-RB13-363-131	22.7	2.1	Straight
KAB-RB13-363-54	19.6	2.4	Slightly curved
KAB-RB13-364-97/1	19.0	2.1	Curved
KAB-RB13-364-97/2	18.0	2.1	Straight
KAB-RB13-446-5	19.3	1.9	Slightly curved
KAB-RB13-46-22/1	20.1	2.2	Straight
KAB-RB13-46-22/2	20.4	2.1	Straight
KAB-RB13-470-72	21.0	2.3	Slightly curved
KAB-RB13-471-117	19.6	2.1	Slightly curved
KAB-RB13-471-118/1	18.8	1.9	Slightly curved
KAB-RB13-471-118/2	21.0	2.2	Straight
KAB-RB13-471-118/3	19.1	2.2	Straight
KAB-RB13-471-118/4	20.2	2.2	Slightly curved
KAB-RB13-649-70	20.2	2.0	Straight
KAB-RB13-85-18	20.3	2.0	Slightly curved
OL-RB13-21-2/1	20.4	2.0	Straight
OL-RB13-21-2/2	21.1	2.0	Slightly curved
SUB-RB13-106-12/1	20.1	2.0	Straight
SUB-RB13-106-12/2	19.8	2.2	Slightly curved
SUB-RB13-133-80/1	22.5	2.2	Slightly curved
SUB-RB13-133-80/2	20.3	2.2	Slightly curved
SUB-RB13-234-13	20.8	2.3	Straight
SUB-RB13-240-125/1	20.5	2.2	Straight
SUB-RB13-240-125/2	20.1	1.9	Straight
SUB-RB13-240-126/1	18.8	1.9	Slightly curved
SUB-RB13-240-126/2	19.6	1.8	Slightly curved

Continued: Pod quality of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season.

Genotype	Pod length (cm)	Pod diameter (cm)	Pod curvature
SUB-RB13-271-78/1	18.9	1.9	Straight
SUB-RB13-271-78/2	20.0	2.0	Straight
Check			
W. Emergo	20.0	2.0	Straight
Mean	19.8	2.0	
LSD $_{0.05}$	0.2	1.2	
CV%	5.2	3.8	

LSD-Least significant difference, CV-Coefficient variation

Appendix 15: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-1-105/1	10.8	9705.9	33.9	66.1
KAB-RB13-1-105/2	19.6	18353.7	21.3	78.7
KAB-RB13-1-105/3	4.7	10114.1	93.9	6.1
KAB-RB13-1-105/4	4.7	4090.5	18.2	81.8
KAB-RB13-129-121/1	1.4	1473.5	2.8	97.2
KAB-RB13-129-121/2	10.3	8667.3	43.8	56.2
KAB-RB13-138-38	1.2	607.1	29.9	70.1
KAB-RB13-240-119	0.7	629.3	23.3	76.7
KAB-RB13-296-111/1	2.8	2638.2	63.5	36.5
KAB-RB13-296-111/2	4.3	4280.3	40.4	59.6
KAB-RB13-299-43/1	0.6	549.2	0.0	100.0
KAB-RB13-299-43/2	1.1	984.3	45.9	54.1
KAB-RB13-301-39	3.0	532.5	11.4	88.6

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-301-46	1.0	2891.1	31.3	68.7
KAB-RB13-302-100/1	0.1	905.2	72.5	27.5
KAB-RB13-302-90	1.5	2765.6	69.1	30.9
KAB-RB13-303-32	0.2	1362.2	69.5	30.5
KAB-RB13-305-130/2	3.5	538.8	31.0	69.0
KAB-RB13-308-114	5.5	3143.6	25.3	74.7
KAB-RB13-30-87	0.6	5654.4	19.3	80.7
KAB-RB13-309-62	4.4	4145.7	61.5	38.5
KAB-RB13-310-86	2.2	1987.3	41.9	58.1
KAB-RB13-311-102/3	0.8	753.1	15.2	84.8
KAB-RB13-311-103/1	10.9	9027.2	21.6	78.4
KAB-RB13-311-103/2	1.0	1108.9	0.0	100.0
KAB-RB13-311-103/3	4.4	3768.6	60.3	39.7
KAB-RB13-311-103/5	5.5	4992.7	32.0	68.0
KAB-RB13-312-35	4.3	3758.6	62.9	37.1
KAB-RB13-314-91	2.1	2002.7	45.7	54.3
KAB-RB13-318-34/1	2.2	1940.2	24.1	75.9
KAB-RB13-318-34/2	2.7	2241.6	45.8	54.2
KAB-RB13-320-104/1	2.4	2124.4	70.9	29.1
KAB-RB13-320-104/2	3.1	2685.3	52.8	47.2
KAB-RB13-320-104/3	3.0	2921.1	24.3	75.7
KAB-RB13-320-104/4	5.8	6075.2	45.0	55.0
KAB-RB13-327-48	1.3	1204.0	15.9	84.1
KAB-RB13-327-92	1.8	1810.5	54.4	45.6
KAB-RB13-330-116/1	1.3	1096.3	22.6	77.4
KAB-RB13-330-116/2	4.3	4019.4	15.5	84.5
KAB-RB13-330-116/3	4.1	3436.4	30.1	69.9

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-331-112	0.8	753.8	26.8	73.2
KAB-RB13-331-113	6.8	5452.1	62.6	37.4
KAB-RB133-312-37	2.5	1564.4	68.7	31.3
KAB-RB13-331-66/1	1.7	1968.3	36.3	63.7
KAB-RB13-331-66/2	2.0	9455.6	20.9	79.1
KAB-RB13-331-66/3	10.1	1922.0	29.1	70.9
KAB-RB13-331-66/4	2.1	2278.2	5.1	94.9
KAB-RB13-331-66/5	2.6	5057.4	54.8	45.2
KAB-RB13-336-63	5.3	928.9	57.8	42.2
KAB-RB13-338-38	1.0	5305.6	35.5	64.5
KAB-RB13-339-95	0.3	2182.2	35.5	64.5
KAB-RB13-341-94/1	2.6	2250.8	35.7	64.3
KAB-RB13-341-94/2	2.2	4100.3	58.6	41.4
KAB-RB13-363-131	4.2	3372.6	18.9	81.1
KAB-RB13-363-54	3.5	875.6	81.6	18.4
KAB-RB13-364-97/1	0.9	2841.4	47.7	52.3
KAB-RB13-364-97/2	3.0	1269.4	77.6	22.4
KAB-RB13-379-33	15.3	17162.8	27.8	72.2
KAB-RB13-380-55	1.3	1693.9	36.7	63.3
KAB-RB13-380-56/2	4.0	1461.6	47.3	52.7
KAB-RB13-380-56/3	1.6	4260.3	38.0	62.0
KAB-RB13-396-53	4.0	972.6	24.5	75.5
KAB-RB13-403-88/1	1.2	2331.3	36.7	63.3
KAB-RB13-403-88/2	2.6	1088.3	30.1	69.9
KAB-RB13-426-84A	1.0	3086.7	15.0	85.0
KAB-RB13-446-4	3.3	1893.8	22.6	77.4
KAB-RB13-446-5	2.1	2451.2	60.4	39.6

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-46-22/1	2.9	2629.6	68.0	32.0
KAB-RB13-46-22/2	2.8	7959.7	58.8	41.2
KAB-RB13-470-72	8.4	5693.8	57.2	42.8
KAB-RB13-471-118/1	5.9	3190.7	18.5	81.5
KAB-RB13-471-118/2	3.4	4639.1	62.2	37.8
KAB-RB13-471-118/3	4.9	6454.6	32.4	67.6
KAB-RB13-471-118/4	7.3	7960.0	44.0	56.0
KAB-RB13-471-118/5	8.4	4335.1	23.6	76.4
KAB-RB13-50-15	5.0	1028.2	66.7	33.3
KAB-RB13-64-107/1	1.0	1732.0	22.9	77.1
KAB-RB13-64-107/2	2.0	474.2	44.7	55.3
KAB-RB13-64-107/3	0.6	3312.1	15.9	84.1
KAB-RB13-64-107/4	3.3	2997.7	31.6	68.4
KAB-RB13-85-20	3.2	3694.9	29.7	70.3
KAB-RB13-96-115	4.0	2810.2	20.3	79.7
KAB-RB13-97-14	3.2	2370.6	0.0	100.0
OL-RB13-21-2/1	6.3	5011.5	61.1	38.9
OL-RB13-21-2/2	2.0	1679.0	45.6	54.4
SUB-RB13-106-12/1	1.8	1699.9	29.2	70.8
SUB-RB13-106-12/2	7.4	6567.8	33.6	66.4
SUB-RB13-117-68	2.8	2412.3	16.2	83.8
SUB-RB13-133-11	1.5	1485.1	41.8	58.2
SUB-RB13-133-80/1	8.0	7428.9	59.7	40.3
SUB-RB13-133-80/2	6.4	7763.8	81.5	18.5
SUB-RB13-221-128	4.6	4521.9	42.9	57.1
SUB-RB13-234-13/1	9.5	8936.1	11.0	89.0
SUB-RB13-234-13/2	1.4	1242.7	68.5	31.5

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at Kabete Field Station during 2014 long rain season.

