Management of Aphid vectors of virus diseases on commercial potato (*Solanum tuberosum* L.) cultivars in Kenya

Luiza M. Munyua, B. Sc. (Agric) (Nairobi)

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Declaration

I hereby declare that this thesis is my original work except where acknowledged and has not been presented for the award of a degree in any other University.

Luiza M. Munyua, B.Sc. Agric (Nairobi)

Department of Plant Science and Crop Protection

University of Nairobi

Signature..Date 20/07/2007..................................

Supervisors

This thesis has been submitted for examination with our approval as University Supervisors.

Dr. F. M. Olubayo (B.Sc. Agric, M.Sc., Ph.D)

Department of Plant Science and Crop Protection

University of Nairobi

Signature..Date 20/07/2007........

Prof. J.H. Nderitu (B.Ed., M.Sc., Ph.D)

Department of Plant Science and Crop Protection

University of Nairobi

Signature..Date 20/7/07..................................

Epigraph

"A journey of a thousand miles begins with one step"

(Chinese Proverb)

Dedication

To my heavenly Father

For His peace, presence and provision throughout my studies

To my parents, Prof. W. K, Munyua and Mrs. M. N. Munyua

For their never ending love, support, encouragement;

For never giving up on me.

I am forever grateful

Psalms 111[10] The fear of the Lord is the beginning of wisdom;

all who follow His precepts have good understanding.

To Him belongs eternal praise.

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ABSTRACT

Aphid resistance in the potato (*Solanum tuberosum* L.) crop is one of the methods of managing aphid pests in potato production, which are also known vectors of virus diseases. Results from field experiments using 18 commercially available potato varieties to evaluate varietal differences to aphid infestation indicated that *Aphis gossypii*, *Macrosiphum euphorbiae* and *Myzus persicae* species infested the potato crop. *A. gossypii* and *M. persicae* were the most and least abundant species respectively. *A. gossypii* and *M. euphorbiae* differed significantly (P=0.05) in times of sampling and among treatment means. Kerr's Pink and Anett had the highest infestation of *A. gossypii* and *M. euphorbiae.*

Desiree supported the highest population of *M. persicae* while Roslin Tana was the least infested variety. Kerr's Pink, Desiree and Anett can be considered as susceptible varieties and Roslin Tana as relatively aphid resistant. All other varieties were moderately infested and can be considered as moderately susceptible. Mavuno and Desiree varieties had high incidence of Potato leaf roll disease while Tigoni and D.Robyjn varieties had low disease incidence. There was no correlation of time of aphid infestation and the incidence of Potato leaf roll disease, hence the aphids present on the potatoes may not have been responsible as vectors in the transmission of the virus observed on the potatoes. Potato leaf roll disease may have been introduced to the potatoes from alate viruliferous vectors and not from apterae aphids present in the potato crop.

Total yields were highest in Nyayo, Asante and Tigoni varieties, which supported low aphid populations. Mavuno and Desiree recorded relatively low yields. Aphid resistant and moderately susceptible varieties are therefore recommended to farmers, as these are more likely to support low aphid populations and low viral incidence.

Several years of seed multiplication may be lost if attention is not paid to aphid dissemination of viruses during storage. *M. euphorbiae* populations on the sprouted Tigoni and Asante potatoes in the store were observed to increase from the onset of the study. With ideal temperatures and relative humidity, the aphid populations multiplied rapidly with new generations being formed within a period of two weeks. Since aphid population increased throughout the storage phase, stringent aphid and viruses control measures need to be put in place to reduce seed degeneration. It is recommended that specific control measures be implemented and adopted for specific aphid species on specific potato cultivars. This would target the reduction of aphid infestation over the growing period of the crop when the aphid species is known to infest over and this would in turn lower the virus load present in the seed potato over time.

CHAPTER 1

NTRODUCTION AND LITERATURE REVIEW

.1 Introduction

l.1.1 The potato plant

The potato (*Solanum tuberosum* L. and other tuber producing species of *Solanum*) originated in the high Andean region of South America. It is the most important species in the solanaceae family, which includes tobacco, tomato, pepper and eggplant. More than 200 species of potato have been found but just eight are cultivated (Huaman, 1986). The potato ranks fourth in the world in economic importance with the potential of meeting requirement of the world and is used for human consumption, animal feed and as a source of starch and alcohol (Purseglove, 1968; Dickey *et al*., 1974; Horton, 1992). It also has an excellent food value. Commercial propagation of potato is normally done vegetatively using seed tubers. Potato is one of the major food and cash crops grown in Kenya Highlands in areas between 1200-2800 masl and receiving an average annual rainfall of 850-1200mm. It plays an important role in feeding the population as well as being one of the main agricultural based sources of income for low-income families.

Potato varieties differ in the length of time required to reach maturity. Those of subspecies *andigena* usually have a longer vegetative period (4 to 6 months) than those of subspecies *tuberosum* (3 to 4 months). The potato's growth cycle has three stages: pre-emergence/emergence, vegetative growth and tuber development. These stages are however not clearly sequential, rather, they overlap during development. The potato can be grown at latitudes that have 12 to 16 or more hours of daylight. Most varieties require moderate ambient temperatures (preferably not higher than 25°C) during the day and low temperatures during the night to stimulate tuberization (soil temperatures of 15-18°C are the most favourable). The potato plant is very susceptible to drought conditions because of its shallow root system. Therefore, the crop requires frequent irrigation. The crop develops well in deep and freely drained light to medium textured soils. Potato responds well to organic and mineral fertilization.

Potato is the second most important food crop after maize in Kenya especially in Central, Eastern, Rift Valley, Western and Nyanza provinces, currently occupying 108,000 hectares planted by about half a million farmers. Kenya produces close to 1.2million tonnes of potato annually with an estimated turn over of Ksh5 billion (MOA, 2003). The total production is 670,300 tonnes annually (Ng'anga *et al.*, 2002) on 93,000 ha (FAOSTAT, 2002). Production has steadily been increasing from some 241,000 metric tons in 1990 to one million metric tons in 2002 (FAOSTAT, 2003).

Potato in Kenya plays a major nutritional role comparable to that of cereals. It's popularity as a food crop in Kenya is due to its palatability, ease of cooking and convenience. The tuber is highly nutritious and 100g of edible portion contains' 80% Water; 2.1g Protein; 76 kcal Food energy; 27 Protein/calorie ratio (g/000kcal); 0.1g Fats; 0.9g Ash; 7mg Ca; 53mg P; 0.6mg Fe; 3mg Na; 407mg K; 0.09mg Thiamine; 0.04mg Riboflavin; 1.5mg Niacin and 16mg Ascorbic acid (Horton, 1987; Cit. Wheatley *et al.*, 1995). Among the staples, potato is perhaps the richest source of total niacin. Minerals and trace elements in the potato provide a moderate source of iron, a good source of phosphorous and magnesium, and a rich source of potassium. Its low sodium content is useful in salt-free diets (Bradshaw *et. al.*, 1994).

About 35-40% of Kenya's population consumes potatoes regularly. Consumption of the potato in Kenya is limited to rural areas in the central highlands and to urban centers. Per capita consumption is highest in producing areas, where it is estimated at 70-100 kg per year; in urban centers in Kenya, per capita consumption is estimated at 50kg per year (Durr, 1976). The demand for French fries (chips) and potato crisps is increasing rapidly in Kenya (Kabira, 2000). The long oval white varieties (Nyayo and Roslin Tana) are the most popular for French fries while the round red-skinned types (Kerr's Pink and Dutch Robyjn) are commonly used for crisps. Red skin colour such as that of Asante is usually associated with good quality by Kenyan consumers (Durr and Lorenzyl, 1980). The good storability potential of Asante is an additional favourable characteristic when the variety is grown for distant markets (Walingo *et al.*, 1996).

The crop is grown twice per year coinciding with the rainfall pattern. Potato cultivation is particularly favourable at high altitudes where maize, the major food crop performs poorly. The most important areas suitable for potato production in Kenya are: Molo and Mau Narok (2100-2700m) in Nakuru District, Rift Valley Province, the Western parts of the Aberdare, Ol-Kalou and Kinangop (1500-2100m), Central Province, and the North and Eastern slopes of Mt. Kenya in Meru (2100-2700m) and Embu (1500-2100m) districts (Were, 1996). On the Western parts of the highlands (Uasin Gishu) and the

Western Province, potatoes are grown only to a limited extent although climatic conditions are favourable (Ballestrem *et al.*, 1980).

1.1.2 Production constraints

Lack of quality seed potatoes among growers is still a major problem adversely affecting the expansion of potato production in Kenya (Were, 1996; Crissman *et al.*, 1993; Kinyae *et al.*, 1994). Non-availability of quality seeds and inadequate seed production technologies for smaller holder farming has contributed to below potential agricultural growth. Government programmes have produced small amounts of certified seed for blight resistant varieties but these have not been widely accepted due to their long maturing time, poor marketability, expensive and difficult to obtain in time for planting.

Prices of potato fluctuate according to the seasonality of supply and are particularly low during harvesting time. Consumers prefer certain red-skinned varieties, and these have about 30% higher prices than white skinned varieties. Results of an earlier study indicated that processors are very selective on the type of potato varieties they are prepared to buy (Haugerad and Kimani, 1995). Yields are generally low. An average yield level of about 5 ton/ha has been maintained since the crop was introduced in the country although yields of more than 20 ton/ha are achieved as well (MOA, 2000). Kenya does not import potatoes but has few informal exports across the border with its neighbours. Prevention of post harvest losses and improvement of processing and marketing would help increase the sector's output. There has been a decline in area harvested countrywide: 94153 Ha in 1997 to 93000 Ha in 2001 (FAOSTAT, 2001). Low yields are attributed to intensive and continuous cultivation, declining soil fertility, various diseases and the poor quality of seed potatoes used by growers leading to increased diseases and pests build-up and consequently, low yields and poor quality tubers.

The potato crop is susceptible to more than 300 pests and diseases (Horton, 1992). The most important potato disease in the world is Late blight caused by *Phytophthora infestans* (Mont de Bary) (Mulakazi *et al.*, 2000). Bacterial wilt caused by *Ralstonia solanacearum* is another important endemic disease in humid regions and the lowland tropics. Diseases rank high among the factors limiting potato production in Kenya with fungi and bacteria being known for their association with reduced yields. Critical studies conducted on viral diseases on potato show that viruses may be equally important in yield reduction in potato fields free of fungal and bacterial diseases (De Bokx, 1972).

Among the most important insect pests is the Potato tuber moth (*Phthorimaea opercullela* Zeller) (Ngugi, 1983) and Aphids, as pests and vectors of different viruses. Potato tuber moth, which is both a storage and field pest, is seriously threatening potato production. Aphids are known vectors of many virus diseases that cause degeneration of potato seeds. Some of the aphid species that colonise potatoes are *Myzus persicae* Sulzer, *Macrosiphum euphorbiae* Thomas, *Aphis gossypii* Glover and *Aulacorthum solani* Kaltenbach which were also known to transmit viruses like Potato leaf roll, Potato virus Y and Potato virus X. The aphid complex on potatoes is of great economic importance to potato production.

The important nematodes in potato production are *Globodera* sp., the cyst nematode and *Meloidogyne* sp., the root knot nematode (Salazar, 1996). Other insects like the ladybird beetle *Epilachna hirta* Thnb., American bollworm, *Heliothis armigera* Hb. and green semi-loopers *Plusia orichalcea* F. are leaf defoliators which may occur during some seasons, assuming epidemic proportions.

Weeds can also be alternate hosts for some potato pests and diseases. Aphid vectors of potato viruses can live on a wide range of weed species which also increased infection of potato crops with black scurf disease caused by *Rhizoctonia solani* (Griesbach and Eisbein, 1975).

1.2 Literature Review

1.2.1 Potato aphids

Aphids are the insect pests of greatest economic importance on potato worldwide. Their primary importance is as vectors of virus diseases and high infestations of these pests can result in substantial losses (Anon, 1983). Aphids are known to cause direct injury to potato and also transmit viral diseases that decrease potato yield by as much as 80% in some cases (Goffinet, 1982). Although the classification of aphids is not clearly defined, most virus vectors belong to the family Aphididae, except *Phylloxera vitifolii* from the family Phylloxeridae, which is known to transmit grapevine-mottling virus (Eastop, 1977). Most important is the green peach aphid, *Myzus persicae* (Sulzer), a cosmopolitan pest of solanaceous plants. Other important potato infesting species include potato aphid, *Macrosiphum euphorbiae* (Thomas); buckthorn, *Aphis nasturtii* (KLTB); foxglove aphid (glasshouse aphid), *Aulacorthum solani* (Kalt); cotton aphid, *Aphis gossypii* (Glover) and stolon-infesting *Rhopalosiphum latysiphon*. Other species of minor importance associated with potato are *Aphis fabae, Aphis craccivora* (Koch), *Myzus ascalonicus, Myzus ornatus, Aulacorthum circumflexum, Rhopalosiphum padi, Lipaphis erysimi, Acrythosiphum pisum* Harris and *Rhopalosiphum pisum* Kalt (Lian *et al*., 1994; Hansen, 1995; Nakata, 1995; Karimullah *et al*., 1995; Raman, 1987; Difonzo *et al*., 1997; Stoltz *et al*., 1997; Berlandier, 1997; Duvauchelle and Dubois, 1997; Tahtacioghu and Ozbek, 1997; Seyedoleslaami *et al*., 1995).

The most important and common aphid vector species in Kenya are *M. persicae, M. euphorbiae, A. solani* and *A. gossypii* (Robertson and Wambugu, 1975). The species prevalence varies in different parts of the country. Nderitu and Mueke (1986a), reported heavy infestations by *M. euphorbiae* and to a less extent by *M. persicae. M. persicae* is by far the most prominent virus vector and is widespread wherever potatoes are grown in Kenya (Gibson, 1974). In the field, potato cultivars display different levels of aphid infestation (Nderitu and Mueke, 1986a and Were *et al*., 1996). Among the six most popular cultivars grown in Kenya, only Roslin Tana was found to be relatively resistant to aphid infestation (Nderitu and Mueke, 1986b). Aphids are also reported to occur on potato tuber sprouts under storage conditions. Three major potato aphids *Aulacorthum solani, Myzus persicae* and *Macrosiphum euphorbiae* were identified in farmers' stores in Kiambu and Nyandarua districts (Kibaru, 2003). *A.solani* was the most abundant (53.1%) while *M. euphorbiae* had the lowest numbers (31.3%). In all the stores where the aphids were recorded, Potato leaf roll virus (PLRV) and Potato virus Y (PVY) were also serologically detected from the potato sprouts (Kibaru, 2003).

The degeneration of seed potato is correlated to the initial appearance, population build up and vector activity of the main aphid vectors. Assessment of aphid populations and virus disease incidence on the seed potato crop is useful as a management tool for the virus and aphid problems (Cerato *et al.*, 1994; Parker, 1997) and is important for deciding where, when and how to grow and protect seed potato crops. Sticky traps, yellow water traps and leaf samples have been used to assess aphid populations on potatoes in many parts of the world (Seyedoleslaami *et al.*, 1995; Nakata, 1995; Rongai and Cerato, 1997; Duvauchelle and Dubois, 1997). The aphid populations may be the best indicator of the risk of virus spread in the potato crop (Difonzo *et al.*, 1997). Counts of the numbers of aphid individuals on 100 leaves taken at the middle of potato stems gave a good representation of the numbers and proportions of the different species of aphids present on the crop. Alate aphids monitored by sticky traps and yellow water traps are the most important indicator of virus spread from long distance farms by viruliferous alate aphids. Aphids cause damage but the damage may be insignificant, the exception being “top roll disease” which results from feeding by *M. euphorbiae* (Gibson, 1974).

1.2.2 Biology of potato aphids

The behaviour of aphids on the plant, their biology, and other factors such as environmental conditions and the activities of natural enemies determine the type and amount of virus they can transmit (Salazar, 1996). Increasing our knowledge of the ecology, ethology, and biology of the pest is important for developing better strategies for its control and for resistance management (Barbagallo *et al*, 1972).

All potato-colonizing aphids have four nymphal instars. Their parthenogenetic lifestyle coupled with a rapid turnover of generations, typically 7-10days, allows for spectacular population increases (Raman, 1987).

In most potato growing areas, *A. solani* is one of the most economically important pests and causes injury either directly by their feeding punctures sap-sucking or indirectly by spreading virus diseases. The biology of *A. solani* is complicated, as is the case in some of the most important aphid pest species, by the occurrence of numerous races or subspecies, including some with particular host-plant associations. Holocyclic (host alternating, with sexual reproduction during part of life cycle) *A. solani* have either apterous or (more rarely) alate males, and the unusual ability to overwinter as eggs on many different host plant species. Eastop (1953) stated that sexuales of *A. solani* are not known in Africa. One generation takes about two weeks in favourable weather conditions.

