# OPTIMIZATION OF LOW-COST FOOD PROCESSING TECHNIQUES FOR THE DEVELOPMENT OF COWPEA LEAVES SOUP MIXES


**BY**

**OMBAKA JOSHUA OWADE**

**B.Sc., M.Sc. (UNIVERSITY OF NAIROBI)**


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**DEPARTMENT OF FOOD SCIENCE, NUTRITION AND TECHNOLOGY**

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**UNIVERSITY OF NAIROBI**


**2021**

**DECLARATION**

This thesis is my original work and has not been presented for a degree in any other University

Joshua Ombaka Owade (A81/89053/2018)

Signature…………………………………. Date 10/08/2021

This thesis has been submitted with our approval as university supervisors:

**Dr. George Ooko Abong'**

Department of Food Science, Nutrition and Technology, University of Nairobi

Signature: Date: August 14, 2021

**Prof. Michael W. Okoth**

Department of Food Science, Nutrition and Technology, University of Nairobi

Signature Date: August 17, 2021

**Prof. Agnes W. Mwang'ombe**

Department of Plant Science and Crop Protection, University of Nairobi

Signature…………………………………. Date…17th August 2021……….

**UNIVERSITY OF NAIROBI**

**COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES (CAVS)**

**Declaration of Originality Form**

**Name of Student: Ombaka Joshua Owade**

**Registration Number: A81/89053/2018**

**College: University of Nairobi**

**Faculty/School/Institute: College of Agriculture and Veterinary Sciences**

**Department: Department of Food Science Nutrition and Technology (DFSNT)**

**Course: Doctor of Philosophy in Food Science and Technology**

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## DEDICATION

To every young man and woman, who in the struggle to make it in the field of science and technology, will come across this research work, I would wish to let you know:

“*The journey is too good to turn back, keep on reading and researching. For no price is too high to pay for your valid and divine dream*.”

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**LIST OF ABBREVIATIONS**

| | |
|---|---|
| AACC | American Association of Cereal Chemists |
| AAT | Accelerated Aging Time |
| AFA | Agriculture and Food Authority of Kenya |
| AHP | Analytic Hierarchy Process |
| ALVs | African Leafy Vegetables |
| ANOVA | Analysis of variance |
| AOAC | Association of Analytical Chemists |
| API | Analytical Profile Index |
| ASALs | Arid and Semi-Arid Lands |
| CCD | Central Composite Design |
| CE | Catechin Equivalent |
| CI | Consistency Index |
| CJOICE | Choosing Interventions that are Cost-Effective |
| CR | Consistency Ratio |
| CV | Coefficient of variation |
| DCPIP | Dicholorophenolindophenol |
| DPPH | 2,2-diphenyl-2- picryl hydrazyl |

| | |
|---|---|
| dwb | Dry Weight Basis |
| FAO | Food and Agriculture Organization |
| FGD | Focus Group Discussion |
| FRuVaSe | Fruits and Vegetables for All Seasons |
| GAE | Gallic Acid Equivalent |
| HDPE | Higher Density Polyethene |
| HSD | Honest Significant Difference |
| ISO | International Organization for Standardization |
| K80 | Katumani 80 |
| KEBS | Kenya Bureau of Standards |
| KII | Key Informant Interviews |
| KNBS | Kenya National Bureau of Statistics |
| LAB | Lactic Acid Bacteria |
| LP | Linear Programming |
| M66 | Machakos 66 |
| MCDA | Multi-Criteria Decision Analysis |
| MRS | de Man, Rogosa, and Sharpe |

| | |
|---|---|
| MT | Metric Tonnes |
| PCA | Principal Component Analysis |
| PCoA | Principal Coordinate Analysis |
| PEM | Protein Energy Malnutrition |
| PV | Peroxide Value |
| RDA | Recommended Dietary Allowance |
| RSM | Response Surface Methodology |
| SSA | sub-Saharan Africa |
| TA | Texture Analyzer |
| TBS | Tanzania Bureau of Standarda |
| TE | Trolox Equivalent |
| TVC | Total Viable Count |
| USAID | United States Agency for International Development |
| UV/VIS | Ultraviolet–visible |
| WAE | Weeks After Emergence |
| WHO | World Health Organization |

**GENERAL ABSTRACT**

Seasonality in the availability coupled with limited value addition practices of the cowpea leaves is great impediment to its utilization. The current study evaluated value addition approaches for the production of superior quality shelf-stable cowpea leaves based product to bridge limitation in the availability of the crop. The study was implemented using a desk review that identified optimized modern processing techniques for the vegetables; a field survey incorporating a mixed method convergent study design in the eastern and coastal arid and semi-arid lands (ASALs) in Kenya, Kitui and Taita Taveta Counties, to identify the trends and constrains in the utilization of cowpea leaves; and experimental study that utilized optimization approach in processing and evaluating product quality of cowpea leaves.

The desk study established that hurdle technology, combining two preservation techniques, has the advantage of optimal retention of product quality than the use of a single preservation technique. The field study showed that the mean period of availability of fresh leaves in the areas was 4.8 ± 4.3 weeks in each cropping season. Sun-drying was the most utilized preservation technique among the households, 27.5%. Households in the coastal ASALs significantly ($p < 0.05$) consumed more of dried forms (odds ratio: 3.3) but less of boiled ones (odds ratio: 0.1) than those in the Eastern parts of Kenya. Involvement of households in the commercialization of cowpea leaves and sale of the preserved forms in the open-air market significantly increased the likelihood ($p<0.001$, OR=2.47 and $p<0.001$, OR=2.3; respectively) of utilization of the vegetables during scarcity. Marketing challenges, lack of access to inputs and inadequate postharvest technologies for preservation of the vegetables constrained the production and utilization of cowpea leaves.

Optimal fermentation of the leaves was achieved at a sugar and salt concentrations of 5% and 2%, respectively, for 16 days; attaining a pH of 3.8 and titratable acidity of 1.22% with a desirability

of 0.859; $R^2$ for 0.89 and 0.60 for the model predicting pH and titratable acidity, respectively ($p<0.001$). Comparative analysis between optimally and locally processed dehydrated vegetables sourced from the farmer groups showed that, the optimally dehydrated cowpea leaves combined better retention of beta-carotene and the minerals than the latter ($p<0.001$).

The optimal ratio for incorporation of dried cowpea leaves in soup mixes was established as 49%. Use of low-cost processing of processing (sun-drying) are half less costly than the mechanized techniques, the derivative benefits are lower. The most optimal technique, however, the solar-drying technique had the most optimal benefit-cost (1.55). The low-cost processing techniques imparted invariably similar quality parameters in terms of the physico-chemical attributes of the soup mixes. The keeping and sensory quality were, however, lower than the soup mixes processed through mechanized techniques ($p<0.05$). Cowpea leaves processed using modernized techniques had no significant ($p>0.05$) difference on the acceptability. The low-cost techniques provided alternative pathways for processing cowpea leaves soup mixes thus recommended in resource-constrained settings. Input of feasibility studies focusing on socio-determinants for uptake would be required for instituting dissemination approaches of these technologies.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background information

Traditional leafy vegetables rank high in the diet of most rural communities in sub-Saharan Africa (SSA). These crops tend to withstand the abiotic and biotic stresses prevalent in SSA, making then viable to help fight food and nutrition insecurity in the region. The production of the traditional leafy vegetables largely smallholder-focused and for subsistence (Opiyo et al., 2015a). The value chain of these crops is greatly limited in spite of the rich nutritional property they possess. African leafy vegetables (ALVs) such as cowpea (*Vigna unguicullata*) leaves are a great source of micronutrients that are essential to health (Chikwendu et al., 2014). Most households remain deprived of these benefits due to less utilization of the crop especially in the urban areas.

SSA countries struggle with hunger in its form as protein energy malnutrition (PEM) and micronutrient deficiencies (hidden hunger). A study that evaluated the nutritional quality of edible parts of cowpea crops, found that the leaves are a better avenue of eradicating micronutrient deficiencies than the seeds (Mamiro et al., 2011). The varieties of cowpeas cultivated and consumed in Kenya include local varieties such as Khaki, Macho, Kaima-koko, Kutambaa, Mwandato, Nyekundu, and Nyeupe and improved varieties such as KVU 419, K80 and KVU 27-1 (Ndiso et al., 2016). These varieties are suited to survive under varied environmental conditions, with improved varieties showing more resilience. The improved varieties have richer micronutrient composition than the local varieties (Mamiro et al., 2011). Improved varieties of were found to have iron, zinc, 21.2-23.8, 26.1-32.2 and 684.8-1112.9 mg/100g, respectively, compared to the landraces iron, zinc and calcium contents that were as low as 9.24-9.9, 17.1-19.6 and 363  mg/100g, respectively. Micronutrients such as zinc, calcium and iron have been made greatly bioavailable in cowpea leaves through improved breeding (Mamiro et al., 2011). Ngalamu et al. (2014) postulates that cowpea leaves are also a good source of β-carotene and other essential vitamins like ascorbic acid and B vitamins.

Current practices have point to the success of hurdler technology in ameliorating on the aesthetic quality, consumer acceptability and nutrient retention in processed vegetables. Studies have found fermentation accompanied with solar drying as having less deleterious effects on some of the very labile nutrients such as beta-carotene (Kasangi et al., 2010). However, much of these nutrient-preserving with potential of serving the urban and high-end markets are still limited in practice in Kenya; with varied levels of efficiency where they are done. Moreover, the sensory and nutritional quality remains largely a challenge occasioning low acceptability of traditionally preserved leaves. Development of value-added products with great sustainability in production can serve to expand the market thus create an incentive for more production.

## 1.2 Statement of the problem

Food and nutrition insecurity has yielded the challenge of undernutrition both in its form of protein energy malnutrition and micronutrient deficiencies in Kenya. National reports in 2014 found that among children aged below five years, stunting and underweight rates still stand at 26% and 11%, respectively (KNBS et al., 2014). The report also found that significant proportion (87%) is at risk of iron deficiency due to limited consumption of iron rich foods. The situation was found to be worse among the rural population where there is low intake of both vitamin A and iron rich foods and high rates of stunting and underweight. This situation exists despite nutritious foods such as cowpea leaves and other ALVs being produced in rural areas in Kenya (Mwaura et al., 2013). The utilization of cowpea leaves in their fresh form has been hindered by the seasonality in their availability and short shelf-life. Limited value addition practices have further acted to the detriment of providing alternative solutions of enhancing availability of this nutritious vegetable.

Value addition practices for cowpea leaves currently in practice have also yielded less satisfactory results in terms of the quality of the products: while the keeping quality of the product has been improved, the sensory and nutritional qualities have remained quite a challenge. Cowpea leaves preserved through current technologies in practice have low nutrient retention and a great deviation from the fresh leaves in terms of sensory quality. This has been attributed to textural and colour changes and degradation of nutrients during storage of preserved cowpea leaves (Kirigia et al., 2018): improper packaging techniques and lack of optimal processing have been the major causes of this. Appropriate technologies that would improve nutrient retention while minimizing deterioration of sensory quality in these preserved cowpea leaves are limited or missing in practice. Additionally, information with regard to the effect of preservation techniques based on the maturity of the cowpea leaves on the chemical attributes and acceptability of the value-added cowpea leaves also remains scanty. This research will for the first time come up with soup mix whose main ingredient is the local nutritious cowpeas leaves.

## 1.3 Justification of the study

Generating information and evidence of soup mixes as possible value-added products of cowpea leaves would promote the uptake and utilization of cowpea leaves which have been shown to be nutritious. Value addition practices for cowpea leaves are limited in practice with less diversity of these value-added products; this coupled with the fact that most consumers consider the processing and preparation of fresh cowpea leaves as tedious has occasioned less utilization of these vegetables (Abukutsa-Onyango, 2010). Providing a soup mix would encourage the consumption of the vegetable by the population including the vulnerable. The utilization of these vegetables has been recommended for possible alleviation of micronutrient deficiencies (Ochieng et al., 2016). Product diversification of value-added cowpea leaves have an extended effect of increasing the consumer base that would benefit from consumption of the products, thus promoting food and nutrition security among these consumers. As it has also been established that good nutrition status is a prerequisite for development (KNBS et al., 2014), it necessitates concerted efforts aimed at promoting the nutritional well-being of the population especially of developing countries such as Kenya. The importance of this study is that it will contribute to the government's efforts of promoting food security in the country that happens to be a priority area. Moreover, promotion of value addition approaches is with the aim of improving on market orientation of the vegetables thus improving returns to the producers and value chain actors.

It is also important to note that the proposed study areas of Taita Taveta and Kitui Counties experience shortage of the vegetable during drought whereas there is glut with massive spoilage during rainy season. The areas have arid conditions whereby sourcing for nutritious vegetables are a great challenge. The study will seek to improve availability of the vegetable in these areas through developing alternative products that are acceptable.

### 1.4 Purpose of the study

To generate market solutions for surplus cowpea leaves through value addition.

## 1.5 Objectives

### 1.5.1 General objective

The general objective of the study is to optimize the cost of production and in-process physico-chemical, sensory and keeping quality changes in the development of soup mixes incorporating cowpea leaves as dominant raw material.

### 1.5.2 Specific objectives

1. To establish the trends and constraints in the utilization, traditional preservation and processing techniques of cowpeas leaves among communities in Kitui and Taita Taveta Counties of Kenya.

2. To optimize the retention of the physico-chemical quality of cowpea leaves subjected to processing.

3. To comparatively evaluate the physico-chemical quality of cowpea leaves processed through traditional artisanal and optimized techniques.

4. To optimize the cost of production of cowpea leaves soup mixes subjected to processing using optimized techniques.

5. To evaluate the physico-chemical, sensory and keeping qualities of cowpea leaves soup mixes subjected to low-cost optimal processing.

## 1.6 Hypotheses

The null hypotheses for the specific objectives are:

1. The rate of utilization, preservation and processing techniques of cowpea leaves in Kitui and that in Taita Taveta Counties are the same.
2. Improving the processing parameters does not improve the retention of the physico-chemical quality of processed cowpea leaves.
3. Artisanal traditional processing techniques of cowpea leaves does not significantly alter the physico-chemical quality of the cowpea leaves than the mechanized optimal techniques.
4. Utilization of different dehydration techniques in the processing of cowpea leaves soup mixes yield similar benefit-cost ratios.
5. There was no significant alteration in the physico-chemical, sensory and keeping qualities of the soup mixes produced using different dehydration techniques.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Production of cowpeas

The global estimates by Food and Agriculture Organization of the United Nations (FAO) on cowpea production only relate to the cowpea grains with Western Africa as the largest producer in the last half a decade as shown in Table 2.1. The estimates show that Western Africa accounted for 83.4% of the 6.99 million tonnes global production in 2016. The crop is drought tolerant and warm weather crop that adapt well to drier areas of the tropics where other legumes cannot grow (Rashid et al., 2016). The production of this crop in West Africa is both for domestic consumption and sale (Akpalu et al., 2014). The crop is mainly cultivated in mixed farming with cereals such as sorghum and millet due to its shade tolerance characteristics (Agbogidi, 2010). This has enabled cowpea vegetables and grains not only to aid in dietary diversification but also serve as a security food in case of failure of the main crop. Cultivation of the crop can be done in soils that are poor as the crop has the ability to fix nitrogen for utilization in growth thereby encouraging its production by farmers in SSA (Edeh and Igberi, 2012; Horn et al., 2016). In most places, the production is mainly in subsistence agriculture and on a small-scale (Saidi et al., 2010).

The production of cowpeas is spread across Asia, Europe, Africa and America (Carvalho et al., 2017; De Souza et al., 2017). However, cowpea still remains a minor crop across Europe with most of the consumed vegetable being imported. Of the developed countries only USA is a substantial producer and exporter of cowpeas (Directorate Plant Production, 2014). Asia has for a long period of time ranked second to Africa in terms of production of cowpeas (Nedumaran et al., 2015).

Cowpeas are mainly grown for subsistence in SSA with only a small proportion entering the international market (Directorate Plant Production, 2014). Young leaves and immature pods and seeds have been exploited as vegetables whereas mature seeds have been consumed as pulses. However, harvesting of the leaves has been shown to affect the mean yield of the seeds. Kabululu et al. (2014) reported a mean yield for cowpea leaves of 25 g/plant/two week harvest period accompanied with a 59% on farm reduction of grain yield for a local cowpea variety in Tanzania. Similar findings were also reported by Matikiti et al. (2009) where termination of leaf harvesting 7 weeks after emergence (WAE) resulted in 50.1-70.4% reduction in grain yield. On the other hand, increasing the frequency of harvesting the leaves from 7-day interval to 14-day intervals was noted to increase the leaf yields by up to 100 percent (Saidi et al., 2010).

**Table 2.1: Global production of cowpea grains in tonnes for the period 2012-2016**

| **Region** | **2012** | **2013** | **2014** | **2015** | **2016** |
|---|---|---|---|---|---|
| Africa | 8,054,899 | 8,030,197 | 5,357,312 | 5,552,211 | 6,739,689 |
| Eastern Africa | 510,357 | 474,479 | 490,131 | 471,779 | 465,687 |
| Middle Africa | 213,131 | 233,444 | 244,766 | 253,993 | 262,272 |
| Northern Africa | 39,000 | 79,000 | 101,100 | 54,148 | 172,162 |
| Southern Africa | 5,700 | 5,710 | 5,705 | 5,679 | 5,664 |
| Western Africa | 7,286,711 | 7,237,564 | 4,515,611 | 4,766,612 | 5,833,904 |
| Americas | 93,403 | 79,231 | 69,849 | 75,358 | 80,458 |
| Asia | 185,805 | 147,121 | 146,698 | 147,146 | 142,695 |
| Europe | 23,833 | 25,099 | 25,652 | 25,389 | 28,332 |
| **World** | **8,357,941** | **8,281,648** | **5,599,511** | **5,800,105** | **6,991,174** |

Sourced from FAOSTAT (2018)

## 2.2 Cultivation of cowpeas in Kenya and East Africa

In East Africa, cultivated cowpeas are a source of vegetables and grains for human consumption. The major cowpea producing countries in East Africa include Kenya, Tanzania, South Sudan and Uganda (USAID, 2010). The cowpeas that have been utilized across the region include both the landraces and improved varieties (Mamiro et al., 2011). A study done in Tanzania found that only 11% of the total cowpea leaves harvested ended up in the market for sale (Putter et al., 2007). The average quantity of cowpea leaves sold per salesperson in the market per day in Tanzania was reported as 5.6 kg per day (Lotter et al., 2014). This quantity is low when compared to the amount sold per salesperson for other traditional vegetables such as amaranth (7.3 kg), nightshade (8.1 kg), cassava (6.1 kg) and ipomoea leaves (6.8 kg).

Kenya currently has the largest land area under cultivation of cowpea leaves in East Africa, standing at 227,809 hectares (FAOSTAT, 2021). The major cowpea production areas in Kenya include Bungoma, Kakamega, Kisumu, Siaya, Migori, Kitui, Makueni, Machakos, Kilifi, Kwale and Tharaka Nithi Counties (Muniu, 2017). Kenya has steadily had an increasing trend in the cultivation of cowpea with the largest area under cultivation realized in 2014 in recent years (Figure 2.1**)**. A report by Horticultural Crops Directorate in 2016 rated cowpea leaves as the most cultivated ALVs in Kenya; ranking second in Eastern and Central Africa region **(**Figure 2.1 and 2.2**)** and contributing up to 43% of the total value of AIVs (Horticultural Crops Directorate, 2016). The cowpea varieties that have been cultivated in Kenya include landraces such as *Khaki*, *Macho*, *Kaima-koko*, *Kutambaa*, *Mwandato*, *Nyekundu*, and *Nyeupe* and improved varieties such as KVU 419, Katumani 80, M-66, *Kenya-Kunde* and KVU 27-1 (Nderi and Kamau, 2018; Ndiso et al., 2016; Oyoo et al., 2017). Some of the cowpea varieties that have been grown in Tanzania and Uganda include the improved varieties such as *Ex-Iseke*, KOL42 (UG-CP-9), *Dakawa*, IT93K204529, IT85F-2841, MU-93 and IT82D-889 (Bisikwa et al., 2014; Kabululu, 2008). Other cowpea landraces spread across East Africa include *Cirikukwai and Ebelat.*

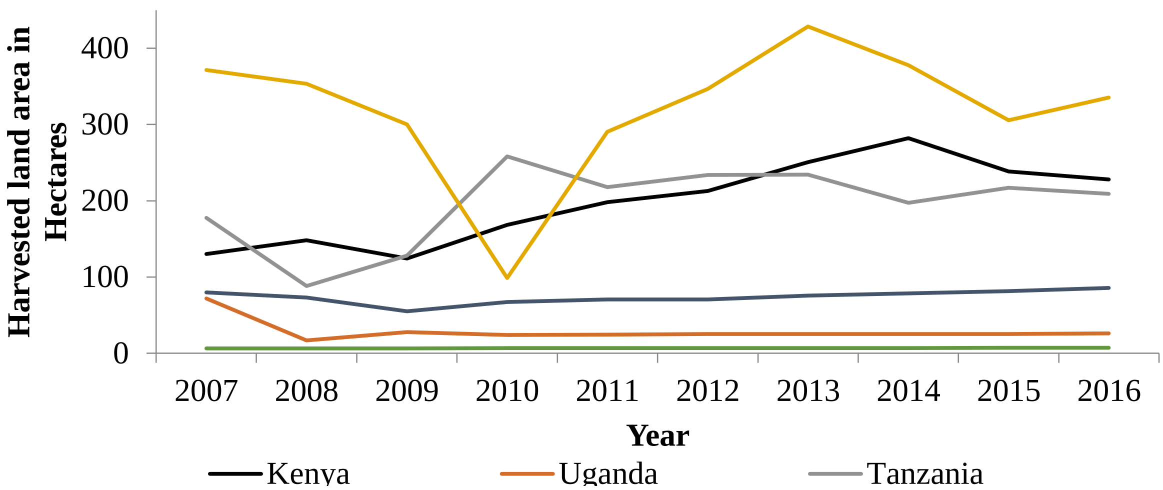


**Figure 2.1: Trend of cultivation of cowpea in East and Central Africa.** Adapted from (FAOSTAT, 2021).

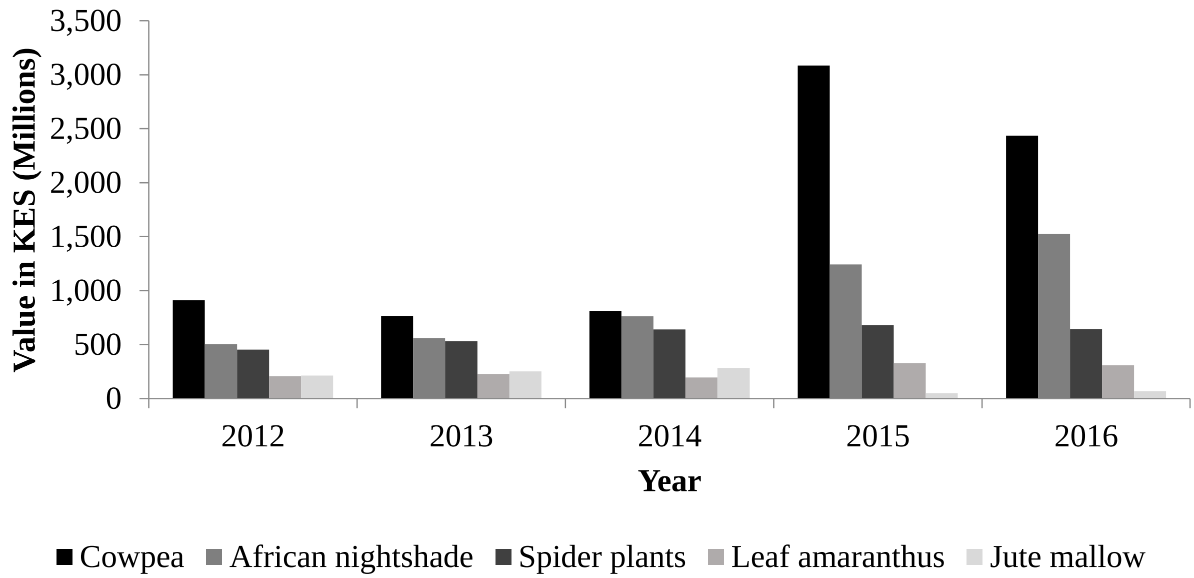


**Figure 2.2: Value of some of the most utilized African indigenous vegetable in KES.** Adapted from Horticultural Crops Directorate (2016) and Horticultural Crops Directorate (2014).