Genotype	Pods per plant	Pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
SUB-RB13-240-125/1	7.3	6664.1	9.2	90.8
SUB-RB13-240-125/2	3.9	3502.9	44.4	55.6
SUB-RB13-240-126/1	6.0	6231.6	52.0	48.0
SUB-RB13-240-126/2	3.0	2794.1	9.1	90.9
SUB-RB13-240-126/3	1.5	1278.3	38.4	61.6
SUB-RB13-271-78	1.9	1688.9	6.3	93.7
SUB-RB13-305-76	2.6	2473.2	67.3	32.7
Check				
W. Emergo	1.0	895.6	50.0	50.0
Mean	3.7	3535.9		
LSD $_{0.05}$ Genotype	0.2	146.1		
LSD $_{0.05}$ Harvest	0.1	59.3		
LSD $_{0.05}$ G X H	0.5	439.8		
CV %	10.3	9.6		

G x H-Genotype x Harvest, LSD-Least significant difference, CV-Coefficient variation

Appendix 16: Pods per plant and pod yield of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	Pod plant $^{-1}$	Total pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-1-105/1	14	7564.5	59.8	40.2
KAB-RB13-1-105/2	18	10809	25.4	74.6
KAB-RB13-1-105/3	18	12919.5	31.4	68.6
KAB-RB13-1-105/4	9	7956	50.9	49.1
KAB-RB13-129-121	14	8217	44.6	55.4
KAB-RB13-294-24	5	4158	69.0	31.0

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	Pod plant $^{-1}$	Total pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-299-43	14	9625.5	37.3	62.7
KAB-RB13-301-39	18	8302.5	35.3	64.7
KAB-RB13-305-130/1	5	3118.5	26.0	74.0
KAB-RB13-305-130/2	18	12627	9.2	90.8
KAB-RB13-309-62	18	10381.5	55.1	44.9
KAB-RB13-311-103	14	7947	25.3	74.7
KAB-RB13-312-35	23	10260	50.0	50.0
KAB-RB13-312-37	23	16884	57.2	42.8
KAB-RB13-318-34	5	3033	9.2	90.8
KAB-RB13-320-104/1	9	1818	54.7	45.3
KAB-RB13-320-104/2	9	4779	22.8	77.2
KAB-RB13-320-104/3	9	5674.5	49.4	50.6
KAB-RB13-320-104/4	5	1885.5	25.3	74.7
KAB-RB13-331-66/1	5	2227.5	17.8	82.2
KAB-RB13-331-66/2	9	6174	45.3	54.7
KAB-RB13-363-131	14	9355.5	34.5	65.5
KAB-RB13-363-54	5	5832	26.9	73.1
KAB-RB13-364-97/1	14	9459	6.0	94.0
KAB-RB13-364-97/2	5	5814	24.7	75.3
KAB-RB13-446-5	5	3762	24.3	75.7
KAB-RB13-46-22/1	23	15462	23.5	76.5
KAB-RB13-46-22/2	14	7141.5	14.1	85.9
KAB-RB13-470-72	9	7564.5	44.3	55.7
KAB-RB13-471-117	9	4279.5	42.6	57.4
KAB-RB13-471-118/1	9	3753	29.5	70.5
KAB-RB13-471-118/2	14	10458	33.1	66.9

Continued: Pods per plant and pod yield of vegetable runner bean lines grown at KALRO-Ol Joro Orok during 2014 long rain season

Genotype	Pod plant $^{-1}$	Total pod yield (kg ha^{-1})	Grade I (%)	Grade II (%)
KAB-RB13-471-118/3	5	3321	40.8	59.2
KAB-RB13-471-118/4	5	4855.5	40.8	59.2
KAB-RB13-649-70	9	4509	20.6	79.4
KAB-RB13-85-18	9	7965	36.4	63.6
OL-RB13-21-2/1	9	7888.5	32.3	67.7
OL-RB13-21-2/2	14	7618.5	29.8	70.2
SUB-RB13-106-12/1	14	14391	32.3	67.7
SUB-RB13-106-12/2	14	9090	20.8	79.2
SUB-RB13-133-80/1	9	3424.5	0.0	100.0
SUB-RB13-133-80/2	9	8914.5	41.6	58.4
SUB-RB13-234-13	14	9999	35.1	64.9
SUB-RB13-240-125/1	9	1971	0.0	100.0
SUB-RB13-240-125/2	14	6885	46.3	53.7
SUB-RB13-240-126/1	14	6970.5	28.2	71.8
SUB-RB13-240-126/2	14	12298.5	53.8	46.2
SUB-RB13-271-78/1	14	6241.5	49.1	50.9
SUB-RB13-271-78/2	9	7681.5	34.2	65.8
Check				
W. Emergo	9	5401.5	37.0	63.0
Mean	9	6174.0		
LSD $_{0.05}$	14	1187.6		
CV%	26	25.4		

LSD-Least significant difference, CV-Coefficient variation

Appendix 17: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

									Days							
	50% DF				**Vigour**				**First harvest**				**Last harvest**			
	[J]LR	[J]**SR**			**LR**	**SR**			**LR**	**SR**			**LR**	**SR**		
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**
KSB13-31	35.0	38.0	33.0	35.3	5.0	3.0	1.5	3.2	50.0	47.0	47.0	48.0	77.7	71.0	63.0	70.6
KSB13-23	36.3	37.5	32.5	35.4	5.7	5.0	2.0	4.2	50.7	47.0	42.0	46.6	74.0	70.0	65.0	69.7
KSB13-47	37.0	38.5	33.5	36.3	4.3	5.0	2.0	3.8	52.0	47.0	42.0	47.0	75.6	68.0	62.0	68.5
KSB13-49	36.7	39.0	34.0	36.6	3.7	3.0	1.5	2.7	51.3	47.0	44.0	47.4	77.0	68.0	63.0	69.3
KSB13-55	37.3	40.0	35.0	37.4	3.0	3.0	2.5	2.8	52.7	51.0	45.5	49.7	78.3	71.0	63.0	70.8
KSB13-18	39.7	39.5	34.5	37.9	3.7	4.0	2.5	3.4	55.0	51.0	44.0	50.0	77.0	71.0	65.0	71.0
KSB13-41	35.7	37.5	32.5	35.2	5.0	4.0	4.0	4.3	50.0	47.0	43.0	46.7	74.0	68.0	63.0	68.3
KSB13-50	26.9	39.5	34.5	33.6	3.0	2.0	2.0	2.3	53.3	50.0	44.5	49.3	73.0	70.0	65.0	69.3
KSB13-34	37.3	40.0	35.0	37.4	3.7	4.0	1.5	3.1	52.7	48.0	45.5	48.7	74.7	71.0	65.0	70.2
KSB13-14	37.3	37.0	32.0	35.4	5.0	4.0	2.0	3.7	51.3	47.0	42.0	46.8	75.3	71.0	63.0	69.8
KSB13-15	36.0	39.5	34.5	36.7	4.3	4.0	2.0	3.4	50.0	48.0	46.5	48.2	72.7	68.0	63.0	67.9
KSB13-33	37.3	38.0	33.0	36.1	4.3	4.0	2.0	3.4	52.7	51.0	44.5	49.4	73.3	68.0	65.0	68.8
KSB13-46	36.3	39.0	34.0	36.4	3.0	3.0	1.0	2.3	50.7	47.0	42.0	46.6	78.0	68.0	65.0	70.3
KSB13-25	36.0	39.5	34.5	36.7	4.3	4.0	1.5	3.3	50.7	48.0	44.5	47.7	78.3	71.0	65.0	71.4
KSB13-43	36.0	39.0	34.0	36.3	3.0	4.0	2.0	3.0	50.7	47.0	43.0	46.9	80.0	67.0	63.0	70.0
KSB13-32	38.0	39.0	34.0	37.0	4.3	2.0	1.0	2.4	53.3	48.0	43.0	48.1	78.3	71.0	61.0	70.1
KSB13-27	37.7	38.5	33.5	36.6	3.7	2.0	1.5	2.4	53.0	51.0	42.0	48.7	80.0	71.0	64.0	71.7
KSB13-45	37.3	40.0	35.0	37.4	4.3	3.0	2.0	3.1	54.3	48.0	45.5	49.3	77.7	71.0	65.0	71.2