M. persicae is a major pest everywhere potatoes are grown. It is the most important vector of potato leaf roll virus, which causes leaf roll and tuber rot necrosis. Seed potatoes have low tolerance for PLRV and low aphid populations can be very damaging (van Emden *et al*., 1969). It is usually anholocyclic in the tropics and sub-tropics. In laboratory experiments, low temperature promoted, while high temperature tended to suppress the development of winged forms of *M. persicae*. (Kuo, 1991) described development and reproduction of *M. persicae* on radishes and potatoes at six constant temperatures (5-30 ^{0}C) in the laboratory. *M. persicae* is relatively cold resistant. Wingless parthenogenetic females produce 30-80 progeny each. Higher growth rates have been observed in the virus-infested plants. The average life span is about 18 days in warm temperatures. Longevity may be affected by temperature, type of life cycle and plant host. Studies in cooler temperatures report the life cycle lasting up to 50 days with nymphal development being completed in 6-11 days (Toba, 1964).

The most dangerous activity of the potato aphid (*Macrosiphum euphorbiae*) is the transmission of phytopathogenic viruses especially the potato virus Y (PVY) and the beet yellows virus (BYV). This species is very polyphagous and cosmopolitan. Aphid colonies increase rapidly and can double in less than 3 days with the number of nymphs varying between 30-50. During warm weather, each of these nymphs matures in 2 or 3 weeks. Each unmated female may give birth to 50 or more active nymphs within 2 weeks. A generation develops on potato every 2 or 3 weeks.

1.2.3 Potato viruses

More than 30 viruses infect potatoes of which five or six are important (Khurana, 1992; Singh and Khurana, 1993). The losses due to viruses are usually quantitative but some cause qualitative losses as well. Yield losses in potato due to one or more virus (es) infecting potatoes vary from low to very high (Garg, 1987); Khurana and Singh, 1988). Infections by Potato virus Y (PVY) and Potato leaf roll virus (PLRV) have the potential to reduce yields up to 60-80% while mild viruses like Potato virus X (PVX), Potato virus S (PVS), Potato virus M (PVM), also decrease the yields by 10-30% in infected plants. Potato viruses and viroids cause economic damage not only due to crop losses but also affect seed quality and seed trade.

Direct losses due to viruses in potato production are rather difficult to assess because of too many variables in the field and especially the compensatory effect of healthy plants in the vicinity of mildly or severely infected plants. The virus-free seed stocks also become rapidly re-infected upon field multiplication done without much care or in unsuitable areas for seed production, due to infected volunteer plants, high vector activity and careless intercultural operations. Degeneration of seed stocks due to viruses and virus-like symptoms is common. If seed stocks are not maintained well, or not frequently replaced with fresh ones, the virus infiltration reaches almost 100% level within 3-4 successive crops (Khurana, 1992 and 2000).

Potato viruses are either contagious and/or aphid transmitted. Normally, combined infections of two or more important viruses are found in a plant causing either mild or severe mosaics and/or leaf roll. The spread of viruses in the field is not uniform but often limited to patches. Use of infected seed tubers is the main reason for the spread of potato viruses from one place to another. Contagious viruses, namely PVX and PVS are readily spread upon contact of plant foliage and roots in the field as well as upon injury/cutting of the tubers. PVY and PLRV spread either through alatae aphids from far off fields or within the field by viviparous apterous aphids, especially *Myzus persicae* (Salazar, 1996; Jayasinghe *et al*., 1989).

In the field, one can easily recognise viral disease symptoms. But not all viruses cause severe/clear symptoms nor is it true that the same symptoms appear in all varieties for the virus. Symptoms depend mainly on the host, weather and the virus involved. Therefore, for seed production, it is important to detect viruses in low concentration prior to their symptom expression. Visual field inspection for symptoms is the oldest and easiest way to rogue out the diseased plants. Counting the number of plants showing disease symptoms certifies the crop health or standard of the seed. Even in the absence of obvious symptoms, plants may be stunted and tuber production may be reduced (Hanafi, 1998). Using healthy seeds and planting undamaged whole tubers are important controls.

Potato leaf roll virus is the most important viral disease affecting potato crops in developing countries (Peters and Jones, 1981). It is particularly troublesome in tropical and subtropical areas where aphid populations tend to be extremely high throughout the year (Were, 1996). Upon transmission by aphids, PLRV symptoms appear mainly in the young leaves, which usually stand upright, roll and turn slightly pale. Rolling sometimes affects the base of the leaflets rather than the whole leaflets. These symptoms may spread later to lower leaves. Leaves appear thick, leathery, and brittle in texture and crackle when squeezed in the hand (Singh and Khurana, 1993). Symptoms appear one month after planting or when plants are about six inches high. Secondary infection is more damaging to the plant than primary infection and severity depends on the isolate of virus, potato cultivars and environmental conditions (Were, 1996). PLRV infection results in stunted chlorotic plants with top young leaves standing upright with pale rolling leaflets, often with pink-reddish margins. Older leaves are stiff, dry, leathery and rolled like paper, with pink to brownish margins. Plants infected late in the season usually remain asymptomatic, but tubers produced by these plants develop net necrosis, unless they are immune to this phase of the leaf roll syndrome (Were *et al.*, 1996). Aphids are the sole vectors for transmission and natural spread of the virus (Jayasinghe, 1988). Several aphid species may transmit PLRV but the green peach aphid (*Myzus persicae*) is the most important vector and transmits PLRV persistently (Harrison, 1984). PLRV is disseminated by planting material (tuber borne) and is efficiently transmitted and spread in the field by aphids colonising potatoes, *M.persicae* being the most efficient vector. Research at the International potato Center (CIP) has shown that tubers in storage can also become completely infected by aphids feeding on the sprouting tubers (Jayasinghe, 1988).

1.2.4 Management of potato aphids and virus diseases

Control of vector spread is the most effective way to reduce virus diseases in potato production, because eliminating viruses from the infected plants is not feasible. Virus ecology should be considered as the logical basis for applying virus control methods (Harrison, 1981). This emphasis becomes even more important in tropical countries, where the main focus is still on identifying viruses that affect crops. Establishment of a virus at a particular site depends not only on the host but also on the total biophysical environment or ecosystem.

Various measures are recommended in order to produce virus free seed potatoes. Cultural practices such as growing of seed potatoes during periods of zero tolerance or reduced aphid population; avoiding alternative hosts of aphids that include carrots, cotton, peppers, egg plants and tobacco in the proximity of potato seed crops; roughing diseased plants as the crop approaches maturity to avoid infestation by aphids and infection by potato virus diseases (Ioanou, 1988; Woodford and Gordon, 1990; Agrawal and Misra, 1992; Kim *et al*., 1992; Lian-Yong *et al*., 1994; Difonzo *et al*., 1996). In most situations the control of aphids is an indirect management of viruses that are transmitted by aphids. Control of aphids by insecticides has in some occasions reduced viruses such as Potato leaf roll and Potato virus Y (Boiteau *et al*., 1988; Woodford and Gordon, 1990; Riekman, 1995; Nisbet *et al*., 1996; Collar *et al*., 1997; Thomas *et al*., 1997). A careful selection and combination of border crops, pesticides and monitoring aphid population using sticky traps can make a significant contribution to aphid and virus management in seed potato production. However, any strategies developed for aphid and virus management must have minimal extra expense, labour demands or disruption to the farmer's normal practices, to be successful (Kibaru, 2003).

Mineral oil and Neem products reduced virus transmission efficiency by *Myzus persicae* (Ji and Pirone, 1989; Powell and Picket, 1998; Heuvel *et al*., 1998). However, over-reliance on insecticide use in the control of aphids has caused insecticide resistance (Harrington *et al*., 1989; Rongai *et al*., 1998; Duvauchelle *et al*., 1997). Differences in susceptibility of some potato clones and commercial varieties in aphid infestation in Kenya have been noted (Nderitu and Mueke, 1986a; Were *et al*., 1996). However, cultivars that have some degree of aphid resistance may be of little value, as frequent probing could be stimulated, which is unfavourable with regard to the dispersal of non-persistent viruses (Harrewjin, 1989). Resistant genotypes to PLRV are known to reduce feeding, growth and development rate to *Myzus persicae* (Barker and Woodford, 1992; Castle and Berger, 1993; Jayasinghe *et al.*, 1993). Some potato genotypes have some tolerance to virus diseases (Difonzo et al., 1995). Certain potato varieties in Kenya are reported to be less susceptible to infection by a particular virus than others (Ballestrem and Holler, 1974; Were *et al.*, 1996). The spread of PLRV and PVY which are aphid-borne virus diseases seriously affecting potato production, could be decreased by the use of resistant potato genotypes.

Monitoring the presence of viruses just after emergence and again 45 days after emergence, infection rates greater than 3% just after emergence indicate that there is a serious problem of viruses in the seed potato crop (Rongai and Cerato, 1997). A rapid spread of PLRV has been observed in plots with a point source of the virus, in the presence of aphid infestation (Thomas *et al.*, 1997).

Parasites and predators attack aphids on potatoes and reduce their numbers (Ray, 1989; Kish et al., 1994; Stoltz *et al.*, 1997; Tae and Long, 1998). The natural enemies identified are *Aphidius nigripes, Coccinella septempuncta and Menochilus sexmaculatus (Cheilomenes sexmaculata).* The effect of predation of ladybird beetles on the population of aphids on potatoes has been evaluated (Dogan *et al.*, 1996; Branquart *et al.*, 1996; Lagnaoui and Radcliffe, 1998; Birch *et al.*, 1999).

1.2.5 Resistance/ Tolerance to aphids and virus diseases

Plants with resistance to infection and infestation do not become easily infected, and high levels of inoculum or viruliferous aphid numbers are required for successful infection or infestation (Walkey, 1991). Resistance to infection depends on environmental conditions especially temperature, nutritional status, and health status of the plant. Plants infected with PVX, PVY are in general more susceptible to PLRV and PLRV resistant varieties may loose the resistance capacity (Rich, 1983). In plants with resistance to virus multiplication, virus concentration is lower than in susceptible plants. Usually plants show mild or no symptoms at all and yield losses may be less severe than in susceptible plants. Nevertheless, the infected plants continue to be sources of infection that are more difficult to identify and eliminate (Jayasinghe, 1988). Folson and Stevenson (1946) recognized that some cultivars and seedlings are more resistant than others.

Were (1996) observed that inoculation of PLRV at early stages of 2-5 weeks after plants emerged, adversely affected tuber weight, number of tubers, length and diameter of the first tuber. Variety Roslin Eburu (B53) showed a high percentage of leaf roll infection followed by Kerr's Pink while Annet showed some degree of tolerance. PLRV has been found not to significantly reduce the total number of tubers on the plants; but reduced the marketable tuber number and weight. Reduction due to PLRV infection is due to reduction in light intercepted due to leaf rolling (Were, 1996). Nderitu and Mueke (1986b) reported Roslin Tana to be resistant to aphid infestation.

Some plants genotypes have mechanisms that affect the normal activity of vectors. One of these is apparently of a physical nature in which foliage pubescence avoids infestation by trapping and immobilizing insect that feed on the foliage. Gibson (1971) noted that potato species *S. berthaultii* had large amounts of secretory pubescence. When insects come into contact with these exudates it accumulates in the tarsus of the insects thus preventing movement or "sticking" it to the leaf surface. The exudate also accumulates in the mouthparts thus preventing feeding and subsequent death of the insect. This mechanism is important in controlling the spread of viruses by *Myzus persicae* and *Macrosiphum euphorbiae.* Antibiosis includes all adverse effects within the plant that alter the biology of the vector. Factors such as growth and multiplication rate, number of nymphs produced as well as death of the insect are involved in antibiosis. Antixenosis or nonpreference is the repellent action of a plant toward an insect. This can result from toxins or volatile compounds released by the plant (Gibson, 1971; Salazar, 1996).

1.3 Justification

In Kenya, healthy seed potato is a costly input but key to increasing ware potato production (Anon., 1998). The formal seed potato supply has not been efficient in the delivery of significant quantities of good quality seeds to farmers. As a result, farmers use their own or seed purchased from the local market. The farmer-based seed production scheme is an attempt to alleviate the scarcity of good quality seed tubers to the small-scale farmers.

Knowledge on aphid species infesting potato in the fields and which of those are known vectors of virus diseases is needed to develop management strategies that minimise virus spread. There is need for continued effort in the search for strategies that will enable the farmers to produce virus free seeds in the country. Affordable aphid management methods will be an added advantage to the farmers' efforts to produce virus free seed potato. Proper seed storage is necessary for the establishment of a viable and sustainable agricultural system. Aphid infestation of stored seed tubers and their importance in disseminating viruses during the storage phase to healthy tubers poses a major threat to seed quality. Degeneration of seed potato in stores occurs within short storage periods in unprotected seeds due to virus infections. Tubers in storage can also become completely infected by aphids feeding on the sprouting potatoes.

Studies of vector population dynamics thus helps to decide whether a specific location or season is appropriate to grow seed potatoes and assist in the determination of the management strategy to employ. Life cycle and population build up studies are important so as to assess the behaviour of the aphid species on potato sprouts under storage conditions and thus come up with effective management strategies targeting aphids as they occur in farmers' potato stores. Data from aphid population studies may help in forecasting the degree of virus infection. However, additional variables must be considered, including: varietal susceptibility, date of planting, aphid control measures, crop management practices and weather conditions during crop growth. Data on aphid population studies during crop growth are useful for selecting the best potato seed production areas, selecting the best growing season, scheduling dates for sowing/ planting and harvesting and calculating action thresholds of vector populations.

1.4 Objectives

1.4.1 The overall objective of this study was to contribute towards the development of an aphid and virus management strategy for farmers in commercial potato production and storage in Kenya.

1.4.2 The specific objectives were:

i. To evaluate commercial potato cultivars grown in Kenya for comparative resistance/ tolerance to major aphids and aphid transmitted viral diseases.

ii. To monitor the life cycle and population build up of aphids on stored potato tubers.

CHAPTER 2

EVALUATION OF COMMERCIAL POTATO CULTIVARS FOR RESISTANCE/ TOLERANCE TO MAJOR APHIDS AND APHID TRANSMITTED VIRUSES IN KENYA

2.1 Introduction

Aphid resistance in the potato crop is one of the methods that can be used in the management of aphids. In the field, potato cultivars display different levels of aphid infestation (Nderitu and Mueke, 1986a and Were *et al.*, 1996). To increase potato production in Kenya, there is need for information on population dynamics of aphid species infesting potato varieties, the correlation of aphid numbers and species with yield and spread of potato virus diseases on potato varieties. The aphid populations may be the best indicator of the risk of virus spread in the potato crop (Difonzo *et al.*, 1997). Differences in susceptibility of some potato clones and commercial varieties in aphid infestation in Kenya have been noted (Nderitu and Mueke, 1986a; Nderitu and Mueke, 1989; Were *et al.*, 1996). Among the six most popular cultivars grown in Kenya, only R.Tana was found to be relatively resistant to aphid infestation (Nderitu and Mueke, 1986b). Assessment of aphid populations on the seed potato crop is useful as a management tool for the aphid problems (Cerato *et al.*, 1994; Parker, 1997) and is important for deciding where, when and how to grow and protect seed potato crops. Plants with resistance to infection and infestation do not become easily infected, and high levels of inoculum or viruliferous aphid numbers are required for successful infection or infestation (Walkey, 1991).

2.2 Materials and methods

The study was carried out at the National Potato Research Centre (N.P.R.C.), Tigoni during the short rains (October 2002-February 2003) and was repeated during the long rains (March-July 2003). Tigoni is in Kiambu district and is at an altitude of 2,100 metres above sea level (m.a.s.l) and an average annual rainfall of 550 to 740mm. Fourteen commercial potato varieties; Asante, Bvumbwe, Dutch Robyjn (D.Robyjn), Desiree, Kenya Baraka (K.Baraka), Kenya Dhamana (K.Dhamana), Kenya Faulu (K.Faulu), Kenya Furaha (K.Furaha), Kenya Karibu (K. Karibu), Kerr's Pink (K.Pink), Mavuno, Nyayo, Roslin Tana (R.Tana) and Tigoni, obtained from N.P.R.C. were planted during the short rains (October 2002-February 2003). The experiment was repeated during the long rains (March-July 2003). During the long rains, additional potato varieties Anett, Roslin Eburu (B53), Kenya Chaguo (K.Chaguo) and Kenya Sifa (K.Sifa) were screened. Kenya Faulu from the short rains was not included in the study during the long rains; hence, seventeen commercial varieties were screened. Certified seed potato obtained from N.P.R.C. Tigoni was used in both seasons. Potato tubers were planted in plots of 3m x 3m with potato tuber seed varieties as treatments. The inter-row spacing was 75cm and inter-plant spacing was 40cm. The distance between blocks was 2 meters while inter plots was 1 meter. The length of every row was eight hills. Each plot consisted of 5 rows: the 2 outer rows acted as guard rows while the 3 inner rows acted as sampling rows. In each potato seed hole, 10grams of Diammonium Phosphate (DAP) was added and thoroughly mixed with soil before placing the seed tuber. Weeding in the plots was done on the 3rd and 6th weeks while ridging was done on the 6th week after emergence of potatoes. Late blight was managed by spray applications of a protective fungicide, Mancozeb (Dithane

M 45) and a curative fungicide, Metalaxyl (Ridomil) in each season. Treatments were replicated four times and arranged in a Complete Randomised Block Design.