The production of cowpeas in East African region is mainly done in the arid and semi-arid lands, ASALS (Wambugu and Muthamia, 2009). In Kenya, Makueni County ranks the top in terms of cowpea leaves production area and quantity as shown in Table 2.2**.** The typical production area per person in Kenya ranges between 0.25 and 1 ha (Kiambi and Mugo, 2016). A study in Machakos and Tharaka Nithi Counties, known for their semi-arid conditions, ranked the crop as the third and second most cultivated respectively in the two areas (An et al., 2016). The study also found that the farmers are willing to allocate up to 10% of their land for production of cowpeas. The greatest constraint in the production of cowpea leaves currently being experienced in Kenya is that it is majorly limited to small-scale farming (Ndungu et al., 2018).

**Table 2.2: Performance of cowpeas in top producing counties in Kenya for the years 2013-2016**

| County | Year 2013 | | Year 2014 | | Year 2015 | | Year 2016 | |
|---|---|---|---|---|---|---|---|---|
| | Area (Ha) | Volume (MT) | Area (Ha) | Volume (MT) | Area (Ha) | Volume (MT) | Area (Ha) | Volume (MT) |
| Makueni | Na | na | na | na | 6,850 | 52,355 | 6,770 | 42,076 |
| Kwale | 217 | 878 | 1,122 | 6,982 | 4,337 | 18,845 | 4,130 | 13,612 |
| Kitui | 12,800 | 15,310 | 13,000 | 15,470 | 3,600 | 14,700 | 2,520 | 12,520 |
| Machakos | 1,593 | 5,441 | 2,668 | 4,814 | 3,629 | 8,280 | 3,945 | 9,642 |
| Kilifi | na | na | na | na | 4,648 | 9,186 | 6,030 | 9,355 |
| Taita Taveta | na | na | na | Na | 549 | 4,037 | 580 | 4,133 |
| Homa Bay | na | na | na | Na | 639 | 2,442 | 927 | 3,613 |
| Siaya | 407 | 2,304 | 1,039 | 3,029 | 2,800 | 7,925 | 1,291 | 3,205 |

na- data not available. Adapted from USAID and AFFA (2014) and Horticultural Crops Directorate (2016).

In areas where it is grown in East Africa, the availability of cowpea leaves is along the cropping seasons (Okonya and Maass, 2014). The crop is mostly intercropped with cereals such as sorghum and maize.

### 2.3 Utilization of cowpea leaves

The under-exploitation and lack of proper utilization of cowpea leaves and other traditional leafy vegetables has been a major undoing in the promotion of food security in sub-Saharan Africa (SSA). A study by Madodé et al, (2011) cited the limited shelf life of cowpea leaves of just 24 hours at ambient temperatures as a major bottleneck to its utilization. For promotion of utilization of cowpea vegetables; extension of the shelf-life, optimization of production and processing techniques and reduction of post-harvest losses have been recommended as possible strategies (Kirakou et al., 2017).

Harvesting of cowpea leaves usually begins as early as two WEA and continues until flowering (Saidi et al., 2010). There is massive utilization of cowpea leaves during glut but less utilization during acute shortages in times of drought (Okello et al., 2015). This has been due to the limited shelf-life of the cowpea vegetables. The high moisture content of cowpea leaves renders them highly perishable while their seasonality in supply has resulted into limited utilization all year round (Njoroge et al., 2016). Moreover, most consumers utilize the vegetable in its fresh form and make less use of the value-added products.

Cowpea leaves have also been consumed as boiled, blanched, dried or fermented vegetables (Kasangi et al., 2010; Kirakou et al., 2017; Muchoki et al., 2010). Among West African communities, these vegetables are consumed as accompaniment with cereals or as vegetable sauces with other foods such meat and fish (Madodé et al., 2011). In Kenya, cowpea leaves are consumed as potherbs just as other ALVs (Kanali et al., 2017). The utilization of cowpea leaves in its different forms in the rural areas in Tanzania is to the tune of 30% of the households (Ochieng et al., 2016). In Asia, the leaves are boiled then sundried and stored for later use (Zia-Ul-Haq et al., 2013). This aims at beating the constraints of seasonality in terms of availability of cowpea leaves. The utilization of cowpea leaf concentrates, which are known to be rich in micronutrients, has been one of the modern techniques of its utilization (Jethwani et al., 2015). Other value-added products of cowpea leaves that have been used in high end markets such as supermarkets include the vacuum-packed, solar-dried, powder, canned and frozen forms (Jethwani et al., 2015; Okello et al., 2015; Onyeoziri et al., 2018). However, the incorporation of cowpea leaves into other renowned and widely acceptable products as it has been done with other indigenous and underutilized crops for example orange-fleshed sweetpotato roots remains less explored (Owade et al., 2018).

Cowpea leaves have also been utilized as fodder for livestock (Mahama, 2012). They are recommended as protein rich animal feeds to be incorporated in feeds during formulation (Martens et al., 2012). The utilization of cowpea leaves as livestock fodder is not a common practice in SSA as it is mainly exploited for food.

## 2.4 Post-harvest losses of cowpea leafy vegetables

The ALVs are usually in scarce supply during dry seasons but plenty during rainy seasons that occasion high postharvest losses (Seidu et al., 2012). Post-harvest losses for cowpea leaves and other AIVs in East Africa have been estimated to be as high as 30-40% of the production quantity with some countries recording even higher figures (Babatola et al., 2008). Gogo et al., (2018) reported postharvest losses exceeding half of the production quantity of cowpea leaves and other ALVs among some of the farmers in Kenya. Postharvest losses in these vegetables have largely been attributed to handling, production practices, distribution and marketing dynamics (Ndirangu et al., 2017). The quality of cowpea leaves deteriorates with storage. Storage conditions based on their temperature affect the physico-chemical attributes of cowpea leaves in terms of antioxidant properties, nutritional quality, colour and texture (Kirigia et al., 2018; Natabirwa et al., 2016). Value addition of cowpea leaves through adoption of optimal preservation techniques is seen as a possible way of improving the shelf-life while retaining the nutritional and sensory quality (Zheng et al., 2009).

Poor postharvest handling practices aggravate the losses, which may rise up to 70% (FAO and World Bank, 2010). Poor transport and distribution network are some of the underlying economic factors that may increase these losses (Shiundu and Oniang'o, 2007). Low temperature storage ($4^oC$) improves retention of the phytochemicals in the fresh cowpea leaves, thus enhanced keeping quality compared to those stored at room temperature (50-55% relative humidity) in which the phytochemicals strongly declined at 4 days (Kirigia et al., 2018). Most of the farmers of cowpea leaves still rely on traditional techniques for handling the vegetables along the value chain resulting in greater losses (Gogo et al., 2018). The smallholder farmers lack necessary facilities such as low temperature storage equipment and reliable transportation means for the postharvest handling of cowpea leaves, thus significant proportion of their produce lose the saleable value (Onyango and Imungi, 2007). These produce attract less returns in the market or are rejected at the high end markets such as supermarkets.

### 2.5 Nutrient contribution of cowpea leaves to human diet

Dietary diversification has been employed over time as a strategy in improving nutrition status of the population. The cowpea leaves have a richer nutritional composition compared to the grains (Mamiro et al., 2011). The utilization of cowpea leaves for food has mainly been done in various dishes, soups and sauces (Imungi and Potter, 1983). Cowpea leaves even in their preserved forms are known to be rich in nutrients that are essential for life (Table 2.3**)**. Cowpea leaves have also been recommended as possible sources of leaf protein to enrich the diet (Ghaly and Alkoaik, 2010). Cowpea leaves are known to be rich in proteins, vitamins such as provitamin A, folate, thiamin, riboflavin and vitamin C and minerals such as calcium, phosphorus and iron (Kirakou, 2014; Xiong et al., 2016). Okonya and Maass (2014) reported the crude protein and iron contents of fresh cowpea leaves on a dry mass basis to be as high as 33 g/100g and 379 µg/g respectively. A study by Van Jaarsveld et al. (2014) reported that a 90g portion of cowpea leaves could meet ≥75% and 25-50% RDAs for vitamin A and iron, respectively, for children 4-8 years. However, it is worth noting that the nutrient composition of cowpea leaves vary depending on the cultivar (Carvalho et al., 2012), thus cultivar selection should be carefully done.

### 2.5.1 Antinutritional factors in cowpea leaves

Cowpea leaves have antinutritional factors such as oxalates, phytates and nitrates which are known to have negative impact on the nutrient intake of individuals (Muchoki et al., 2010; Oulai et al., 2015). Optimal processing and preservation techniques should seek to reduce or minimize the accumulation of these antinutritional factors as a way of ameliorating the nutritional quality. Some of the processing techniques that have been used successfully in reducing antinutrients in foods include fermentation, soaking, germination, debranning and autoclaving (Ertop and Bektaş, 2018). Removal or reduction of the antinutrients serves to improve the nutritional quality of the food by increasing the bioavailability of nutrients such as protein, calcium, iron and zinc. Muchoki (2007) reported a reduction of 38.4% and 8.3% respectively in the nitrate and oxalate contents of dried cowpea leaves that were subjected to fermentation. Another study by Chikwendu et al. (2014) similarly reported a reduction of 33.3%, 73.9%, 85.9% and 70.7% in the tannin, saponins, flavonoid and polyphenols contents respectively for cowpea leaves that were parboiled, sundried and drained. The practice in the latter study may not be encouraged as it would also result in greater losses in the important nutrients especially the micronutrients. Any techniques aimed at reducing these antinutritional factors must have minimal deleterious effects on essential nutrients.

**Table 2.3: Nutritional composition of cowpea vegetables (mg/100g dry weight)**

| **Nutrient** | **Cowpea leaves (per 100g dry matter)** | | | |
|---|---|---|---|---|
| | **Raw fresh** [a, b, d, e, f, k] | **Dried** [d, h] **(Solar and sun dried)** | **Blanched** [b, h, i, j] | **Fermented** [g, i] |
| Moisture (g) | 85-90 | 7.04-7.35 | 12.0-15.02 | 6.31-7.29 |
| Crude Protein (g) | 28-42 | 29.09-39.24 | 4.0-31.86 | 28.07-29.40 |
| Crude lipid (g) | 9.00-10.26 | 1.31-2.28 | 4.33-12.91 | 1.68-1.92 |
| Crude ash (g) | 4.80-13.58 | 10.84-14.80 | 7.5-11.87 | 10.6-11.0 |
| Crude fibre (g) | 10.09-25.51 | 14.26-29.31 | 12.53-14.35 | 17.10-29.48 |
| Energy value (kCal) | 325.36-390.26 | 219.8-290.51 | 246.27-384.43 | 214-226.9 |
| Micronutrients | | | | |
| Beta-carotene (mg) | 32.74-36.55 | 0.25-24.76 | 19.21-20.35 | 0.8-30 |
| Vitamin C (mg) | 70-203 | 1.39-137.9 | 40.1-42.8 | 45 |
| Iron (mg) | 66-75 | 0.58-7.50 | 0.56-0.57 | 0.17-0.23 |
| Calcium (mg) | 17.1-39.87 | 1.40-25.1 | 24.3-24.6 | 1.27-1.28 |
| Zinc (mg) | 5.22-12.91 | 1.66-144.5 | 0.14-7.9 | 0.05-0.07 |

Adapted from [a]Nekesa (2016), [b] Aathira et al. ( 2017), [c] Ahenkora et al. (1998), [d]Chikwendu et al. (2014), [e]Belane and Dakora (2012), [f]Kirakou (2014), [g]Muchoki (2007), [h] Kirakou et al. (2017), [i]Kasangi et al. (2010), [j]Oula et al. (2015) and [k]Imungi and Potter (1983).

## 2.6 Traditional processing and preservation of cowpea leaves among East African Communities

There are different customized recipes among the communities growing the cowpea vegetables. In Kenya, cowpea leaves can be consumed stewed as vegetables or even as mixed dishes with other vegetables such as jute mellow (FAO and GoK, 2018). Cowpea leaves are a common delicacy among Kenyan communities with the Mijikenda consuming it boiled mixed with coconut milk (Okello et al., 2015). Other preparation techniques that cowpea leaves have been subjected to include boiling with lye (traditional salt) and milk and frying (Akello, 2014). The boiled vegetables are at times subjected to fermentation for about 48 hours before its consumption in certain communities or even sun-dried and stored for later use. The *per capita* consumption of cowpea leaves in the producing areas in Tanzania was reported to be 41-200 g (Mamiro et al., 2011). The vegetables are consumed in varied forms including the preserved ones.

### 2.6.1 Fermentation

Fermentation of cowpeas has been in practice among traditional African communities for a long time. The overall aim of the fermentation process has been to improve on the shelf-life of the cowpea leaves; while at the same time the nutritional quality has also been improved. Muchoki et al. (2010) reported a reduction of 71.9% in the nitrate content of cowpea vegetables subjected to fermentation. However, the fermentation techniques employed in these traditional practices are spontaneous and the product quality in terms of the nutritional and sensory is still varied and not optimal. Attempt has been made to try and standardize the fermentation processes of these vegetables. Kasangi et al. (2010) used fermentable sugars at the rate of 1-3% to enhance the cowpea leaves fermentation process and achieved a crude fibre and ash contents of 16.29-17.61% and 22.37-22.61% respectively. These values were higher than those he reported for cowpea leaves that were solar dried (12.76% and 13.08% crude fibre and ash contents respectively) or blanched solar dried (11.76% and 9.49% crude fibre and ash contents respectively). However, the study fell short of establishing the effect of such treatment on the sensory appeal and colour changes of the vegetables. Muchoki et al. (2010) while using the one-factor method had established the salt and sugar concentrations each at 3% as the optimal for cowpea leaves fermentation. However, this has been shown to ignore the influence of interactions of the factors under investigation on the response. Further work should consider incorporating the influence of the interactions of the factors on the product quality It is also recommended that in fermentation of cowpea vegetables, fermentable sugar such as glucose or fructose should be added at the level of 2-3%, followed by a starter culture; this gives a better product in terms of its quality compared to the cowpea leaves subjected to spontaneous fermentation (Wafula et al., 2016).

### 2.6.2 Sun drying

Utilization of sun-drying as a technique of food preservation was reported by Nnadi et al. (2013) as the most practiced technique by people, 94% of households, in traditional communities in Nigeria. The dried vegetables have been utilized in Uganda to overcome the shortage of cowpea leaves during drought (Aleni, 2017). Sun-dried leaves are at times first steamed before being dried (Directorate Plant Production, 2014). The method is known to have concentration effect on nutrients thus increases the nutrient density (Chikwendu et al., 2014). However, the limitation of this technique has been that it results into decreased micronutrient contents. Ndawula et al. (2004) reported a nutrient loss of 58% and 84% for β-carotene and vitamin C respectively during open drying. In another study Chikwendu et al. (2014) reported a decrease in the iron, zinc, calcium, iodine and phosphorus contents by 90.3%, 87.1%, 96.5%, 73.8% and 64.6% respectively for cowpea leaves that had been boiled and sundried. Drying under a shade is recommended to minimize the deleterious effects on micronutrient content (Directorate Plant Production, 2014).

Sun drying is one of the preservation techniques that have been recommended to improve the availability of cowpea vegetables to aid in the promotion of food and nutrition security in SSA. Consumption of sundried cowpea leaves together with other traditional indigenous vegetables was shown to improve the mean serum retinol content by 25.9% in a 13 week feeding trial study (Nawiri et al., 2013). Thus, the preserved vegetables are recommended for amelioration of nutritional status of vulnerable populations.

### 2.7 Modernized cowpea leaves processing techniques

Processing of cowpea vegetables has been used to improve the nutritional and keeping qualities of the vegetables using modernized technologies with the aim of increasing their utilization. Some of the processing techniques that have been utilized include solar-drying, freezing, freeze-drying, blanching and vacuum-packaging (Okello et al., 2015). The degree of deterioration in the nutritional and sensory quality of these preserved products vary depending on the cooking methods and preservation techniques in use (Okonya and Maass, 2014). Kirakou *et al.* (2017) reported low retention of beta-carotene and ascorbic acid at 52.78% and 20.24% respectively for cowpea vegetables that were blanched in salty water for 2 minutes at 94$^{o}$C followed by solar dying. Conventional cooking of cowpea vegetables that entailed boiling for 10 minutes resulted into total loss of vitamin C (Rashid et al., 2016). Thus, the processing technique used should be carefully selected with the aim of maximum retention of the nutritional and sensory quality.

### 2.7.1 Blanching

Blanching has been used to preserve cowpea vegetables and extend their utilization. Variation of the blanching temperature-time combination has an effect on the nutritional composition and microbial quality of the vegetables (Njoroge et al., 2016). Oulai et al. (2015) reported β-carotene and vitamin C losses of up to 55.5% and 61.1% respectively for cowpea vegetables blanched in a pressure cooker (121$^{o}$C) for 15 minutes. Increasing the blanching time resulted in more nutrient losses, however, with a positive impact of reduction of antinutritional components. Aathira et al. (2017) also reported a similar trend in the loss of protein in cowpea leaves blanched at 100$^{o}$C for 20 minutes (35.4%) compared to those blanched at 100$^{o}$C for 15 minutes (31.3%). Even so, blanching also has the positive impact of attenuating the deleterious effects of drying on antioxidant activity such as 2,2-diphenyl-2- picryl hydrazyl (DPPH) scavenging activity thus blanched vegetables are highly recommended as alternative sources of antioxidants (Nobosse et al., 2017).

The other non-nutritional benefit of blanching is that it improves the rehydrability, reduces microbial load and increases the ease of packaging as it shrinks and softens the vegetables (Njoroge et al., 2016).

### 2.7.2 Solar drying

Solar drying has also been used in the preservation of cowpea leaves as a modern technique. The greatest concern with this preservation technique still remains the retention of micronutrients such as ascorbic acid and β-carotene as it exposes these nutrients to oxidation in the presence of oxygen. Visqueen-covered solar dried cowpea vegetables showed great losses for β-carotene and vitamin C at 34% and 71% respectively (Ndawula et al., 2004). Blanching of the vegetables before solar drying improved the retention of β-carotene and vitamin C by 15% and 7.5%, respectively. This gives greater credence to the use of hurdle technology in the preservation of cowpea leaves.

## 2.8 The concept of hurdle technology

A combination of at least two preservation techniques has been reported to produce the best results in terms of nutritional and keeping quality. Njoroge et al. (2016) reported that blanching at 80$^{o}$C for 10 minutes and hot-air drying of cowpea vegetables had a retention of 53.7% and 53.8% for vitamin C and β-carotene respectively, whereas blanching at 80$^{o}$C for 10 minutes and solar-drying recorded a retention of 58.2% and 49.2% for vitamin C and β-carotene respectively. These values were higher when compared with that of conventional method of boiling at 100$^{o}$C for 30 minutes. In the traditional preparation of cowpea leaves blanching was not included in the preparatory processes prior to sun drying, lower retention of β-carotene was noted (Mulokozi and Svanberg, 2003). Without blanching, sundried vegetables are exposed to continued enzyme activity that would easily expose the carotenoids to oxidation reactions.

Utilization of a combination of different storage technologies and appropriate storage conditions can also improve the micronutrient retention. Anyango (2015) reported the least losses of 13.6-13.8% in β-carotene content of sun-dried cowpea leaf vegetables under inert conditions as compared to losses of 56.3-57.3% and 29.6-33.3% under normal conditions and modified atmospheric packages respectively. However, this too has had a fair share of challenges in achieving faultless results as storage conditions affected acceptability. A study by Natabirwa et al. (2016) that evaluated the acceptability of cowpea leaves that were blanched and then either sun-dried or solar dried reported that the preserved products had lower acceptability scores (5.6-6.5) than the fresh cowpea vegetables (8.0) on a 9-point hedonic scale. It is therefore important that these studies must also establish the impact of these technologies on the acceptability of the product.

## 2.9 Consumer acceptance of value-added cowpea products

The greatest incentive for promotion of value addition practices is successful adoption of the products (Owade et al., 2018). Increased utilization of cowpea leaves can only be achieved when the preserved cowpea leaves are marketable. A study by Okello et al. (2015) reported that Kenyan consumers were willing to pay as high as KES. 5 for both the sun-dried and frozen cowpea leaves. The same study notes that some consumers attach no great significance on value addition practices and would not be willing to pay extra for such. The current low consumption can be attributed to wrong consumer perception about the cowpea leaves. Lekunze (2014) in his market analysis study of cowpea leaves reported that households who were regular consumers of the vegetables would more likely substitute these vegetables with other vegetables in the likely event that their income levels increased.

Another study that evaluated the acceptability of different cowpea leaves established that nutritional composition such as ascorbic acid, moisture and phosphorus content and the leaf size were correlated with the acceptability of cowpea leaves (Ahenkora et al., 1998). Dehydration of cowpea leaves as a way of preservation results into alteration of the nutritional and thus the sensory quality too. Descriptive sensory analysis of dehydrated cowpea leaves revealed that the solar dried leaves had similar appearance and texture to the fresh cowpea leaves whereas greater alterations existed in the sundried cowpea leaves (Nyambaka and Ryley, 2004). The greatest gap that has to be filled is to have the consumers adopt value-added cowpea leaves.

## 2.10 Constraints of value addition practices for cowpea vegetables

The primary bottleneck for the utilization and value addition practices for cowpea leaves stems from the production practices. The production practices in the SSA for cowpea leaves are below the optimal levels, thus low production quantities have been realized (Oyewale and Bamaiyi, 2013). Some of agricultural practices also impoverish the soil thus affecting the nutrient content of cowpea leaves produced from these soils. All the above highlighted factors thereby result into lower economic returns that greatly discourage the production of cowpea leaves (Mucheru-Muna et al., 2010).

The marketing system for cowpea leaves and other ALVs is mainly through the informal sectors where quality parameters are less observed (Onyango and Imungi, 2007). The seasonal nature of the supply of cowpea leaves makes its handling in the less organized informal market difficult resulting to major losses in form of spoilage (Omulo, 2016). These farmers rely on traditional preservation techniques such as storage under a shade and sprinkling of water on vegetables in stores which has its limitations as the keeping quality is only extended by a few days (Kirigia et al., 2018). The modernized cold storage facilities such as cold rooms are unaffordable to the smallholder farmers (Onyango and Imungi, 2007). Lack of time, inadequate knowledge and additional costs have resulted into less practice of value addition among most handlers in the value-chains (Kirui et al., 2017). A study in Malawi and Mozambique reported that the weak value chain linkages and less value addition practices for traditional vegetables including cowpea leaves as a major bottleneck in their marketing (Chagomoka et al., 2014). Another study in South Africa found that these farmers lacked technical knowledge and ability of  value addition that would be important in improving their revenues (Senyolo et al., 2018).

## 2.11 Future prospects

Future prospects of vegetables preservation are looking into techniques that retain most of the nutritional and sensory quality, minimize microbial contamination and improve the shelf-life of the vegetables. Zheng et al. (2009) in his study of vegetable dehydration found that a combination of centrifugation after washing and microwave drying with proper packaging of the material reduced dehydration time and improved nutritional and sensory quality. Minimizing drying time is recommended for maximum retention of physico-chemical and sensory quality of the vegetables (Chege et al., 2014). Incorporation of centrifugation in the production of dehydrated vegetables can help reduce the drying time, thus improve the nutrient retention in dried vegetables. Value-addition of the under-utilized crops has the extended effect of increasing commercialization of the crop; providing an incentive for increased production.