Continued: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

									Days							
	50% DF				**Vigour**				**First harvest**				**Last harvest**			
	[J]LR	[J]**SR**			**LR**	**SR**			**LR**	**SR**			**LR**	**SR**		
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**
KSB13-48	37.7	38.0	33.0	36.2	4.3	5.0	2.5	3.9	51.3	47.0	43.0	47.1	80.0	68.0	64.0	70.7
KSB13-30	35.0	37.0	32.0	34.7	3.7	3.0	1.5	2.7	50.0	47.0	42.0	46.3	78.3	71.0	63.0	70.8
KSB13-12	36.7	37.0	32.0	35.2	5.0	5.0	1.5	3.8	51.0	47.0	42.0	46.7	79.0	70.0	65.0	71.3
KSB13-38	36.0	37.5	32.5	35.3	5.0	4.0	1.0	3.3	50.7	47.0	42.0	46.6	80.0	68.0	65.0	71.0
KSB13-26	35.7	38.0	33.0	35.6	5.0	4.0	3.5	4.2	50.0	47.0	43.0	46.7	72.3	70.0	64.0	68.8
KSB13-37	39.7	40.0	35.0	38.2	5.7	4.0	1.5	3.7	55.0	54.0	43.0	50.7	79.3	71.0	63.0	71.1
KSB13-54	36.7	39.0	34.0	36.6	4.3	5.0	3.0	4.1	51.0	48.0	43.0	47.3	75.0	68.0	65.0	69.3
KSB13-56	38.3	40.0	35.0	37.8	3.7	3.0	1.0	2.6	53.3	51.0	42.0	48.8	77.7	71.0	65.0	71.2
KSB13-39	38.0	40.0	35.0	37.7	4.3	2.0	2.0	2.8	53.7	50.0	44.0	49.2	77.3	71.0	65.0	71.1
KSB13-24	36.7	38.5	33.5	36.2	4.3	4.0	1.5	3.3	51.3	47.0	43.0	47.1	77.7	67.0	63.0	69.2
KSB13-51	35.0	38.0	33.0	35.3	4.3	4.0	1.5	3.3	50.0	47.0	47.0	48.0	79.0	71.0	64.0	71.3
KSB13-52	39.0	40.0	35.0	38.0	3.7	2.0	1.5	2.4	54.3	53.0	43.0	50.1	75.3	71.0	65.0	70.4
KSB13-13	36.7	36.5	31.5	34.9	4.3	3.0	1.5	2.9	52.0	48.0	42.0	47.3	74.7	71.0	64.0	69.9
KSB13-22	37.0	38.0	33.0	36.0	3.0	2.0	1.5	2.2	52.7	50.0	42.0	48.2	74.0	70.0	61.0	68.3
KSB13-36	35.7	39.0	34.0	36.2	4.3	2.0	1.0	2.4	50.0	47.0	44.0	47.0	76.7	71.0	63.0	70.2
KSB13-44	35.7	37.5	32.5	35.2	4.3	3.0	1.5	2.9	50.0	47.0	44.0	47.0	80.7	70.0	61.0	70.6
KSB13-11	35.3	38.5	33.5	35.8	3.7	3.0	1.0	2.6	50.0	47.0	44.5	47.2	75.3	68.0	65.0	69.4
KSB13-28	36.0	37.0	32.0	35.0	5.0	3.0	1.0	3.0	50.0	47.0	43.0	46.7	82.0	71.0	65.0	72.7
KSB13-19	36.7	37.0	32.0	35.2	4.3	3.0	1.5	2.9	50.0	48.0	44.0	47.3	74.7	71.0	65.0	70.2

Continued: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

									Days							
	50% DF				**Vigour**				**First harvest**				**Last harvest**			
	[ʃ]LR	[ʃ]**SR**			**LR**	**SR**			**LR**	**SR**			**LR**	**SR**		
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**
KSB13-29	35.7	37.5	32.5	35.2	4.3	3.0	2.5	3.3	50.0	47.0	44.5	47.2	82.0	71.0	65.0	72.7
KSB13-35	35.3	38.5	33.5	35.8	4.3	4.0	1.5	3.3	50.0	50.0	42.0	47.3	80.0	71.0	65.0	72.0
KSB13-16	35.3	37.0	32.0	34.8	3.0	3.0	1.5	2.5	50.7	47.0	45.5	47.7	79.0	71.0	65.0	71.7
KSB13-42	35.3	36.5	31.5	34.4	3.7	3.0	1.0	2.6	50.0	47.0	43.0	46.7	78.3	71.0	64.0	71.1
KSB13-40	37.3	36.5	31.5	35.1	6.3	4.0	3.0	4.4	52.0	47.0	42.0	47.0	74.7	71.0	65.0	70.2
KSB13-53	36.7	37.5	32.5	35.6	3.0	5.0	2.0	3.3	51.3	47.0	45.5	47.9	82.0	70.0	65.0	72.3
KSB13-17	36.3	36.0	31.0	34.4	3.7	5.0	1.0	3.2	52.0	50.0	44.5	48.8	82.0	65.0	65.0	70.7
KSB13-20	36.7	38.5	33.5	36.2	4.3	3.0	1.5	2.9	50.7	47.0	44.5	47.4	82.0	71.0	61.0	71.3
KSB13-21	38.3	39.0	34.0	37.1	3.7	3.0	1.5	2.7	52.7	51.0	43.0	48.9	74.7	71.0	63.0	69.6
Checks																
Julia		40.0	35.0	37.5		4.0	2.5	3.3		51.0	51.5	51.3		71.0	65.0	68.0
Samantha	39.7	40.0	35.0	38.2	6.3	5.0	1.5	4.3	54.3	50.0	47.0	50.4	79.0	71.0	65.0	71.7
Serengeti		38.5	33.5	36.0		3.0	2.5	2.8		48.0	45.5	46.8		68.0	65.0	66.5
Mean	37.0	38.4	33.4		4.3	3.5	1.8		51.6	48.0	43.9		77.4	70.0	64.0	
$LSD_{0.05}$ Genotype	0.4	0.8	0.8		0.4	0.8	0.4		0.5	1.1	1.3		1.2	1.2	1.0	
CV (%)	2.8	0.8	1.0		20.7	9.0	17.0		2.1	0.1	1.2		3.7	0.9	0.0	

[ʃ]LR=Long rain and SR=Short rain, LSD-Least significant difference, CV-Coefficient variation

Appendix 18: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB14 snap bean lines grown at Kabete Field station and Mwea during 2014 short rain season

	50% DF			Vigour			Days					
							First harvest			Last harvest		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSB14-10	40	35	37	3	2	2	47	49	48	71	65	68
KSB14-17	39	34	37	4	2	3	48	45	46	71	65	68
KSB14-23	41	36	38	5	2	4	48	50	49	71	65	68
KSB14-14	41	36	38	3	2	3	44	48	46	71	65	68
KSB14-08	39	34	36	3	1	2	47	46	46	71	63	67
KSB14-13	39	34	36	3	2	3	47	43	45	71	64	68
KSB14-21	38	33	36	4	2	3	47	45	46	71	63	67
KSB14-11	40	35	37	5	2	3	47	44	46	70	63	67
KSB14-05	40	35	37	2	2	2	47	43	45	61	63	62
KSB14-07	40	35	38	4	2	3	44	46	45	68	65	67
KSB14-15	38	33	35	6	2	4	47	45	46	71	65	68
KSB14-24	38	33	35	4	2	3	47	44	46	66	63	65
KSB14-02	38	33	36	5	2	3	47	43	45	71	63	67
KSB14-22	40	35	38	3	1	2	47	46	46	71	65	68
KSB14-18	40	35	37	3	3	3	47	46	46	71	63	67
KSB14-19	40	35	37	2	2	2	47	43	45	68	65	67
KSB14-04	39	34	36	3	2	3	47	43	45	71	63	67

Continued: Duration to 50% flowering, plant vigour and days to first and last harvest of KSB14 snap bean lines grown at Kabete Field station and Mwea during 2014 short rain season

							Days					
	50% DF			Vigour			First harvest			Last harvest		
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**
KSB14-06	39	34	36	3	1	2	47	44	46	71	65	68
KSB14-16	40	35	37	5	3	4	47	47	47	61	65	63
KSB14-12	39	34	37	2	1	2	47	46	46	71	65	68
KSB14-20	40	35	37	2	2	2	47	47	47	71	65	68
KSB14-27	40	35	37	2	3	2	47	46	46	70	65	68
KSB14-26	40	35	38	5	2	3	47	47	47	71	65	68
KSB14-01	39	34	37	3	2	2	48	47	48	71	65	68
KSB14-25	40	35	38	3	3	3	47	47	47	71	63	67
KSB14-09	40	35	38	3	2	2	47	47	47	71	65	68
KSB14-28	40	35	38	4	2	3	47	47	47	71	65	68
KSB14-03	39	34	36	2	1	2	47	42	45	71	63	67
Checks												
Julia	41	36	39	5	4	5	50	47	49	71	65	68
Samantha	40	35	38	7	3	5	50	48	49	66	65	66
Serengeti	40	35	37	4	2	3	47	43	45	71	65	68
Mean	39.3	34.3		3.6	1.8		47.0	45.5		70.0	64.3	
LSD $_{0.05}$ Genotype	0.4	0.4		0.9	0.6		0.7	1.1		2.6	1.0	

CV (%)	0.9	1.1	1.3	14.0	0.0	0.3	2.0	0.9

LSD-Least significant difference, CV-Coefficient variation

Appendix 19: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB13 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain seasons.