2.2.1 Aphid population assessment

Sampling of aphids was done on 3 leaflets clipped from the top, middle and bottom leaf of each of four plants per plot. The four plants were chosen randomly from the three inner rows of each plot. Leaflets from each plant were placed in a labelled paper bag and taken to the laboratory at Upper Kabete Campus, University of Nairobi. Aphids were brushed off from the leaves with a camel brush onto petri dishes then carefully transferred to a universal bottle half-filled with 70% alcohol for counting and identification as described by Eastop (1953). The plants began emerging after two weeks from planting and sampling began three weeks later when the crop was in its 5th week of growth and at a time when 40% of the plants in a plot had emerged. Sampling was done on weekly basis, for a period of nine weeks.

2.2.2 Visual disease incidence assessment

Visual disease incidence was estimated by identifying plants within a plot that showed potato leaf roll symptoms and the incidence was expressed as a percentage of the total plants in the plot. The plants began emerging two weeks after planting. Visual disease assessment commenced four weeks after crop emergence when the crop was six weeks old. Assessment was carried out over a period of five weeks. Over the short rains, the sampling was carried out on the 6th, 8th, 10th, 11th and 13th weeks of crop growth. Over the long rains, viral assessment was carried out between the 8^{th} to 12^{th} weeks of crop growth.

2.2.3 Tuber yield assessment

Potato tubers were harvested at full maturity. Fourteen weeks after crop emergence, dehaulming or cutting of stems was done followed by the lifting of tubers per hill two weeks later. Total number of tubers and their weights, number of marketable and unmarketable tubers and number grading per treatment were recorded at harvest time. Tubers with a diameter of 6cm and above were considered as large and marketable (ware) or Grade 1. Tubers with a diameter of 3-6 cm were considered as medium and marketable (seed) or Grade 2 while those with a diameter below 3cm as small and unmarketable (chats) or Grade 3. Total potato tuber weights were obtained by adding together the weights of the ware grade, seed grade and chats grade, for each potato variety.

2.2.4 Statistical analysis

Treatment effects were determined by ANOVA procedures. Data was subjected to Log (base 10) transformation and conformed to assumptions of ANOVA as dictated by tests of normality (GENSTAT 6.1) and tests of homogeneity of variance. The means were separated by Least Significant Difference test at P=0.05.

2.3 Results

2.3.1 Aphid population assessment

Three aphid species occurred during the sampling period over the short rains, *A. gossypii, M. euphorbiae* and *M. persicae*. *A. gossypii* was found to be the highest in number while *M. persicae* was found to be lowest in number. The three aphid species populations were highest between the 5th to 9th weeks of crop growth. The aphid populations were observed to be lowest in the 12th week for all three species. With the exception of *M. persicae* the other two species were observed to start increasing in number in the 13th week of the crop growth. *A. gossypii* populations were however not significantly different (P=0.05) between the 5th to 8th weeks of the crop growth but differed significantly (P=0.05) in population from the 9th to 13th weeks of crop growth. Aphid populations were not significantly different (P=0.05) between the 9th and 10th weeks but differed significantly from those in the 11th, 12th and 13th weeks of crop growth. The aphid populations for the three aphid species were observed to be significantly (P=0.05) high between the 7th and 10th weeks during the short rains and in the 11th week over the long rains. Aphid populations were observed to be low in 5th week and 11th to 13th weeks of the crop growth over the short rains while they were significantly (P=0.05) low in the 5th to 10th weeks of the crop growth in the long rains. It was also observed that aphid populations were high at the beginning of the short rains but increased slightly at later stages of potato growth during the long rains (Table 2.1)

M. euphorbiae populations in the 6th week of the crop growth differed significantly (P=0.05) from all other periods of the potato crop growth. Aphid counts in the 7th week showed no significant (P=0.05) differences with the counts in the 8th week but there were significant differences with all other weeks of the crop growth. The aphid counts in the 5th, 10th and 13th weeks of growth did not differ significantly (P=0.05) from each other but differed significantly from the counts in the 11th and 12th weeks of crop growth. *M. persicae* counts showed no significant (P=0.05) differences between the 7th, 8th and 9th weeks of crop growth but differed significantly from all the other weeks. This trend was observed over the 8th, 9th and 10th weeks of the crop growth. There was however no significant (P=0.05) difference observed in the aphid counts during the 5th, 6th, 11th, 12th and 13th weeks of the crop growth (Table 2.1).

Table 2.1 Mean numbers of aphids during October 2002-February 2003 short rains and March-July 2003 Long rains at NPRC, Tigoni

Short rains Oct '02-Feb 2003				Long rains March-July 2003			
Age of Crop (In weeks)	*A.g*	*M.e*	*M.p*	Age of Crop (In weeks)	*A.g*	*M.e*	*M.p*
5	2.61	0.49	0.00	5	0.80	0.73	0.70
6	2.74	1.64	0.00	6	1.10	0.74	0.69
7	2.81	1.35	0.53	7	0.92	0.72	0.69
8	2.66	1.26	0.48	8	1.28	0.82	0.74
9	1.52	1.01	0.36	9	2.02	0.95	0.79
10	1.58	0.69	0.31	10	2.66	1.22	0.78
11	0.82	0.38	0.13	11	2.94	1.52	0.93
12	0.45	0.37	0.04	12	3.55	1.66	0.87
13	0.74	0.66	0.03	13	3.86	2.04	0.86
LSD	0.31	0.25	0.16		0.24	0.16	0.07

A. g = Aphis gossypii; M. e = Macrosiphum euphorbiae; M. p = Myzus persicae

Over the sampling period during the long rains, *A. gossypii* was found to be in abundance while *M. persicae* was found to be lowest in numbers, as was observed during the short rains season. The *A. gossypii* and *M. euphorbiae* counts differed significantly (P=0.05) and were significantly high between the 9^{th} to 13^{th} weeks of the crop growth (Table 2.1). No significant differences were noted between the 5^{th} to 8^{th} weeks of the crop growth for these two aphid species. *M. persicae* counts differed significantly (P=0.05) in the 11^{th} to 13^{th} weeks. Differences in *M. persicae* counts were noted between the 5^{th} to 10^{th} weeks of the crop growth but these differences were not significant (P=0.05). Aphid counts over the long rains were observed to be significantly (P=0.05) different from those over the short rains, for all aphid species throughout the sampling period except for *M. euphorbiae* in the 9^{th} week of the crop growth, where no significant difference was observed in aphid counts in the two seasons

A. gossypii populations were observed to be highest between the 5^{th} to 8^{th} weeks of the crop growth during the short rains and between the 10^{th} to 13^{th} weeks of the crop growth, over the long rains. The populations were significantly (P=0.05) low in the 11^{th} to 13^{th} weeks of the crop growth in short rains while they were low in the 5^{th} to 8^{th} weeks over the long rains. It was also observed that *A. gossypii* populations were significantly (P=0.05) high at the beginning of the short rains but high at later stages of the potato growth over the long rains. Slight peaks were observed at the 10^{th} and 13^{th} weeks of the crop growth during the short rains. Desiree and Anett varieties had the highest peak populations of *A. gossypii* in both the short and long rain seasons. This was observed in the 5^{th} and 13^{th} weeks respectively.

Over the short rains, *M. euphorbiae* populations were observed to be highest between the 6^{th} and 9^{th} weeks of the crop growth then decreasing towards the 11^{th} week and increasing again slightly between the 12^{th} and 13^{th} weeks of the crop growth. Desiree and Anett had the highest peak populations of *M. euphorbiae* over both short and long rains and this was when the crop was in its 6^{th} and 13^{th} weeks of growth, respectively (Table 2.1). Over the long rains, *M. euphorbiae* populations were observed to increase significantly (P=0.05) between the 10^{th} and 13^{th} weeks of the crop growth. Aphid populations were however not significant (P=0.05) between the 5^{th} to 9^{th} weeks of the crop growth over the long rains. It was also observed that *M. euphorbiae* populations were significantly (P=0.05) high at the beginning of short rains and at later stages of the potato growth in long rains.

A. gossypii was the most abundant species among the potato varieties planted over the short rains, with *M. persicae* being the least abundant. *A. gossypii* and *M. euphorbiae* were least abundant in R.Tana and most abundant in K.Pink potato varieties while *M. persicae* was most abundant in Desiree and least abundant in K.Baraka varieties. *A. gossypii* was the most abundant species among the potato varieties planted over the long rains period with *M. persicae* being the least abundant, as was observed over the short rains period. *A. gossypii* was least abundant in Asante variety and most abundant in K.Pink variety. *M. euphorbiae* was least abundant in R.Tana and most abundant in Anett varieties while *M.persicae* was least abundant in K.Karibu and most abundant in Anett varieties (Table 2.2). The three aphid species were observed to be significantly more abundant over the long rains when compared with the aphid populations over the short rains.

Table 2.2 Mean number of aphids on potato varieties during October 2002-February 2003 short rains and March-July 2003 long rains at NPRC, Tigoni

	Short rains			Long rains		
Treatment/ Varieties	*A.g*	*M.e*	*M.p*	*A.g*	*M.e*	*M.p*
Asante	1.58	0.65	0.16	1.59	1.10	0.83
Bvumbwe	1.16	0.67	0.13	1.94	1.19	0.75
D.Robyjn	1.86	1.14	0.27	2.35	1.27	0.83
Desiree	1.94	1.14	0.36	2.63	1.34	0.81
K.Baraka	1.50	0.85	0.08	2.32	1.19	0.79
K.Dhamana	1.89	0.99	0.19	1.94	1.07	0.79
K.Furaha	1.90	0.81	0.14	2.21	1.27	0.78
K.Karibu	1.93	0.71	0.16	1.76	0.98	0.72
K.Pink	2.26	1.30	0.26	2.83	1.26	0.78
Mavuno	2.06	0.89	0.33	1.63	1.17	0.77
Nyayo	2.07	0.86	0.17	1.80	1.23	0.87
R.Tana	1.08	0.34	0.12	1.63	0.91	0.74
Tigoni	1.76	0.93	0.29	1.91	1.09	0.74
K.Faulu	1.76	0.94	0.28	-	-	-
B53	-	-	-	2.46	1.06	0.75
K.Sifa	-	-	-	2.16	1.12	0.73
Anett	-	-	-	2.81	1.45	0.93
K.Chaguo	-	-	-	2.17	0.91	0.74
LSD	0.38	0.31	0.19	0.33	0.21	0.10

A. g = Aphis gossypii; M. e = Macrosiphum euphorbiae; M. p = Myzus persicae

There were significant differences in the aphid populations in the potato varieties planted in the two rain seasons. The potato varieties that exhibited significant (P=0.05) differences for *A. gossypii* populations over the long rains compared to those planted over the short rains were Bvumwbwe, D.Robyjn, Desiree, K.Baraka, K.Furaha, K.Pink, R.Tana and Tigoni. For *M. euphorbiae* species, there were significant (P=0.05) differences in aphid populations in all the varieties planted in both seasons except for K.Dhamana and K.Pink. *M. persicae* was observed to have significant (P=0.05) difference between all the potato varieties planted over the long rains and those planted over the short rains (Table 2.2).

Temperatures over the short rains were observed to increase from November and December 2002, peaked in January 2003 and thereafter dropped in February the same year. Rainfall was highest in November 2002 and was seen to reduce in the following months with very little rainfall in the month of February 2003 (Fig. 2.1). During the short rains, the aphid populations were observed to be significantly high at the onset of crop emergence and the counts reduced significantly towards the harvest period of the crop, for all the three aphid species. Rainfall was highest at the beginning (397.2mm) and reduced towards the end of the cropping period (137.6mm), averaging 267.4mm. Temperatures were lower at the beginning (16^{o}C) and highest (18^{o}C) towards the harvest period of the crop with an average of 16.5 ^{o}C. Over the long rains, rainfall was highest at the start (472.6mm) of the cropping period in May 2003 and reduced in the month of June towards the harvest period of the crop (229.1mm). Temperatures were observed to be constant throughout the crop growth period, with an average of 15.7 ^{o}C (Fig. 2.1).

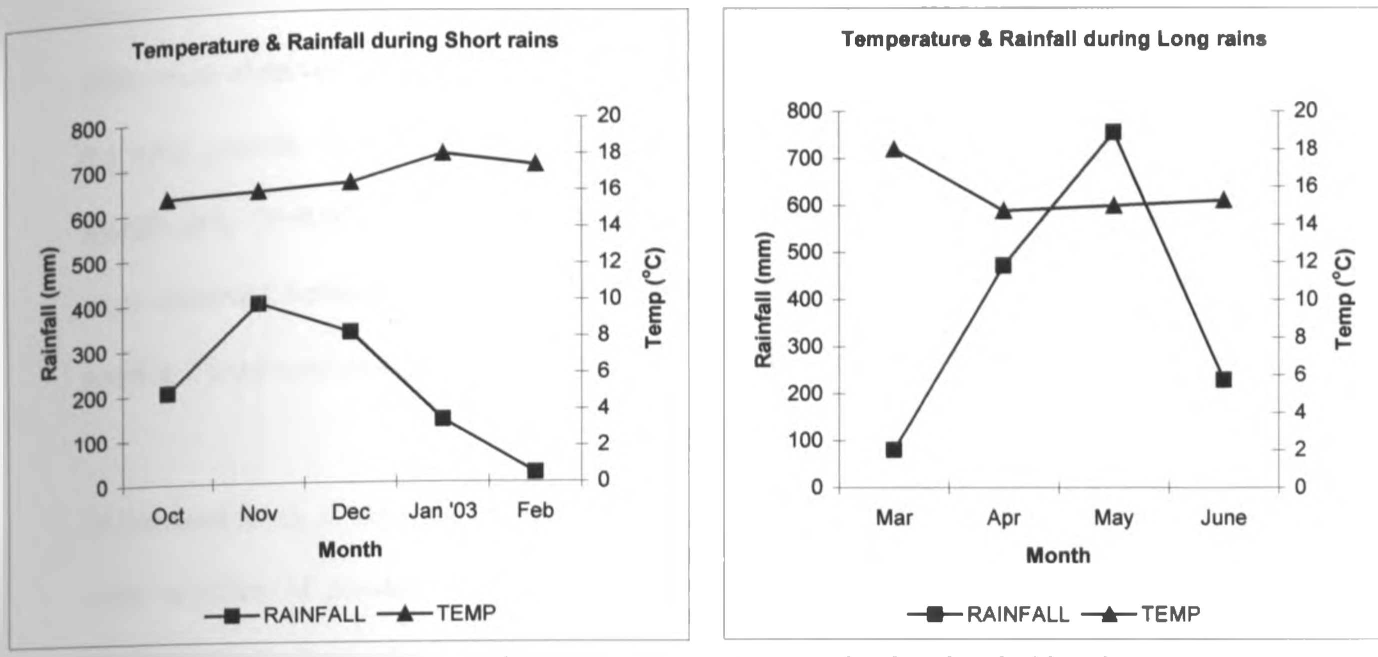

Fig. 2.1 Rainfall distribution and temperature ranges over the October 2002-February 2003 Short rains and March-July 2003 Long rains at NPRC, Tigoni

Aphid populations during the long rains were significantly (P=0.05) low at the start of the period after crop emergence then increased significantly towards the end of the cropping period for all aphid species. Increase in aphid numbers was observed at the time when temperatures were relatively high and rainfall was significantly reduced. Over the short rains, rainfall was lower and temperatures were higher than over the long rains. Rainfall was highest towards the middle of the cropping period and decreased towards the end of the cropping period over both the short and long rains.

During the short rains *A. gossypii* and *M. euphorbiae* differed significantly (P=0.05) among treatment means. Significant differences among varieties were however only observed between the 5th to 9th weeks of the crop growth. *M. persicae* showed no significant (P=0.05) differences among treatment means. However, there were significant differences observed in the populations of *M. persicae* between the 7^{th} and 10^{th} weeks of the crop growth. In the long rains, *A. gossypii* and *M. euphorbiae* species differed significantly (P=0.05) among treatment means. Significant differences among varieties were observed between the 10^{th} to 13^{th} weeks of the crop growth, for the two aphid species. There were no significant differences among treatment means for *M. persicae*.

In the short rains, *A. gossypii* and *M. euphorbiae* were highest in K.Pink and lowest in R. Tana varieties. *M. persicae* populations were highest in Desiree and lowest in K. Baraka varieties. In the long rains, *A. gossypii* populations were highest in Anett and lowest in Mavuno varieties. *M. euphhorbiae* was observed to be highest in Anett and lowest in K. Chaguo and R.Tana varieties. *M.persicae* species was also observed to be highest in Anett and lowest in K. Karibu varieties. The observed differences were significant (P=0.05)

The potato varieties with the highest mean aphid counts of *A. gossypii* species over the short rains were K.Pink, Mavuno, Nyayo and Desiree, while those with low counts of the same aphid species over this period were R.Tana and Bvumbwe. In the case of *M. euphorbiae* species in the short rains, the potato varieties with the highest aphid counts were K.Pink, Desiree and D.Robyjn while those with low *M. euphorbiae* aphid counts were R.Tana, Asante and Bvumbwe. Over this period, *M. persicae* had high counts in Mavuno and Desiree varieties while the varieties with low aphid counts were K.Baraka and R.Tana (Fig. 2.2).