Other vegetables have also been preserved through fermentation by dry salting techniques that largely retained the physical and chemical attributes (Vatansever et al., 2017). Such techniques can be extended to the preservation of cowpea leaves. However, such studies must establish optimal conditions for retention of nutrient and sensory quality of the products. Such a study would also need to establish the diffusion coefficient of salt into the vegetables during preservation as it has an influence on the physical attributes of the vegetables (Kusnadi and Sastry, 2012). The role of packaging in enhancing the keeping quality while maximizing the retention of nutritional and sensory quality of cowpea leaves still remains largely unexplored. Khatoniar and Barooah (2018) reported a higher efficiency in the preservation of dehydrated vegetables packaged in higher density polyethene (HDPE) pouches, moisture penetration as low as 4.2% in storage period of six months, as compared to polypropylene pouches and plastic bottles. Polymeric films and antimicrobial packaging have been exploited as preservation techniques for other foods (Scetar et al., 2010), but are yet to be utilized in the preservation of cowpeas.

## 2.12 Research gaps

The quality in terms of nutritional and sensory quality of the value-added cowpea leaves greatly deviate from those of fresh produce pointing to less optimal practices. There is need for research on optimization of some of these traditional techniques such as fermentation to develop highly acceptable products whose uptake in the market would be almost as much as the fresh cowpea leaves. Moreover, the focus of research should be to promote affordable techniques of preservation of cowpea leaves that are acceptable among the value-chain actors that in turn will promote their utilization.

# CHAPTER THREE: TRENDS AND CONSTRAINTS IN THE PRODUCTION AND UTILIZATION OF COWPEA LEAVES IN THE ARID AND SEMI-ARID LANDS OF KENYA

**Abstract**

Cowpea (*Vigna unguiculata*) leaves are nutritious indigenous vegetables that are produced and consumed among local communities in Kenya. However, seasonal production limits their utilization. The study investigated the changing trends in the consumption and utilization of cowpea leaves among cowpea producing households in arid and semi-arid land (ASAL) areas. A cross-sectional survey of randomly selected households producing and consuming cowpea leaves was carried out in eastern and coastal ASALs of Kenya to determine the trends and constraints in the production and utilization of the vegetable, thus evaluating its efficiency as a food security crop. The average household production in a season was found to be 3.03 ± 0.9 of 90 kg bags. Lesser severity of the constraints, poor soils, drought, lack of access to seeds and massive spoilage with an odds ratio of 0.4, 0.9, 2.0 and 2.3, respectively, significantly ($p < 0.05$) predicted the production quantities among households, R2 = 0.21. The study also found that the reliance on own production among households for sourcing the leaves in-season and off-season was 97.5% and 24.9%, respectively. The households consumed the leaves in boiled (87.5%), sundried (27.5%) or blanched (13.6%) forms. Households in the coastal ASALs significantly ($p < 0.05$) consumed more of dried forms (odds ratio: 3.3) but less of boiled ones (odds ratio: 0.1) than those in the Eastern parts. Households that had more members or a female deciding the food to be bought had significantly ($p < 0.05$) higher frequency of consumption of cowpea leaves. Marketing challenges, lack of access to inputs and inadequate postharvest technologies for preservation of the vegetables constrained the production and utilization of cowpea leaves. In order to promote the availability

and utilization of cowpea leaves both in and out of season, accessibility of good quality seeds and postharvest management are necessary.

## 3.1 Introduction

Cowpea (*Vigna unguiculata*) is a multi-purpose indigenous crop that grows largely in the tropics of sub-Saharan Africa, SSA (Enyiukwu et al., 2018a; Sobda et al., 2018). FAOSTAT (2021) reported that 95.6% of the area under cultivation of cowpea leaves globally in 2017 was in SSA. The crop is also known to be short-term and drought tolerant. The leaves and the grains of the crop are utilized for food in various cuisines among local communities in Kenya (Owade et al., 2020a). Additionally, the crop also has shade tolerance property that has made it easier to intercrop it with other major crops including maize and sorghum. The leaves of the crop have been identified as one of the African leafy vegetables (ALVs) for the improvement of food and nutrition security in SSA (Kirigia et al., 2018). On top of being a human food, the crop has also been utilized for forage.

With the rising interest in orphan crops that are well suited to the harsh environmental conditions in semi-arid and arid lands (ASALs), cowpea leaves is one of the vegetables that is being promoted for both the leaves and the seeds. The annual production of cowpea leaves in 2016 was reported as 115,801 MT (Horticultural Crops Directorate, 2016). The leaves are consumed fresh, dried or fermented among local communities in the country. The utilization of the leaves of the crop for food avails nutrients such as beta-carotene, iron and protein whose deficiency is rampant among the vulnerable population of SSA (Kirigia et al., 2018). Moreover, the cowpea leaves are also rich in calcium, zinc, fibre and phytonutrients (Enyiukwu et al., 2018b). Due to this, there are nutrition intervention programmes that are promoting the cultivation of the crop for its leaves.

Even with the known nutritional benefits of cowpea leaves, their utilization and production for food has been less than optimal. The crop has largely been neglected and has a limited value chain due to limited research on its utilization and value addition (Mfeka et al., 2019). The production and utilization of cowpea leaves has largely been seasonal owing to a myriad of challenges including limited postharvest handling technologies. The producers of the leafy vegetable lack appropriate storage and postharvest technologies that would enhance its availability in and out of season (Kirigia et al., 2018). Additionally, during glut, there are massive postharvest losses of cowpea leaves. Local communities in Kenya have indigenous value addition techniques that they employ to enhance availability of this vegetable; however, documented studies are yet to report on such practices, their scope and their constraints. The current study seeks to avail this information with a view of ensuring that good traditional practices can be improved, scaled up and replicated in these areas to enhance availability of the vegetable and contribute to the efforts aimed at alleviating food and nutrition security.

## 3.2 Materials and methods

### 3.2.1 Study area

The study was conducted in Kitui and Taita Taveta Counties **(Figure 3.1)** which are rated among the highest producers and consumers of cowpea vegetables (Horticultural Crops Directorate, 2016). Taita Taveta County is located in the Coastal arid and semi-arid lands (ASALs) and is divided into four Sub-Counties and twenty administrative wards (County Government of Taita Taveta, 2018). The county is situated between the latitudes 20° 46´ and 40° 10´ North and the longitudes 37° 36´ and 39° 14´ East (Apollo et al., 2017). According to the Kenya National Bureau of Statistics (KNBS), the estimated population of Taita Taveta County in 2018 was 323,867 persons of which 57.2% were living in absolute poverty (contributed 1.1% to national poverty) (GoK, 2015).

Kitui County is the sixth largest county by land area in Kenya covering 30,496.4 $km^2$. The County is the largest in the Eastern ASAL areas; a region that has erratic rainfall and drier conditions than the coastal ASAL areas (County Government of Kitui, 2014). It lies between the latitudes 0˚ 10´ South and 3˚ 0´ South and the longitudes 37˚ 50´ East and 39˚ 0´ East (County Government of Kitui, 2018). Kitui County is divided into 8 Sub-Counties which are further divided into wards that are 40 in number in the whole county. The population of the county according to 2009 census stood at 1.013 million people (County Government of Kitui, 2014), with a projection for it to have increased to 1.1 million in 2018. The main economic activity of the county is Agriculture (Wambua et al., 2016). Crops grown in the area include vegetables, fruits, sweetpotatoes, cassava, green grams, maize, beans, sorghum, pigeon peas (Mutunga et al., 2017).

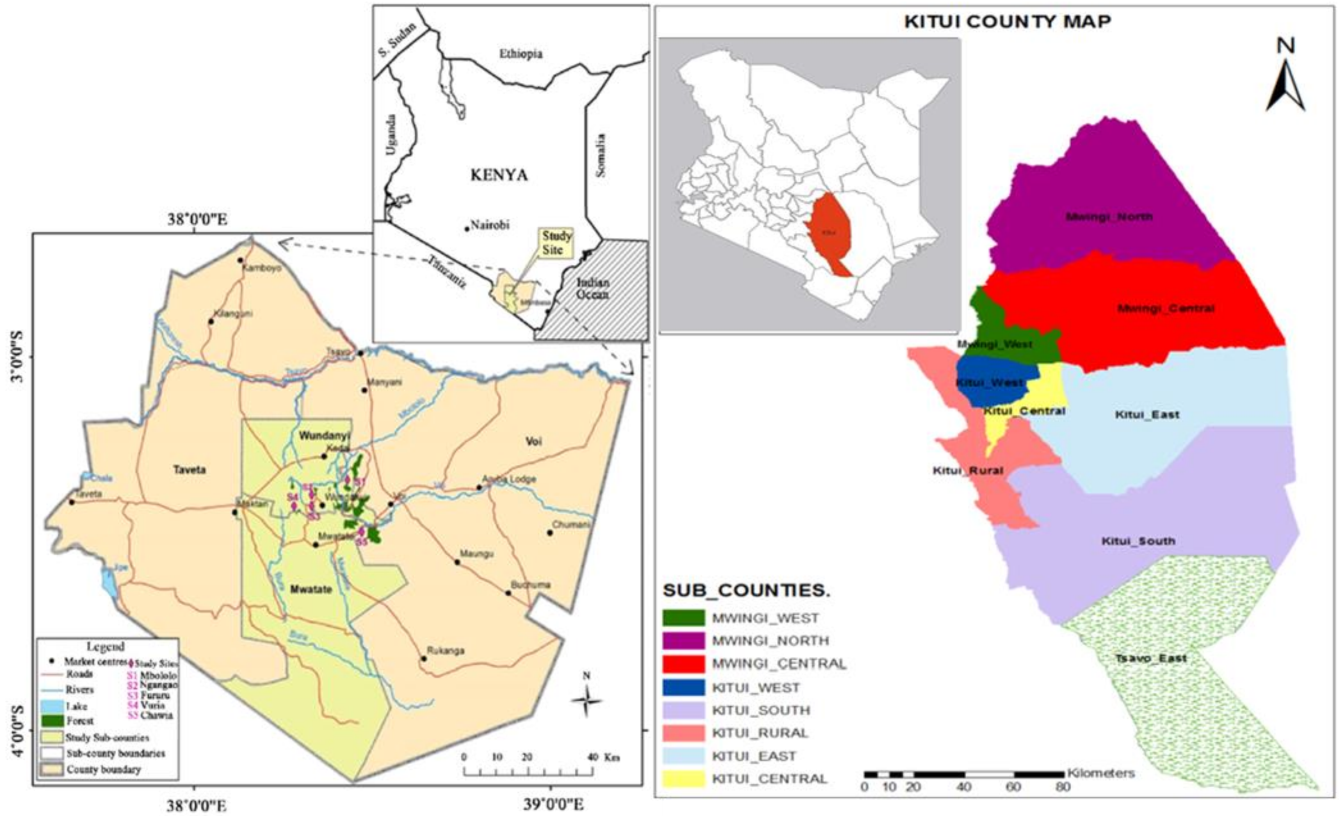


**Figure 3.1: Map of Taita Taveta and Kitui Counties.** Source County Government of Kitui (2018) and GoK (2015).

### 3.2.2 Study design

The study involved a cross-sectional survey of randomly sampled households that were involved in the production of cowpea leaves in Kitui and Taita Taveta Counties. Households that were producers and consumers of cowpea leaves were incorporated into the study. A semi-structured questionnaire (Appendix 1) was administered using the open data kit (ODK) mobile application.

### 3.2.3 Study population and sampling

#### 3.2.3.1 Sampling criteria

Kitui and Taita Taveta Counties were purposively selected for the study as they ranked among highest producers and consumers of cowpea leaves. Nguuni ward in Kitui and Mwanda Mgange, Wumingu and Bura wards from Taita Taveta which were the highest cowpea leaves producing areas in the study area were further purposively selected for the study. These wards were located in Kitui Central Sub-County in Kitui County and Mwatate and Wundanyi Sub-Counties in Taita Taveta County. The respondents from households involved in the production of cowpea leaves from these wards were then randomly selected for the study.

#### 3.2.3.2 Sample size determination

The study included 405 respondents as per the minimum sample size determined using the Yamane 1967:886 formulae (Equation 3.1) as explained by Israel (1992), **.**

$$\boldsymbol{n = \frac{N}{1+N(e)^2}} \qquad \textbf{Equation 3.1}$$

$n = \frac{276581}{1+276581(0.05)^2}$=399.42 (400), Where $N$ (276,581) was the total number of households in the two counties as per KNBS (2013) and $e$ is the maximum variability (0.05) permitted.

### 3.2.4 Data collection procedures

#### 3.2.4.1 Data collection tools

A semi-structured questionnaire (Appendix 1) was developed evaluating the production, processing and utilization of cowpea leaves across seasons. The questionnaire had sections on socio-demographics and trends and constraints of production and utilization. The questionnaire was pretested among twenty households in Wundanyi Sub-County in an area that was not included in the actual study. Additional questions and multiple responses were generated from the exercise. Data on the trends and constraints of utilization and consumption of cowpea leaves was collected.

#### 3.2.4.2 Inclusion and exclusion criteria

Only cowpea leaves producing households in the selected study areas were included in the cross-sectional survey. Both male and female headed households were included in the study. Households that have not been residents in the study areas for the last one year before the survey were excluded.

#### 3.2.4.3 Recruitment and training of enumerators

Enumerators and research assistants were recruited and trained on open data kit (ODK) application for data collection and the data collection tools. The enumerators were trained on data collection ethics, administration of the questionnaire and operation of the ODK application. The questions were also explained to the enumerators. The questionnaire was then pretested among ten randomly sampled respondents in areas in the study area that were not part of the study.

#### 3.2.4.4 Household survey

Data collection was done by administering semi-structured questionnaires to systematically randomly selected households that were producers of cowpea leaves. Written consents of the respondents were sought once the study objective had been explained to them but before their participation in the study.

### 3.2.5 Statistical analysis

The data was analyzed in *R* Project for *Statistical* Computing, R-3.6.3 (R Core Team, 2019). Summary statistics such as frequencies for the socio-demographic and economic characteristics, challenges faced and forms of utilization were obtained. Chi-square ($\chi^2$) test of association was used to ascertain the influence of the county of residence on the trend of utilization and production. Principal component analysis (PCA) was used to establish the similarity of trends of the constraining factors of production and utilization. Generalized linear model was used to test the predictor constraints of production on the quantity of cowpea leaves produced. Dummy variables were first generated from the categorical variables for ease of creating a linear model. Linear modeling was used to determine socio-demographic factors that would predict the utilization and intake of cowpea leaves. Significance was tested at $p<0.05$.

## 3.3 Results and discussion

### 3.3.1 Socio-economic and demographic characteristics

The socio-demographic and economic characteristics of the study population were as summarized in Table 3.1. Of the households that were involved in the study, 50.6% were from Coastal ASAL areas (Taita Taveta County) whereas 49.4% were from Eastern part (Kitui County). The household heads were mainly males (72.3%) and had farming (72.9%) as their main occupation. Majority (97.5%) of the households sourced their vegetables from their farm. Reliance on the farm as the major source of the vegetable was significantly ($p<0.05$) associated with the county of residence. Cowpea leaves was the most preferred priority vegetable across the two counties with over 80% of the households preferring it (Figure 3.2). The county of residence of the households and the gender of the household head significantly ($p<0.05$) influenced the prioritization of the cowpea leaves as a vegetable and the reliance on the farm as its major source. The cowpea leaves were regarded more in the eastern region as a major farm produce based on the yields compared to Coastal areas ($p<0.05$) as shown in Figure 3.3.

**Table 3.1: Socio-economic and demographic characteristics of households producing cowpea leaves**

| Socio-economic and demographic characteristics | County of residence | | Total | $\chi^2$ (P-Value, df) |
|---|---|---|---|---|
| | **Taita Taveta** | **Kitui** | | |
| Number of respondents **(%)** | 50.6 | 49.4 | 100 | Na |
| **Gender of household head (%)** | | | | |
| Male | 66.8 | 78.0 | 72.3 | 6.3 |
| Female | 33.2 | 22.0 | 27.7 | (0.012, 1) |
| **Level of education of household head (%)** | | | | |
| Never went to school | 12.7 | 21.0 | 16.8 | 47.4 |
| In primary | 3.4 | 21.5 | 12.4 | (<0.001, 4) |
| Completed primary | 47.5 | 24.5 | 36.1 | |
| In secondary | 1.5 | 2.0 | 1.7 | |
| Completed secondary | 14.2 | 15.0 | 14.6 | |
| University and Tertiary | 4.9 | 5.0 | 5.0 | |
| **Main occupation of the household head (%)** | | | | |
| Salaried employment | 5.9 | 7.5 | 6.7 | 5.8 |
| Farmer | 71.8 | 74.0 | 72.9 | (0.325, 5) |
| Trading and other informal businesses | 9.4 | 10.5 | 10.0 | |
| Casual labour | 7.9 | 6.0 | 7.0 | |
| Unemployed | 4.5 | 1.0 | 2.7 | |
| Not applicable: students and underage | 0.5 | 1.0 | 0.7 | |
| **Who decides food to be bought (%)** | | | | |
| Man | 46.8 | 34.5 | 40.7 | 21.5 |
| Woman | 52.7 | 55.5 | 54.1 | (<0.001, 2) |
| Both man and woman | 0.5 | 10.0 | 5.2 | |
| **Consumption of cowpea leaves in glut (%)** | | | | |
| Yes | 99.0 | 99.5 | 99.3 | 0.3 |
| No | 1.0 | 0.5 | 0.7 | (0.573, 1) |
| **Household monthly income (%)** | | | | |
| KES. <3000 | 59.5 | 35.5 | 47.7 | 40.1 |
| KES. 3000-10000 | 33.2 | 37.0 | 35.1 | (<0.001, 4) |
| KES. 10000-25000 | 5.9 | 13.0 | 9.4 | |
| KES. 25000-50000 | 1.0 | 12.0 | 6.4 | |
| KES. >50000 | 0.5 | 2.5 | 1.5 | |
| Average age of household head (yrs)** | 50.1±16.2 | 50.7±16.1 | 50.4±16.1 | -0.3* (0.731, 403) |
| Household size (persons)** | 3.4±2.2 | 6.8±3.1 | 5.0±3.2 | -12.5* (<0.001, 359) |

Significance for all the dependent variables was tested using chi-square except for those indicated with ** where t-test was used. *t-value. na-significance was not tested due to lack of variation.

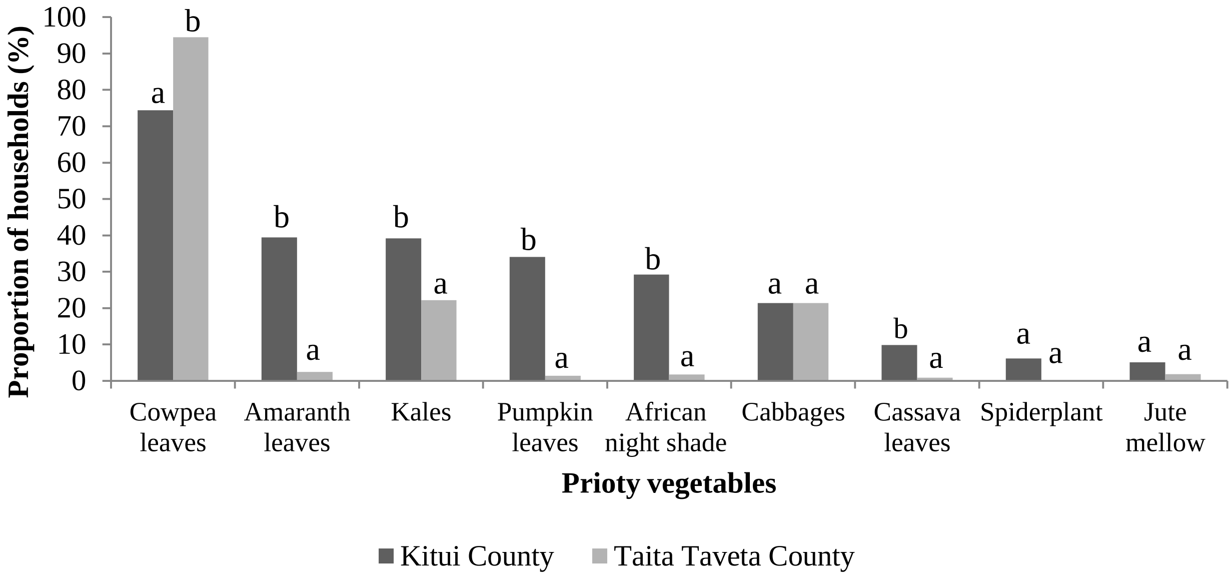


**Figure 3.2: Priority vegetables in the study areas.** Different letters for an attribute indicate significant difference at $p<0.05$.

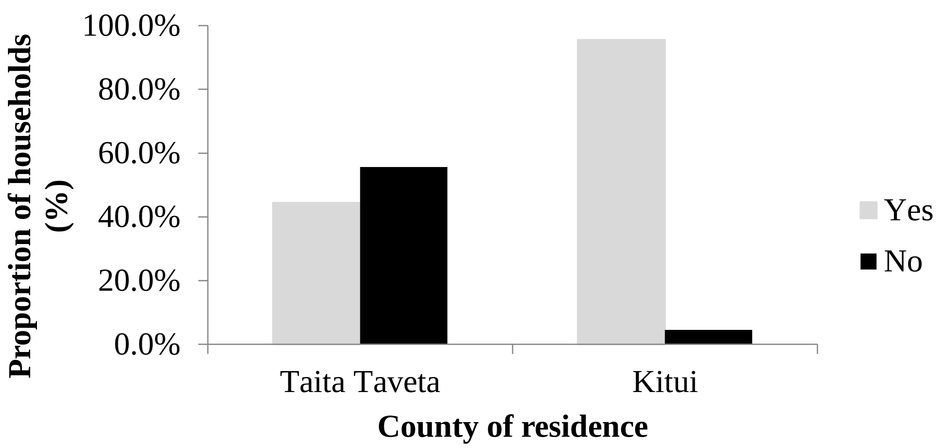


**Figure 3.3: Prioritization of cowpea leaves as a farm produce based on farm yields in the different counties**. $p<0.001$, df=1 and $\chi^2$=125.05.

### 3.3.2 Constraints to the production

Drought and field pests and diseases were ranked as the top two severe challenges constraining the utilization of cowpea leaves in the two counties (Table 3.2). The challenges experienced did not significantly ($p>0.05$) differ between the two regions. Five principal component analysis (eigen values ≥ 1) explained 63.7% of the variation of the constraints of utilization and production of cowpea leaves by the households. Households that had their utilization and production of cowpea leaves constrained diseases also were constrained by field pests, weeds and drought (Figure 3.4). These households were least constrained by lack of land in the production and utilization of cowpea leaves.

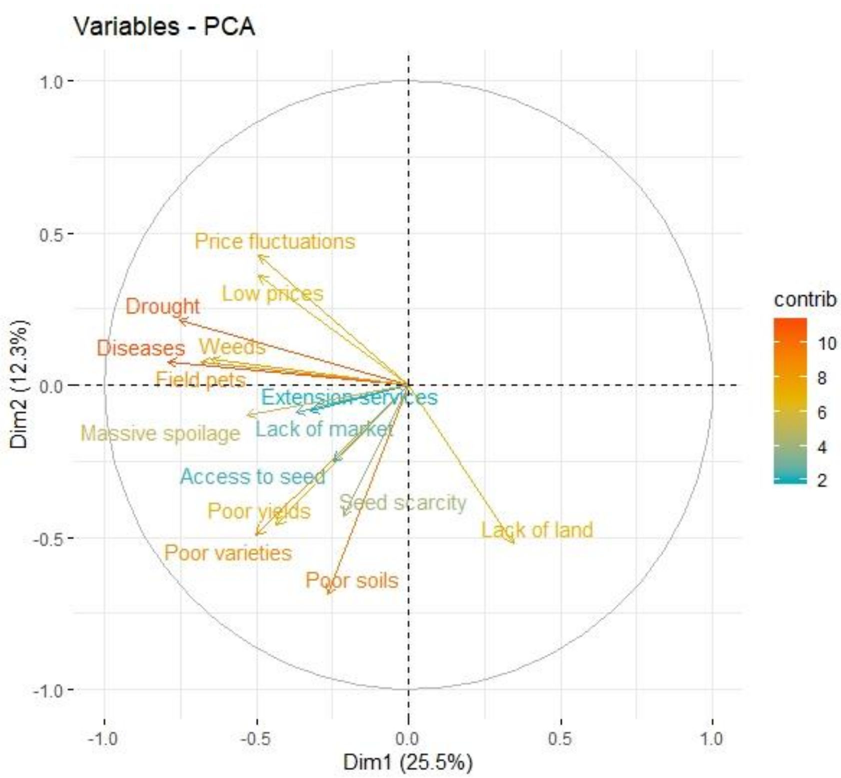


**Figure 3.4: Principal component analysis challenge constrained the utilization and production of cowpea leaves by the households.** Contrib- constitutes contribution (in percentages) of the variables to the principal components.