											Diseases								
	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Rust			ALS[§]			CBB[§]		
	SR										LR	SR	Mean	LR	SR	mean	LR	SR	Mean
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**								
KSB13-31	9.8	9.0	9.4	7.8	8.8	8.3	Flat	Round	Straight	Straight	3.3	4.0	3.7	2.0	4.0	3.0	2.0	1.3	1.7
KSB13-23	11.4	10.6	11.0	7.4	6.4	6.9	Flat	Flat	Straight	Curved	2.3	1.0	1.7	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-47	9.0	7.9	8.4	6.6	6.4	6.5	Flat	Round	Straight	Straight	1.7	1.0	1.3	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-49	7.8	8.0	7.9	7.8	7.6	7.7	Flat	Flat	Straight	Straight	3.3	5.0	4.2	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-55	10.8	10.3	10.6	6.3	7.3	6.8	Flat	Flat	Straight	Curved	2.3	1.0	1.7	2.7	1.0	1.8	2.7	2.0	2.3
KSB13-18	10.2	10.6	10.4	6.4	6.2	6.3	Flat	Round	Straight	Straight	2.3	1.0	1.7	2.3	1.0	1.7	2.0	1.3	1.7
KSB13-41	11.1	8.2	9.7	6.5	5.9	6.2	Round	Round	Curved	Straight	2.3	1.0	1.7	2.0	1.0	1.5	2.7	2.0	2.3
KSB13-50	10.9	10.3	10.6	6.2	5.9	6.1	Round	Round	Curved	Curved	3.0	1.0	2.0	2.3	1.0	1.7	2.3	1.6	2.0
KSB13-34	11.2	10.8	11.0	6.3	6.6	6.4	Flat	Round	Straight	Straight	3.3	1.0	2.2	2.0	1.0	1.5	2.0	1.3	1.7
KSB13-14	12.3	11.0	11.6	9.3	9.3	9.3	Flat	Flat	Straight	Curved	3.3	1.0	2.2	2.3	1.0	1.7	2.0	1.3	1.7
KSB13-15	8.3	9.7	9.0	6.2	7.3	6.7	Flat	Round	Straight	Curved	2.3	4.0	3.2	2.0	2.0	2.0	2.7	2.0	2.3
KSB13-33	9.4	9.0	9.2	6.0	5.7	5.9	Flat	Round	Straight	Curved	3.3	1.0	2.2	2.0	1.0	1.5	2.7	2.0	2.3
KSB13-46	10.4	10.4	10.4	6.3	6.0	6.2	Flat	Flat	Straight	Straight	1.0	2.0	1.5	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-25	10.0	9.6	9.8	7.0	7.5	7.2	Round	Flat	Curved	Curved	3.3	2.0	2.7	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-43	9.8	8.7	9.2	7.5	6.4	6.9	Flat	Flat	Straight	Straight	1.0	1.0	1.0	2.7	1.0	1.8	2.7	2.0	2.3
KSB13-32	9.9	8.3	9.1	7.0	7.6	7.3	Flat	Flat	Straight	Curved	3.0	1.0	2.0	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-27	10.2	10.9	10.5	6.9	6.9	6.9	Flat	Flat	Straight	Curved	2.3	1.0	1.7	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-45	10.2	11.3	10.8	6.5	8.1	7.3	Flat	Round	Straight	Curved	1.7	1.0	1.3	2.0	1.0	1.5	2.0	1.3	1.7
KSB13-48	8.8	8.2	8.5	6.5	5.8	6.1	Flat	Flat	Straight	Straight	3.3	1.0	2.2	2.3	1.0	1.7	2.0	1.3	1.7

Continued: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB13 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain seasons.

											Diseases								
	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Rust			ALS[§]			CBB[§]		
	[ǀ]SR										[ǀ]LR	SR	Mean	LR	SR	mean	LR	SR	Mean
Genotype	Kabete	Mwea	Mean	Kabete	Mwea	Mean	Kabete	Mwea	Kabete	Mwea	Kabete								
KSB13-30	8.8	9.5	9.2	6.4	6.5	6.4	Flat	Round	Straight	Straight	3.3	1.0	2.2	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-12	9.0	9.4	9.2	6.6	7.2	6.9	Round	Round	Curved	Straight	3.0	7.0	5.0	2.3	2.0	2.2	2.7	2.0	2.3
KSB13-38	9.4	8.3	8.8	6.7	6.3	6.5	Flat	Round	Straight	Straight	1.0	7.0	4.0	2.0	1.0	1.5	2.7	2.0	2.3
KSB13-26	10.0	10.0	10.0	6.2	6.2	6.2	Round	Round	Straight	Curved	3.3	2.0	2.7	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-37	8.5	9.4	8.9	6.3	6.9	6.6	Flat	Flat	Straight	Straight	1.0	6.0	3.5	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-54	8.8	7.4	8.1	6.3	6.6	6.4	Flat	Round	Straight	Straight	3.7	1.0	2.3	2.0	1.0	1.5	2.7	2.0	2.3
KSB13-56	9.5	8.9	9.2	6.6	6.7	6.6	Flat	Round	Straight	Straight	4.0	1.0	2.5	2.0	1.0	1.5	3.0	2.3	2.7
KSB13-39	8.9	9.0	9.0	6.1	6.0	6.0	Flat	Flat	Straight	Curved	3.3	1.0	2.2	2.3	1.0	1.7	2.3	1.6	2.0
KSB13-24	11.4	10.6	11.0	6.3	6.4	6.3	Flat	Round	Straight	Straight	2.3	3.0	2.7	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-51	11.7	14.0	12.8	5.8	6.2	6.0	Flat	Round	Straight	Straight	3.0	4.0	3.5	2.0	1.0	1.5	3.0	2.3	2.7
KSB13-52	9.8	10.0	9.9	6.2	6.4	6.3	Flat	Round	Straight	Straight	1.0	1.0	1.0	2.0	1.0	1.5	2.0	1.3	1.7
KSB13-13	10.2	7.5	8.9	6.3	7.0	6.6	Round	Flat	Curved	Curved	1.7	1.0	1.3	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-22	9.9	8.9	9.4	6.3	6.8	6.6	Flat	Flat	Straight	Curved	3.0	1.0	2.0	2.3	1.0	1.7	2.3	1.6	2.0
KSB13-36	11.9	15.5	13.7	6.5	5.7	6.1	Flat	Round	Straight	Curved	3.3	1.0	2.2	2.3	1.0	1.7	2.0	1.3	1.7
KSB13-44	14.2	9.1	11.6	5.7	6.3	6.0	Flat	Round	Straight	Curved	1.7	4.0	2.8	2.0	1.0	1.5	3.3	2.6	3.0
KSB13-11	13.1	15.4	14.3	6.9	6.5	6.7	Flat	Flat	Straight	Straight	1.7	1.0	1.3	2.7	1.0	1.8	2.0	1.3	1.7
KSB13-28	14.9	13.8	14.4	6.7	5.7	6.2	Flat	Flat	Curved	Curved	2.7	3.0	2.8	2.3	1.0	1.7	2.3	1.6	2.0
KSB13-19	10.7	10.6	10.7	8.1	9.9	9.0	Flat	Round	Straight	Straight	3.0	1.0	2.0	2.3	2.0	2.2	2.0	1.3	1.7
KSB13-29	9.7	10.4	10.0	6.1	6.3	6.2	Round	Round	Straight	Straight	1.7	1.0	1.3	2.0	1.0	1.5	2.0	1.3	1.7

Continued: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB13 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain seasons.

											Diseases								
	Pod length (cm)			Pod diameter (mm)			Pod shape		Pod curvature		Rust			ALS[§]			CBB[§]		
	[ʃ]SR										[ʃ]LR	SR	Mean	LR	SR	mean	LR	SR	Mean
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**								
KSB13-35	12.0	11.4	11.7	6.7	6.4	6.5	Flat	Round	Straight	Straight	1.7	4.0	2.8	2.7	1.0	1.8	2.3	1.6	2.0
KSB13-16	12.1	11.7	11.9	6.6	6.4	6.5	Flat	Flat	Straight	Curved	1.7	1.0	1.3	2.0	1.0	1.5	3.0	2.3	2.7
KSB13-42	10.6	8.9	9.7	6.6	7.3	7.0	Flat	Flat	Straight	Straight	3.3	2.0	2.7	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-40	8.3	6.3	7.3	6.5	7.8	7.2	Flat	Flat	Straight	Curved	1.7	1.0	1.3	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-53	7.8	8.0	7.9	6.1	5.7	5.9	Round	Round	Straight	Straight	3.3	1.0	2.2	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-17	7.9	9.3	8.6	5.8	5.6	5.7	Flat	Flat	Straight	Curved	4.0	1.0	2.5	2.0	1.0	1.5	2.0	1.3	1.7
KSB13-20	10.7	9.7	10.2	6.2	6.3	6.2	Flat	Round	Straight	Curved	3.0	2.0	2.5	2.0	1.0	1.5	2.3	1.6	2.0
KSB13-21	11.6	11.2	11.4	6.3	8.5	7.4	Flat	Flat	Straight	Straight	1.0	1.0	1.0	2.3	1.0	1.7	2.0	1.3	1.7
Checks																			
Julia	10.1	9.4	9.8	5.3	4.5	4.9	Round	Round	Straight	Straight		6.0	6.0		2.0	2.0		4.0	4.0
Samantha	11.7	10.6	11.2	5.9	5.2	5.6	Round	Round	Straight	Straight	2.7	6.0	4.4	2.3	3.0	2.7	2.0	5.0	3.5
Serengeti	12.1	9.5	10.8	5.9	4.4	5.2	Round	Round	Straight	Straight		2.0	2.0		1.0	1.0		3.0	3.0
Mean	10.3	9.9		6.5	6.6						2.6	2.1		2.1	1.2		2.3	1.1	
LSD$_{0.05}$ (G) [§]	0.7	1.2		0.3	0.6						1.3	0.8		0.5	0.3		0.8	0.2	
CV (%)	1.7	1.1		0.5	0.4						31.8	15.9		15.4	2.4		21.1	2.1	