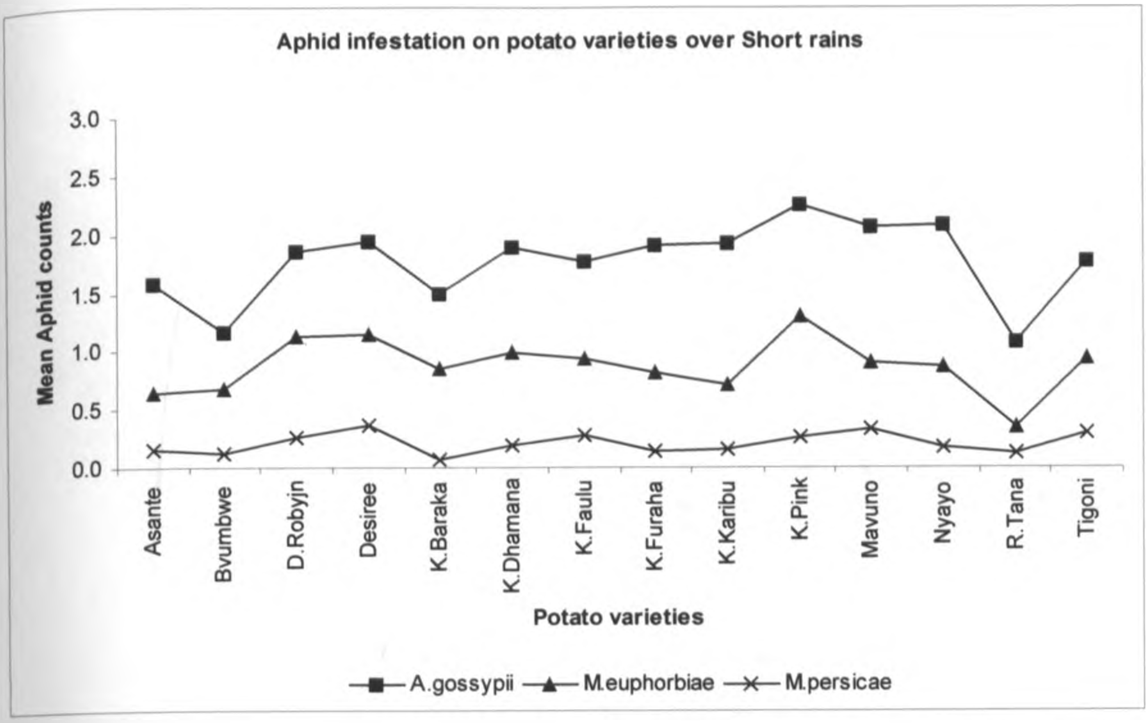

Fig. 2.2 Aphid infestation on potato varieties during October 2002- February 2003 short rains at NPRC, Tigoni

In the long rains, the potato varieties with high mean *A. gossypii* counts were Anett, K.Pink, Desiree and Roslyn Eburu (B53) while those with low *A. gossypii* counts were Asante and R.Tana. The potato varieties with high mean *M. euphorbiae* counts over the long rains were Anett and Desiree while those varieties with low aphid counts were R.Tana, K.Chaguo and K.Karibu. Potato varieties with the highest *M. persicae* counts were Anett, Nyayo and Asante while those with low *M. persicae* counts were K.Karibu, K.Sifa and K.Chaguo (Fig. 2.3).

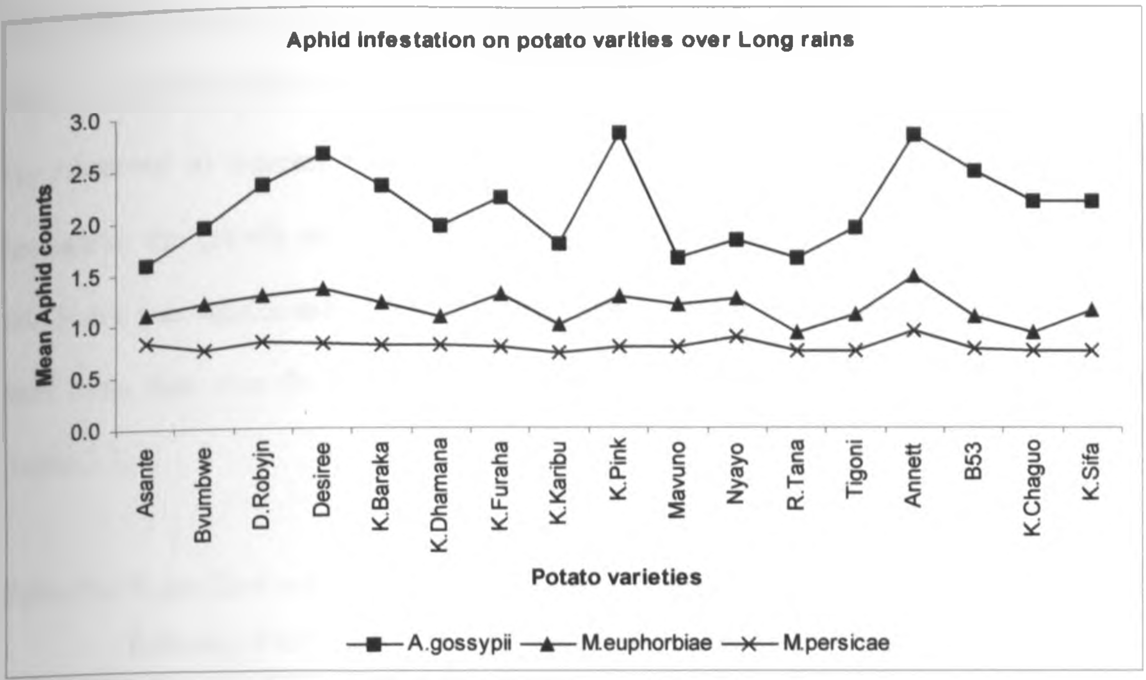

Fig. 2.3 Aphid infestation on potato varieties during March- July 2003 long rains at NPRC, Tigoni

R.Tana was found to have low *A. gossypii* counts in both seasons, while Desiree and K.Pink had high *A. gossypii* counts in both seasons. R.Tana was also found to have low *M. euphorbiae* counts in both seasons, while Desiree had high *M. euphorbiae* counts in both seasons. Mavuno and Anett had the highest peak populations of *M. persicae* over the short and long rains respectively.

2.3.2 Visual disease incidence in the field

Potato Leaf roll

During the short rains, Mavuno, K. Karibu and Desiree varieties were observed to have the highest incidences of Potato leaf roll throughout the sampling period while D. Robyjn, Tigoni and Asante varieties had the lowest Potato leaf roll incidence. During the long rains, Mavuno and Desiree varieties had the highest incidences of Potato leaf roll while K. Baraka had the lowest incidence of Potato leaf roll. Incidence of Potato leaf roll was observed to increase steadily in Desiree, K.Pink, R.Tana and K.Furaha varieties throughout the growth period of the crop when viral incidence assessment was carried out. There was significantly (P=0.05) higher Potato leaf roll incidence observed over the short rains than over the long rains in all potato varieties except for D.Robyjn variety (Table 2.3).

Table 2.3 Potato leaf roll incidence (%) on potato varieties during the October 2002-February 2003 short rains and March-July 2003 long rains at NPRC, Tigoni

	October 2002-February 2003 Short rains	March-July 2003 Long rains
Treatment/ Varieties	Potato leaf roll incidence (%)	Potato leaf roll incidence (%)
Asante	1.70	1.54
Bvumbwe	2.22	1.54
D.Robyjn	1.53	1.52
Desiree	2.39	1.98
K. Baraka	1.80	1.50
K. Dhamana	2.29	1.58
K. Furaha	2.05	1.73
K. Karibu	2.53	1.59
K. Pink	2.15	1.50
Mavuno	2.65	1.98
Nyayo	1.98	1.52
R. Tana	1.81	1.50
Tigoni	1.66	1.50

K. Faulu	-	-
B53	-	1.52
K. Sifa	-	1.58
Anett	-	1.59
K. Chaguo	-	1.53
LSD	0.12	0.17

It was observed that Mavuno and Desiree varieties had high Potato leaf roll incidence while Tigoni and D.Robyjn varieties had low Potato leaf roll incidence for the two seasons (Plate 1).

Plate 1: Desiree variety with symptoms of Potato leaf roll infection. Leaves in the foreground appear rolled and pale

The peak of Potato leaf roll incidence was observed in the 9th and 10th weeks of the crop growth for the two potato varieties, Mavuno and Desiree. Bvumbwe variety showed an increase in disease incidence in the 8th week of the crop growth and disease incidence rose thereafter as the crop matured. Disease incidence was observed to decline thereafter towards the 12th week of the crop growth (Fig 2.4). In all the other varieties, disease incidence was observed to increase and peaked between the 9th and 10th weeks of the crop growth. Disease incidence decreased thereafter for all the varieties. Potato leaf roll incidence was observed to increase steadily over the growth period of the crop during the short rains. Disease incidence increased significantly (P=0.05) from the 6th week of the crop growth when disease incidence assessment commenced, to the 13th week of the crop growth when assessment ceased. There was however no significant difference (P=0.05) in the disease incidence during the 11th and 13th weeks of the crop growth. Over the long rains, there was a significant (P=0.05) increase in disease incidence from the 8th week to the 10th week of the crop growth. Increase in disease incidence was however not significant (P=0.05) between the 9th and 10th week of the crop growth. Disease incidence then decreased in the 11th and 12th weeks of the crop growth (Fig 2.4).

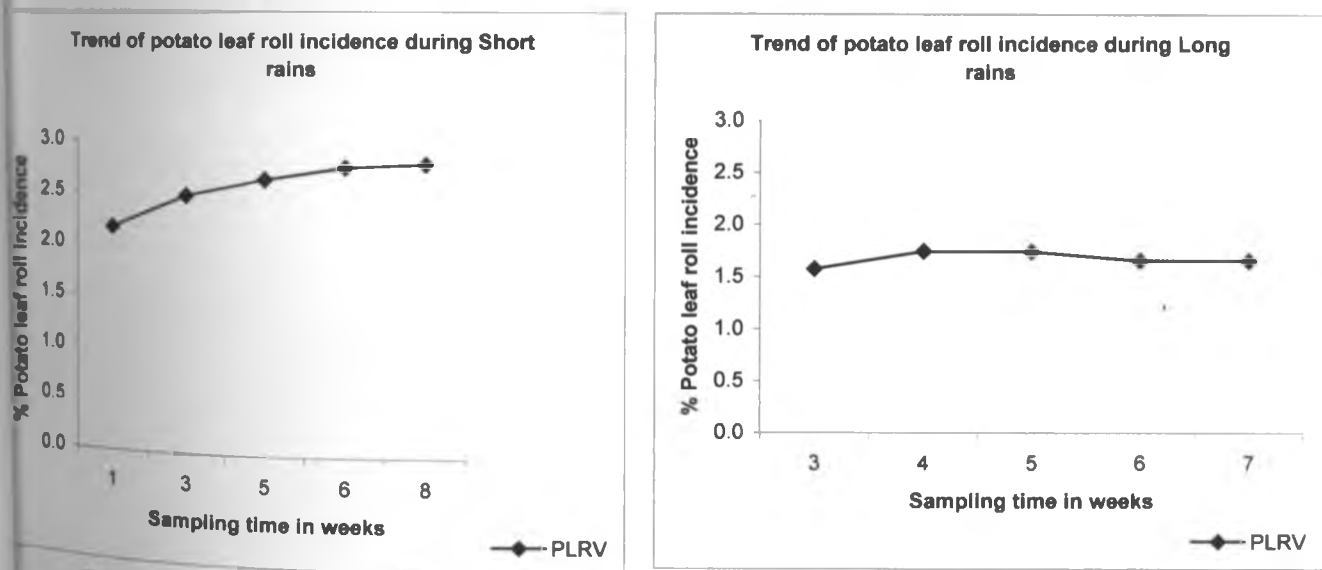

Fig. 2.4 General trend of Potato leaf roll incidence for all varieties during October 2002-February 2003 short rains and March-July, 2003 long rains at NPRC, Tigoni

2.3.3 Yield assessment

Potatoes were separated into the various grades at harvest. The Tigoni potato varieties in the plate below are divided into two grades. To the left of the plate are the large and marketable (ware) or Grade 1. To the left of the plate are the medium and marketable (seed) or Grade 2. (Plate 2)

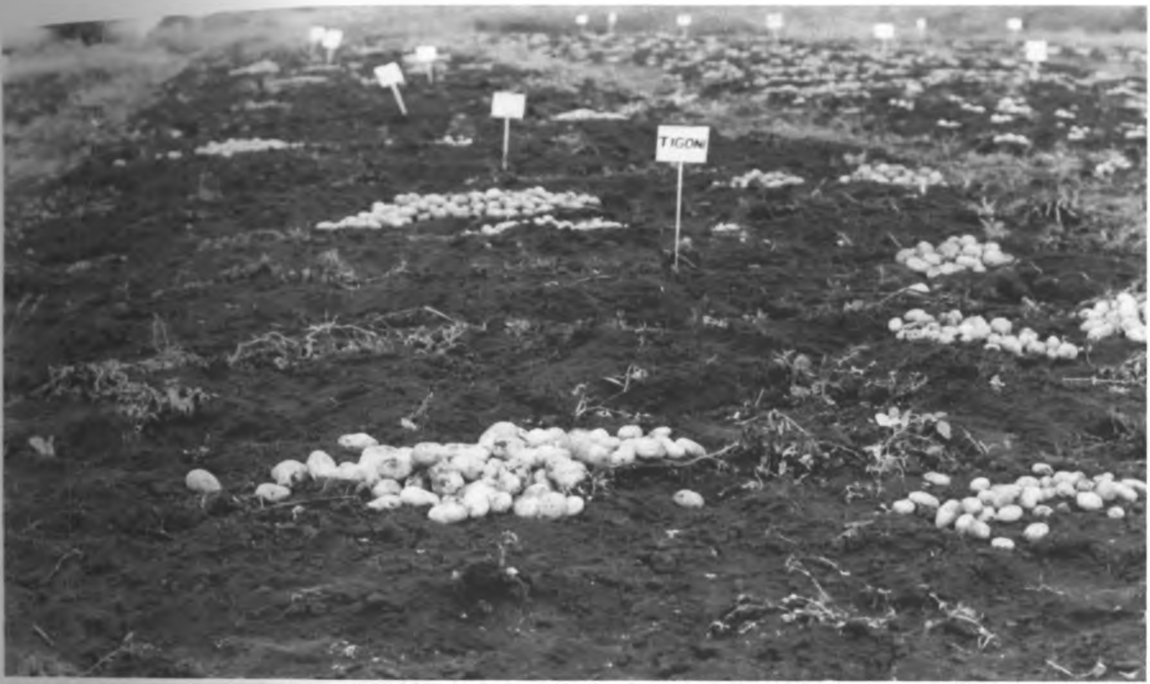

Plate 2: Potatoes separated into different grades during harvest

The total yield (weights) was significantly different (P=0.05) for all the treatments during the two rain seasons except for K. Baraka and K. Pink. Seed weights were significantly different (P=0.05) during the two seasons. There was also significant difference (P=0.05) in unmarketable weights among treatments in both seasons. Yields in terms of total weight were observed to be higher over the long rains than over the short rains. Nyayo, Tigoni and Asante varieties had the highest total weight in yields over both the short rains and long rains. The differences in total yields were significantly different (P=0.05). K. Sifa and Roslin Eburu (B53) had the lowest total yields observed over the short rains while Mavuno and K. Sifa had the lowest total yields over the long rains. K. Faulu was planted and harvested only over the short rains while Anett and K. Chaguo were planted and harvested only over the long rains. There was approximately 67% and 57% increase in the total yield for Roslin Eburu (B53) and K. Sifa during the long rains as compared to the short rains, respectively (Table 2.4).