**Table 3.2: Extent to which the challenge constrained the utilization and production of cowpea leaves by the households (%)**

| Constraint | Extent to which the challenge constrain production | | |
|---|---|---|---|
| | **Low** | **Moderate** | **Severe** |
| Drought | 7.6 | 12.4 | 79.9 |
| Diseases | 9.4 | 23.6 | 67.0 |
| Field pest | 11.5 | 30.2 | 58.4 |
| Extension services | 15 | 36.2 | 48.8 |
| Price fluctuations | 14.5 | 41.6 | 43.9 |
| Lack of market | 23.4 | 33.8 | 42.9 |
| Weeds | 15 | 42.4 | 42.6 |
| Low prices | 17.7 | 40.3 | 42.1 |
| Access to seeds | 16.5 | 60.7 | 22.8 |
| Massive spoilage | 26.5 | 51.1 | 22.4 |
| Seed scarcity | 23.4 | 54.4 | 22.2 |
| Lack of land | 23.4 | 54.4 | 22.2 |
| Poor yields | 31.9 | 47.9 | 20.2 |
| Poor varieties | 30 | 52.6 | 17.4 |
| Poor soils | 56.3 | 32.7 | 10.9 |

### 3.3.3 Trends of production of cowpea leaves

The mean average time for initiation of harvesting the leaves was found to be 2.58 ± 1.26 WAE, with an average harvesting period of 2.22 ± 1.79 weeks and a termination period of 7.36 ± 3.99 WAE. The period of initiation, interval and termination of harvesting was not significantly ($p>0.05$) different across the two counties. The demographic characteristics of the household head did not significantly ($p>0.05$) influence the period of initiation, interval and termination of harvesting of cowpea leaves.

About three quarters (73.8%) of the households growing cowpea leaves preferred it to other crops as it gave higher yields. The households planted cowpea leaves for averagely two seasons (1.9±0.3). The landrace (local) varieties were the most grown varieties by up to 86.2% of the households. Nearly all (98.5%) the households preferred plucking the leaves rather than uprooting the plant as the method of harvesting cowpea leaves. Averagely in both counties, both intercropping and monocropping were practiced in equal measure (Figure 3.5). However, majority (65.7%) of the households in Kitui County preferred intercropping cowpea leaves with other crops whereas majority (67.2%) of those in Taita Taveta County used the monocropping system for cultivation of the crop. Significantly ($p<0.05$) higher proportion of households in Kitui County preferred to harvest in the morning compared to those from Taita Taveta County as shown in Figure 3.6**.** Only two thirds (66.9%) of the households were involved in the sale of the produce they harvested. Of the households that sold the vegetable, women were more involved (84.6%) than the men (53.3%). Three quarters (77.8%) of the households would also harvest the grains from the crops. A higher proportion of households in Taita Taveta County (43.1%) than in Kitui County (1.7%) did not utilize the grains, ($p<0.001$, df=2 and $\chi^2$=102.9).

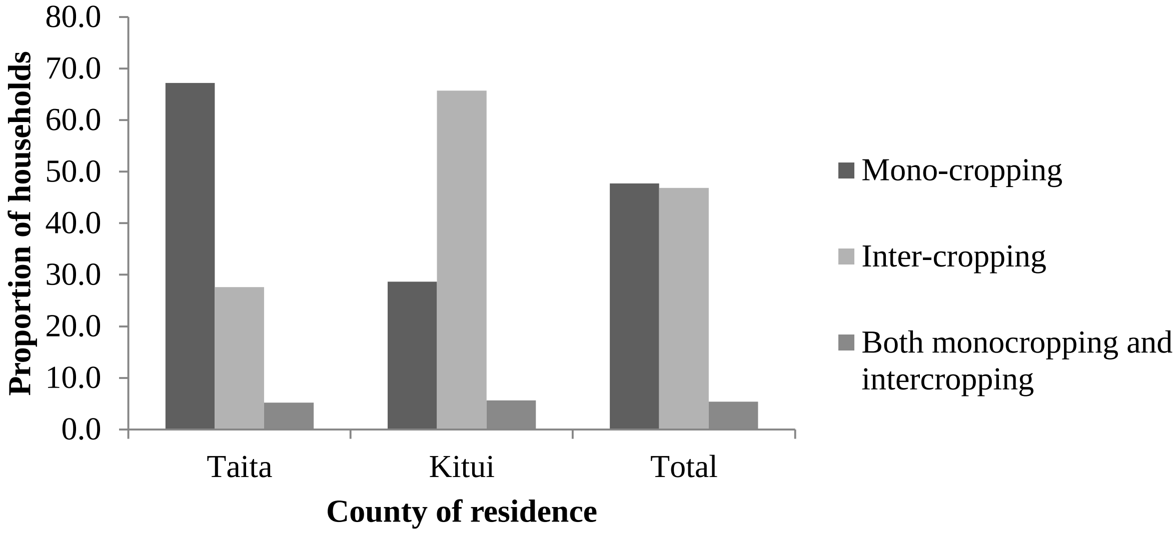


**Figure 3.5: Association between county of residence and system of farming for cowpea leaves.** $\chi^2$=54.8, p<0.001 and df=2.

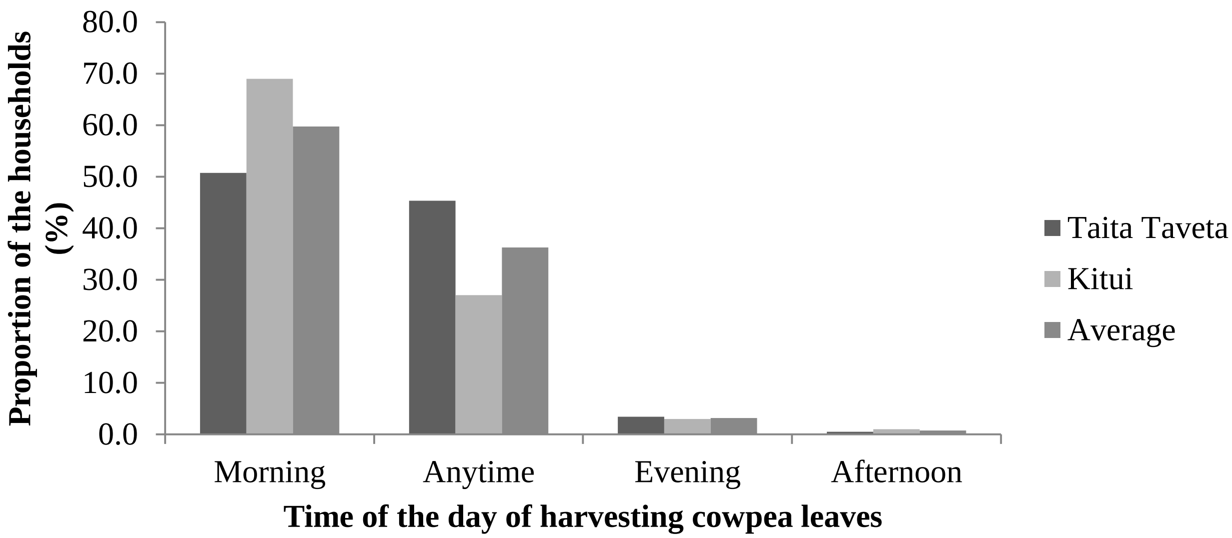


**Figure 3.6: Association between time of harvesting cowpea leaves and county of residence.** $\chi^2$=15.5, df=3 and P=0.001.

The average production quantities of cowpea leaves of the farmers was 3.03 ± 0.9 of 90kg bags in a season. The production quantities among cowpea growing households in Kitui county was

4.5±0.3 of 90kg bags per season; this was significantly ($p<0.05$, $t=254.8$) higher than those of households from Taita Taveta County that had production quantities of 1.5 ± 0.1 90kg bags. The significant ($p<0.05$) predictors factors of production quantities of cowpea leaves included access to seeds, availability of market and weeds with an $R^2$ of 0.21 (Table 3.3). The regression equation for production quantity of cowpea leaves was as shown in Equation 3.2.

$$\boldsymbol{y = 2.5 - 1.0x_1 - 0.1x_2 + 0.7x_3 + 0.9x_4,} \qquad \textbf{Equation 3.2}$$

where y is the production quantity in 90kg bags (number of bags); $x_1$, $x_2$, $x_3$ and $x_4$ are the variables lack of poor soils (moderate), drought (moderate), lack of access to seeds (moderate) and massive spoilage (low) respectively.

### 3.3.4 Trends of utilization of cowpea leaves

The most preferred forms of cowpea leaves that were utilized in the households included the boiled (87.5%), sundried (27.5%) and blanched (13.6%). Households from Taita Taveta had odds of 3.3 and 0.1 of consuming boiled and sundried forms of cowpea leaves, respectively, compared to those from Kitui County whereas the male-headed households also had odds of 2.5 of consuming the blanched forms as compared to the female-headed ones at $p<0.05$. In as much as the frequency of consumption of cowpea leaves in the households across the two counties averaged at 3.4 ± 1.7 days in a week, households in Kitui County posted a higher frequency of 4.1 ± 1.7 days in a week as compared to 2.7 ± 1.3 days a week for households in Taita Taveta County ($p<0.05$) during in-season.

**Table 3.3: Beta values for predictor factors of production quantity of cowpea leaves**

| Constraints on production | Beta values of intensity of constraints on production (odds ratios) | |
|---|---|---|
| | Low | Moderate |
| Field pest | 0.4(1.4) | -0.6 (0.5) |
| Seed scarcity | -0.4(0.7) | -0.4(0.7) |
| Lack of land | 0.6(1.9) | -0.2(0.9) |
| Lack of market | 0.4(1.4) | 0.6(1.8) |
| Poor yields | -0.6(0.5) | -0.7(0.5) |
| Poor varieties | -0.5(0.6) | -0.9(0.4) |
| Poor soils | -0.2(0.8) | -1.0(0.4)* |
| Price fluctuations | 0.6(1.8) | 0.4(1.5) |
| Low prices | 0.0(1.0) | 0.8(2.2) |
| Drought | -1.1(0.3) | -0.1(0.9)* |
| Diseases | 0.6(1.7) | 0.9(2.5) |
| Lack of access to seeds | 1.1(3.0) | 0.7(2.0)* |
| Weeds | -0.2(0.9) | 2.5(12.7) |
| Massive spoilage | 0.9(2.3) ** | -0.4(0.7) |
| Lack of extension services | 0.6(1.8) | 0.6(1.9) |

The regression equation has an $R^2$ of 0.21 and a constant of 2.5 at $p<0.05$. The reference category for both low and moderate groups is severe. *significant at $p<0.05$, ** significant at $p<0.001$.

### 3.3.5 Constraints of utilization of cowpea leaves

The fitted linear model found that the household size and occupation of the household head were significant socioeconomic and demographic factors that influenced the frequency of intake of cowpea leaves in the households (Table 3.4). With increasing household size, the frequency of weekly consumption of cowpea leaves increased with a correlation coefficient of 0.35 ($p<0.001$). Additionally, households where the food to be bought was determined by the female had a weekly frequency of intake of cowpea leaves of $3.7\pm1.9$ which was significantly ($p<0.001$) higher than that recorded in households where this decision was with the males, $3.0\pm1.4$. In seasons of scarcity, 75.1% of the households would either source the cowpea leaves from elsewhere or not eat it completely. A higher proportion of the households from Taita Taveta County (42.9%) as compared to those from Kitui County (4.5%) used the preserved forms of cowpea leaves during scarcity ($p<0.05$).

## 3.4 Discussion

### 3.4.1 Trends in production and utilization of cowpea leaves

The survey showed that households that produced and consumed cowpea leaves were mainly male headed with the average age of the household heads being 50 years. This implies that the crop is mostly farmed among the elderly population rather than the youthful age. Ddungu (2013) in his study in Uganda also reported a similar trend where the population farming cowpea leaves was dominated by the elderly. However, findings of a study done in Ghana and Tanzania were different as the farming population of cowpea leaves was dominated by the youthful age group (Akpalu et al., 2014; Mamiro et al., 2011). Kenya currently grapples with low involvement of the youth in agriculture and more so in subsistence agriculture like that of the production of cowpea leaves. The subsistence nature of this value-chain results in low revenue generation which has been adduced to low levels of adoption of appropriate inputs (Afande et al., 2015). Additionally, the land tenure system has been another factor that has contributed to the low involvement of youths in production agriculture in Kenya.

**Table 3.4: General linear model of the frequency of intake of cowpea leaves in a household based on their socio-demographic and economic factors**

| Socio-demographic and economic factors of the households | Degrees of freedom | Mean square | P-value |
|---|---|---|---|
| Intercept | 1 | 70.636 | 0.000 |
| Gender of the household head | 1 | 1.56 | 0.213 |
| Level of education of the household head | 6 | 2.727 | 0.014 |
| Main occupation of the household head | 5 | 1.514 | 0.185 |
| Who decides food to be bought in the household | 2 | 2.549 | 0.020 |
| Age of the household head | 60 | 0.84 | 0.791 |
| Number of household members | 16 | 5.317 | 0.000 |
| Monthly income | 4 | 1.666 | 0.158 |

The production of cowpea leaves in the study areas was done in both monocropping and intercropping production systems. This finding is similar to that of a study done in Taita Taveta and Makueni Counties where farmers in various agro-ecological zones grew cowpeas in both intercropping and monocropping systems (Njonjo et al., 2019). The crop is a legume with nitrogenfixing property and has always been recommended for intercropping especially with cereals (Iqbal et al., 2019; Mucheru-Muna et al., 2010). Experimental studies by Egesa et al. (2016) reported more than 50% increase in sorghum yield in an intercropping production system as compared to a solely sorghum monocropping system. Additionally, Sebetha et al. (2010) reported an increase of 26.7% in the leaf protein of the intercropped cowpea leaves as compared to the monocropped. The attribute of the crop of early maturity has made it to be favoured in the ASAL areas (Njonjo, 2018). Of the households that produced cowpea leaves, the harvesting began at two weeks and was done at an interval of a similar period. Based on the findings by Saidi et al. (2010), such a practise has a mixed impact on the leaf yield as delayed initiation of leaf harvesting to 3 weeks rather than of 2 weeks that was practiced in the current study and harvesting at an interval of 14 days (similar to that of the study) rather than 7 days improved the leaf yields.

The results indicated that cowpea leaves was a priority crop in the ASAL areas of the country. The prioritization of the crop in both the eastern and coastal ASAL lands of the country is as a result of its drought-tolerance property. According to the Horticultural Crops Directorate(Horticultural Crops Directorate, 2016), the leading cowpea leaves producing counties are in the ASAL lands of Eastern and Coastal region. The households in the ASAL areas relied on the farm as their major source of cowpea leaves. This has the implication that less marketing of the vegetable is done in the area and the crop is largely grown for subsistence. A study done in South Africa also reported that cowpea leaves was one of the least commercialized crops thus less trading on it is done (Lekunze, 2014). With such limited commercialization, this exposes the farmers to huge postharvest losses during glut and massive scarcity of the vegetable during drought.

The study also found that cowpea leaves were consumed as boiled, blanched and sundried in the ASAL areas. These are majorly the traditional methods of preparation that have remained unchanged over the years. The consumption of cowpea leaves was found to be at least 3 days in a week with the eastern ASAL region of the country consuming about twice as frequent as the coastal ASAL areas. Such a level of intake of cowpea leaves has a nutritional advantage as Enyiukwu et al. (2018a) recommends the consumption of the leaves over the seeds for they are rich in minerals, vitamins and antioxidants that have disease prevention and nutrition-promoting characteristics. Moreover, the vegetables have also been found to be low in antinutrients thus the nutrients have a high bioavailability (Chikwendu et al., 2014). All households consumed their cowpea leaves from their own production during glut but had no cowpea leaves to consume or had to source from elsewhere during drought and seasons of scarcity. This shows insufficiency of the postharvest storing technologies of the leaves in this area in ensuring uninterrupted availability of the vegetable.

### 3.4.2 Constraints of production and utilization of cowpea leaves

Drought, diseases and field pests were found to be the most prevalent challenges experienced by farmers in the ASAL areas of the country. Diseases, field pests, weeds and drought had similar trends as constraining factors of utilization and production of cowpea leaves among producing households. Another study in Uganda that focused on cowpea production rated similar challenges of pest and diseases together with unreliable rainfall as among the most prevalent challenges constraining production (Ayaa et al., 2018). The challenges of pest and diseases and drought result in pre-harvest losses leading low production quantities. The rural population also largely relied on landrace varieties for their production. This has the effect of limited yields being realized. Using the generated linear models, increasing severity of massive spoilage and constrained access to seeds as challenges aggravated limited production quantities of the leaves among the households. This limited access to seeds is evidenced by the high proportion of the households that rely on the landraces rather the improved varieties for cultivation. Massive spoilage limits the quantities available for use among the households, lest such households initiate postharvest management measures to preserve the leaves. Increasing severity of drought and poor soils did not constrain the production quantities of the households. The area of study is arid and the communities tend to have coping strategies to the adverse environmental conditions (Opiyo et al., 2015b).

Smaller household sizes and households where males decided food to be eaten recorded lower frequencies of intake of cowpea leaves. Lekunze (2014) in his market analysis study in South Africa reported that with increasing standards of living, households would abandon the cowpea leaves for other foods. Smaller households have usually been associated with higher living standards and this explains the positive correlation between household size and frequency of intake of cowpea leaves. Even so, the consumption of cowpea leaves as reported in various studies has not been satisfactory despite it being nutritious. Gido et al. (2017) reported that the acceptance of cowpea leaves in the urban areas is still lower than in the rural areas as they preferred other forms of vegetables. Additionally, Mamiro et al. (2011) reported a range of 10-500 g daily per capita consumption of cowpea leaves in season among the households with more extremities than the grains, 40-200 g. This is due to the prioritization of the harvesting of the seeds over the leaves as it has been established in other studies that harvesting of the leaves reduce the grain yield (Saidi *et al.*, 2010). The harvesting of the leaves are usually abandoned to allow for development of the grains. Off-season utilization declined greatly as up to 75.1% of the households lacked their own production of cowpea leaves to consume. This is as a result of lack of appropriate postharvest technologies and inadequate production quantities that could sustain the households through the off-season period.

## 3.5 Conclusion

Cowpea leaves were a major source of food and a priority crop in the ASAL areas of Kenya. In times of glut, the households majorly relied on their own production for sourcing the vegetable; however, scarcity of the vegetable would have most households not consuming the crop. The major forms of utilization of the cowpea leaves in the ASAL areas were traditional with limited value-addition practices being done. The eastern ASAL regions have lesser diversity of forms in which they consume cowpea leaves as compared to the ASAL areas in the coastal region.

Pest, diseases and drought were major constraints that greatly constrained the utilization and production of cowpea leaves in these ASAL areas. Limited production quantities of the vegetable among the households was aggravated by lack of access to good quality seeds and massive spoilage. In order to increase the availability and intake of the vegetables, it is necessary to address these two constraining factors among these cowpea producing households in ASAL areas.

# CHAPTER FOUR: TRENDS AND CONSTRAINTS OF UTILIZATION OF PRESERVED COWPEA LEAVES AMONG HOUSEHOLDS IN ARID AND SEMI-ARID LANDS IN KENYA: A CONVERGENT MIXED METHOD STUDY


**Abstract**

In order to determine the utilization of cowpea leaves as food security crop in the food insecurity hotspots of arid and semi-arid lands (ASALs); a qualitative and quantitative study was conducted in the eastern and coastal ASALs of Kenya to evaluate preserved forms of the vegetable as alternative sources to fresh during scarcity. The mean period of availability of fresh leaves in the areas was $4.8 \pm 4.3$ weeks in each cropping season. Over half (58%) of the households therefore supplemented their supplies with preserved forms of the vegetables. In scarcity, 73.6% of the households could not get the vegetables from their own sources during scarcity. The linear regression model predicting availability of fresh cowpea leaves found cropping seasons and cultivation of pulses were positive predictors whereas the stage of initiation of harvesting was a negative predictor ($p<0.001$, Adjusted R-squared=0.510). Only 24% of the households had constant supply of the vegetables in and off-season. Households that were involved in commercialization of cowpea leaves and sale of the preserved forms in the open air market significantly increased the likelihood ($p<0.001$, OR=2.47 and $p<0.001$, OR=2.3; respectively) of utilization of the vegetables among the households during scarcity. In conclusion, the preserved forms of cowpea leaves promote availability of the vegetable especially in seasons of drought. In as much as there is limited practicing of preservation of the vegetables, its availability is enhanced through dehydration and other value-addition techniques among a significant number of the households.

## 4.1 Introduction

Cowpea (*Vigna unguicuata*) is a drought tolerant crop that is well suited for growth across several agro-ecological zones (Drahansky et al., 2016). The crop is a dual purpose for it is grown both for its grains and leaves especially in sub-Saharan Africa, SSA (Muñoz-Amatriaín et al., 2017). In Kenya, the crop has been grown mainly in the semi-arid and arid lands (ASAL) including eastern and coastal counties (Njonjo et al., 2019; Owade et al., 2020b); for instance Taita Taveta and Kitui counties accounted for a total of 43.16% of the total national production quantities of 3941 MT (Horticultural Crops Directorate, 2016). These areas are characterized with adverse weather conditions limiting crop cultivation and production either for commercial or subsistence (County Government of Kitui, 2018; County Government of Taita Taveta, 2018). The crop has served well in complementing the diets of the communities in these areas which mainly comprises starchy grains (Owade et al., 2020b). Its suitability in these areas are due to a variety of traits in displays including early maturity, thus they complete reproductive cycles before the onset of drought (Huynh et al., 2018). Recent studies point to interest in increasing productivity of the crop in order to harness more benefits from the leaves and grains (Huynh et al., 2018; Lo et al., 2018).

The greatest limitation to the utilization of cowpea leaves is the seasonality in their production (Kirakou et al., 2017). The vegetable has huge postharvest losses during glut whereas with the onset of drought, there is scarcity (Kirigia et al., 2018). Local communities have come up with traditional processing techniques aimed at enhancing availability of the vegetables even during seasons of drought (Owade et al., 2020a); however, the efficiency of these techniques in promoting the availability of the vegetables among these vulnerable households is yet to be determined. A study done in Uganda showed that the consumer acceptability of preserved cowpea leaves did not significantly differ across various traditional processing techniques that included open sun-drying and blanching (Natabirwa et al., 2016). Additionally, the study found that traditional preservation of cowpea leaves did not significantly alter the proximate composition of the leaves. This study has the implication that traditional processed cowpea leaves can be possible alternatives in cases of scarcity. Moreover the abundant production of the vegetable in these areas make it a feasible strategy in addressing the high malnutrition rates (Horticultural Crops Directorate, 2016; KNBS et al., 2014). The study therefore sought to evaluate the utilization of preserved cowpea leaves as a complementary of fresh forms in effort to promote the off-season availability of the vegetables among households in ASAL areas.

## 4.2 Materials and Methods

### 4.2.1 Study design

A convergent mixed method study design that incorporated quantitative household survey and qualitative methods of key informant interviews and focus group discussion was utilized in the study. The study was undertaken in arid ASAL areas of Kitui and Taita Taveta Counties of which the socio-demographic and economic characteristics are as described in Section 3.2.1.

### 4.2.2 Sampling criteria of for quantitative field survey

Using the sampling criteria outlined in Section 3.2.1, 405 households formed the sampling units of this study in the two study areas.