ʃ LR= long rain, SR, short rain seasons; [§]G= Genotype, ALS= angular leaf spot, CBB= common bacterial blight, LSD-Least significant difference, CV-Coefficient variation

Appendix 20: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB14 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

											Diseases	
	Pod length (cm)			**Pod diameter**			**Pod shape**		**Pod curvature**		**Rust**	**ALS§**
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	
KSB14-10	12	10	11	6	5	6	Round	Round	Straight	Straight	3	2
KSB14-17	12	14	13	6	7	7	Round	Round	Straight	Straight	2	1
KSB14-23	11	10	10	6	7	7	Flat	Flat	Straight	Curved	6	1
KSB14-14	12	8	10	6	6	6	Flat	Flat	Straight	Curved	1	1
KSB14-08	15	13	14	7	7	7	Flat	Round	Straight	Straight	2	1
KSB14-13	15	11	13	7	6	6	Flat	Round	Straight	Straight	2	1
KSB14-21	15	12	14	7	6	6	Flat	Round	Straight	Straight	2	3
KSB14-11	11	11	11	6	6	6	Round	Round	Straight	Straight	1	2
KSB14-05	12	8	10	7	5	6	Flat	Round	Straight	Straight	1	1
KSB14-07	15	11	13	6	6	6	Flat	Round	Straight	Straight	1	1
KSB14-15	9	8	8	6	5	6	Flat	Round	Straight	Straight	1	1
KSB14-24	12	11	11	6	6	6	Flat	Flat	Straight	Straight	2	2
KSB14-02	15	13	14	7	7	7	Round	Round	Straight	Straight	2	2
KSB14-22	11	12	12	6	6	6	Round	Flat	Straight	Curved	2	1
KSB14-18	14	13	14	7	6	6	Flat	Round	Straight	Straight	2	2
KSB14-19	14	12	13	6	6	6	Flat	Round	Straight	Straight	3	3

Continued: Pod length, pod diameter, pod shape, pod curvature and disease reaction of KSB14 advanced snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season.

	Pod length (cm)			Pod diameter			Pod shape		Pod curvature		Diseases	
											Rust	ALS§
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	
KSB14-04	16	12	14	7	6	6	Flat	Round	Straight	Curved	3	1
KSB14-06	14	13	13	6	6	6	Flat	Round	Straight	Straight	2	2
KSB14-16	15	14	14	7	7	7	Flat	Flat	Straight	Curved	2	2
KSB14-12	14	16	15	7	7	7	Flat	Round	Straight	Curved	3	3
KSB14-20	13	12	13	7	6	6	Flat	Round	Straight	Curved	1	2
KSB14-27	13	11	12	6	6	6	Round	Round	Straight	Straight	2	2
KSB14-26	12	13	13	6	6	6	Round	Round	Straight	Straight	1	1
KSB14-01	13	13	13	6	6	6	Round	Round	Straight	Straight	2	1
KSB14-25	12	12	12	6	6	6	Round	Round	Straight	Straight	1	1
KSB14-09	14	12	13	6	6	6	Round	Round	Straight	Straight	3	2
KSB14-28	12	11	11	6	5	6	Round	Round	Straight	Straight	2	2
KSB14-03	13	12	13	6	6	6	Flat	Round	Straight	Straight	3	2
Checks												
Julia	11	17	14	6	8	7	Flat	Flat	Straight	Straight	6	1
Samantha	11	8	10	6	5	6	Flat	Round	Straight	Straight	5	3
Serengeti	12	12	12	6	6	6	Flat	Round	Straight	Straight	2	1

Mean	12.9	11.8	6.3	6.0			2.3	1.6
LSD $_{0.05}$ (G) §	0.6	0.9	0.2	0.3			0.6	0.4
CV %	1.5	4.8	2.8	0.8			20.2	0.9

§G= Genotype, ALS= angular leaf spot, LSD-Least significant difference, CV-Coefficient variation

Appendix 21: Pod yield, pod per plant and grade distribution of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

	Pod yield (kg ha^{-1})				**Pods plant^{-1}**				**% Grade distribution**								
									Extra-fine			**Fine**			**Bobby**		
	ǀLR	**ǀSR**			**LR**	**SR**			**LR**	**SR**		**LR**	**SR**		**LR**	**SR**	
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**
KSB13-31	7626.3	6331.8	6407.7	6788.6	40.1	16	13	23	**45.4**	35.8	32.4	52.5	53.7	47.1	2.1	10.5	20.4
KSB13-23	7542.1	5585.9	8537.5	7221.8	52.2	14	25	30	54.4	44.9	41.1	44.2	50.6	58.9	1.4	4.5	0.0
KSB13-47	7961.6	3036.6	4831.1	5276.4	48.1	9	13	23	61.3	44.7	45.0	38.6	55.3	54.4	0.1	0.0	0.5
KSB13-49	5962.3	4543.1	5161.1	5222.2	59.6	10	17	29	52.2	34.3	44.2	47.0	60.4	55.8	0.9	5.3	0.0
KSB13-55	3262.0	3497.4	7066.7	4608.7	18.4	9	17	15	40.6	42.1	32.9	59.1	57.9	60.4	0.3	0.0	6.7
KSB13-18	10736.7	4385.8	8421.7	7848.0	67.6	13	26	35	54.1	50.1	61.0	45.7	49.9	39.0	0.2	0.0	0.0
KSB13-41	6979.5	7003.9	4550.0	6177.8	39.3	12	19	23	59.2	30.9	58.2	39.9	69.1	41.8	0.9	0.0	0.0
KSB13-50	5019.2	5529.2	4949.1	5165.8	34.9	13	14	21	41.2	44.3	54.2	57.3	52.9	45.8	1.4	2.8	0.0
KSB13-34	7972.4	4923.9	7184.6	6693.6	37.5	13	18	23	56.5	51.3	36.8	39.8	47.8	63.2	3.8	0.9	0.0
KSB13-14	6721.0	6053.4	13273.2	8682.5	38.3	14	32	28	47.8	30.4	32.7	49.3	69.6	60.5	3.0	0.0	6.8
KSB13-15	7686.0	2634.1	14360.7	8226.9	48.4	5	32	29	35.2	39.8	26.4	59.6	60.2	71.5	5.1	0.0	2.1
KSB13-33	6114.2	2696.5	11322.2	6711.0	35.9	8	23	22	43.4	39.3	21.1	55.3	60.7	75.2	1.3	0.0	3.7
KSB13-46	6034.4	4424.4	5532.3	5330.4	42.8	12	17	24	49.9	47.9	47.8	49.3	50.3	50.0	0.8	1.9	2.2
KSB13-25	8282.6	4780.8	8144.5	7069.3	51.8	15	20	29	42.4	50.2	39.7	57.0	47.7	60.3	0.5	2.1	0.0

Continued: Pod yield, pod per plant and grade distribution of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