Table 2.4 Potato tuber grade weights (kg) during the October 2002-February 2003 short rains and March-July 2003 long rains at NPRC, Tigoni

	October 2002-February 2003 Short rains			March-July 2003 Long rains		
	Mean weights in Kgs			Mean weights in Kgs		
Treatment/ Varieties	Total weight	Seed	Chats	Total weight	Seed	Chats
Asante	33.80	32.86	0.47	31.60	21.70	4.95
Bvumbwe	13.37	11.53	0.92	30.87	15.53	7.67
D.Robyjn	19.90	18.60	0.65	29.32	14.08	7.62
Desiree	14.69	13.77	0.47	18.22	9.67	4.28
K.Baraka	13.67	12.03	0.82	14.60	7.75	3.42
K.Dhamana	25.90	25.06	0.42	18.92	11.58	3.67
K.Furaha	29.00	25.61	1.07	30.25	14.75	7.75
K.Karibu	20.90	18.46	1.23	16.10	8.04	4.03
K.Pink	16.25	13.95	1.15	17.15	5.8	5.67
Mavuno	13.05	10.85	1.10	11.37	5.13	3.12
Nyayo	40.12	36.56	1.78	38.20	16.34	10.93

R.Tana	19.90	18.56	0.67	24.80	15.50	4.65
Tigoni	39.22	37.13	1.05	31.90	16.70	7.60
K.Faulu	19.17	17.93	0.62	-	-	-
B53	6.04	4.60	0.72	18.37	10.32	4.03
K.Sifa	5.47	4.83	0.32	12.65	9.15	1.75
Anett	-	-	-	25.32	10.52	7.40
K.Chaguo	-	-	-	15.62	9.58	3.02
LSD	6.70	6.94	0.57	7.67	6.00	2.50

2.4 Discussion

Three aphid species namely *Aphis gossypii, Macrosiphum euphorbiae* and *Myzus persicae* infested the potato varieties. These results are consistent with the findings of Salazar (1996) and Robertson and Wambugu (1975) who found these aphid species to be the most important and common aphid vector species in Kenya and are among those that colonise potatoes. In the field, potato varieties display different levels of aphid infestation. *A.gossypii*, which does not transmit potato leaf roll virus (PLRV), was found to be in high abundance in the two seasons while *M.persicae* was the least abundant. This is in agreement with the work done by Rongai *et al*., (1998) and Nderitu (1983). The study revealed that Kerr's Pink had the highest infestation of *A. gossypii* and *M. euphorbiae* over the short rains while Desiree supported the highest *M. persicae* population over the same period. Anett had the highest population of all the three aphid species identified over the long rains while Roslin Tana was the least infested variety by the three identified aphid species in both seasons. This is consistent with the findings made by Nderitu (1983) whose field experiments revealed similar occurrence. Therefore, on a comparative basis, Kerr's Pink, Desiree and Anett can be considered as susceptible varieties while Roslin Tana is an aphid tolerant variety. The other potato varieties being investigated were moderately infested and can be considered to be moderately susceptible.

The peak periods of aphid infestation over the short rains was between the 6^{th} and 7^{th} weeks of the crop growth, while over the long rains, it was between the 11^{th} and 13^{th} weeks of the crop growth. Broadbent and Heathcote (1961) reported that in general, aphids are adversely affected by cool wet weather and favoured by warm sunny weather. Variation in abundance of aphids on the potato varieties could be attributed to the climatic conditions as this determines the kind of aphid species, abundance and nature of infestation. Raman (1980) observed that low rainfall and high temperatures are ideal for aphid multiplication and movement. Increase in aphid numbers was observed at the time when temperatures were relatively high and rainfall was significantly reduced.

Knowledge on the peak period of infestation by aphids is important, as it can act as a guide on when to implement different aphid vector management strategies for both the alate and apterae aphids. Control of aphids on potatoes has been accepted as an indirect means of controlling the spread of PLRV within potatoes (Till, 1971). Anett, Kerr's Pink and Desiree, which were heavily infested by aphids, are early to medium-early maturing varieties. R.Tana, which is a late maturing variety, was the least infested potato variety. It has coarse leaves and this factor may make the feeding process of *A. gossypii* and *M. persicae* a difficult one. Bald (1946) showed that varietal differences in vegetative development are manifested at the beginning of the second stage of development, which opens with the beginning of rapid development of auxiliary shoots above ground, or stolons below, and ends when plants attain their maximum leaf area. Varietal differences in aphid infestation may have followed growth pattern of the potato varieties. Vigorous growth during the long rains clearly brought out varietal differences in aphid infestation. Aphid infestation was higher over the short rains than over the long rains. Aphid infestation over the long rains was observed to peak towards the end of the growing period when the potato varieties were already mature and senescing. New plant growth and shoots, which came up may have supported these aphids late in the season. Radcliffe (1982) reported that temperatures of less than 17.8°C greatly restrict the number of *M. persicae* flights in the laboratory. This observation is in agreement with the findings by Thackray *et al.*, (2002) that rainfall promotes growth of weeds and pasture plants, which aphids can build on and acquire virus before flying to crops. The peak occurrence of all aphid species during the 9th and 10th weeks of the potatoes crop growth over the short rains in this study could be the critical period when maximum PLRV infection occurs. This observation is consistent with the work done by Handiziz and Legorburu (2002) who found that, the first third of the vegetation period is the most important for the virus infection, even if the aphid flights are relatively low.

Lands *et al.*, (1972) reported that red-skinned potato varieties supported more *M. persicae* than most white skinned potato varieties, while *M. euphorbiae* seemed to produce well on certain white-skinned potato varieties. While Kerr's Pink and Desiree are red-skinned, Anett is white-skinned. Both the white-skinned and the red-skinned potato varieties were highly infested by *A. gossypii* and *M. persicae*. Roslin Tana is a white-skinned potato variety but was the least infested variety by all the three aphid species observed in this study.

Potato leaf roll was high in Mavuno and Desiree in both the short and long rains. The incidence was low in Tigoni and D.Robyjn in both seasons. Over the short rains, Potato leaf roll peaked in the 11th week of the potato growth while over the long rains it peaked at the time when the potato crop was in its 9th to 10th week of growth. There was no correlation of time of aphid infestation and the incidence of Potato leaf roll, hence the aphids present on the potatoes may not have been responsible as vectors in the transmission of the virus observed on the potatoes in this study. Potato leaf roll may have been introduced to the potatoes from alate viruliferous vectors and not from apterae aphids present in the potato field. Virus incidence was higher over the short rains than over the long rains. Bordering the potato field during the study over the short rains were other potato fields which may have acted as a source of the aphid vectors hence higher Potato leaf roll disease incidence over the short rains than over the long rains.

Total yield over the long rains was higher than that over the short rains. Over the short rains, aphids were observed to infest the potatoes earlier in the growing season peaking during the 6th and 7th weeks of the crop growth. This trend may have had an effect on the overall production of tubers, hence lower yields than those over the long rains. Over the long rains, aphid infestation was observed to be later in the growing season peaking during the 11th to 13th weeks of the crop growth. Therefore, the tubers were already formed and the total yields thus not affected by the aphids infesting the potato crop. Unmarketable grade of tubers were however noted to be higher over the long rains than over the short rains. Total yields were highest in Nyayo, Asante and Tigoni varieties in the two seasons. These varieties were noted to support low populations of aphids and low incidence of Potato leaf roll. Mavuno and Desiree had high levels of Potato leaf roll incidence. These varieties recorded relatively low yields in both seasons with Mavuno having the lowest varietal total yields over the long rains. Tigoni and Dutch Robyjn varieties had relatively high total yields in both seasons with Tigoni being noted to be among the potato varieties with the highest total yields in both seasons.

CHAPTER 3

MONITORING OF LIFE CYCLE, POPULATION BUILD UP AND SURVIVAL OF APHIDS ON STORED POTATO TUBERS

3.1 Introduction

Storage of the harvested potato crop through appropriate and adequate low cost storage and processing techniques is necessary to meet the national potato requirements by consumers. In Kenya, the informal potato seed supply produces about 90% of the country's annual seed requirement (Walingo *et al*., 2002). Such seed is selected from farmer's own seed and kept under their rustic storage conditions until when required. Storage is important at family level and even nationwide as the potato crop becomes an important dietary constituent. Potato storage should be in low cost stores and should not be reliant on electrical or mechanical power that is unaffordable by Kenyan farmers. Research on post harvest storage in the past has shown that simple storage in the Kenyan highlands (1800-3000 masl) can be economically viable (Taylor-Hunt, 1992). Duration of storage and aphid infestation of the potato seed was found to have a significant positive correlation. Kibaru (2003) found that most farmers in Nyandarua and Kiambu districts had wooden stores while a few others preferred other modes of storage such as gunny bags, drums, underground, iron sheet structures and bricks constructed stores. Storage in Kenya has been done to protect potatoes from undesirably high air temperatures and correspondingly low relative humidity and reduce opportunities for predators and pests to aggravate losses. Storage temperature affects keeping quality of potatoes by promoting fast metabolic rates which in turn increases the rate of deterioration. Proper seed storage is necessary for the establishment of a viable and sustainable agricultural system. PLRV and PVY are aphid-transmitted and tuber borne-diseases. Their main vectors are widely distributed in most potato growing areas and multiply throughout the year. This double way of transmission and favourable conditions of aphid population build up in stores has contributed to the spread of aphid borne potato viruses in the country. Robertson and Wambugu (1975) observed that aphid infestation of stored seed tubers and their importance in disseminating severe viruses during the storage phase poses a major threat to seed quality. Booth (1984) found that degeneration of seed potato in stores occurs within short storage periods in unprotected seeds due to virus infections. Research at the International Potato Centre (CIP) has shown that tubers in storage can also become completely infected with viruses by aphids feeding on the sprouting potatoes (Jayasinghe, 1988). The objective of this study was to monitor the life cycle and population build up of aphids on stored potato tubers and consequently use the knowledge obtained in contributing towards the development of an aphid and virus management strategy for farmers in commercial potato production in Kenya.

3.2 Materials and methods

Two commercial potato varieties, Tigoni and Asante from the National Potato Research Centre (NPRC), Tigoni were used to assess the life cycle, population build-up and survival of aphids under storage conditions. The experiment was carried out at the Field Station, Upper Kabete Campus, University of Nairobi. The two potato varieties had earlier been found to have moderate susceptibility to aphid infestation as they supported low aphid populations and low incidence of the Potato leaf roll disease. The aphid species under observation was the Potato aphid (*Macrosiphum euphorbiae*). The experiment was carried out between January and March 2005 and repeated again between March and May 2005. For each treatment, the experiment was run three times. The runs per treatment were scheduled fourteen days apart.

The Potato aphid was obtained from a crop in the field then introduced onto sprouted potato tubers in the store. Newly borne 2nd instar aphids were used to start off the aphid colony as preliminary studies showed that 1st instar aphids were sensitive. The life stages or instars were identified using certain parameters These parameters were morphological changes of the aphids, colour, size and length of nymph cycle. The 1st nymph instars had a small body with short cornicles. The cornicles were of cream colour. The antennae were also a light cream colour. The 2nd instar aphids had a bigger body than the 1st instar aphids. The cornicles were also longer than those of the 1st instar and had a slight darkening colour. The 3rd instar aphid had a bigger body with long cornicles. The cornicles were dark and the antennae too were dark at the termini. The adult was observed to have a large body with long slender and dark cornicles extending from the abdomen. The antennae had dark termini. Some alate (winged) aphids were also noted in this life stage.

The treatments were the two certified seed potato varieties, Tigoni and Asante. The sprouted potato tubers onto which the aphids were introduced were placed into plastic containers measuring 20cm x 14cm x 8cm. The containers were placed on a wooden platform raised 1M above the floor of the rustic store. For the three runs per treatment, ten plastic containers containing ten sprouted tubers were used. Thirty newly borne 2nd instar aphids were introduced onto the sprouted tubers within the containers. Filter paper was used to line the base of each container and distilled water was sprinkled regularly on the filter paper to keep it moist throughout the experimental period. Netting of fine mesh was used to cover the mouth of the container to provide ventilation and to prevent the aphids from escaping from the containers. The netting was held in place by use of rubber bands. The store had limited supply of light with the sides being covered with black polythene to keep it cool and dark during the day. Mites and mealy bugs within the store were managed by spray applications of Tedion and Dimethoate respectively, before commencing the experiment. Treatments were arranged in a Completely Randomised Design. Three hundred certified sprouted potato tubers were used per treatment.

3.2.1 Aphid life cycle and population build up assessment

Data collection began one day after the introduction of the newly borne 2nd instar aphids on the sprouted potato tubers. The reason for this being that, *M. euphorbiae* colonies increase rapidly and can double in less than three days. Counting of aphids on the tubers was done for a period of thirty days for each run per treatment. The aphids were counted on each of the ten sprouted tubers in all the containers. Each sprouted tuber was placed under the microscope and the number of live aphids counted and recorded so as to monitor the aphid population build-up. The numbers of each life stage on each selected tuber was recorded so as to note the period it took for the aphids to moult from one life stage to another and to monitor how often aphids were borne. Parameters that were observed and recorded were morphological changes of the aphids, colour, size and length of nymphal cycle. Care was taken not to damage the stylets of the aphids, as this would interfere with the feeding and population build-up of the aphids. Temperature and relative humidity within the store were recorded on a daily basis both in the morning and in the afternoon.

3.2.2 Statistical analysis

Treatment effects were determined by ANOVA procedures. Data was subjected to Regression Analysis and conformed to assumptions of ANOVA as dictated by tests of normality (GENSTAT 6.1).

3.3 Results

M. euphorbiae was noted to have four different life stages. These life stages or instars were identified using parameters that were observed over the period of the study. The aphids were observed to be of a pink colour (Plate 3).

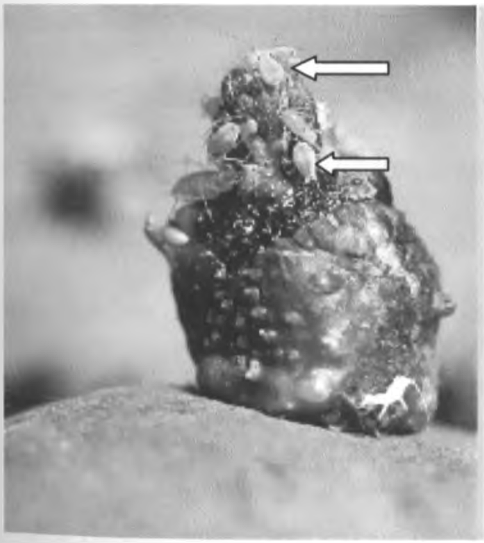

Plate 3: Pink form of *Macrosiphum euphorbiae* feeding on potato tuber sprouts

As the nymphs moulted from one life stage to the next they left behind the cast skins that were observed on the potato tuber sprouts (Plate 4).

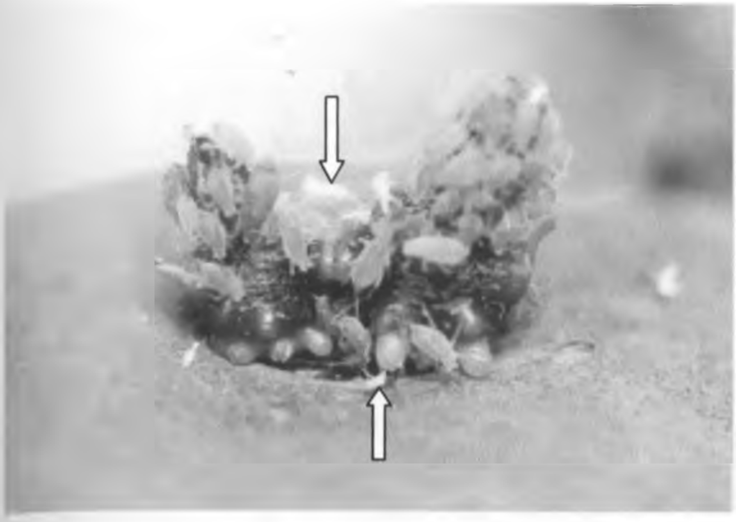

Plate 4: Cast skins of moulted potato aphid on potato tuber sprouts

The study started out with thirty live 2nd instar aphids being introduced onto the sprouted potato tubers. For Tigoni variety, 3rd instar aphids were observed on the second day after introduction of 2nd instar aphids. Adult stage aphids were noted on the sixth and seventh day after introduction of 2nd instar aphids. 1st instar aphids were observed on the sixth, seventh and eigth days after the introduction of the 2nd instar aphids. The second batch of 2nd instar aphids were observed to appear again on the Tigoni sprouts on the eighth and tenth days after the initial introduction of the newly borne 2nd instar aphids.

For Asante variety, 3rd instar aphids were observed on the fourth day after introducing the 2nd instar aphids on the sprouts. Adults were observed on the seventh and eighth day after the introduction of 2nd instar aphids. 1st instar aphids were observed nine days after introducing the 2nd instar aphids. The second batch of 2nd instar aphids were observed to appear again on the Asante sprouts on the tenth and eleventh day after the initial introduction of the newly borne 2nd instar aphids (Plate 5).

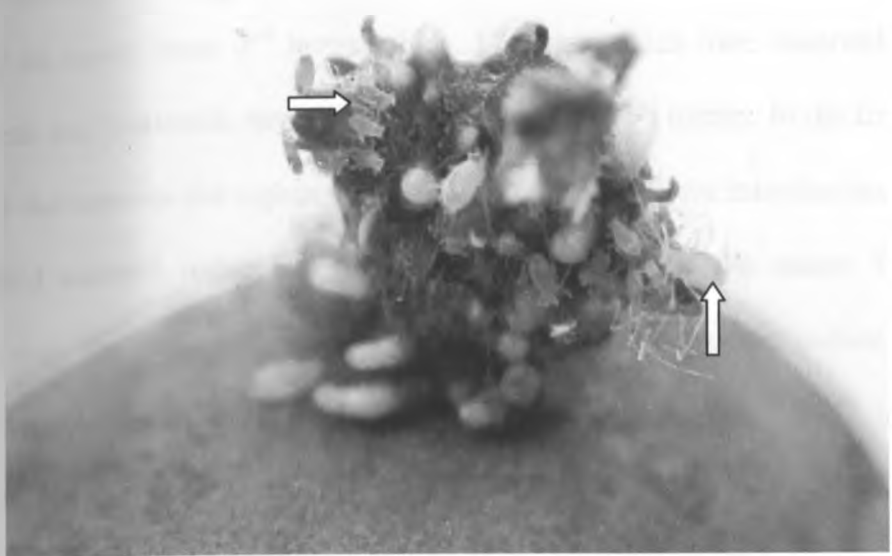

Plate 5: Different life stages of *M. euphorbiae* on a sprouted Tigoni potato tuber

The different life stages of the potato aphid were all observed to be significantly different (P=0.01) at each stage of growth for both potato varieties. The 1st instars occurring on both Tigoni and Asante varieties were found to be significantly (P=0.01) different. The same observation was also made for the 2nd instars, 3rd instars and adult stage aphids on both the potato varieties. The differences in aphid numbers in the three replicates per treatment were also observed to be significantly different (P=0.01).