### 4.2.3 Data quality control of the quantitative field survey

Key aspects to ensure quality control of the data included enumerator training on data collection using the mobile application ODK. A pretest of the data was done in Wundanyi urban areas (Taita Taveta Counties) which were not part of the study areas. From the pretest exercise the questionnaire was revised by including additional multiple responses. In data collection, the daily uploaded data was evaluated for quality by generating summary statistics.

### 4.2.4 Data collection for quantitative survey

A semi-structured questionnaire shown in Appendix 1 was uploaded in the mobile application, open data kit (ODK). Data collection was then administered in Swahili on cowpea producing households. Systematic random sampling that selected every third household in count in villages in every ward. The selected households in every village was determined by stratification of the wards into villages and apportioning equal number of sampling units. Informed consent of the respondents was first obtained before administration of the questionnaire. Information regarding the socio-demographic and economic characteristics, production, availability and utilization practices of preserved forms of cowpea leaves was collected.

### 4.2.5 Statistical analysis of quantitative data

The quantitative data was analyzed using the statistical package for social sciences (SPSS) software version 25 (Landau and Everitt, 2004) and R programming language (R Core Team, 2019). Descriptive statistics including mean and standard deviation for continuous variables and frequencies in the case of categorical variables of the socio-demographic data were generated. With the availability and utilization of fresh and preserved cowpea leaves as the dependent variables, inferential statistical tests including linear modelling, chi-square tests and odds ratios were used to establish associated and predictive factors from the agricultural and socio-demographic independent variables. The linear regression model for the availability of the vegetables was determined as per Equation 4.1.

$$y = a + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$$ **Equation 4.1**

Whereby $y$ is the period of availability of cowpea leaves (weeks) with variables and their beta coefficients indicated by $x$ and $\beta$, with a total number of variables being in the model. The independent variables fitted in the model were the agricultural production and utilization practices of the households.

Exploratory analysis effected through correspondence analysis was used to establish the trends in the availability, sourcing and utilization of cowpea leaves in the producing households as shown in Equation 4.2 to 4.5.

$$\boldsymbol{dist(v_1\,, v_2) = \Sigma \frac{(v_1\, profile - v_2\, profile)^2}{average\; profile}}$$ **Equation 4.2**

Where $v$ exists in $v_1$, $v_2$ ….. $v_n$ and average profiles are calculated as

$$v\; profile = \frac{x}{\Sigma_{\boldsymbol{n}}^{\boldsymbol{1}}(x)}$$ **Equation 4.4**

$$average\; profile \rightarrow \frac{\Sigma_{p}^{\boldsymbol{1}} x}{\Sigma_p^1(\Sigma_{\boldsymbol{n}}^{\boldsymbol{1}}(x))}$$ **Equation 4.5**

Whereby $v$ represent variables (availability, sourcing and utilization of cowpea leaves), $x$ a consistent value to represent a category such as "Yes" or "No" for a variable $v$; and $n$ and $p$ as total number of variables and households, respectively.

### 4.2.6 Data collection for qualitative survey

Qualitative surveys including key informant interviews (KII) and focus group discussions (FGD) of 8-12 members were conducted among the stakeholders in the cowpea value-chain in the area for mutual validation and convergence with the findings from quantitative surveys. Informed consent of these respondents was first obtained before participation. The respondents were purposively selected based on their role in the cowpea leaves value-chain. The key informants had an average of 41.2 ± 5.6 years whereas the FGD participants had 39.2 ± 8.1 years (Table 4.1). Two participants from each of the categories of farmers, farmer group leaders, extension officers and county officers were selected as key informants. On the other hand, the FGD had group members, non-group members and farmer group leaders constituting 45.2, 22.1 and 32.1 of the participants, respectively (n=20)**.** Of the participants in the FGD, 81.1% were females whereas 19.91% were males (n=20). A FGD guide and KII questionnaire (see Appendices 2 and 3) were used in the data collection.

### 4.2.7 Thematic analysis of qualitative data

Thematic analysis of the qualitative data was done using the social sciences queries technique as explained by Ryan and Bernard (2003) to identify emerging themes. Since the quantity of the data was not that large, the analysis was done in the Microsoft word following a six step criteria: 1. Assigned labels, also known as anchor codes, based on the questions asked in the survey; 2. Identified relevant statements in the data and assigned specific codes under respective anchor codes; 3. Compiled a list of the initial codes that had been formulated; 4. The codes were arranged alphabetically under their respective anchor codes; 5. All the codes were grouped and tallied based on frequency of occurrence; 6. From these the emerging themes were generated through checking on the frequency of mention, relationships and underlying concepts in the codes.

**Table 4.1: Socio-economic and demographic characteristics of respondents in the KIIs and FGDs qualitative surveys**

| **Socio-economic and demographic characteristics** | | **Descriptive statistics** |
|---|---|---|
| **Key informant interviews** | | **8** |
| Farmers | | 2 |
| Farmer group leaders | | 2 |
| Extension officers | | 2 |
| County crop officers | | 2 |
| Average age* (yrs) | | 41.2 ± 5.6 |
| **Focus Group Discussion** | | **2** |
| Gender | Male** (%) | 19.9 |
| | Female** | 81.1 |
| Role in the cowpea leaves value chain | Farmer** (not a group member) | 22.1 |
| | Farmer group member** | 45.2 |
| | Farmer group leader** | 32.1 |
| Average age* (yrs) | | 39.2 ± 8.1 |

All the descriptive statistics are expressed in numerical frequencies except for those marked * and ** which denote means ± SD and percentages, respectively.

## 4.3 Results

### 4.3.1 Socio-economic and demographic characteristics of cowpea growing households in the ASALs

The quantitative survey incorporated slightly over half (50.6%) of the households from coastal ASAL areas whereas 49.4% were from eastern ASALs. The household heads were mainly males

(72.3%). The level of education of the household heads was 30.2% not having attended any school, 48.5% with primary education and 21.8% attained secondary level and beyond with no significant difference ($p>0.05$, df=4, $\chi^2=47.4$) in the two ASAL areas. The eastern ASALs (6.8 ± 3.1 persons) had significantly ($p<0.001$, df=359, t=-12.5) larger households sizes than the coastal ASALs (3.4 ± 2.2 persons). Separate thematic analysis of the key informant interview and focus group discussion data identified three and four emerging themes, respectively. The emerging themes from the key informant interviews and the focus group discussion are as shown in **Figure 4.1**, with an elaboration of all the anchor codes and labels shown in **Appendix 4**. The results of the qualitative component of the study were used to corroborate the findings of the quantitative component.

| |
|---|
| Theme 1: Limitations in the production and preservation of cowpea leaves<br>[2](26) |
| Theme 2: Current trends in the production and preservation of cowpeas leaves<br>[3](22) |
| Theme 3: Improving the production, preservation and commercialization of cowpea leaves |
| Theme 4: Policy influence on the production, preservation and utilization of cowpea leaves |

**Figure 4.1: Emerging themes in the qualitative survey.** The figures indicated in [] and () represent the anchor codes and the labels under each thematic area, respectively.

The farm was the major source of cowpea leaves for most (97.5%) of the households, whereas 22.2% and 20.0% of the households sourced their cowpea leaves from the market and roadside vendors, respectively. Significantly ($\chi^2=10.0$, df=1, $p=0.002$) higher proportion of the households from eastern ASAL areas (100%) than coastal ASAL areas (95.0%) sourced the cowpea leaves from the farm as shown in Figure 4.2. In the utilization of the fresh leaves, both study areas utilized the vegetable singly rather than as a composite with other vegetables (Figure 4.3). More households in coastal ASALs (95.6%) consumed the vegetable singly as a vegetable than those in eastern ASALs (76.0%); whereas in the latter, more households mashed and mixed it with other foods than in the former. The nutritional composition of cowpea leaves served as a major selling point for the utilization of cowpea leaves. The greatest desire among the farmers is additional products from the vegetable as it will increase the avenues through which they can gain the nutritional benefits of this crop.

*"If a product like a soup mix is created it can create additional market for the produce. Cowpeas have protein and vitamins and such products can increase its utilization." one farmer said.*

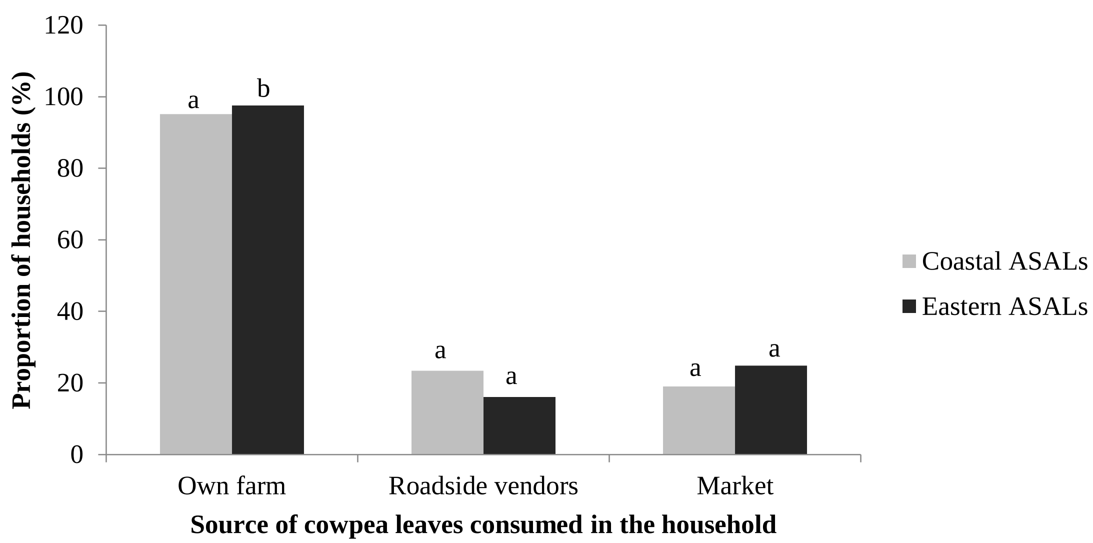


**Figure 4.2: Source of cowpea leaves consumed in the households producing cowpea leaves in the arid and semi-arid lands.** Vertical bars marked with different letters denote significant difference of the values at $p<0.05$.

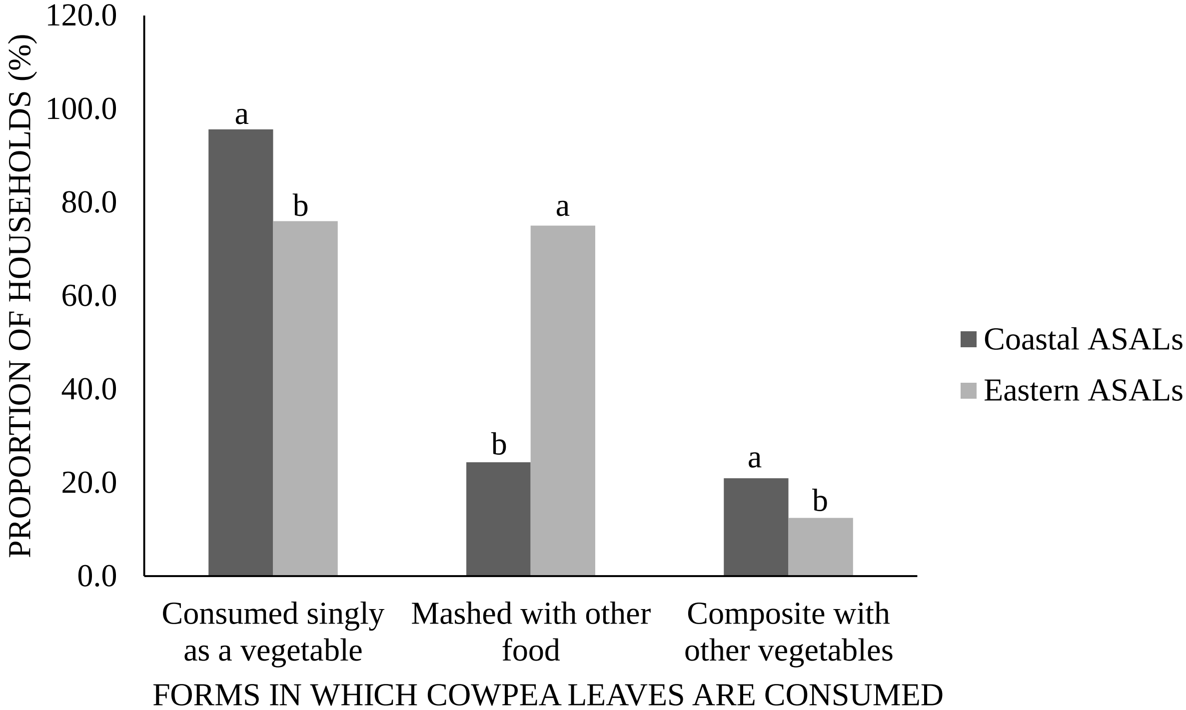


**Figure 4.3: Incorporation of fresh cowpea leaves into diet**. Bars for the same variable marked with different letters at the top are statistically different at $p<0.05$.

### 4.3.2 Utilization and availability of fresh cowpea leaves among cowpea producing households

In as much as cowpea leaves were a priority crop in these ASALs, cereals still remained the most preferred and cultivated crops (Table 4.2**)**. Crop cultivation in a year was largely in two seasons in most of the households in the ASALs, 80% and 98% of the households in coastal ASALs and eastern ASALs, respectively. The general consensus among the stakeholders in the cowpea value-chain is that the crop has received little if no attention from the policy makers and the government. This resulted in majority of the farmers favouring other crops rather than the cowpea leaves. The farmer groups involved in the cultivation of cowpea leaves incorporated it as one among others, not as the sole crop.

*"Cowpea leaves is not taken seriously by policy makers at the County level for we are even surprised today we have sat down to talk about mkunde (cowpea leaves). There is need to create awareness." one of the farmers said.*

"*Cowpea leaves should be highly considered by the ministry like other crops." a farmer group leader added.*

Eastern ASAL areas which happen to have drier conditions had significantly ($p<0.001$) higher preference (95.5%) of the vegetable as a major crop than the coastal ASAL areas (44.4%). Quarter (24.9%) of the households in the eastern ASAL areas cultivated cowpea leaves as the only vegetable; this was significantly ($p<0.001$) higher than that of the coastal ASAL areas (8.5%). Moreover, significantly ($p<0.05$) higher proportion (50.0%) of households in the eastern ASAL areas also produced surplus quantities of cowpea leaves than the costal ASAL (38.5%). In both the production areas, there was preference of landraces for cultivation of the crop, 89.3 and 97.0 for coastal and eastern ASAL areas, respectively. The households took averagely $2.6 \pm 1.3$ weeks after emergence of the crop to initiate harvesting of the leaves. There was no statistical difference ($t=-1.34$, $df=359.24$) in the stage of initiation of harvesting of the leaves across the two different ASAL areas. The households planted cowpea leaves twice ($1.9 \pm 0.3$ cropping seasons) in a year. The households in the ASALs of the coastal region had significantly ($p<0.001$) lower annual frequency ($1.8 \pm 0.03$) of cultivation of the vegetables than those from the eastern ($2.00 \pm 0.01$). The average harvesting of cowpea leaves in a season was $273.1 \pm 51.4$ kg. The eastern ASAL areas had significantly ($p<0.001$, $t=-8.27$) higher production quantity ($409.5 \pm 31.1$ kg) in a season as compared to those from the coastal ASALs ($140.1 \pm 65.0$ kg).

The mean average period for the availability of harvested fresh cowpea leaves for household consumption was 4.8 ± 4.3 weeks in each cropping season. The mean average period of availability of cowpea leaves harvested from their own farm did not significantly ($p=0.971$, $t=0.02$) differ across the two ASAL areas. The model fitting the agricultural production and utilization of fresh cowpea leaves as predictors of availability of the fresh leaves showed that the stage of initiation of harvesting, number of cropping seasons for cultivation of cowpea leaves and prioritization of crops were significant ($p<0.001$, Adjusted R-squared (AR)=0.510) as shown in Table 4.3. Linear regression model showed that whereas the cropping season was a positive predictor (beta=2.5, $p<0.001$) of availability of fresh vegetables, the stage of initiation of harvesting of the vegetables was a negative predictor. Additionally, households that majorly produced pulses were five times more likely to have a lengthier period of availability of fresh cowpea leaves than those that produced majorly cereals.

### 4.3.3 Preservation of cowpea leaves for consumption in producing households

The most practised traditional cowpea leaves processing techniques were sun-drying and combination of blanching and sun-drying by 53.8% and 20.0% of the households, respectively. Spontaneous fermentation and solar-drying were done in minimal levels by 0.7% and 0.5% of the households, respectively, whereas four in every ten households (42.0%) did not practise any form of preservation of the leaves. Both the farmers and the stakeholders interviewed in the study identified low awareness on value-addition practices as major constraints that limited both production and preservation of cowpea leaves in the area. Extension services were viewed majorly as avenues to disseminate agricultural practices rather than value-addition practices.

*"Market is really necessary to encourage utilization of the crop. Seeds should be availed and awareness on value-addition practices be done. The people should be exposed to value-addition practices."*

**Table 4.2: Agronomic and utilization practices of cowpea producing households in arid and semi-arid lands**

| **Agronomic and utilization practices** | | **Coastal ASAL areas** | **Eastern ASAL areas** | **p-value ($\chi^2$,df)** |
|---|---|---|---|---|
| Priority crops | Cereals | 86.30 | 63.50 | <0.001 |
| | Pulses | 12.70 | 18.00 | (56.6,3) |
| | Vegetables | 0.50 | 18.50 | |
| | Root crops | 0.50 | 0.0 | |
| Number of cropping seasons in a year | One | 19.5 | 1.5 | <0.001 |
| | Two | 80.0 | 98.0 | (40.6,2) |
| | Three | 0.5 | 0.5 | |
| Cowpea leaves is a major crop | Yes | 44.4 | 95.5 | <0.001 |
| | No | 55.6 | 4.5 | (125.1, 1) |
| Cowpea varieties cultivated | Landraces | 89.3 | 97.0 | 0.004 |
| | Improved | 10.7 | 3.0 | (9.4,1) |
| Agronomic performance of cowpea leaves to compared other vegetables | Higher yields | 82.2 | 70.9 | <0.001 |
| | Poorer yields | 7.8 | 0.0 | (28.1,3) |
| | More pest and disease resistant | 1.1 | 4.2 | |
| | Only grows cowpea leaves | 8.9 | 24.9 | |
| Produced cowpea leaves for subsistence | Yes | 75.1 | 68.5 | 0.138 |
| | No | 24.9 | 31.5 | (2.1, 1) |
| Produce surplus cowpea leaves | Yes | 38.5 | 50.0 | 0.020 |
| | No | 61.5 | 50.0 | (5.4, 1) |

**Table 4.3: Fitted linear model of agronomic and utilization practices of cowpea leaves on the availability of fresh vegetables**

| Independent variables | | Beta coefficient (β) | Standard error | Odds ratio | p-value |
|---|---|---|---|---|---|
| Intercept | | 3.26 | 1.59 | | 0.042 |
| Cropping seasons* | | 1.99 | 0.66 | | 0.003 |
| Production quantities* | | 0.00 | 0.00 | | 0.467 |
| Initiation of harvesting* | | -1.49 | 0.15 | | 0.000 |
| Priority crop | Yes | 0.07 | 0.70 | 1.07 | 0.922 |
| | No [R] | | | 1.00 | |
| Agronomic performance of cowpea leaves | Produces only cowpea leaves | 0.42 | 0.64 | 1.53 | 0.509 |
| | Gives more yields | -2.66 | 1.74 | 0.07 | 0.126 |
| | Gives poor yields | -0.63 | 1.41 | 0.53 | 0.656 |
| | More resistant to pest and diseases [R] | | | 1.00 | |
| Surplus production of cowpea leaves | Yes | 0.15 | 0.46 | 1.16 | 0.741 |
| | No [R] | | | 1.00 | |
| Subsistent production of cowpea leaves | Yes | 0.57 | 0.47 | 1.77 | 0.229 |
| | No [R] | | | 1.00 | |
| Varieties planted | Landrace | 0.81 | 0.79 | 2.25 | 0.302 |
| | Improved [R] | | | 1.00 | |
| Crops cultivated | Pulses | 1.74 | 0.58 | 5.68 | 0.003 |
| | Tubers and root crops | -4.83 | 3.91 | 0.01 | 0.217 |
| | Vegetables | 0.50 | 0.68 | 1.65 | 0.462 |
| | Cereals [R] | | | 1.00 | |

Adjusted R-squared (AR) = 0.510. [R] The reference category of the categorical variable.

*Continuous variable.

Households from coastal ASALs had significantly higher odds of drying and blanching cowpea leaves (8.3 and 2.6, respectively) compared to those from eastern. Drying of the vegetables was necessitated by the huge production quantities of the vegetables during the rainy season. Utilization of the preserved forms of cowpea leaves is limited to the household subsistence with the local market being the furthest point of marketing for most of those involved in the preservation of cowpea leaves. The dried vegetables are known to enhance availability of the vegetable especially in the off-season when more sales are made. This is another factor that has resulted in less utilization of preserved cowpea leaves. Preference of blanched sun-dried vegetables was because of the quality of the product.

*"Shade drying (shadow drying), combination of sun-drying and blanching and only sun-drying are used in the preservation of cowpea leaves." As it emerged in the FGD.*

*"Sun-drying without blanching produces products that are chewy like the bubble-gum. This drying takes a week in hot sun to be ready. The tender leaves though wouldn't produce the chewy products." said farmer one.*

*"During drought more sales are made. In the area, cowpea leaves are blanched and then sun-dried. Other techniques involve shredding the vegetables and shadow-drying. The cowpea leaves are majorly sold in the area or consumed domestically." a farmer group leader said.*

*"Dehydration techniques increases availability of the vegetable." a farmer said*.

Two thirds (66.92%) of the households that sundried the cowpea leaves preferred to blanch them before drying. Dried vegetables had a mean keeping period of 51.0 ± 4.2 weeks. The period of keeping and utilization of dried vegetables did not significantly ($p>0.05$) differ across the two counties. Drying of the vegetables were majorly done on the mats (77.5%), raised platform

(48.2%), rocks (2.8%) and bare ground (2.3%). The average blanching time for cowpea leaves before drying was found to be 15.8 ± 11.8 minutes. Additionally, the communities have not embraced modern technologies such as solar and oven drying in the preservation of the vegetables. This has been due to lack of appropriate equipment and facilities; thereby the utilization of low-tech and traditional preservation techniques is the most feasible. The farmers opted for some of the less optimal preservation techniques such as drying without blanching when they lack necessary facilities:

*A farmer group leader, "We also use jikos (traditional charcoal cooker) to dry the vegetables for we were trained on its use."* and "*Shadow-drying has challenges too as it requires a large space as intactness leads to spoilage."*

*"When there is severe drought, we don't blanch the vegetables we dry due to lack of water." said another farmer group leader.*

Marketing challenges was shown as a major drawback in the production and preservation of cowpea leaves. The interviewees had not adequately explored the avenues of commercialization of the dried forms of the vegetables due to low uptake from the market. The limited commercialization of the vegetables was as a result of widespread production of cowpea leaves, which made most of the households to source their vegetables from their own farms. Among the farmers that did preservation of cowpea leaves, the domestic market served as the main point of sale

*An extension officer said, "The marketing of the cowpea leaves is not that good in the area. This has been occasioned by the fact that majority of community members all farm cowpea leaves."*

*A farmer said, "I have never tried an external market."*

*"Consumption is largely domestic."* *said another farmer*.

The cost of a 250 ml cup of dried cowpea leaves (USD. 0.13±0.10) was not significantly ($p>0.05$) different from the same quantity of fresh leaves (USD. 0.11±0.09). Of the households that sourced the preserved forms of the vegetables, the points of purchase majorly the kiosks (66.1%), farmer groups (23.5%) and open-air markets (70.4%). Commercialization of the preserved forms of cowpea leaves in the open-air markets increased the odds ($p<0.001$, OR=2.3) of continued utilization of the cowpea leaves sourced from outside the household during scarcity. However, commercialization of preserved cowpea leaves through farmers groups resulted in less likelihood ($p<0.001$, OR=3.26) of consumption of cowpea leaves sourced from outside the households during scarcity. More households showed preference to utilize dried cowpea leaves (36.8%) as compared to the fermented forms (0.7%) even during the in-season. Households that showed such a preference for the fermented cowpea leaves were twice less likely to consume cowpea leaves during scarcity ($p=0.04$, OR=1.81).