	Pod yield (kg ha^{-1})				Pods $plant^{-1}$				% Grade distribution								
									Extra-fine			Fine			Bobby		
	LR	SR			LR	SR			LR	SR		LR	SR		LR	SR	
Genotype	Kabete	Kabete	Mwea	Mean	Kabete	Kabete	Mwea	Mean	Kabete	Kabete	Mwea	Kabete	Kabete	Mwea	Kabete	Kabete	Mwea
KSB13-43	6162.8	8062.1	3414.3	5879.7	35.8	19	9	21	40.3	33.4	40.1	59.1	66.2	59.9	0.6	0.4	0.0
KSB13-32	9464.7	6489.3	4405.0	6786.3	53.8	16	15	28	56.2	43.1	57.5	43.8	52.2	42.5	0.0	4.7	0.0
KSB13-27	9073.0	4021.0	7830.4	6974.8	54.9	11	21	29	42.1	33.5	48.7	57.4	64.2	51.3	0.5	2.3	0.0
KSB13-45	4505.0	5866.4	6587.9	5653.1	33.8	13	17	21	48.7	43.1	45.9	48.7	56.6	54.1	2.6	0.4	0.0
KSB13-48	9586.4	2951.7	3228.3	5255.5	44.4	7	10	20	41.3	47.6	61.1	58.3	48.0	38.9	0.3	4.5	0.0
KSB13-30	3427.7	6740.7	10239.3	6802.5	25.9	16	26	23	47.8	42.3	33.5	52.2	56.4	63.9	0.0	1.3	2.6
KSB13-12	9450.8	4474.3	14338.9	9421.3	56.4	12	35	34	42.2	55.3	40.3	56.8	44.7	59.7	0.9	0.0	0.0
KSB13-38	6499.5	3435.3	9325.3	6420.0	36.1	10	22	23	46.2	48.8	38.5	52.0	44.9	47.8	1.8	6.3	13.7
KSB13-26	8151.9	4958.6	7823.8	6978.1	44.1	12	23	27	43.4	40.6	51.2	46.8	58.9	48.8	9.8	0.5	0.0
KSB13-37	5334.1	3655.0	10681.3	6556.8	29.9	9	25	21	47.5	47.4	37.5	51.9	44.7	52.4	0.6	7.9	10.2
KSB13-54	5600.6	4178.6	4337.8	4705.7	37.8	11	14	21	42.6	49.4	63.0	56.6	48.9	37.0	0.8	1.7	0.0
KSB13-56	4932.7	2984.5	4814.4	4243.9	39.2	7	13	20	41.1	59.1	64.6	54.9	40.9	35.4	4.0	0.0	0.0
KSB13-39	7047.7	3734.9	7958.3	6247.0	57.3	11	21	30	44.7	63.7	46.3	53.8	36.3	53.7	1.6	0.0	0.0
KSB13-24	2865.7	7647.7	11126.7	7213.4	20.3	19	24	21	62.4	45.9	47.0	37.6	53.3	44.9	0.0	0.8	8.1
KSB13-51	8863.6	3439.2	3159.8	5154.2	54.9	7	9	24	27.7	65.1	67.4	71.4	34.9	32.6	0.8	0.0	0.0
KSB13-52	5093.0	3573.6	6047.6	4904.8	47.8	11	16	25	77.0	39.5	48.6	23.0	58.5	51.4	0.0	2.0	0.0
KSB13-13	8132.3	7515.6	11236.4	8961.4	42.8	18	25	29	57.6	37.1	29.9	42.4	54.7	69.5	0.0	8.2	0.6
KSB13-22	8268.9	7703.5	6430.0	7467.5	47.7	18	18	28	44.8	40.6	43.8	53.4	57.0	54.7	1.7	2.4	1.4
KSB13-36	10502.5	5987.6	3431.3	6640.4	55.6	12	9	26	44.0	50.6	42.8	48.6	47.1	57.2	7.4	2.3	0.0
KSB13-44	6875.1	5671.0	4482.6	5676.2	38.8	12	12	21	52.3	48.8	74.5	45.0	47.1	25.5	2.7	4.2	0.0
KSB13-11	7511.3	8199.2	12968.7	9559.7	40.7	18	21	26	50.1	37.3	23.8	48.3	61.0	69.3	1.6	1.7	6.9

Continued: Pod yield, pod per plant and grade distribution of KSB13 snap bean lines grown at Kabete Field Station and Mwea during 2014 long and short rain season

									% Grade distribution								
	Pod yield (kg ha^{-1})				**Pods plant^{-1}**				**Extra-fine**			**Fine**			**Bobby**		
	[J]**LR**	[J]**SR**			**LR**	**SR**			**LR**	**SR**		**LR**	**SR**		**LR**	**SR**	
Genotype	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**	**Kabete**	**Kabete**	**Mwea**
KSB13-28	10895.3	5833.5	4100.0	6943.0	60.3	11	9	27	53.1	40.0	47.9	38.8	59.3	52.1	8.1	0.7	0.0
KSB13-19	7554.0	5729.7	10226.5	7836.7	47.1	11	18	25	55.0	30.5	25.6	42.1	54.9	61.7	2.9	14.6	12.7
KSB13-29	8844.0	4664.3	6928.4	6812.2	50.8	10	22	27	35.2	35.9	50.0	62.3	61.4	49.0	2.5	2.8	1.1
KSB13-35	9115.0	5508.3	5301.0	6641.4	48.8	14	16	26	47.6	54.2	65.3	49.2	43.2	34.7	3.1	2.6	0.0
KSB13-16	7894.5	6922.5	9740.0	8185.7	44.7	17	23	28	50.7	53.9	58.1	47.6	45.9	41.8	1.7	0.2	0.1
KSB13-42	6477.6	4287.8	7161.5	5975.6	38.4	11	18	22	46.4	40.8	42.6	53.2	50.4	57.4	0.5	8.8	0.0
KSB13-40	7440.0	4643.3	6600.0	6227.8	24.9	14	18	19	36.1	51.5	36.1	59.6	47.5	32.2	4.3	1.0	31.7
KSB13-53	8405.2	2160.9	3724.0	4763.4	54.5	9	16	26	57.3	82.6	80.0	40.7	13.7	20.0	2.0	3.6	0.0
KSB13-17	8650.8	3741.8	11626.7	8006.4	42.8	13	31	29	41.8	84.2	54.7	57.7	15.8	45.3	0.5	0.0	0.0
KSB13-20	8711.0	4585.6	9848.3	7715.0	38.7	12	19	23	63.5	62.5	30.8	35.9	31.4	68.2	0.6	6.1	1.0
KSB13-21	8808.8	4946.8	8878.3	7544.6	74.6	12	23	37	56.6	54.7	39.4	42.2	43.2	58.6	1.3	2.1	2.0
Checks																	
Julia		1434.4	3271.4	2352.9		6	15	11		96.1	100.0		3.9	0.0		0.0	0.0
Samantha	7419.4	3490.3	5144.7	5351.5	34.3	9	15	20	60.1	84.9	88.7	36.2	13.9	11.3	3.6	1.2	0.0
Serengeti		4340.0	4160.2	4250.1		14	12	13		90.9	84.3		9.1	15.7		0.0	0.0
Mean	7272.0	4535.9	6580.1		2.9	12.1	18.9										
LSD $_{0.05}$ (G) [§]	445.8	258.7	417.0		0.8	0.6	1.0										
LSD $_{0.05}$ (H) [§]	553.1	103.9	337.3		1.0	0.2	0.6										
LSD $_{0.05}$ (G X H) [§]	1789.7	773.0	1271.1		3.2	1.9	3.1										
CV (%)	22.7	1.9	12.0		19.7	0.4	8.6										

[§]G= Genotype, H= Harvest, G X H= Genotype X Harvest, LSD-Least significant difference, CV-Coefficient variation

Appendix 22: Pod yield, pod per plant and grade distribution of KSB14 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

							% Grade distribution					
	Pod yield (kg ha^{-1})			Pod $plant^{-1}$			Extra fine		Fine		Bobby	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSB14-10	8419.9	4554.6	6487.2	14	11.9	13.1	42.3	56.2	53.2	43.8	4.5	0.0
KSB14-17	5101.4	5941.7	5521.5	8	15.3	11.6	45.3	49.8	48.9	50.2	5.8	0.0
KSB14-23	6854.9	3025.0	4940.0	15	5.5	10.3	35.7	54.5	64.3	45.5	0.0	0.0
KSB14-14	10715.8	1620.9	6168.4	21	5.0	12.9	49.5	69.3	47.8	30.7	2.6	0.0
KSB14-08	7753.7	5520.3	6637.0	10	12.8	11.2	39.1	51.9	60.2	48.1	0.7	0.0
KSB14-13	5638.0	6710.8	6174.4	9	14.3	11.6	35.2	46.4	59.6	53.6	5.2	0.0
KSB14-21	7755.5	4770.9	6263.2	10	13.4	11.9	43.6	59.4	52.5	39.9	3.9	0.7
KSB14-11	5398.5	4577.3	4987.9	12	14.5	13.4	53.9	76.4	46.1	23.6	0.0	0.0
KSB14-05	7592.7	6081.5	6837.1	16	21.1	18.7	51.5	68.7	45.5	31.3	3.0	0.0
KSB14-07	5597.3	7690.0	6643.7	12	20.8	16.3	49.0	66.7	51.0	33.3	0.0	0.0
KSB14-15	4014.1	7602.8	5808.4	13	32.0	22.4	60.5	69.4	34.0	30.6	5.4	0.0
KSB14-24	2361.9	7384.1	4873.0	5	14.5	9.7	46.4	40.0	52.0	60.0	1.7	0.0
KSB14-02	10624.5	5944.5	8284.5	19	12.1	15.6	48.8	33.6	51.2	66.4	0.0	0.0
KSB14-22	4798.2	5110.7	4954.5	9	11.7	10.3	47.9	63.5	52.1	36.5	0.0	0.0
KSB14-18	4706.8	6166.7	5436.7	9	12.3	10.4	43.1	52.6	56.5	47.4	0.4	0.0
KSB14-19	6551.1	4140.3	5345.7	10	10.2	10.2	47.7	44.1	51.3	55.9	0.9	0.0