Aphid population increase that was observed for the Tigoni variety during the first run was where the 2nd instar aphids that were used to start the aphid colony, decreased in number after two days. 3rd instar nymphs were observed on the second day after introduction of 2nd instars. The adult stage aphids were observed on the potato sprouts on

The population increase was similar for the second run though reduction in aphid numbers was observed on the twenty-third and twenty-fourth day after the introduction of 2nd instars and again between the twenty-eigth and thirtieth day after the introduction of 2nd instars (Fig. 3.2).

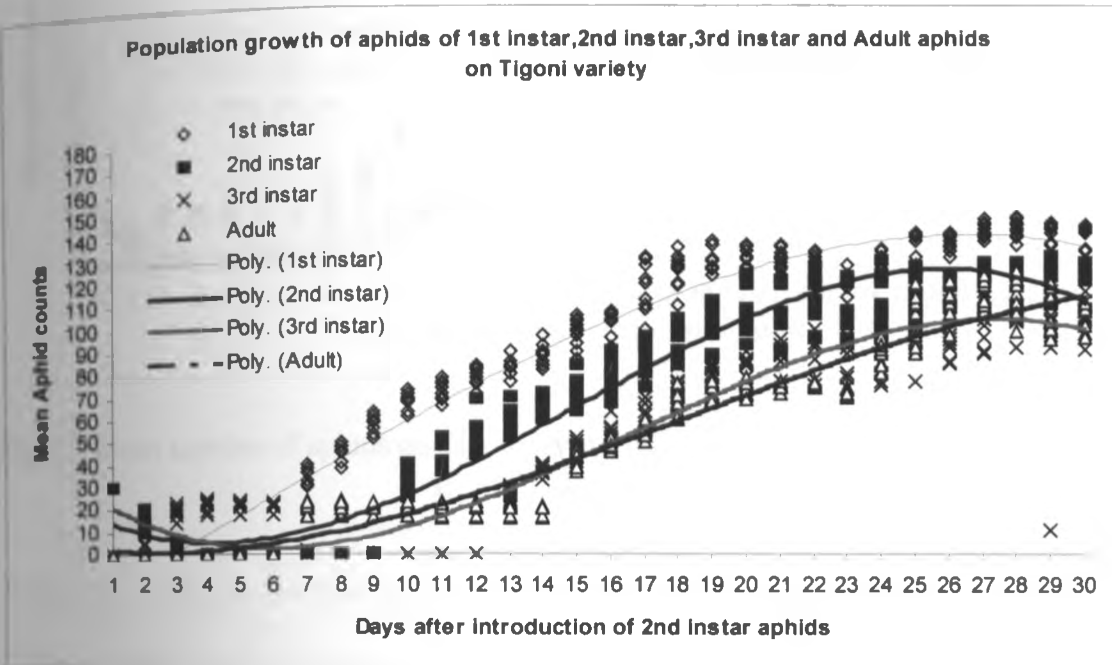

Fig. 3.2 Mean number of aphids on Tigoni potato sprouts in the second run

For the third run, there was a slight decrease in the number of 1st instar aphids on the twenty-third day after the introduction of 2nd instars. The aphid counts increased on the twenty-fourth after the introduction of 2nd instars and an increase in counts was observed thereafter for all aphid life stages. Another reduction in aphid counts was observed again between the twenty-eigth and thirtieth day after the introduction of 2nd instars (Fig. 3.3). The aphid populations on the Tigoni variety were observed to increase over time for all the three runs.

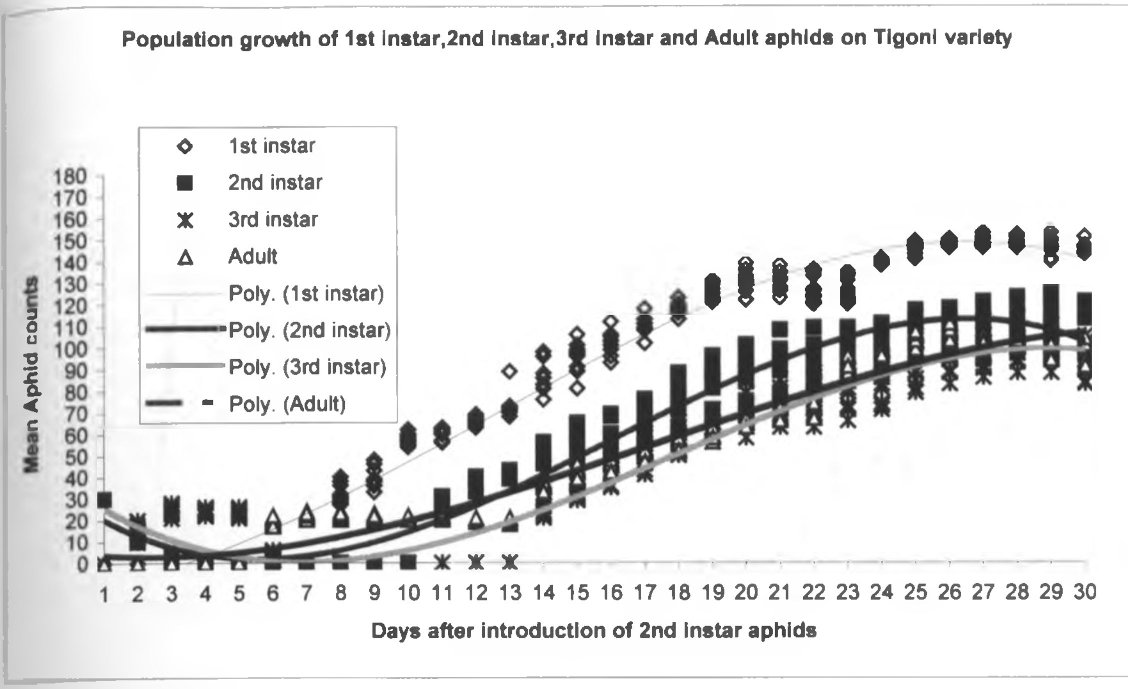

Fig. 3.3 Mean number of aphids on Tigoni potato sprouts in the third run

The aphid population increase for the Asante variety during the first run was whereby the 2nd instar aphids that were used to start the aphid colony decreased in number after two days. On the fourth and fifth day after the initial introduction, there were no 2nd instar aphids observed. 3rd instar nymphs were observed on the fourth day after the introduction of 2nd instars. Three to four days later, this being on the seventh and eigth day after the introduction of 2nd instars, adult stage aphids were observed. On the eigth and ninth day after the introduction of 2nd instars, 1st instar nymphs were borne. At this stage there were no 2nd or 3rd instar aphids present on the Asante potato sprouts. 2nd instar and 3rd instar aphids began to be observed again on the eleventh and fourteenth days after the introduction of 2nd instars, respectively. In the first run, it was observed that between the thirteenth and sixteenth day after the introduction of 2nd instars, the adult aphid numbers reduced slightly and were observed to increase thereafter after the seventeenth day after the introduction of 2nd instars. On the twenty-seventh day, the aphid numbers for all life stages reduced and were observed to increase again on the thirtieth day after the introduction of 2nd instars (Fig.3.4).

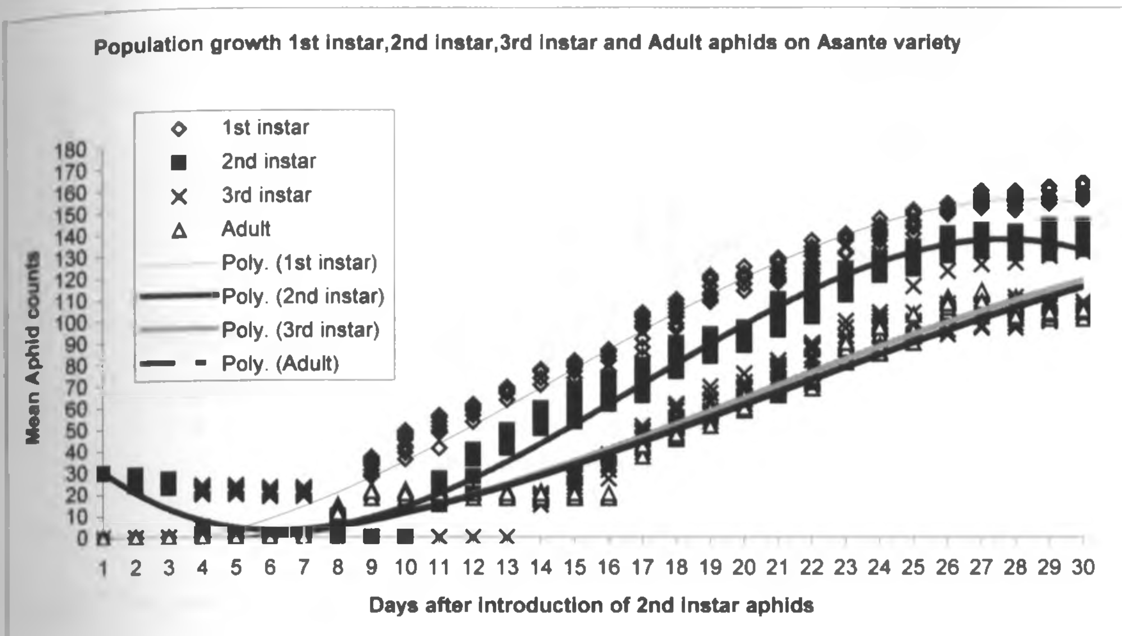

Fig. 3.4 Mean number of aphids on Asante potato sprouts in the first run

For the second and third runs for Asante variety, the aphid numbers for all life stages were observed to increase significantly from the fifteenth day to the thirtieth day after the introduction of 2nd instars (Fig.3.5) and (Fig. 3.6).

The population growth of the different aphid life stages showed two distinct peaks for the Tigoni variety. In the case of the Asante variety, the peaks in the population growth were not as distinct as in the case of Tigoni variety but were still present. These peaks in the population growth were observed in all the three runs per treatment.

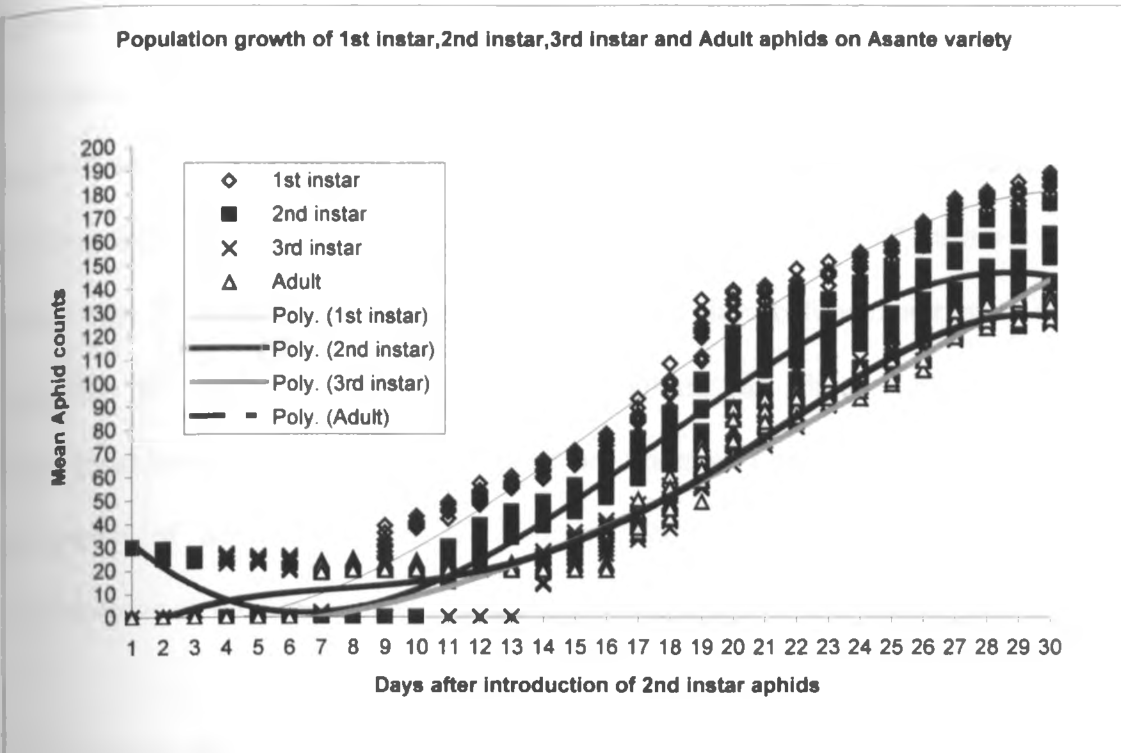

Fig. 3.5 Mean number of aphids on Asante potato sprouts in the second run

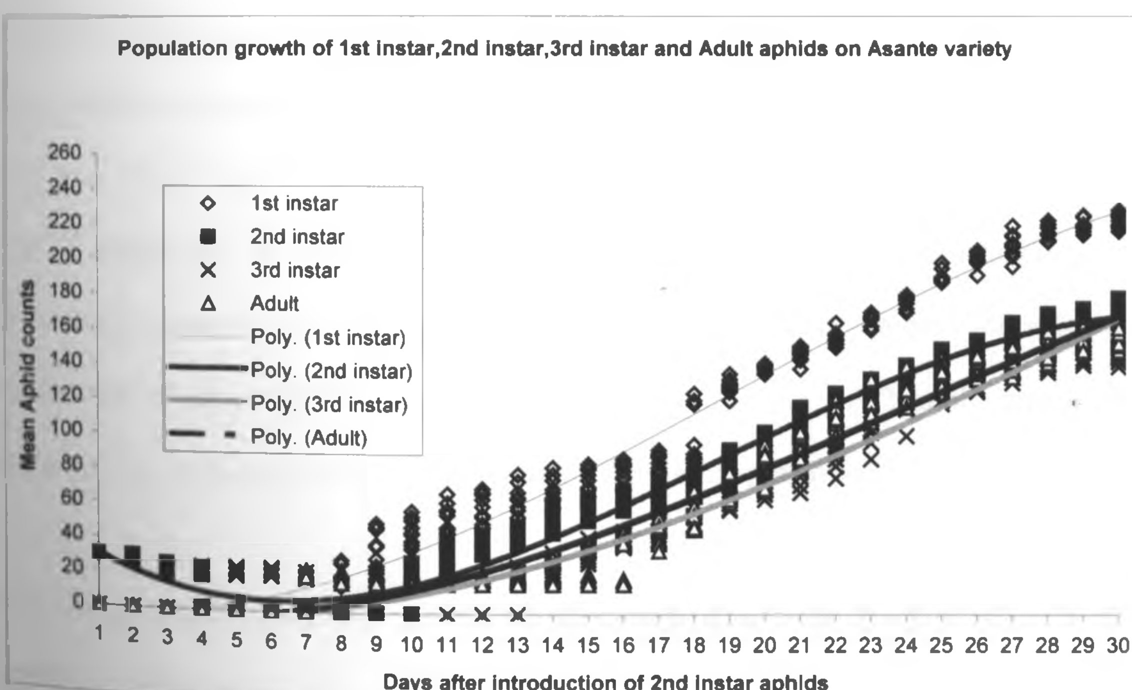

Fig. 3.6 Mean number of aphids on Asante potato sprouts in the third run

From the three runs for the Tigoni variety, it was observed that it takes two days from the 1st instar to 2nd instar stage of growth. Between the 2nd instar and 3rd instar stage, it takes a period of one day. The duration of time between the 3rd instar phase and the adult phase is four days and from the adult stage to the appearance of newly borne 1st instars is a period of one day. The 1st and 2nd instars survive for three days before moulting to the next stage. The 3rd instars live for one day before moulting into adults. Adults begin giving birth almost immediately as 1st instar aphids are observed one to two days following the appearance of adult aphids in the colony. The complete life cycle period for *M.euphorbiae* on the Tigoni potato variety is seven days.

For the Asante variety, it was observed that it takes three days from the 1st instar to 2nd instar stage of growth. Between the 2nd instar and 3rd instar stage, it takes a period of three days. The duration of time between the 3rd instar phase and the adult phase is three days and from the adult stage to the appearance of newly borne 1st instars is a period of two days. The 1st and 2nd instars survive for three days before moulting to the next stage. The 3rd instars live for one to two days before moulting into adults. Adults begin giving birth almost immediately as 1st instar aphids are observed one to two days following the appearance of adult aphids in the colony, as is the case for the Tigoni variety. The complete life cycle period for *M.euphorbiae* on the Asante potato variety is nine days.