#### 4.3.4 Trends in the utilization of preserved cowpea leaves among cowpea producing households

A quarter (28.4%) of the households had either taken part in the selling or purchase of cowpea leaves in drought. During drought three quarters (73.6%) of the households sourced their vegetables from other places or did not consume the vegetables whereas a quarter used the dried vegetables. A quarter of the households (25.0%) did not consume the vegetables at all during scarcity. Individuals who were involved in commercialization of preserved cowpea leaves were twice more likely to consumed dried vegetables in seasons of scarcity than those who were not ($p<0.001$, odds ratio (OR) =2.47). Largely, the traditional processing techniques and products are fading in the area as most of the households opt for other vegetables and foods. Nevertheless, there are still households involved in the preparation of local products made from cowpea leaves.

*"We also consume other vegetables like kales from other areas."* a farmer said.

*"It can also make Kimanga from it. A blend with sweetpotato. Pumpkin and cowpea leaves."* said a farmer group member.

Only a quarter (24.0%) of the households had enough supply of cowpea leaves for consumption during dry seasons. The coastal ASAL areas had significantly ($p<0.001$, $\chi^2=82.1$) higher proportion of the households (42.9%) with sufficient supply of the cowpea leaves than the eastern ASALs. Neither socio-demographic of the producing households nor preservation techniques practised in the ASAL areas were significantly ($p>0.05$) associated the availability of the vegetables during scarcity. In as much as utilization of the vegetables has been hampered by a myriad of challenges, the farmers still prioritize the crop for it is fast-maturing. Value addition and preservation of the vegetables was viewed as one of the possible ways to promote their utilization and commercialization.

*One of the farmers said, "Train other farmers on already existing value addition methods and research on new methods for preservation and value addition."*

Only a quarter (24.0%) of the households had enough supply of cowpea leaves in and off-season for their utilization. A significantly ($p<0.002$, 80.0) higher proportion of households in the coastal ASALs (42.9) than in the drier eastern ASALs (4.5%) had consistent supply of cowpea leaves in and off-season. Data variability (100%) of food processing techniques and sourcing of cowpea leaves associated with consistent supply of cowpea leaves was explained by 10 principal components (Figure 4.4). Utilization of in-stock cowpea leaves among the households had the greatest effect in increasing the consistent availability of cowpea leaves (Figure 4.5). Preservation techniques had larger dissimilarities with the trends of consistent availability of the vegetables. Overreliance on the fresh vegetables rather than the preserved ones is the major contributor to the inconsistency in the supply of the vegetable among several households as noted by stakeholders. Additionally, the farmers also had the belief that with accreditation and certification by the standards body, Kenya Bureau of Standards (KEBS), cowpea leaves value-added products would easily penetrate the market.

*"Awareness can work and the crop can pick up so fast. The crop has good uses. People are used to the fresh ones and not many are aware of the traditional preservation techniques." an extension officer said.*

*"Fear of the KEBS and authorities prevent market entry of most of those who do value-addition." a farmer said.*

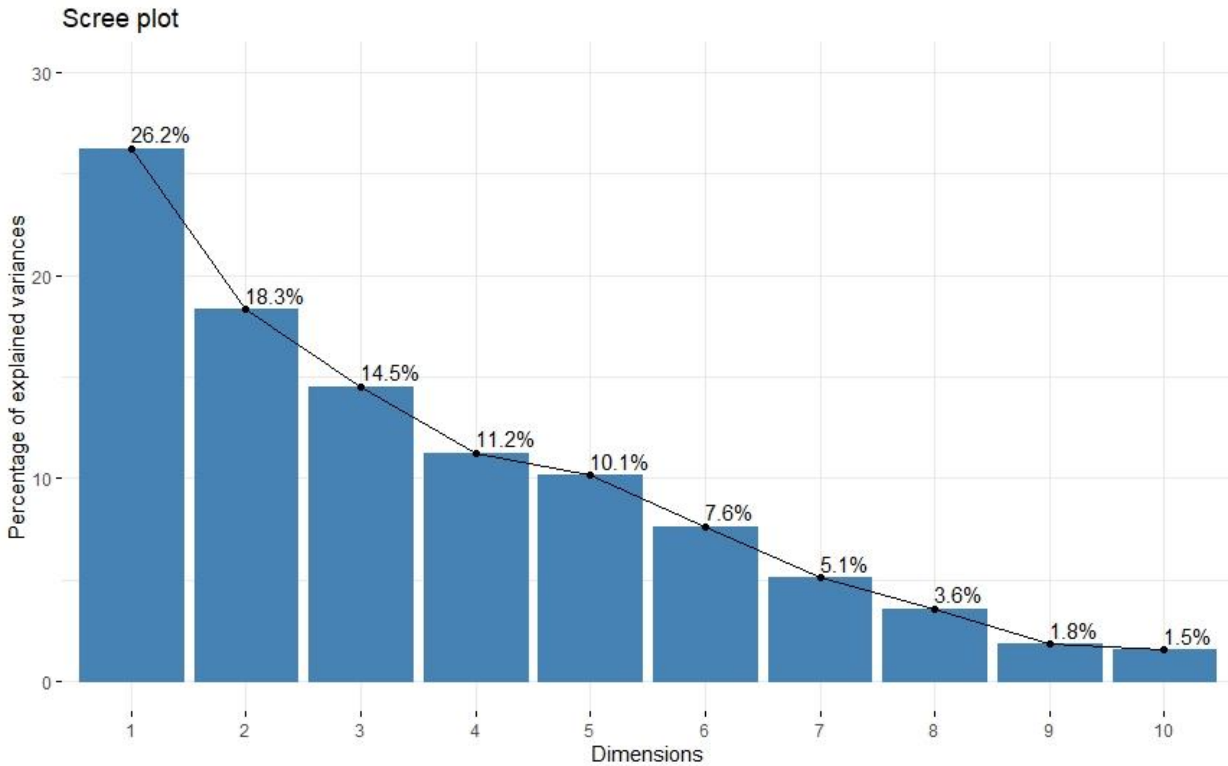


**Figure 4.4: Scree plot of principal components explaining variability in the availability, preservation and sourcing of the cowpea leaves**

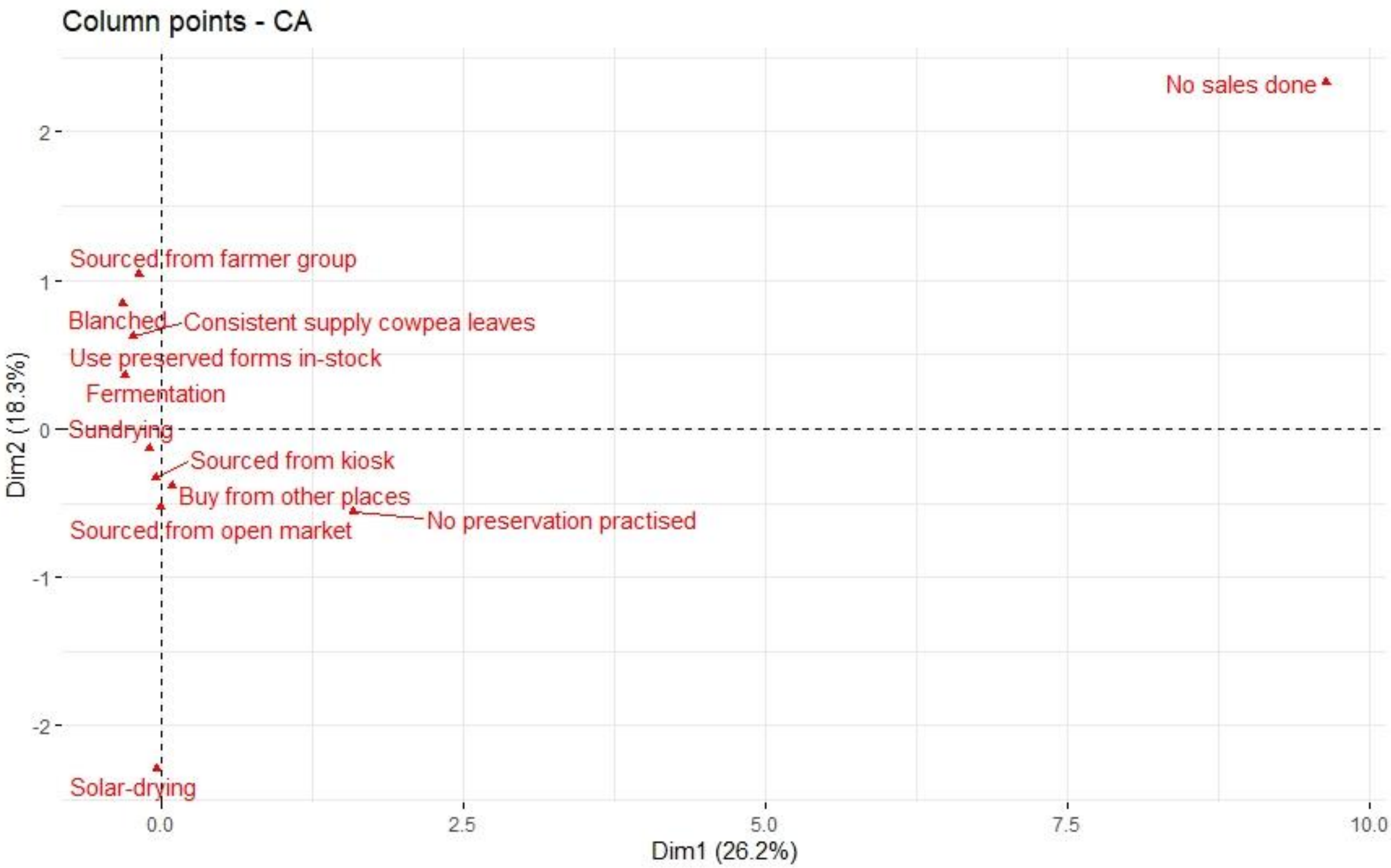


**Figure 4.5: Factor mapping of the trends in the availability, preservation and sourcing of the cowpea leaves**

## 4.4 Discussion

**Trends and constraints in the utilization and availability of fresh cowpea leaves among households**

The study settings were largely a rural area thus the reliance on the farm as the main source of the vegetables for households' consumption. The low dependence of marketing avenues for sourcing of these vegetables point out a prevalent problem that has been identified as a constraint in the promotion of African Leafy Vegetables (ALVs) as food security crops for these food insecurity hotspots (Krause et al., 2019). Notably, with increasing aridity the reliance on sourcing from farms than other sources increased, the drier ASAL areas of eastern ASALs tended to use cowpea leaves from their farms more as compared to those from coastal ASALs. This increasing preference of the subsistent cowpea leaves could be explained by its drought tolerance property (Noubissié, 2011); for in the drier areas there is less diversity of crops that are planted thus the more dominance of cowpea leaves as a farm produce (Owade et al., 2020b). Limited diversification in the dietary incorporation of cowpea leaves was reported in the study areas.

The preference of cereals as major crops over vegetables is corroborated by the across utilization of crops such as maize as the staples (Fujisao et al., 2020). The skewed prioritization of the cereals over the legumes such as cowpeas has partly been adduced to limited commercialization and policy focus as reported in this study. In order to increase their intake of vegetables, the households initiated consumption of the vegetables as early as two weeks after emergence which has the advantage of improving the yield of cowpea leaves harvested but the demerit of reduced yields of grains (Saidi et al., 2010). This was replicated in the frequency of cultivation and production quantities of the crop with those in drier areas having higher frequency and producing more.

The existing higher proportion of households utilizing the landraces over the improved varieties can explained by the findings by Njonjo (2019) whereby three quarters of the households were found to rely on farm-saved seeds for the further production of cowpea leaves in the eastern and coastal ASALs. Additionally, 80% of these households preferred the informal seed supply chains to the formal ones. The choice of these landraces has the implication of missing out on some of the advantages of the improved varieties such as early maturity. Averagely, households in the ASAL areas had harvested fresh cowpea leaves available for subsistent consumption for four weeks with findings that late initiation limits vegetable availability for the households will have limited time of harvesting the leaves as termination of harvesting is done upon flowering of the crop (Saidi et al., 2010). This stage of termination has been reported to be 7-9 weeks after emergence depending on the variety (Matikiti et al., 2009; Saidi et al., 2010). These households utilize the crop both for the grains and leaves, thereby the advent of flowering implies readiness of the crop to yield grains, thus most of the households leave them to obtain the second produce (Owade et al., 2019). Consumption of these leaves also favour the tender leaves with the most mature ones being too chewy and less tasty (Pottorff et al., 2012), thereby the households tend to cease the harvesting.

### 4.4.1 Preservation of cowpea leaves for consumption in producing households

The costs of the dried and the fresh cowpea leaves were found to be the same. This has the implication that preservation of cowpea leaves had no economic advantage in terms of commercialization. Okello et al. (2015) in their marketing study reported that consumers attached no greater economic value to traditionally preserved cowpea leaves. However, the present study also established that the open-air markets are the most efficient points for the sale of cowpea leaves. This therefore presents an opportunity to be explored in the commercialization of the traditional and other value-added products of cowpea leaves; accessibility of the crop in the off-season can be improved selling the produce through the open-air markets. However, the limitation of this based on the current study is that only a quarter (28.3%) of the households are involved in the commercialization of preserved cowpea leaves.

The study found that dehydration was a major technique of preservation of cowpea leaves utilized among the households in the ASALs. The technique is so feasible and economical thus the greater preference among the households (Owade et al., 2019). The incorporation of the positive technique of blanching before drying improves quality retention of the vegetables (Natabirwa et al., 2016). In another study, Nobosse et al. (2017) point out the advantage of blanching in improving the antioxidant activity in the preserved vegetables. On the other hand, Kirakou et al. (2017) reported that the technique can also lower  the retention of some of the nutrients including iron, beta carotene and vitamin C. Contrary to the scientific recommendations by Oulai et al.  (2015) and Aathira et al. (2017), the prolonged blanching time as found in the study aggravate nutrient losses.

Limited use of value added products in drier ASAL areas left these communities are exposed to severe shortages of the vegetables during the dry season; for at such a time it has been reported that in as much as the prices would still remain the same, the quantity of leaves sold in a unit measure reduces (Okello et al., 2015). The findings in the current study showed than the drier ASAL areas had the lowest availability of the vegetables during dry seasons. In order to bridge the gaps in availability, households source other vegetables which are expensive in nature (Okello et al., 2015). The limited value addition practices among farmers is explained by Danso-Abbeam et al. (2018)  that reported limited efficiency of agriculture extension system of transferring value-addition technology. Another study by Oluwasusi and Akanni (2014) among food crop farmers in Nigeria ranked extension services as the least important medium in transfer of value-addition technology. This component thus needs to be strengthened in extension services to fully realize efficient dissemination of the preservation technologies in the ASAL areas.

### 4.4.2 Trends in the availability and utilization of preserved cowpea leaves among cowpea producing households

The limited diversification of value-added products has been corroborated by the qualitative survey to be resulting from the slowly eroding traditional practices of utilization of the vegetable. Modern techniques of preservation are usually recommended to present the much desired product diversification which is favoured by the consumers (Dandsena and Banik, 2016); however they require necessary equipment to effect. The limitation of the widely practiced sun-drying technique of preservation is the aesthetic quality for it induces browning in the leaves (Nyambaka and Ryley, 2004; Okello et al., 2015). The overreliance on the informal marketing channels was found to contribute to poor commercialization and less exploration of product diversification of this vegetable (Lekunze, 2014).

Going forward, the farmers and other stakeholders in the area viewed the crop as of great importance. In order to increase the utilization and availability of the vegetable, the stakeholders were of the view that diversification of value-addition rather than the traditional preservation techniques would be a great avenue. This shows that there is less conviction among the locals of the sufficiency of traditional preservation in promoting availability of the vegetable across all seasons and underscore the need for dissemination of more techniques. Scientific studies have established that the physical attributes including colour of most traditionally preserved cowpea leaves deteriorate faster in storage than the optimally preserved forms (Natabirwa et al., 2016). This study found that the browning index of the leaves increases with storage in sundried vegetables, thus this explains the preference by the locals for better techniques that would yield better quality products. Greater willingness among the stakeholders to try out new techniques was shown. In order to assure greater vegetable availability, it is therefore essential for a shift to the reliance of the preserved forms from the fresh forms, whose availability is greatly limited due to the harsh environmental conditions in these areas.

## 4.5 Conclusion

The study established that majority of the households utilize the fresh and preserved forms of cowpea leaves; however, in the off-season scarcity of the vegetable affected three quarter of the households in ASAL areas. Furthermore, stocking of the preserved forms had the greatest contribution in ensuring consistent supply of the vegetables in and out of season thus ensuring food security of these households, but the diversification of preserved cowpea leaves products was still limited. There are opportunities that can be explored to promote utilization and consumption of cowpea leaves; however, this has to be done without restricting the focus to the traditionally preserved forms but rather incorporating the modern optimal preservation techniques. With the demonstrated potential to enhance vegetable supply to households in the food insecurity hotspots of the ASAL areas, preservation of cowpea leaves presents the most feasible way of addressing food and nutrition security in cowpea growing areas and enhance availability of vegetables. Optimization of these preservation techniques would serve to enhance the quality concerns raised among the consumers of these preserved forms. Currently, less attention has been granted to the crop; however, the generated evidence in this study can help reshape the strategy of prioritization of value-chains especially in the ASAL areas of sub-Saharan Africa where the crop does thrive.

# CHAPTER FIVE: COMPARATIVE PROFILING OF LACTIC ACID BACTERIA ISOLATES IN OPTIMIZED AND SPONTANEOUS FERMENTATION OF COWPEA LEAVES: A PROCESS OPTIMIZATION APPROACH


## Abstract

In as much as spontaneous fermentation of cowpea leaves enhances product diversification, the process is rather slow with poor product quality. Limited work has been undertaken to provide input towards standardization of the process and enhancing of product quality. The current study sought to evaluate the effect of optimization of fermentation parameters on the lactic acid bacteria (LAB) profile of fermented cowpea leaves. The study utilized biochemical tests to characterize LAB isolates in both spontaneous and optimized fermentation, whereby optimization was done using the Response Surface Methodology model of the central composite design in the Design Expert Software. The RSM models accounted for 89% and 60% variability in the response variables of pH and titratable acidity, respectively ($p<0.001$). Increasing the sugar concentration and period of fermentation significantly ($p<0.05$) increased the titratable acidity, while reducing the pH. The optimal fermentation parameters were established as sugar and salt concentrations of 5% and 2%, respectively, 16 days of fermentation, pH of 3.8 and titratable acidity of 1.22 with a desirability of 0.859. Validation of the response variables yielded pH of $3.75 \pm 0.07$ and titratable acidity of $1.22 \pm 0.01\%$ for the optimally fermented product. Thirteen different LAB isolates were identified from the biochemical characterization of the fermentative bacteria. Whereas the onset stage of spontaneously fermentation was dominated by *Lactobacillus brevis* and *Lactococcus lactis*, that of optimized fermentation was dominated by only *Lactobacillus brevis.* Additionally, the final stage with the dominant isolates of *L. plantarum* was longer in the spontaneous fermentation process than in the optimized process. Evidently, optimizing the fermentation process

resulted in increasing dominance by heterofermenters in the production of soured cowpea leaves, with the yielded product having enhanced acidity, thus to be explored as a pretreatment for preservation of the vegetables.

## 5.1 Introduction

Vegetable fermentation is an ancient practice that has over time gained importance in product diversification (Melini et al., 2019). The practice of vegetable fermentation was passed from generation to generation in the old times without full knowledge of the involved fermentative bacteria and the induced health promoting properties. Often, vegetables that were most abundant within the communities had such processing techniques employed in an effort to diversify their utilization. Recent developments in vegetable fermentation have promoted process optimization to the point of developing starter cultures from the most abundant lactic acid bacteria (LAB) isolates (Touret et al., 2018). This has aided technology transfer and commercialization of good quality products from the vegetables. Fermented vegetable products such as *Kimchi* and *sauerkraut* have been incorporated into diets and recipes of many countries through this (Özer and Kalkan-Yıldırım, 2019). In improving keeping quality of the vegetables, the fermentation process often inhibits the growth of pathogenic and spoilage microorganisms (Khanna, 2019; T. Xiong et al., 2016). Through the hurdle technology, fermented vegetables subjected to drying can keep for three months; bridging the gap of seasonal availability of the vegetables (Muchoki et al., 2010). Moreover, the sensory quality which has often been a limiting factor in the continued utilization of especially the value added African leafy vegetables (ALVs) is improved (Ayed et al., 2020; Owade et al., 2020a).

In effort to address food and nutrition insecurity in the arid and semi-arid lands (ASALs) of sub-Saharan Africa (SSA), drought resilient crops such as cowpea (*Vigna unguiculata*) leaves have been promoted for utilization (Owade et al., 2020b). The cowpea vegetable is a rich source of micronutrients including iron, beta-carotene, calcium and zinc and antioxidants (Owade et al., 2020a; Sombié et al., 2018). Limited value addition practices on the vegetable has often been identified as one of the contributing factors to its seasonal availability (Owade et al., 2020b); militating against the extended utilization and promotion of food and nutrition security among these vulnerable communities. On top of the recommendation of the incorporation of cowpea leaves fermentation for product diversification among the communities, the practice also improves the nutrition quality of the consumed cowpea leaves by improving the bioavailability of the micronutrients (Owade et al., 2020a). In their study Muchoki et al. (2010) reported a reduction of up to 57.7% in the antinutrient content of the vegetable including phenols, nitrates and oxalates. Additionally, Kasangi et al. (2010) established that fermented dried cowpea leaves still had a composition of above 500 mg/100 g of beta carotene after three months of storage; less than half deterioration over the course of storage.

Fermentation of cowpea leaves has often been spontaneous, however, the limitation of this is the variability of the generated product and slowness of the process (Owade et al., 2020a). Moreover, the key attribute in promoting consumer acceptance, sensory quality, in the product often tends to vary when such less optimized techniques are utilized in cowpea leaves fermentation. Since vegetables have been found to be low in fermentable sugars, Kasangi et al. (2010) recommended the addition of sugar at the levels of 1-3%. In another study, while attempting to optimize the fermentation process of cowpea leaves, Muchoki (2007) similarly employed the one-factor method in optimizing the sugar and salt concentrations; however the limitation of the two studies was that they overlooked the interaction of the fermentation parameters being optimized. The proof of this is established through the higher pH and lower titratable acidity values recorded in the two studies compared to values reported in comparative studies on other fermented vegetables, 0.7-1.54% for titratable acidity and a pH of 3.74-4.17 (Vatansever et al., 2017). Additionally, the need for optimization of salt concentration, which is of vital importance in controlling the growth of pathogenic and spoilage microorganisms like coliforms and yeast and moulds during fermentation, results from the global move to control the immoderate use of salt as an ingredient in such processes (Khanna, 2019). The contribution of this study is to improve the low-cost fermentation process of cowpea leaves existent in communities; while providing a case for commercialization of such products. The work also forms the original basis to inform any possible food standards that would be developed for fermented cowpea leaves and other ALVs at large. Therefore, the study explored to characterize the microbial profile of the fermentative bacteria involved in the fermentation of cowpea leaves.

## 5.2 Materials and methods

### 5.2.1 Sample preparation

Cowpeas leaves were harvested at eight WEA which was the optimal stage of maturity as established by Owade et. al. (unpublished data). The vegetables were grown at the Field Station of the College of Agriculture and Veterinary Science, University of Nairobi during the short rain period, October to December, 2019. The field is located West of Nairobi County along the latitudes 1˚ 15´ S, the longitudes 36˚ 44´E and an altitude of 1820 m above sea level (Kirakou, 2014). The area has an annual rainfall of 1060 mm and temperature range of temperature ranges from 13.7 and 24°C. The. The soils of the area are deep well-drained, dark reddish brown to dark brown (Kirakou, 2014). The harvested leaves were destalked to obtain the edible portion, washed and shredded. The residual water from the washing was not drained for further use in the fermentation process.