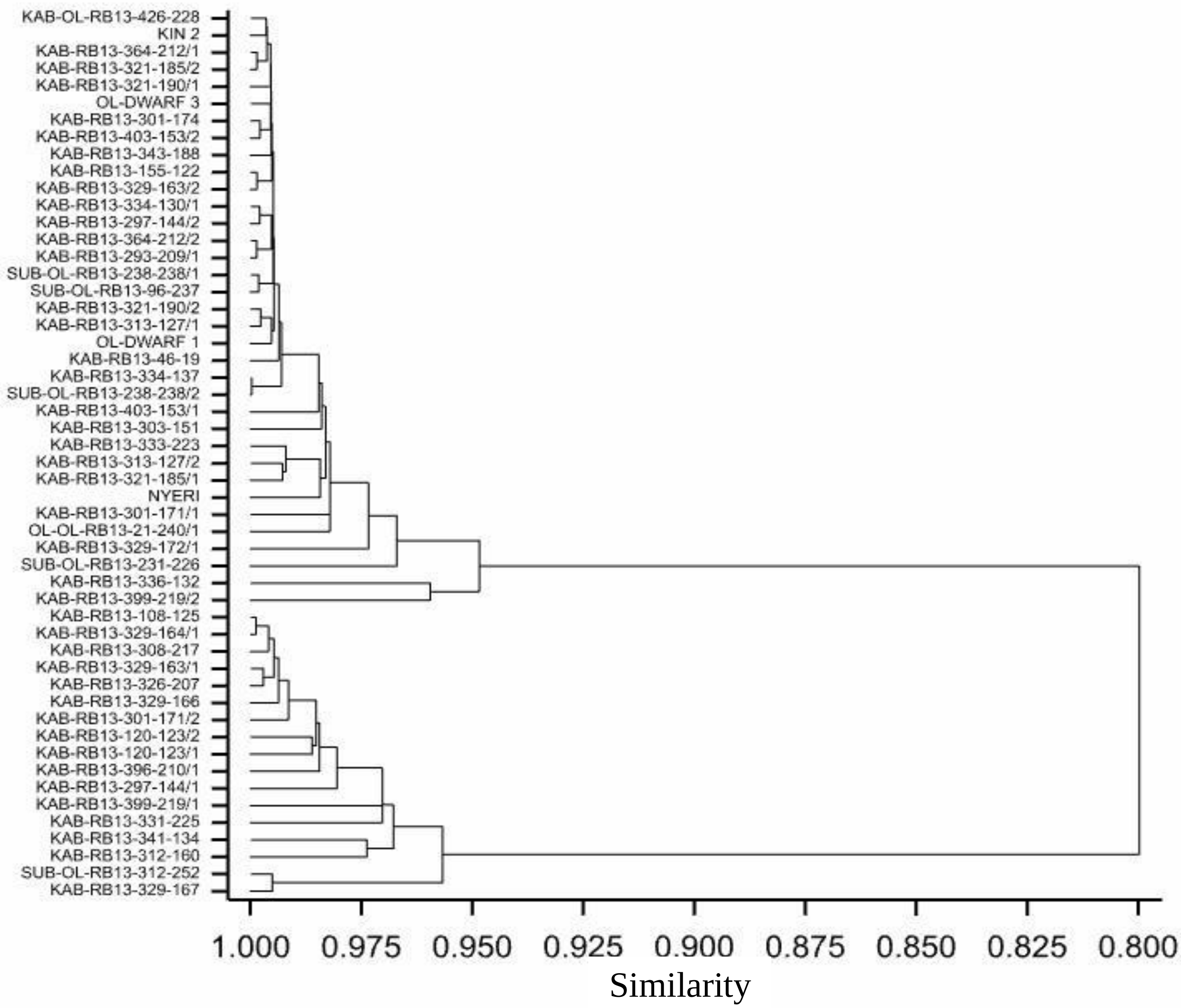
Continued: Pod yield, pod per plant and grade distribution of KSB14 snap bean lines grown at Kabete Field Station and Mwea during 2014 short rain season

	Pod yield (kg ha^{-1})			Pod plant^{-1}			% Grade distribution					
							Extra fine		Fine		Bobby	
Genotype	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Mean**	**Kabete**	**Mwea**	**Kabete**	**Mwea**	**Kabete**	**Mwea**
KSB14-04	7452.5	6319.6	6886.0	10	14.7	12.5	33.4	55.7	58.8	44.3	7.8	0.0
KSB14-06	7737.6	5613.5	6675.5	13	12.5	12.6	47.1	46.1	52.4	53.9	0.5	0.0
KSB14-16	5971.4	5343.3	5657.4	10	11.2	10.6	40.4	57.0	58.2	43.0	1.4	0.0
KSB14-12	3954.0	8527.8	6240.9	7	17.6	12.1	49.0	53.7	48.9	46.3	2.0	0.0
KSB14-20	6956.5	3335.7	5146.1	13	7.7	10.3	42.6	66.8	55.4	33.2	2.0	0.0
KSB14-27	5243.2	3891.7	4567.4	11	9.5	10.1	51.7	67.9	45.8	32.1	2.4	0.0
KSB14-26	4637.1	4833.3	4735.2	9	12.4	10.8	42.6	65.6	57.4	34.4	0.0	0.0
KSB14-01	12922.0	4242.9	8582.4	14	9.6	11.7	61.9	57.3	37.2	42.7	0.9	0.0
KSB14-25	6516.6	3179.9	4848.2	11	7.0	8.9	34.1	73.7	65.7	26.3	0.2	0.0
KSB14-09	8294.6	4800.9	6547.8	13	9.9	11.5	46.2	62.5	51.8	37.5	2.0	0.0
KSB14-28	4538.3	1983.1	3260.7	9	4.8	6.8	43.2	67.8	55.9	32.2	0.9	0.0
KSB14-03	6266.1	9698.2	7982.1	10	18.0	14.1	40.3	36.9	54.7	63.1	5.0	0.0
Checks												
Julia	3834.5	1400.0	2617.2	11	2.8	7.0	87.0	40.7	13.0	59.3	0.0	0.0
Samantha	5180.2	3638.6	4409.4	12	13.2	12.6	63.1	97.8	36.9	2.2	0.0	0.0
Serengeti	7961.7	5744.4	6853.1	16	13.8	14.7	67.0	70.6	31.5	29.4	1.4	0.0

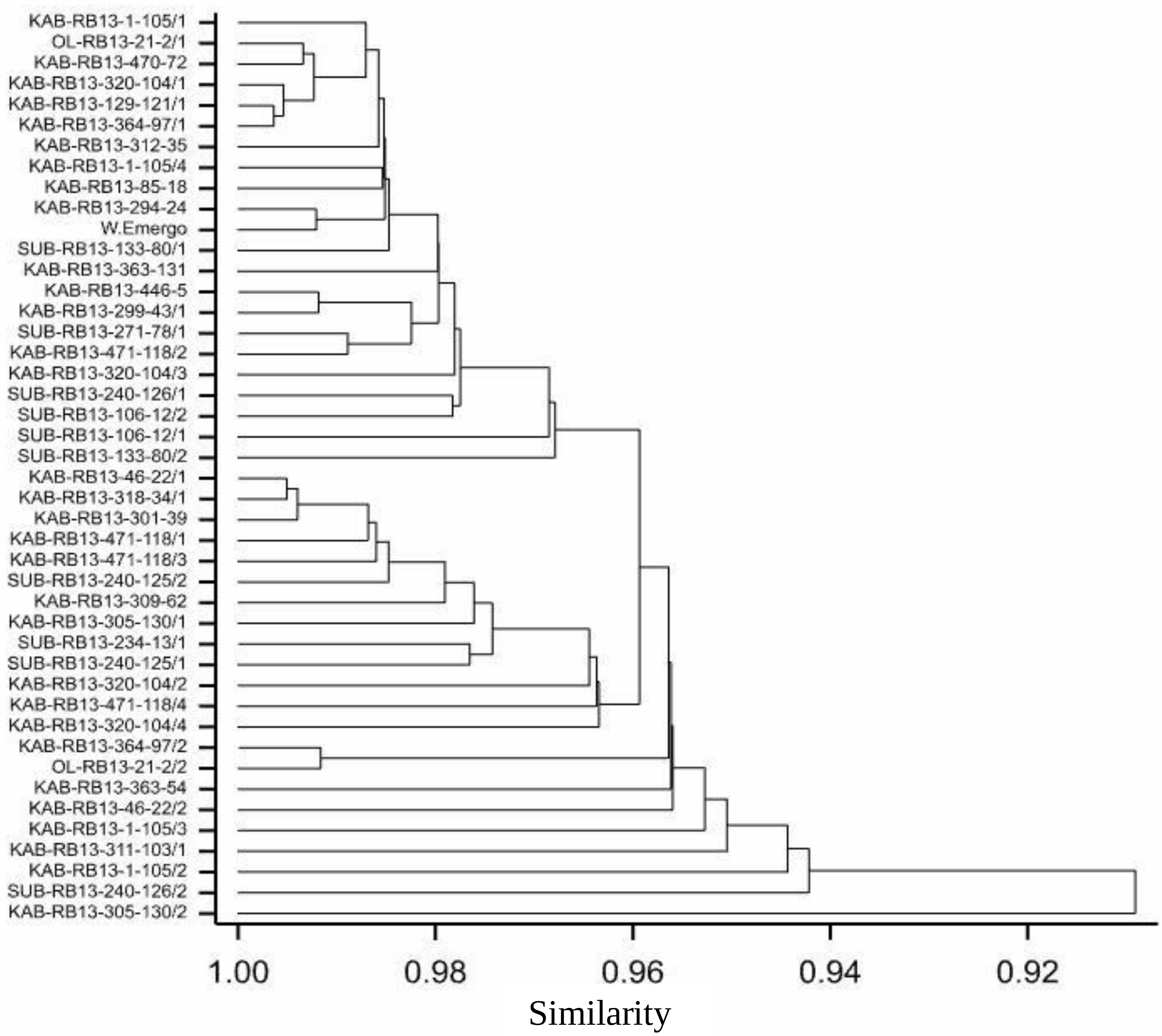
Mean	6163.9	4643.6	11.7	12.7
LSD $_{0.05}$ (G)	370.9	287.6	1	0.8
LSD $_{0.05}$ (H)	175.3	219.5	0	0.5
LSD $_{0.05}$ (G X H)	1104.7	869.1	2	2.3
CV %	3.1	15.2	7	13.1