The average temperatures over the period of the experiment were relatively the same. The average temperatures were 18°C and 25°C for the morning and afternoon hours respectively. However, the average relative humidity over the experimental period for

Asante variety was higher (90%) than over that for the Tigoni variety (75%). The average store temperatures for both treatments were observed to be lower during the morning hours at 9.00am (18°C) and higher during the afternoon at 3.00pm, ranging between 24°C and 26°C. The average relative humidity was higher during the morning hours and lower in the afternoon. The relative humidity over the morning hours ranged between 75% and 90% while the relative humidity over the afternoon hours ranged between 44% and 55%. The relative humidity over the morning hours for the period of data collection for Asante variety was observed to be constant for the three runs, while over the afternoon hours, the relative humidity was higher for the third than for the first or second runs. For Tigoni variety, the average relative humidity over both the morning and afternoon hours was higher for the first run than for the second and third runs (Fig. 3.7).

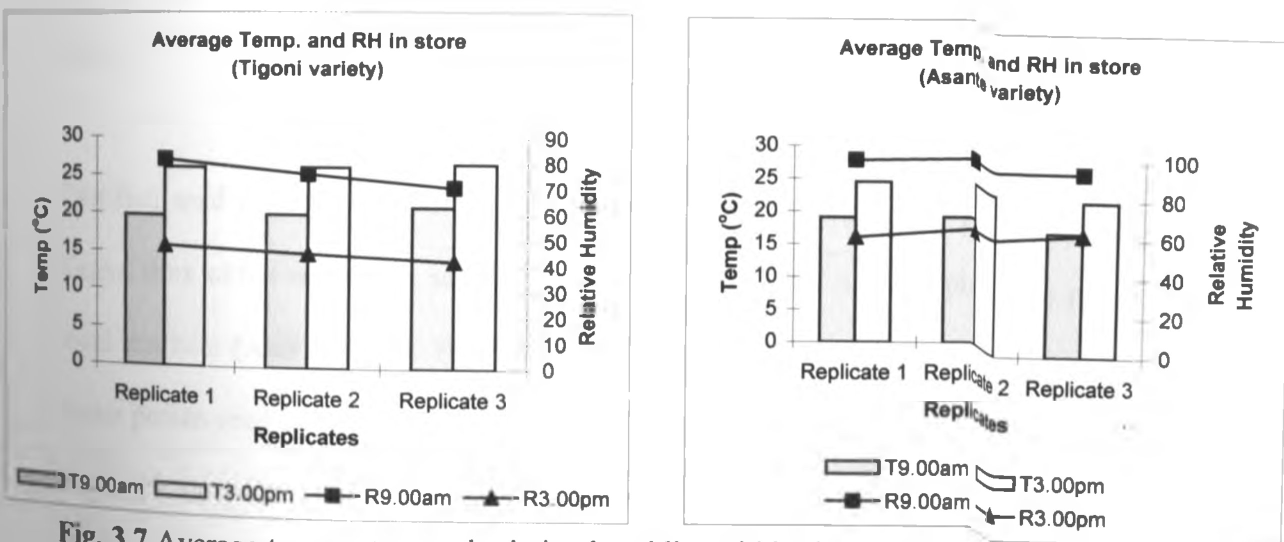

Fig. 3.7 Average temperature and relative humidity within the store for the three runs per treatment

3.4 Discussion

From the study it is clear that *M. euphorbiae* is able to survive on sprouted potato tubers under storage conditions. The population build up of the aphids increased over time, as all the four nymphal instars were observed on the potato sprouts throughout the study. The presence of adequate nutritive source also contributed to the increase in the numbers of aphids over time. Two peaks occurred in the growth curve of the aphids over time on the two potato varieties in this study. New generations were formed over this period. On the Tigoni variety, the first peak occurred eight to eleven days after the initial introduction of the newly borne 2nd instars, while on Asante, it occurred eleven to fourteen days in this study. The second peaks were observed two weeks later towards the end of the study. Aphids have a parthenogenetic lifestyle leading to rapid turnover of generations, typically 7-10 days, which allows for rapid increases in population (Raman. 1987).

Certified seed is expensive and sometimes unavailable (Ajanga, 1993). Most farmers in Kenya thus either use seeds saved from the previous crop or seed purchased from the local markets (Ateka, 1999). Farmers often wait for potatoes to sprout before planting. Some potato seed can over sprout due to prolonged storage period. Long storage periods of the potato seed allows the aphids to complete several generations in the stores even when there is no crop in the field. Aphids are known vectors of virus diseases. Therefore, since aphid populations increased throughout the storage phase, stringent aphid and viruses control measures need to be put in place to reduce seed degeneration. The choice of potato varieties used for the study is as a result of their high yielding capacity as is the case for Tigoni, while Asante is associated with good quality and good storability potential especially when it is grown for distant markets. Tigoni and Asante are commonly grown potato varieties and are threatened by aphids from the field carrying the viral load onto the tubers while in storage.

Three major potato aphids *Aulacorthum solani, Myzus persicae* and *Macrosiphum euphorbiae* were identified in farmers' stores in Kiambu and Nyandarua districts. *A.solani* was the most abundant (53.1%) while *M.euphorbiae* had the lowest numbers (31.3%). In all the stores where the aphids were recorded, Potato leaf roll virus (PLRV) and Potato virus Y (PVY) have also serologically been detected from the potato sprouts (Kibaru, 2003). From these findings one can therefore infer that aphids from the field carrying the viral load can infect sprouted tubers in storage. Infected tubers, if used as seed in subsequent seasons, will rapidly degenerate. Unprotected certified seed is reported to have about 71% PLRV and 53% PVY infection after a storage period of three months (Kibaru, 2003). This information confirms the importance of the storage phase in maintaining the health standards of seed tubers. Thus, if attention is not paid to the risk of transmission of severe viruses by aphids during storage, the expensive results of several years of seed multiplication may be lost in just a few weeks. Additionally, the potential for virus build-up during the storage period may help explain common reports of considerable reduction in virus levels from one crop season to the next and which have previously been attributed to late season aphid activity in the field.

When full grown, the potato aphid is nearly 1/8 inch long. Eyes are distinctly red and they have long slender cornicles extending from the abdomen (Blackman and Eastop 1984). There are two color types, the pink form and the green form. Although the majority of the progeny from a green form parent is green and likewise for the pink form, both color forms are able to parent either color form, (Shull, 1925). Adults are usually without wings. The adult forms in the study were wingless though as the populations increased, winged forms were observed only on the Tigoni tuber sprouts. Winged adults are developed in response to high population densities, decline of the host plant, and changes in environmental conditions. Winged individuals may be of either color form. The two peaks noted on the Tigoni tuber sprouts may have been the ending of and the formation of another new generation. Each unmated female may give birth to 50 or more active nymphs within 2 weeks. A generation develops on potato every 2 or 3 weeks. When population densities are high, winged individuals are produced. These individuals emigrate to new hosts. The production of winged versus wingless individuals is dependent on the day length, parent type, "generation" and temperature (MacGillivary and Anderson, 1964). Winged, or alate, aphids are more common when the photoperiod is between 11-13 hours a day, the parent aphids are unwinged and the first "generation" of aphids under similar environmental conditions, and the temperature ranges from 10-20 ^{o}C (MacGillivary and Anderson, 1964). Barlow (1962) reported that potato aphid populations have the capacity to increase in temperatures between 8^{o}C and 21^{o}C. The optimum temperature for the population increase for the potato aphid is 20^{o}C (Barlow, 1962). High temperatures increase mortality (Walker, 1982). This may explain why the aphid counts reduced on the twenty-second day of data collection on the Tigoni tuber sprouts. The temperatures ranged between 20-29°C, which was one of the highest over the period of the experiment.

Choice of store is an important tool in aphid and virus management. Adoption of semi-diffused light stores technology in the country as observed by Walingo *et al.*, (2002) could lead to reduced seed degeneration due to virus infection. The knowledge gap between potato farmers and researchers needs to be minimized and information on store construction and aphid proof potato seed stores needs to be availed to farmers. With the knowledge obtained from the findings of aphid population growth during storage, management of aphids and hence virus management can be initiated at this level.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

In this study, varieties Asante, Tigoni, Roslyn Tana, Bvumbwe and Kenya Karibu showed tolerance to aphids in the field and therefore may be recommended for increased potato production in the country. Dutch Robyjn, Tigoni, Asante and K. Baraka varieties had low incidence of the Potato leaf roll disease in the field. Aphid tolerant and moderately susceptible varieties may be recommended to farmers as these are more likely to support low aphid populations and low viral incidence. Tigoni, Asante and Roslyn Tana are high yielding and moderately tolerant varieties while Asante has a good storability potential. Aphids were observed to infest all the various potato cultivars planted. Three different aphid species were observed infesting the potato at different stages of the plants growth from the time of planting till the crop was mature for harvest. The levels of infestation varied significantly in terms of the potato variety and over the sampling period. Farmers require knowledge so as to enable them to correlate the presence of aphids and out break of aphid-transmitted virus diseases.

Potato seed tuber storage is aimed at providing viable and productive seed tubers in optimum conditions at the time when they are required for planting. The study revealed that a new generation of aphids develops after every two weeks. With this knowledge, once aphids are noted infesting on a potato crop in the field or on seed tubers in storage, suitable management methods should be applied to control the pests, which are also the known virus vectors. Farmers thus need to be aware of the effects of aphids on their potato crop in the field and also their infestation on tubers in storage. If attention is not paid to the dissemination of viruses by aphids during storage, several years of seed multiplication may be lost.

The study revealed that high temperatures accompanied by low or reduced rainfall support the increase in aphid numbers. Therefore, data from aphid population studies will be useful for selecting the best potato seed production areas and selecting the best growing season by synchronizing the planting times with the weather patterns.

4.2 Recommendations

- Aphids are recorded as vectors of several viruses in potatoes thus reducing the quality of seed potato especially among the small-scale holder farmers. From the results obtained in this study therefore, it would be recommended that specific control measures be implemented and adopted for specific aphid species on specific potato cultivars. This would target the reduction of aphid infestation over the growing period of the crop when the aphid species is known to infest over and this would in turn lower the virus load present in the seed potato over time.
- Based on the knowledge of the aphid cycle over the growing period of the potato crop, effective control measures can be applied and forecasts made early enough so as to target the most active phase of the aphid before infecting the potato. Farmers would in the long run have virus free seed potato.
- During the long rains season, the aphid population was observed to increase towards the end of the crop cycle. Observation over a third season could shed

some light on the aphid population build up and infestation over the cropping season.

- Ladybirds were noted as occurring on the potato crop in the field especially over periods when the aphid populations were high. A study on the use of these beetles in the stores can be carried out so as to assess their efficacy as a possible biological control for aphids on stored tubers.
- The activity of aphids and planting dates should be synchronised where Potato leaf roll disease has been observed in previous growing seasons and where aphids present a problem.

CHAPTER 5

REFERENCES

Agrawal, H. O., Misra, S. S. 1992. Virus free seed potatoes. Indian Horticulture. 37(1): 30-32

Ajanga, S. 1993. Status of bacterial wilt in Kenya. In G.L. Hartman and H. C. Hayward (Eds). Bacterial wilt ACIAR proceeding No. 45, Canberra Australia, pp 338

Anon. 1983. Annual Report CIP, Lima, Peru. Pp54-59

Anon. 1998. National Potato Research Center Annual Reports of 1995-1998.KARI, NPRC-Tigoni, Kenya

Ateka, E. M. 1999. Studies on the interaction between root- knot nematodes and the Bacterial wilt pathogen in potato production system in Kenya. M.Sc. Thesis, University of Nairobi. 66pp

Bald, J. G. 1946. A plan of growth, maturity and yield of the potato plant. Emp. Jour, Expt. Agr. 14-43-48.

Ballestrem, C. G. and Holler, H. J. (Ed.) 1980; 1974. Potato Atlas of Kenya. Published by the Federal Agency for Economic co-operation, Frankfurt, West Germany. 100pp

Barbagallo, S., R. Inserra &. Foster G. N. 1972. Population dynamics of *Myzus persicae* (Sulzer) on potato in Sicily. Entomologica (Bari) 8: 21-33. In Journal of Economic Entomology. 1993. 86(4): 1019-1025

Barker, H. and Woodford, J.A.T. 1992. Spread of potato leaf roll virus is decreased from plants of potato clones in which virus accumulation is restricted. Annals of Applied Biology. 121(2) 345-354)

Barlow, C. A. 1962. The Influence of Temperature on the Growth of Experimental Populations of *Myzus persicae* (Sulzer) and *Macrosiphium euphorbiae* (Thomas) (Aphididae). Can. J. Zool. 40: 146-156.

Berlandier, F. A. 1997. Distribution of aphids (Hemiptera: Aphididae) in potato growing areas of South-western Australia. Aust. Journal of Entomology. 36(4): 365-375

Birch, A. N. E.; Geoghegan, I. E.; Majerus, M. E. N.; McNicol, J. W.; Hackett, C.A.; Scottish, A. M. R. and Gatehouse, J. A. 1999. Tri-trophic interactions involving pest aphids predatory 2-spot ladybirds and transgenic potatoes expressing snowdrop lectin for aphid resistance. Molecular breeding (Netherlands). 5(5): 75-83

Blackman, R. L. and Eastop V.F. 1984. *Macrosiphum euphorbiae* (Thomas). Pp. 296. Aphids on the World's Crops: An Identification and information Guide. John Wiley & Sons: Chichester, New York, Brisbane, Toronto, Singapore. 466 pages.

Boiteau, G., Singh, R. P., Parry, R. H. and Pelletier, Y. 1988. The spread of PVY in New Brunswick potato fields: timing and vectors. American Potato Journal. 65(11): 639-649.

Booth, H. R. 1984. Management of potato insects in stores. CIP, Planning Conference, Integrated Pest Management, June4-8, 1984, Lima, Peru. 75-89 pp

Bradshaw, J. E. and Mackay, G. R. 1994. Potato Genetics: Potatoes for the developing world. CAB International. Pp16

Branquat, E.; Hemptinne, J. L.; Bruyere, M.; Adam, B. and Gaspar, C. 1996. Biological Control of potato aphids by ladybird beetles (*Adalia bipunctata*) International symposium on crop protection, Gent, Belgium. 7th May 1996

Broadbent, L. and Heathcote, G. D. 1961. Winged aphids trapped in potato fields, 1942-1959. Entomol. Exptl. Appl. 4: 226-237.

Castle, J. S. and Berger, P. H. 1993. Rates of growth and increase of *Myzus persicae* on Virus-infected potatoes according to type of virus-vector relationship. Entomologia Experimentalis et Applicata. 69(1): 51-60

Cerato, C.; Rongai, D.; Borgatti, S. and Tamba, M. L. 1994. Study of the aphids populations and virus diseases on seed potato crops. Informatore-Agrario (48): 67-72

Cit - Wheatley, C., Scott, G. J., Best, R. and Wiersema, S. (Eds) 1995. Adding value to root and tuber crops: a manual on product development. Cali, Columbia: CIAT 1651, Page 5.

Collar, J. L., Avilla, C., Duque, M. and Fereres, A. 1997. Behavioural response and virus vector ability of Myzus persicae (Homoptera :Aphididae) probing on pepper plants treated with aphids. Journal of Economic Entomology. 90(6): 1628-1634.

Crissman, C. C., McArthur Crissman, L and Carli, C. 1993. Seed potato systems in Kenya. A case study. Lima, International Potato Centre. 44pp

De Bokx, J. A. (Ed.) 1972. Viruses of potato and seed potato production. Pudoc, Wageningen. Pp 68-72.

Dickey, H. C., Gerry, W.R. and Brugman, H.H. (Eds) 1974. Potato products for feeding Purposes. Life Sciences and Agriculture Experiment Station, University of Maine at Orono U.S. 128pp.

Difonzo, C. D., Ragsdale, D. W. and Radcliffe, E. B. 1995. Potato leafroll virus spread in Differentially resistant potato cultivars under varying aphid densities. American Potato J. 72(2): 119-132

Difonzo, C. D., Ragsdale, D. W., Radcliffe, E. B., Gudmestad, N.C. and Secor, G. A. 1996. Crop borders reduce potato virus Y incidence in seed potato. Annals of Applied Biology. 129(2); 289-302

Difonzo, C. A., Ragsdale, D. V., Radcliffe, E. B., Gudmestad, N. C. and Secor, G. A. 1997. Seasonal abundance of aphid vectors of potato virus Y in the Red River Valley of Minnesota and North Dakota. Journal of Economic Entomology. 90(3): 824-831

Dogan, E. B., Berry, R. E., Reed, G. L. and Rossigno, P.A. 1996. Biological parameters of Convergent ladybird beetle (Coleoptera; Coccinellidae) feeding on aphids (Homoptera: Aphididae) on transgenic potato. Journal of Economic Entomology. 89(5): 1105-1108

Durr, G. 1976. Production and Marketing of Potatoes in Kenya. International Potato Center, Nairobi. Pp 15-17

Durr, G. and Lorenzyl, G. 1980. Potato production and utilization in Kenya. CIP, Lima, Peru. Pp213-219

Duvauchelle, S. and Dubois, L. 1997. Potato aphids in France. Questions asked and research needed. Phytoma. 49(492): 27-30

Eastop, V. F. 1953. E. A. Agriculture and Forestry Research Organization In: The East African Agricultural Journal. Pp 184-187

Eastop, V. F. 1977. Worldwide importance of aphids as virus vector In: Harris, K. F. and K. Maramorosch (eds.) Aphids as virus vectors. Pp156-161

FAOSTAT 2001. Crop Protection Compendium- Agricultural Production for Kenya, (1997-2001).