### 5.2.2 Optimization of the fermentation process

Experimental runs were generated through the Response Surface Methodology (RSM) models of the Central Composite Design (CCD) of the Design Expert 11 software (StatEase, 2020); the illustrative formula is as shown in equation 5.1 (Behera et al., 2018). Three different fermentative factors were evaluated for optimization and they included concentrations of sugar and salt and the period of fermentation. The minimum and maximum entries of the factors were as used in similar studies by Muchoki (2007) and Kasangi et al. (2010), Table 5.1. Six centre points and twenty experimental runs were generated in the study. Low-cost fermentation was done for all the twenty experimental runs with the evaluation of response variables, pH and titratable acidy. Fermentation was done anaerobically with the vegetables submerged in the water with generated ratios of salt and sugar dissolved. Sampling of the fermentative solution for physico-chemical evaluation was done as determined by the generated RSM ratios.

$$N = 2^n + 2n + n_c, \qquad \textbf{Equation 5.1}$$

Where $N$ is the number of experimental runs, $n$ is the number of factors and $n_c$ is the number of central points generated.

**Table 5.1: The minimum and maximum levels of factors in the central composite design**

| **Factor** | **Units** | **Minimum** | **Maximum** | **-α** | **+ α** |
|---|---|---|---|---|---|
| Concentration of salt | % | 1 | 5 | 0.977311 | 6.02269 |
| Concentration of sugar | % | 1 | 5 | 0.977311 | 6.02269 |
| Period of fermentation | Days | 1 | 21 | -4.11345 | 21.1134 |

### 5.2.3 Determination of optimal fermentation parameters

The multivariate design of experiment used in the study had pH and titratable acidity as response variables. The design of the experiment was set up as shown in Equation 5.2 (Behera et al., 2018).

$$y = f(x_1, x_2, x_3)$$ **Equation 5.2**

Where $y$ is the response variable, in this case either pH or titratable acidity, whereas $x_{(1\text{-}3)}$ are the independent variables concentrations of sugar and salt and period of fermentation.

The assumption of the design that both independent and response variables must be continuous was adhered to in the study. Randomization of the experimental variables was assumed to be achieved through the generated experimental runs. The predictor model for the response variables was generated using the second-degree polynomial equation with the consideration of the full quadratic model coefficients and interaction factors as shown in Equation 5.3 (Arslan and Kara, 2017; Yabalak et al., 2019).

$$y = a + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1 x_2 + \beta_5 x_1 x_3 + \beta_6 x_2 x_3 + \beta_7 {x_1}^2 + \beta_8 {x_2}^2 + \beta_9 {x_3}^2 + \varepsilon$$

**Equation 5.3**

Where $y$ is the response variable; $a$ is the constant coefficient; $x_1$, $x_2$ and $x_3$ are fermentation parameters to be optimized; $\beta_1$, $\beta_2$ and $\beta_3$ are linear coefficients; $\beta_4$, $\beta_5$and $\beta_6$ are coefficients of interaction factors; and $\beta_7$, $\beta_8$ and are $\beta_9$ are coefficients of quadratic factors; and $\varepsilon$ is the residual error.

### 5.2.4 Validation of optimal factors

Vegetables harvested at eight WAE, destalked, shredded and washed were subjected to fermentation using the established optimal fermentation parameters. The pH and titratable acidity were evaluated based on the optimized fermentation period.

### 5.2.5 Culturing of LAB

Optimized and spontaneous fermentation of cowpea leaves, each in duplicates, was done for vegetables harvested at 8 WAE. The vegetables were prepared as explained in the optimization process. The fermentative solution of the vegetables was sampled after every two days till the attainment of the optimal fermentation period. LAB cultures were plated on MRS (de Man, Rogosa, and Sharpe)-agar plates as per ISO 15214:1998 method (ISO, 1998a). Serial dilutions were prepared from the fermentative solution and plated on MRS agar. The inoculated plates were incubated anaerobically (in anaerobic jars) at 30$^{o}$C for 72 hours.

### 5.2.6 Isolation of LAB cultures from optimally fermented leaves

Acid producing colonies indicated by a clear zone around each of them were purified twice by replating in MRS agar plates with further incubation at 30$^{o}$C for 72 hours each time. Only plates that numbered between 30 and 300 isolates were replated for the colonies were distinctively identified. Upon purification, the colonies were reselected and evaluated for catalase test and gram staining. Catalase-negative and gram-positive colonies were inoculated in stock solutions of 10% skim milk broth (w/v) and 20% glycerol (v/v). The stock solution was stored at -20$^{o}$C for biochemical characterization within a period of two months.

### 5.2.7 Carbohydrate fermentation tests

A total of 267 microbial isolates (121 and 146 from optimized and spontaneous processes, respectively) were subjected to carbohydrate fermentation tests using the API 50 CHL strip for anaerobes for identification of the Lactic acid bacteria following the manufacturer's instructions (BioMerieux, Lyon, France). The inoculation was done under aseptic conditions and the sugars incubated for 48 hours and recorded as either positive or negative. Trends of biochemical traits were drawn and the data matched with the API 50 CHL database in the catalogue by BioMerieux (2011).

### 5.2.8 Determination of pH and titratable acidity

The experimental runs and end products of spontaneous and optimally fermented cowpea leaves were tested for pH and titratable acidity. The titratable acidity was determined as per the International Organization for Standardization (ISO) method 750:1998 (ISO, 1998b). The fermentative solution of the sample was diluted ten times, 90ml of distilled water was added to 10ml of the fermentative solution, and boiled to release carbon dioxide. Phenolphthalein indicator was added to the diluted solution and titration done using 0.1N sodium hydroxide solution. Titratable acidity was expressed in g of lactic acid per 100g. The readings were determined in duplicate and the average recorded.

pH of the fermentative solution was determined as per the AOAC method number 981.12 (AOAC, 2005). The pH was determined using Ohaus model number ST2100, Ohaus Corporation USA. The pH meter was first calibrated with pH buffers of 4, 7 and 10. The fermentative solution was diluted 10 times with distilled water and the pH readings determined in duplicates and the average recorded.

### 5.2.9 Statistical analysis

The data for optimization of the fermentation parameters were analysed using the analysis of variance (ANOVA) for quadratic models of the RSM models in the Design Expert version 11 software (StatEase, 2020). The statistical significance of the response model generated was tested using the F-test in the same program. Effect of the independent factors on the response variables were generated using contour plots and 3-D graphical display. The accuracy of the polynomial model that was generated was determined by the coefficient of $R^2$. Statistical significance was tested at $p<0.05$.

The data for the biochemical tests for the fermentative bacteria was analysed using the R language for programming (R Core Team, 2019). The positive values were recorded as 1 and the negative as 0. Principal Coordinate Analysis (PCoA) of the biochemical traits was conducted to establish linkages and dissimilarities of the LAB isolates. The data was first standardized to normal distribution. Manhattan distance was used to achieve a better spread on the two dimensions. Dominance of the LAB cultures based on proportions and period of fermentation was generated over time.

## 5.3 Results

### 5.3.1 Response surface methodology model for optimization of cowpea leaves fermentation

The adequacy of the distribution of the data to generate the predicted model was established by determining the normality; the data was found to have a satisfactory normality for the observed points clustered around the diagonal line (Figures 5.1 and 5.2).

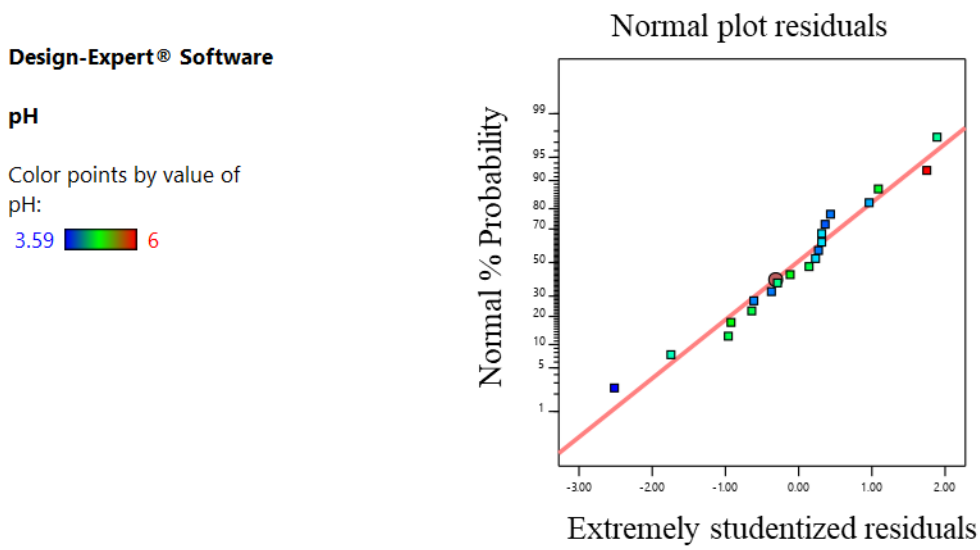


**Figure 5.1: Studentized residuals and percent normality probability for pH**

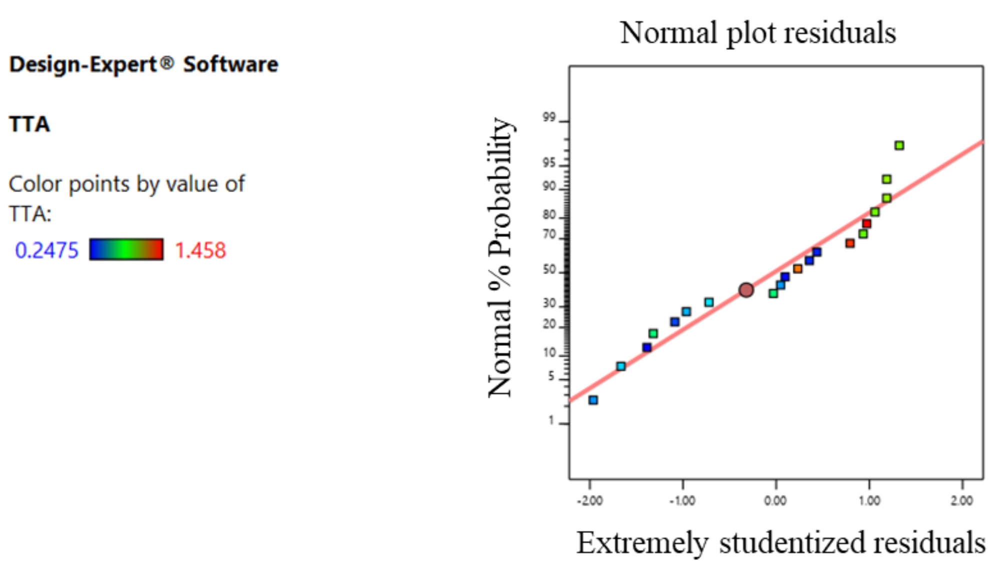


**Figure 5.2: Studentized residuals and percent normality probability for titratable acidity**

The actual and the predicted values for the pH and titratable acidity were as shown in Figure 5.3 and 5.4; the excellent distribution of the experimental points along the line of best of fit shows a good relationship between predicted and actual values. The predictive models for pH and titratable acidity were found to be significant ($p<0.01$) with $R^2$ of 0.885 and 0.60, respectively. The Model fitting the pH as a response variable had an F-value of 8.56 implying that it only had a 0.12% for occurrence of residual error (noise). On the other hand, the model fitting titratable acidity had an F-value of 7.98 with a chance of 0.18% of noise interfering with the model. The lack of fit of the predictive models of the pH and titratable acidity were not statistically significant ($p>0.05$); the lack of fit of the two models occurring due to residual error was 72.7% and 45.7%, respectively. The coefficient estimates of the factors in the polynomial model were as shown in Table 5.2.

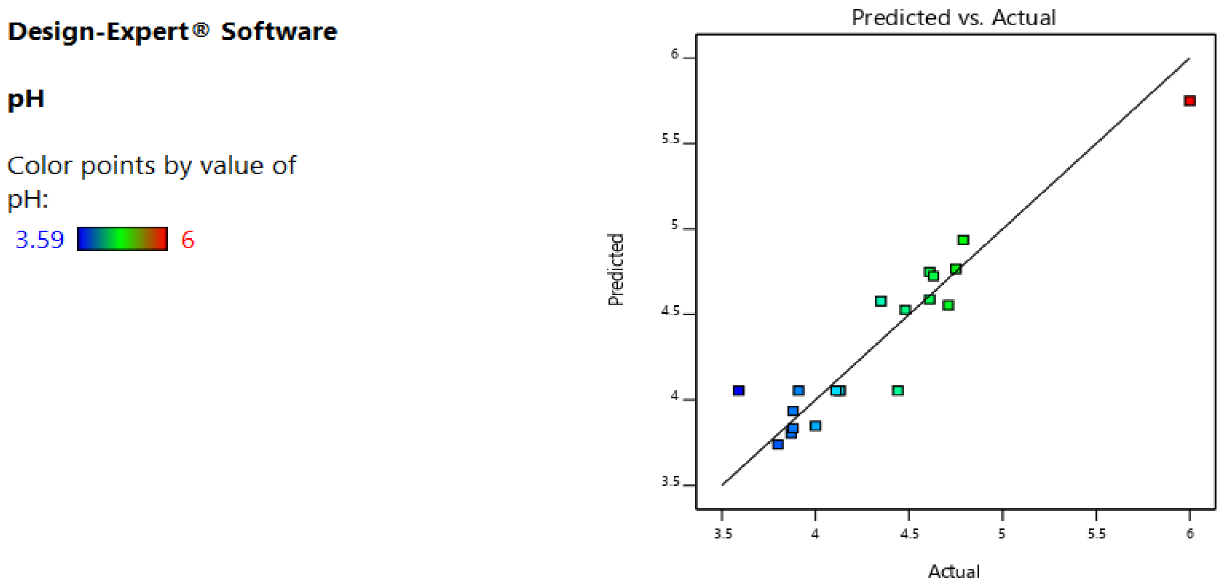


**Figure 5.3: Actual and predicted values of pH of the fermented cowpea leaves**

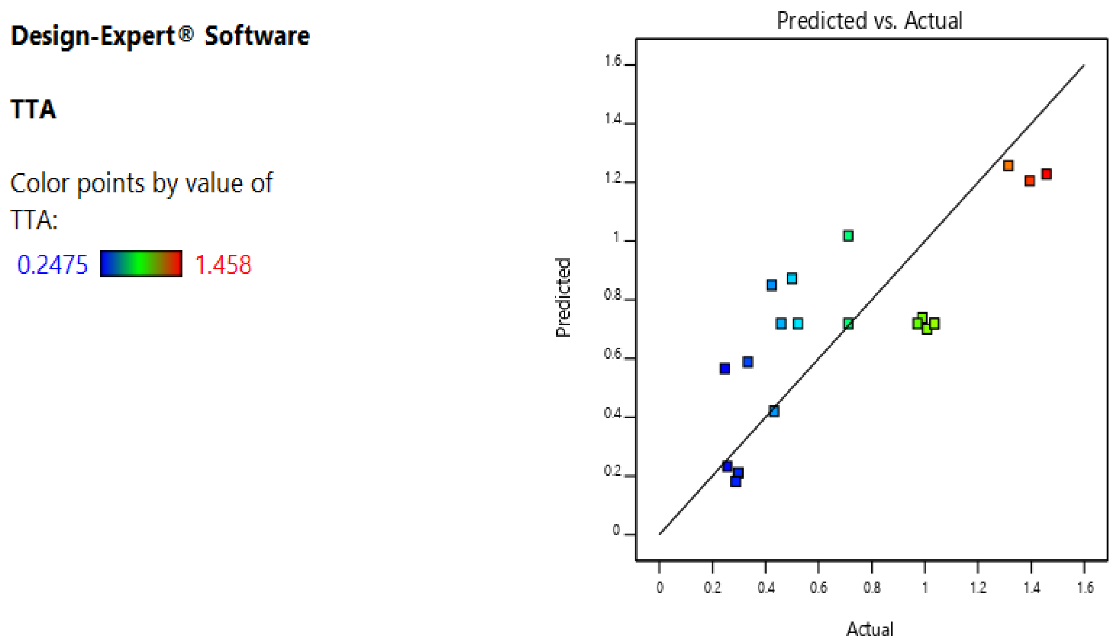


**Figure 5.4: Actual and predicted values of titratable acidity of the fermented cowpea leaves**

**Table 5.2: Coefficient estimates of coded factors for pH and titratable acidity response variables**

| Factor | pH | Titratable acidity |
|---|---|---|
| Intercept | 4.0500** | 0.7193** |
| A-Salt concentration | 0.0282 | -0.0113 |
| B-Sugar concentration | -0.2019** | 0.1777* |
| C-Period of fermentation | -0.2420** | 0.3198*** |
| AB | 0.0412 | Na |
| AC | -0.0038 | Na |
| BC | -0.1488 | Na |
| $A^2$ | -0.0943 | Na |
| $B^2$ | 0.0471 | Na |
| $C^2$ | 0.4555*** | Na |

*Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$. na-the constants were not generated.

### 5.3.2 Effect of concentration of sugar and salts and period of fermentation on pH and titratable acidity

The individual factors of period of fermentation and sugar significantly ($p<0.05$) affected both pH and titratable acidity as shown in Figures 5.5 and 5.6. Increasing the sugar concentration significantly ($p<0.05$) increased both the pH and titratable acidity. Increasing salt concentration influenced the change in the pH, whereas there was no significant change in the titratable acidity. There was no interaction between the factors to influence titratable acidity. On the other hand, the three factors had interactions to influence the pH of the fermented cowpea leaves as shown in Figure 5.7 and 5.8. The optimal points for fermentation parameters were determined as salt concentration of 2%, sugar concentration of 5% and a period of fermentation of 16 days. The optimal response parameters were found to be a pH of 3.8 and titratable acidity of 1.23%; the desirability of the solution generated was 0.859 (Figure 5.9). The validation of the response variables of the optimally fermented cowpea leaves yielded pH of $3.75 \pm 0.07$ and titratable acidity of $1.22 \pm 0.01$%.

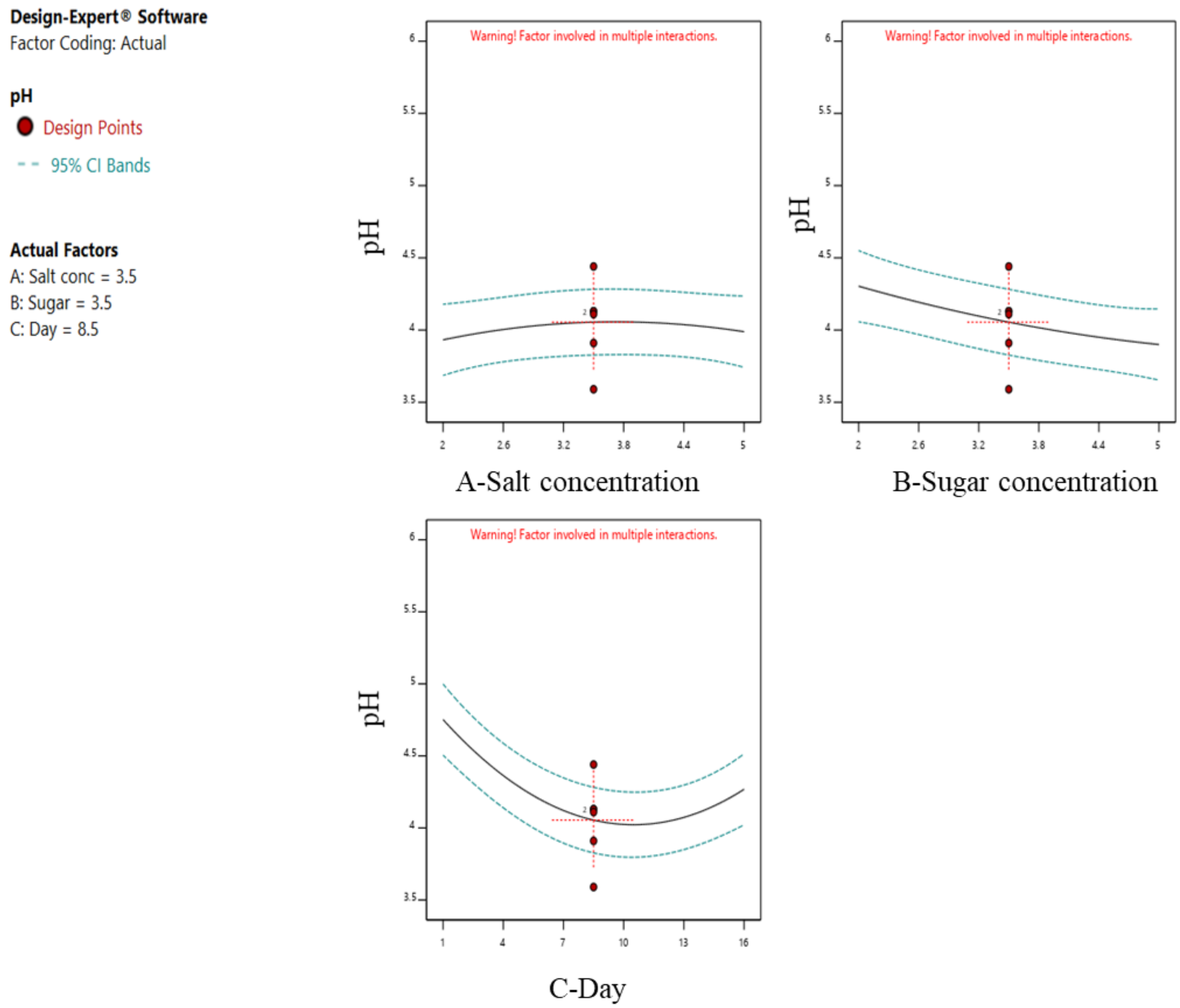


**Figure 5.5: Effect of individual factors of concentrations of sugar and salt and period of fermentation on pH of fermented cowpea leaves.**

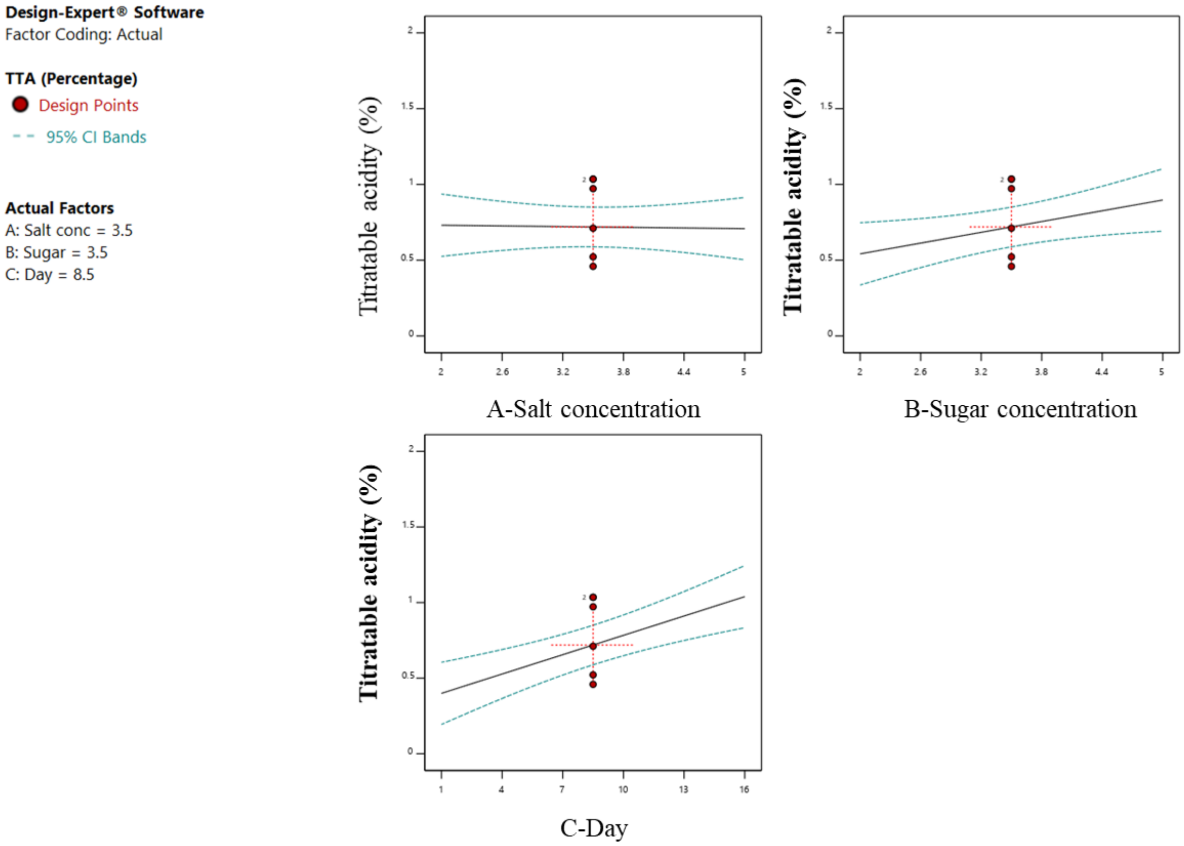


**Figure 5.6: Effect of individual factors of concentrations of sugar and salt and period of fermentation on titratable acidity fermented cowpea leaves.**