G= Genotype, H= Harvest, G X H= Genotype X Harvest, LSD-Least significant difference, CV-Coefficient variation

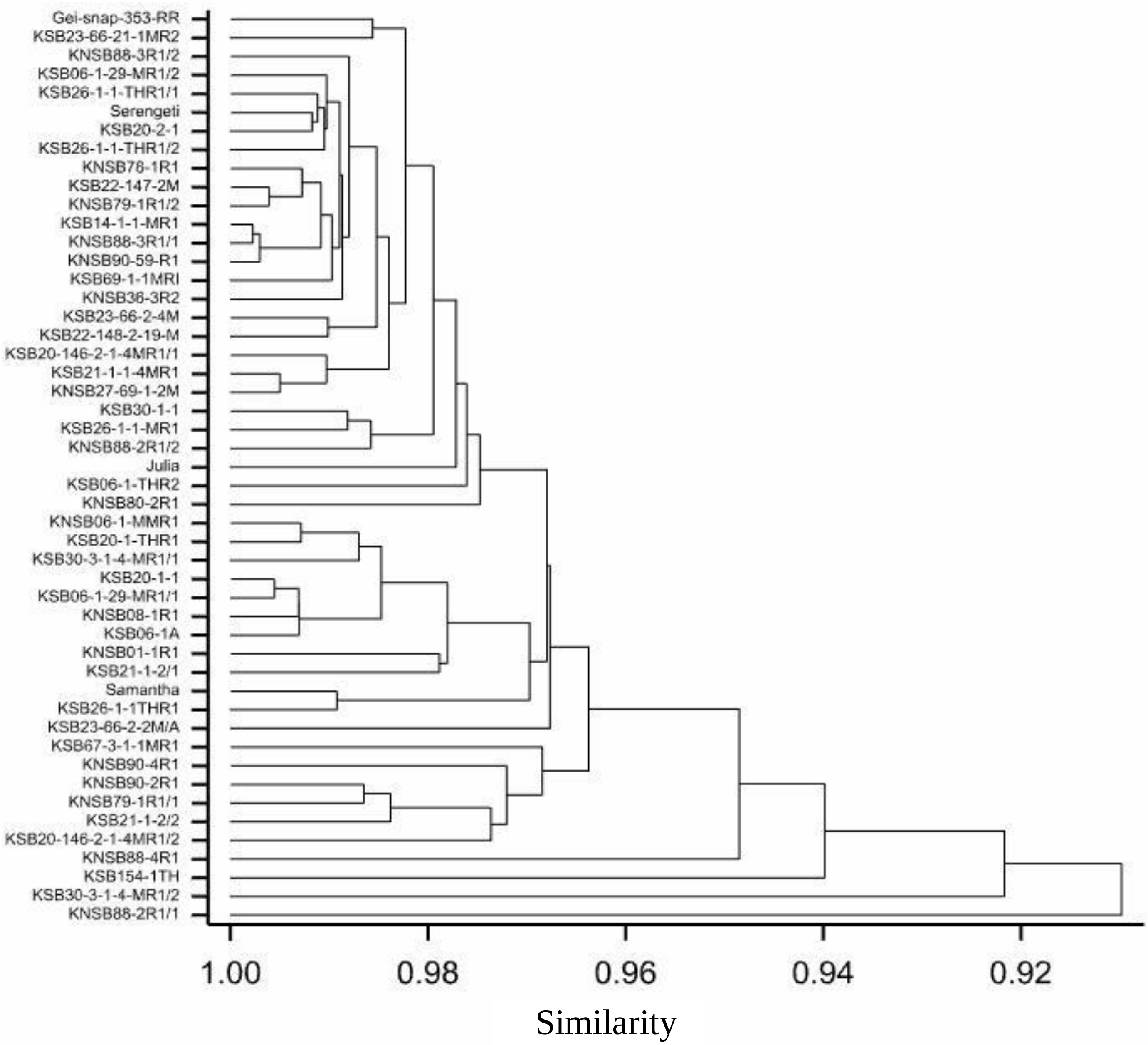
Appendix 23: Grain runner bean dendrogram of the results of running data through single linkage (minimum dissimilarity).



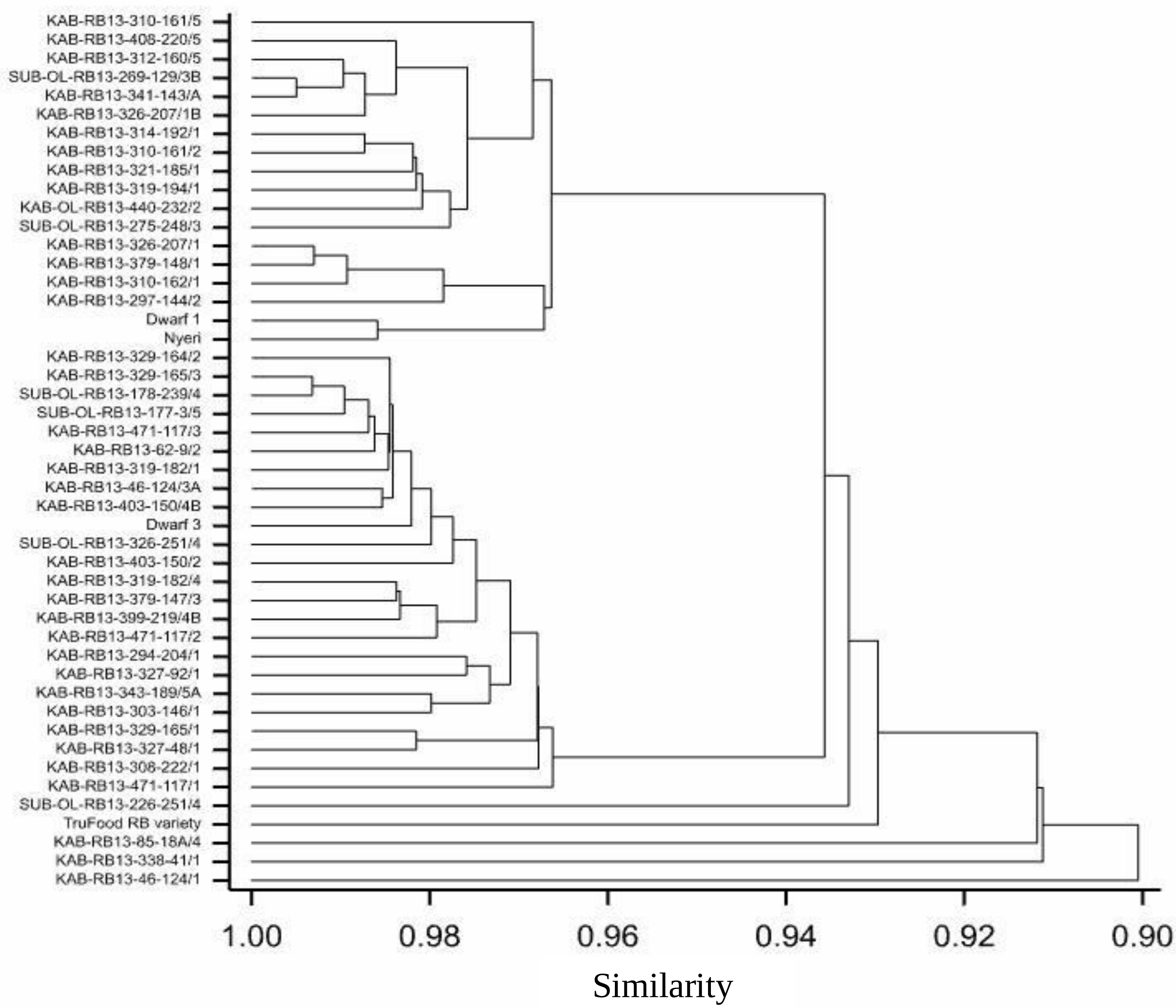
Appendix 24: Vegetable runner bean dendrogram of the results of running data through single linkage (minimum dissimilarity)



Appendix 25: Snap bean dendrogram of the results of running data through single linkage (minimum dissimilarity)



Appendix 26: Grain runner bean canning quality dendrogram of the results of running data through single linkage (minimum dissimilarity)



Appendix 27: Snap bean canning quality dendrogram of the results of running data through single linkage (minimum dissimilarity)