FAOSTAT 2002. http://apps.fao.org/page/collections/subset=agriculture

FAOSTAT 2003. http://apps.fao.org/page/collections/subset=agriculture

Folson, D. and Stevenson, F. J. 1946. Resistance of potato seedlings varieties to the natural spread of leaf roll virus. Am. Potato J. 23: 247-284.

Garg, I. D 1987. Degeneration of potato varieties in Western Maharashtra. J. Indian Potato Assoc. 14,127-128.

Gibson, R. W. 1971. Glandular hair providing resistance to aphids in certain wild potato species. Ann. Appl. Biol. 68: 113-119

Gibson, R. W. 1974. The induction of top-roll symptoms in potato plants by the aphid *Macrosiphum euphorbiae*. Ann. Appl. Biol. 76: 19-26

Goffinet, D. 1982. Economic importance of potato diseases and pests. In: S. Nganga and F. Shideler (eds) *Potato Seed Production for Tropical Africa*. International Potato Center. 63-73.

Griesbach, E. and Eisbein, K. 1975. The importance of weeds for the transmission of *Rhizoctonia solani* (Kuhn). III The influence of weeds on the infestation of potatoes by *Rhizoctonia solani*. Zbl. Bakt. Abt. II Bd., 130, 745-60.

Hanafi, A. 1998 Integrated management strategies for insect transmitted viruses in some vegetable crops. Pp 4-7. In: Newsletter 4. FAO Regional Working Group on Greenhouse Crop Production in the Mediterranean Region. 14 pp.

Handizi, J. and Legorburu, F. T. 2002. Escaping from potato virus Y: Aphid repellents and planting dates. VIII[th] International Plant Viruses Epidemiology Symposium Aschersleben/ Germany 12-17[th] May, 2002. 156pp

Hansen, L. 1995. Aphids: the national pest in Denmark. 12[th] Danish Plant Protection Conf.: Pests and diseases. SP- Rapport-Statens-Planteavlsforsog. No. 4: 115-128

Harrewijn, P. 1989. Integrated control of potato aphids. In Aphids; their biology, natural enemies and control. Vol. 2c(ed.) Minks, A. K. and Harrewijn, P. pp 279-289

Harrington, R., Bartley, E., Riley, D. K., French-Constant, R. H. S. and Clark, S. J. 1989. Resurgence of insecticide resistant *Myzus persicae* on potatoes treated repeatedly with cypermethrin and mineral oil. Crop Protection. 8(5): 340-348.

Harrison, B. D. 1981. Plant virus ecology; ingredients, interactions and environmental influences. Ann. Appl. Biology 99: 195-209.

Harrison, B. D. 1984. Potato leaf roll virus. CMI/AAB Descriptions of plant viruses, No. 291. Commonwealth Agricultural Bureaux Farnham royal, Slough, U.K.

Haugerad, A. and Kimani, J. 1995. Potato varieties in Kenya: Findings from a preliminary field study. CIP Regional Office, Nairobi.

Heuvel, J. F., Hogenhout, S. A., Van-den J. M. Verbeek, M. and Wilk, F. 1998. *Azadirachta indica* metabolites interfere with the host endosymbiot relationship and inhibit the transmission of potato leaf roll virus by *Myzus persicae*. Entomolgia Experimentalis et Applicata. 86(3): 253-260.

Horton, D. 1987. Potatoes: Production, Marketing and Programs for Developing countries. (Boulder, Colorado: Westview).

Horton, D. 1992. La papa: Producion, commercializacion y programas. Centro Internacional de la Papa (CIP), Lima, Peru, and Editorial Hemisferio Sur, Monterideo, Uruguay. 260p.

Huaman, Z. 1986. Systematic botany and morphology of the potato. Technical Information Bulletin 6. International Potato Centre (CIP), Lima, Peru.

Ioannou, T. 1988. Suppression of virus spread in local seed potatoes by eliminating the sources of infection with rouging. Technical Bulletin-Cyprus Agricultural Research Institute. No. 02: 5pp

Jayashinghe, V. 1988. Potato leaf roll virus (PLRV) Technical information bulletin CIP. Lima, Peru. No. 22 pp21.

Jayashinghe, U., Chuquinnlanqui, C. and Salazar, L. 1989. Modified expression of virus resistance in mixed virus infections. American Potato Journal.66: 137-144

Jayashinghe, U., Rocha, J. and Chuquillangui, C. 1993. Feeding behaviour of potato aphids on potato cultivars resistant and susceptible to potato leaf roll virus (PLRV). Fitopatologia. 28(2); 107-111

Ji, Y. Q., Pirone, T. P. 1989. Assessment of the effect of oil on the Potyvirus aphid transmission process. Journal of Phytopathology. 127(30): 331-336.

Kabira, J. N. 2000. French fries and crisps processing characteristics of selected potato varieties in Kenya. APA Conference Proceedings, Vol. 5. Pp. 507-511

Karimullah, N., Ahmad, S., Paracha, A. M. and Jan, M. T. 1995. Infestation of aphid, *Myzus persicae* (Sulzer) on potato in Peshawar, NWFP, Pakistan. Sarhad Journal of Agriculture. 11(6): 741-744

Khurana, S. M. P., Singh, M. N.1988. Yield loss potential of potato viruses X and Y In Indian potatoes. J. Indian Potato Assoc. 15, 27-29.

Khurana, S. M. P. 1992; 2000. Potato viruses and viral diseases. Tech. Bull No.35, CPRI, Shimla, 23 pp.

Khurana, S. M. P. 2002. Potato viruses: Detection and management. African Potato Association Conference Proceedings, Vol. 5. Pp. 257-269

Kibaru, A. 2003. Management of aphids and aphid-transmitted viruses in seed potato (*Solanum tuberosum* L.) production in Kenya. M.Sc. Thesis, University of Nairobi.

Kim, S. L., Shin, K. Y., Hwang, S. J., Hahm, Y. I., Park, C. S., Kim, B. D., Hahn, B. H., Rynon, O. H. and Choi, K. S. 1992. Effect of types of cultivation and time of vine kill on potato yield and virus diseases. Crop Protection. 34(2): 33-40

Kinyae, P. M., Lung'aho, C., Kanguhua, E. and Njenga, D. N. 1994. The status of seed potatoes in Meru, Nyambene, Nyandarua and Laikipia districts. Second Kenya Agricultural Research Institute and International Potato Centre (CIP) Technical workshop in collaborative research. Nairobi, Kenya.

Kish, L. P., Majchrowicz, I. and Biever, K. D. 1994. Prevalence of natural fungal mortality of green peach aphid (Homoptera: Aphididae) on potatoes in Washington and Idaho. Environmental Entomology. 23(5): 1326-1330

Kuo, M. H. 1991. The effect of temperature and host plant on development and reproduction by *Myzus persicae* (Sulzer). Chinese Journal of Entomology, 11 (2): 118-129.

Lagnaoui, A. and Radcliffe, E. B. 1998. Potato fungicides interfere with entomopathogenic fungi impacting population dynamics of green peach aphid. American Potato Journal. 7591: 19-25

Landis, J., Powell, D. M. and Fox, L. 1972. Population of aphids on named varieties of Irish potatoes. Amer. Potato Jour. 49: 63-69.

Lian, Y., Yang, H. F., Jin, L. P. and Cheng, T. Q. 1994. Technical measures for better quality of potato seed tubers in the two season cropping area in Beijing. Beijing Agricultural Sciences Journal. 12(4): 15-19

MacGillivray, M. E. and Anderson, G. B. 1964. The Effect of Photoperiod and Temperature on the Production of Gamic and Agamic Forms in Macrosiphium euphorbiae (Thomas). Can. J. Zool. 42: 491-510.

MOA, 2000. Ministry of Agriculture. Government of Kenya. Interim poverty reduction strategy paper for the period 2000-2003. Government printers. Draft copy. 21-23pp

Mulakazi, J., Adipala, E., Sengooba, T., Olanya, M and Kidanemarium, H. M. 2000. Production structure of *Phytophthora infestans* in Uganda. Crop Protection

Nakata, T. 1995. Population fluctuations of aphids and their natural enemies on potato in Hokkaido, Japan. Applied entomology and Zoology. 30(1): 129-138

Nderitu, J. H. 1983. Aphid infestation on eight selected potato varieties *Solanum tuberosum* L. and their control with insecticides in Kenya. M.Sc. Thesis, University of Nairobi, Kenya.

Nderitu, J. H. and Mueke, J. M. 1986a. Aphid infestation on potato cultivars (*Solanum tuberosum* L.) in Kenya. Insect Sci. and its Applic. 7: 677-682

Nderitu, J. H. and Mueke, J. M. 1986b. Susceptibility of eight potato cultivars to *Myzus persicae* Sulzer in the greenhouse. Insect Sci. and its Applic. 10: 229-234

Ng'anga, N. M., Kinyae, P. M., Kabira, J. N., El-Bedewy, R. and Lemaga, B. 2002. Historical background to the production and utilization of the potato crop in Kenya (1900-2000): Lessons for Research and development programmes in the 21st Century. Paper submitted to PRAPACE.

Ngugi, S. N. 1983. Potato production in Kenya: Potential and limitations. In: Research on potato in the year 2000. Hooker, J. W. (ed). Pp140-142

Nisbet, A. J., Woodford, J. A. and Strang, R. H. C. 1996. The effects of *Azadirachta* on the acquisition and inoculation of potato leaf roll virus by *Myzus persicae*. Crop Protection (UK). 15(1): 9-14.

Parker, W. E. 1997. Forecasting the timing and size of field populations of aphids on potato in England and Wales. Fourth International Conference on pests in Agriculture, 6-8th January 1997, France, Paris

Peters, D. and Jones, R. A. 1981. Potato leaf roll virus In: Compendium of potato diseases. Hooker, W. J. (eds.) The American Phytopathological Society, St. Paul, MN.

Powell, G., Harde, J. and Pickett, J. A. 1998. The effects of antifeedant compounds and mineral oil on stylet penetration and transmission of potato virus Y by *Myzus persicae* (Sulzer) (Homoptera: Aphididae). J. Appl. Ent. 122(6): 331-333.

Purseglove, J.W., 1968. Tropical crops dicots. 2. Longmans green and Co. London 332p.

Radcliffe, E. F. 1982. Insect pests of potato. Ann. Review Entomol. 27: 173-204.

Raman, K. V. 1980. Insect vector transmission of potato viruses. Technical Information Bulletin 2. International Potato Cenre, Lima. Peru.

Raman, K. V. 1987. Survey of diseases and pests in Africa: Pests. Acta-Horticulturae. No 213: 143-150

Ray, B. T. 1989. Seasonal abundance of natural enemies of aphids infesting potato crop. Journal of Aphidiology. 3(1-2): 157-161

Rich, A. E. 1983. Potato diseases. Pp 118-122.

Riekmann, W. 1995. Vector control as a basis for the healthy potato plants. Kartoffelbau 4(5): 188-192.

Robertson, D. G. and Wambugu, J. P. W.1975. Aphid populations and distribution in Kenya. Ministry of Agriculture, Kenya. ODA report, pp 18-19

Rongai, C. and Cerato, C. 1997. Forecasting the best time for the desiccation of seed potato. Informatore Agrarice. 53(17): 51-56

Rongai, D., Cerato, C., Martelli, R. and Ghedini, R. 1998. Aspects of insecticide resistance and reproductive biology of Aphis gossypii Glover on seed potatoes. Potato Research. 41(1): 29-37.

Salazar, L. F. M. 1996. Potato viruses and their control. Pp 3-65

Seyedoleslaami, H., Danesh, D., Naderi, A. and Eslami, A. 1995. Alate aphid monitoring for selecting of potential seed potato production districts in Isfahan and Chahr Mahal Bakhtiari provinces of Iran. Iranian Journal of Agricultural Sciences. 26(3): 19

Shull, A. F. 1925. The Life Cycle of *Macrosiphium solanifolii* with Special Reference to the Genetics of Color. American Naturalist. 59(663): 289-310.

Singh, R. A. and Khurana, S. M. P. 1993. Viral and allied diseases of potato. Pages 491-528. In: Adv. In Hort. Vol. 7. Potato. Chadha, K.L. and Grewal, J.S. (eds.). MPH New Delhi.

Stoltz, R. L., Gaulak, R. G. and Halbert, S. 1997. Survey of potential aphid vectors of potato (*Solanum tuberosum* L.) virus diseases in the Matanuska Valley. Journal of Vegetable Crop Production (USA). 31 (1): 27-36

Tahtacioghu, L. and Ozbek, H. 1997. Monitoring aphids (Homoptera; Aphidoidea) species and their population changes on potato crop in Erzurum (Turkey) province throughout the growing season. Turkiye-Entoloji-Dergisi. 21(1): 9-25

Tae, H. R.; Long, G. E. 1998. Population dynamics pattern of green peach aphid (Homoptera; Aphididae) and its predator complex in a potato system. Korean Journal of Biological Sciences. 2(2): 217-222

Taylor- Hunt, G. L. 1992. Innovative cooling methods for low cost crop storage in the hot humid tropics. Thesis. Cranfield Institute of Technology. Silsoe.

Thackray, D., Ward, L., Thomas, M. and Jones, R. A. C. 2002. Relationship between aphid numbers, BYDV spread and yield loss in wheat grown in Mediterranean type climate. VIIIth International Plant Viruses Epidemiology Symposium Aschersleben/ Germany 12-17th May, 2002. 145pp

Thomas, P. E., Pike, K. S. and Reed, G. L. 1997. Role of green peach aphid flights in the epidemiology of potato leaf roll disease in the Colombian Basin. Plant Disease 81(11): 1311-1316

Till, B. B. 1971. The effect of insecticide on the spread of potato leafroll virus in seed potato fields at Pukelole N. Z. Agric. Res. 14: 458-468.

Toba, H. H. 1964. Life-History Studies of Myzus persicae in Hawaii. J. Econ. Entomol. 57(2): 290-291.

van Emden H. F., Eastop V. F., Hughes H. D. and Way M. J. 1969. The ecology of *Myzus persicae.* Annual Review of Entomology, 14: 197-270.

Walingo, A., Kabira, J. N., Kidanemarium, H. M. and Ewell, P. T. 1996. Evaluating potato clones under seed and ware storage conditions at Tigoni, Kenya. Proceedings of the Trienn. Symposium ISTRC (AB), Lilongwe, Malawi. Pp575-579.

Walingo A., Lung'aho, C., Kinyae, P., Kabira, J. and Ramzy, B. 2002. Studies on potato seed performance under on-farm storage conditions in Mount Kenya region. KARI Technical note no. 10. January 2002. 1-6pp

Walker, G. P. 1982. The Dispersion and Abundance of the Potato Aphid (*Macrosiphum euphorbiae* [Thomas]) on Tomato (*Lycopersicon esculentum* Mill.). Ph.D. Dissertation, Ohio State University, Wooster.

Walkey, D. G. A. 1991. A textbook of Applied Plant Virology. Chapman and Hall, 1985. Van Nostrand Reinhold, 115 5th Avenue, New York NY 1003. 172-256pp

Were, H. K. 1996. A survey for potato leaf roll virus (PLRV), evaluation of some potato clones for resistance to the virus and comparison of elimination methods. M.Sc. Thesis, University of Nairobi.

Were, H. K., Narla, R. D., Nderitu, J. H and Kidanemarian, H. M. 1996. Evaluation of some promising potato clones for tolerance to potato leaf roll virus (PLRV) and for resistance to its vectors *Myzus persicae* Sulzer and *Macrosiphum euphorbiae* Thomas. Afr. J. Plant Prot. 6: 57-66

Woodford, J. A. T. and Gordon, S. C. 1990. New approaches for restricting spread of potato leaf roll virus and different methods of eradicating infected plants from potato crops. Annals of applied Biology. 116(3): 477-487

APPENDIX 1 Weather data for Years 2002 to mid-2003 at the National Potato Research Centre, Tigoni

Weather Data for Year 2002

Month	Temperature (^{o}C)	% Relative Humidity	Rainfall (mm)	Number of days
January	16.2	86.3	115.9	5
February	16.24	87.39	38.5	4
March	15.85	86.56	300.4	11
April	15.6	85.03	835.4	26
May	15.1	85	370	14
June	13.96	87.68	4.5	1
July	13.97	87.71	4.5	1
August	13.63	89.11	21.6	2
September	15.14	90.13	34.4	2
October	15.8	88.2	204.2	11
November	16.07	89.1	397.2	17
December	16.46	92.18	330.4	14

Weather Data for Year 2003

Month	Temperature (^{o}C)	% Relative Humidity	Rainfall (mm)	Number of days
January	18	89.51	137.6	5
February	17.4	89.91	20.2	4
March	18	90.5	80.1	8
April	14.71	90.6	472.6	16
May	15	80	755.3	21
June	15.28	92.63	229.1	8