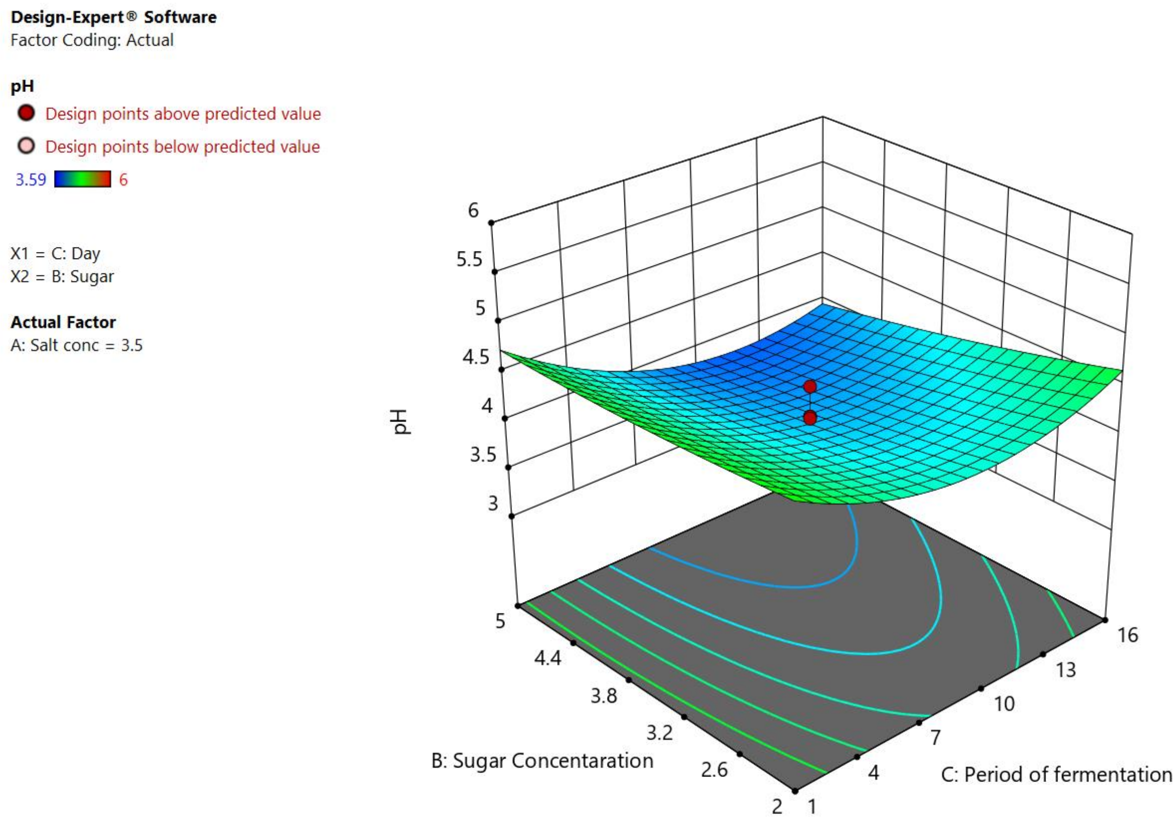


**Figure 5.7: Three-dimensional response surface plots showing the interactive effect of the concentrations of sugar and period of fermentation at 3.5% salt concentration**

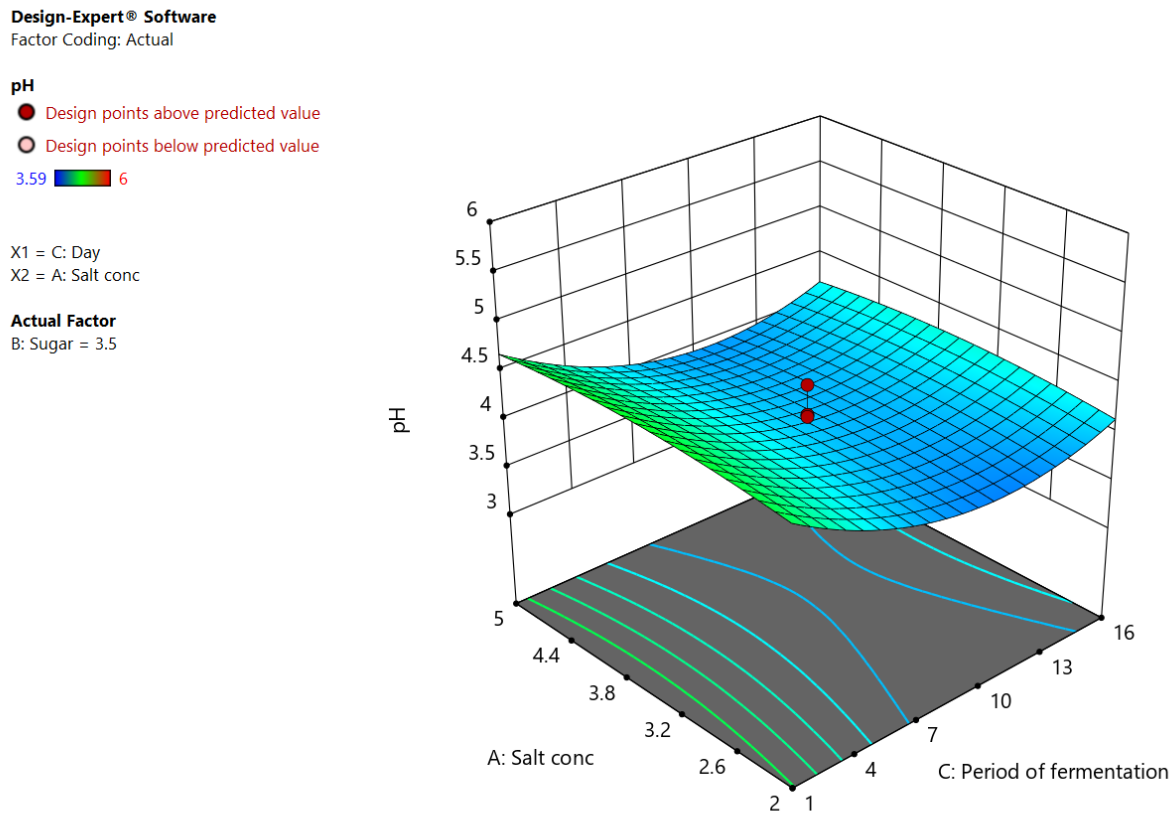


**Figure 5.8: Three-dimensional response surface plots showing the interactive effect of the concentrations of salt and period of fermentation at 3.5% sugar concentration**

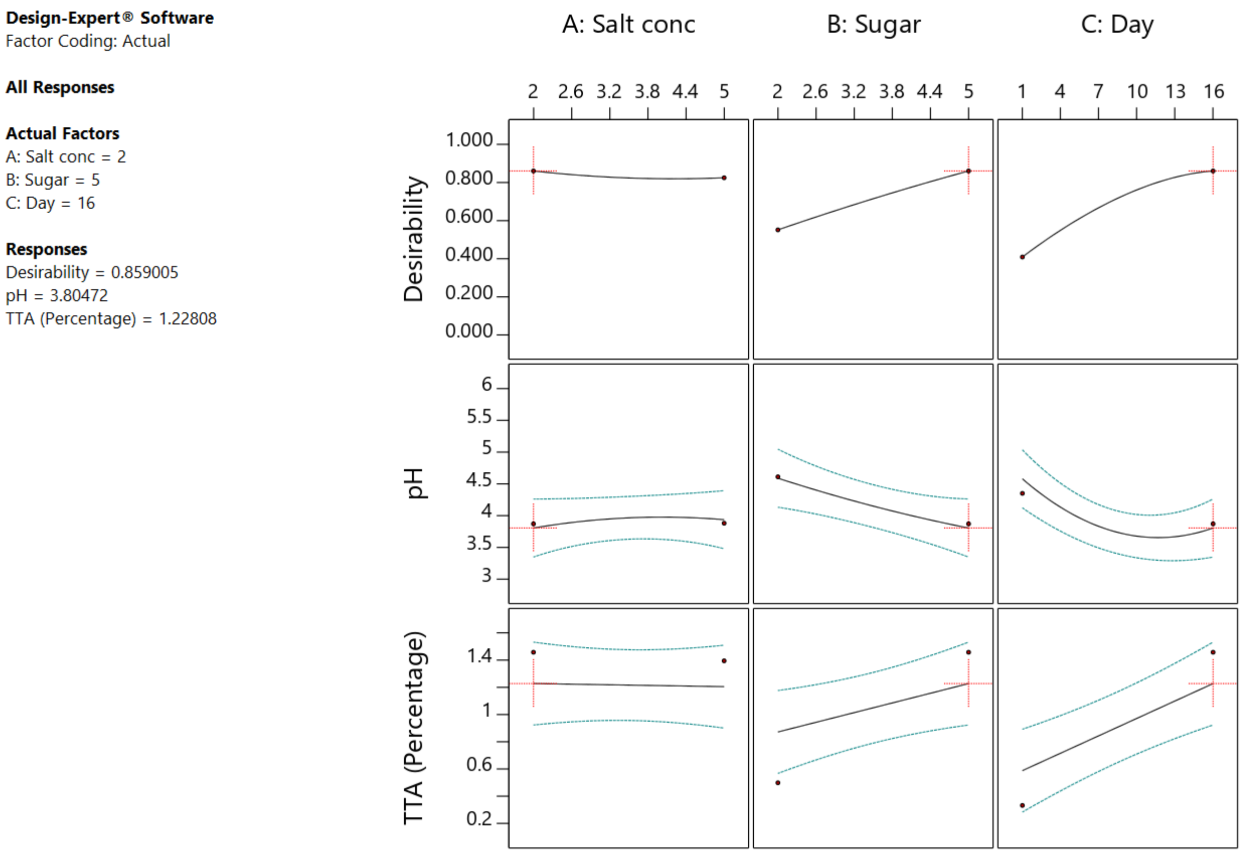


**Figure 5.9: Optimized fermentation parameters for production of soured cowpea leaves**

### 5.3.3 Characterization of LAB isolates in the fermentation of cowpea leaves

The optimally fermented cowpea leaves had a significantly ($p<0.05$) lower pH of 3.8 ± 0.11 and significantly ($p<0.05$) higher titratable acidity of 1.22 ± 0.33 % lactic acid than that of spontaneously fermented leaves, pH and titratable acidity 4.0 ± 0.1 and 0.99 ± 0.07% lactic acid, respectively. The first two principal coordinates explained 57.4% variation in the biochemical traits of the microbial isolates (Figure 5.10). Thirteen different clusters of LAB isolates were formed based on their biochemical characterization that was reduced to thirteen definitive variable traits (Figure 5.11). Thirteen different LAB cultures were identified with the dominant ones being genus *Leuconostoc* (74), *Lactobacillus plantarum* (64), *Lactobacillus brevis* (42) and *Lactobacillus pentosus* (34) as shown in Appendix 2. Fermentation in both spontaneous and optimized processes was divided into three distinct stages based on microbial dominance; initial stage, intermediate stage and final stage. In the initial stage of spontaneous fermentation, the dominant species were *L. brevis* and *L. lactis*, whereas only *L. brevis* dominated the initial stage of the optimized process (Figure 5.12 and 5.13). The genus *Leuconostoc* and species *L. plantarum* were the dominant LAB in both spontaneous and optimized processes at the intermediate and final stages, respectively.

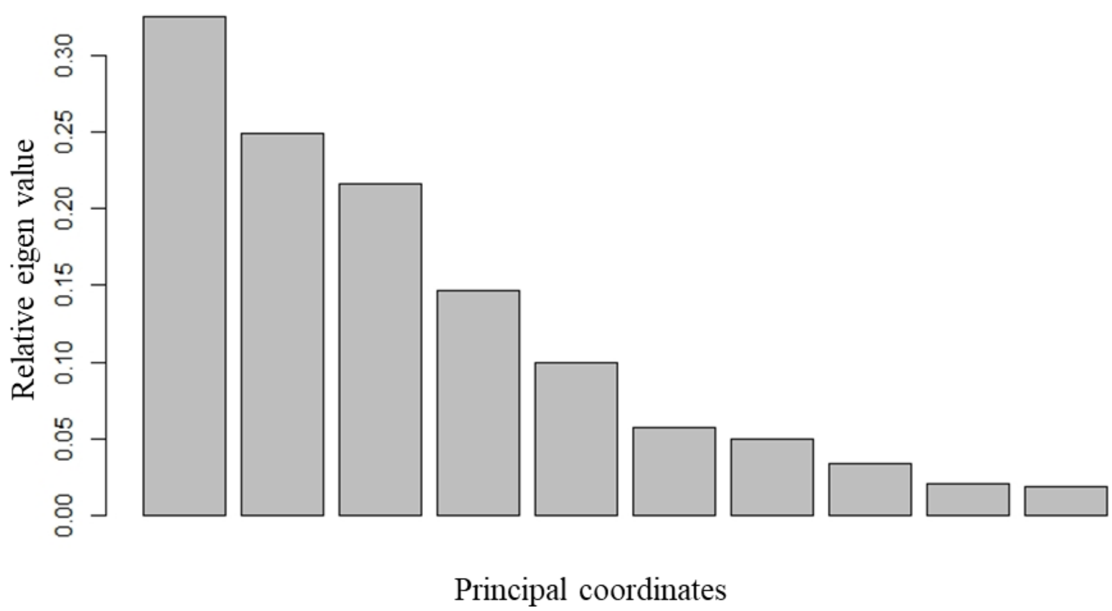


**Figure 5.10: Relative eigen values explaining variation in the biochemical traits of lactic acid bacteria isolates from fermentation of cowpea leaves**

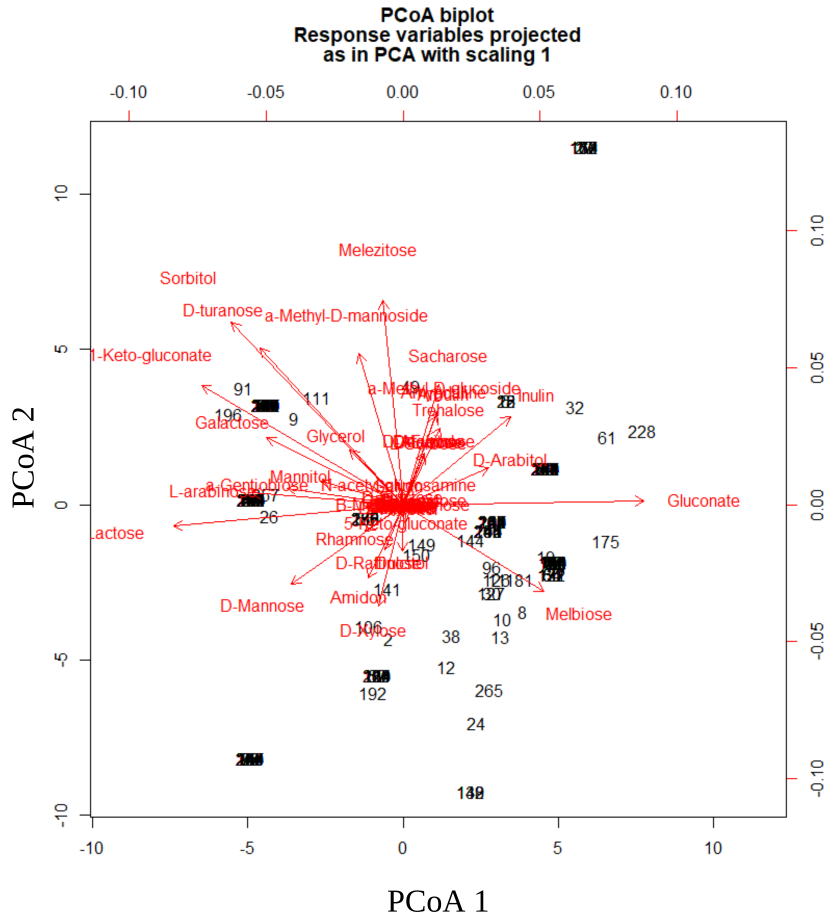


**Figure 5.11: Principal coordinate analysis of biochemical traits of Lactic acid bacteria isolates from spontaneous fermentation of cowpea leaves**

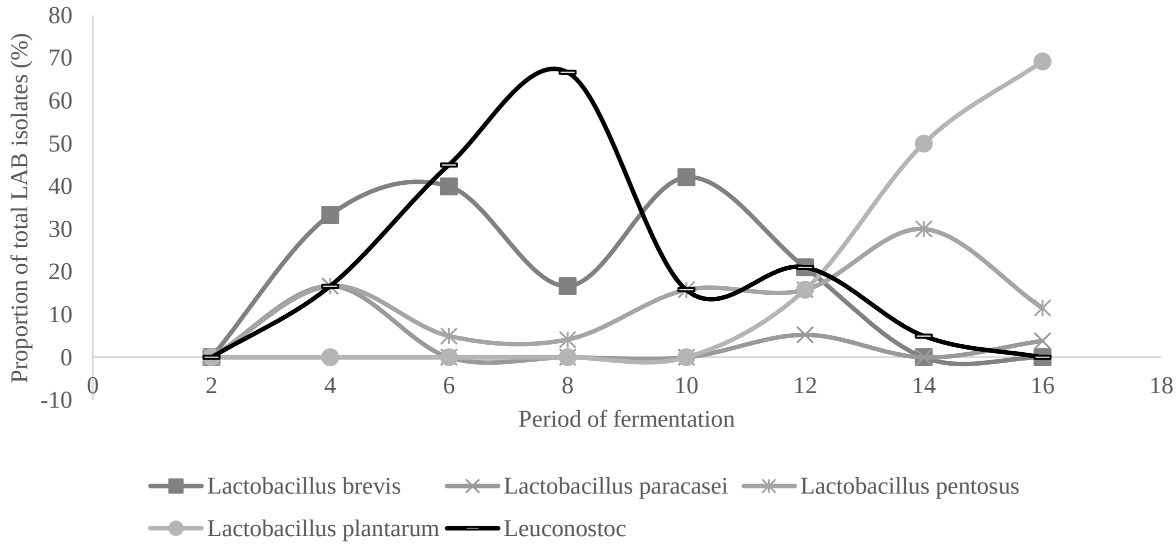


**Figure 5.12: Dominant lactic acid bacteria involved in optimized fermentation of cowpea leaves**

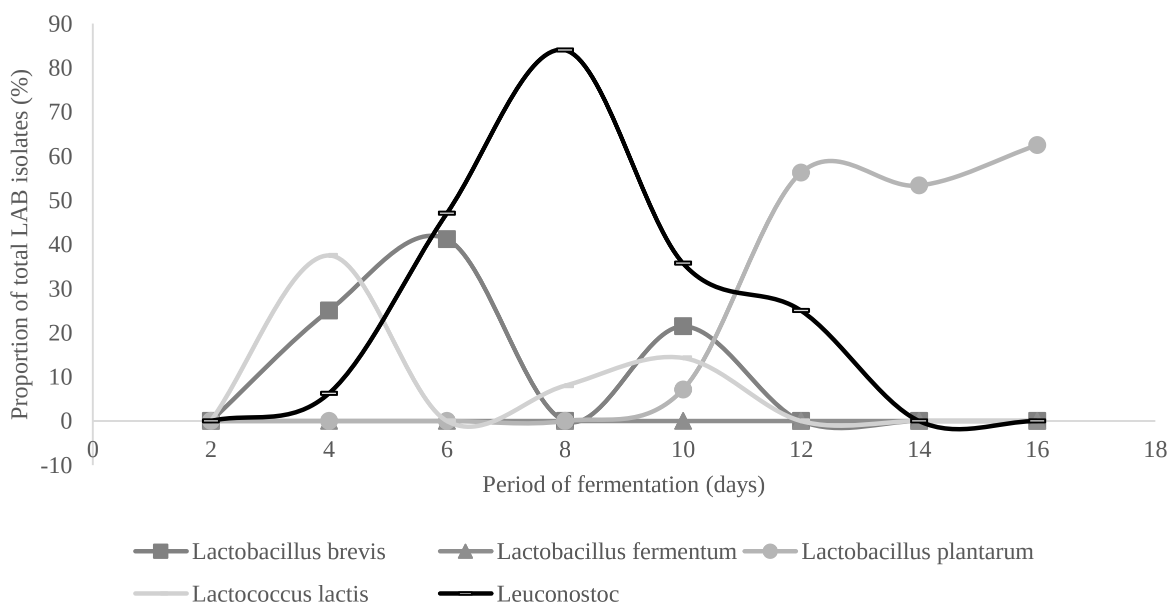


**Figure 5.13: Dominant lactic acid bacteria involved in spontaneous fermentation of cowpea leaves**

## 5.4 Discussion

### 5.4.1 Model fitting for optimization of fermentative parameters

The fitted model revealed that the fermentation parameters (salt and sugar concentrations and period of fermentation) were of significance in influencing the pH and titratable acidity as response variables in fermentation process. The models accounted for 89% variation and 60% variation in the pH and titratable acidity, respectively. The investigative independent variables therefore were good predictors of the response variables owing to the high variation they account for. This is further emphasized by the finding of a good relationship between the actual and predicted values (Bai et al., 2014); qualifying the assumptions of the study that sugar and salt concentrations and period of fermentation influence fermentative action of vegetables. In the current study, pH and titratable acidity were used as proxy indicators of microbial activity in the fermentation process. The utilization of the RSM model is aimed at achieving the optimal points with limited resources and time (Jaiswal et al., 2012). The linear factors significantly affected the pH and the titratable acidity, whereas in the case of pH, there was an added effect of the quadratic factor.

Whereas the interaction coefficient did not show significant effect in predicting the model, the quadratic coefficient of the period of fermentation significantly influenced the rate of fermentative microbial activity. The implication of this is that the optimal parameters of the independent variables (sugar and salt concentrations and period of fermentation) is not within the extremes but rather on the response surface. The relationship between the predictor and response variables can therefore not easily be revealed through a hyperplane but rather a 3-dimensional response surface curve.

### 5.4.2 Effect of sugar and salt concentrations and period of fermentation on pH and titratable acidity of soured cowpea leaves

Concentrations of sugar and salt and the period of fermentation have been independently established as factors that influence the fermentation process of vegetables (Muchoki et al., 2010; T. Xiong et al., 2016). This study found that with increasing sugar concentration, the pH and titratable acidity reduced and increased, respectively. Similarly, the period of fermentation was also of influence on the pH and titratable acidity. However, this only holds as a fact until the fermentable sugars are totally depleted (Muchoki, 2007). Yang et al. (2020) reported that the progressive increase in pH and titratable acidy in vegetable fermentation eventually cease due to the depletion of the available sugar in the fermentative solution. Similarly in another study by Kasangi et al. (2010), it was reported that notwithstanding the concentration of sugar utilized in the fermentation process, the progression curve for fermentation flattened after sometime indicative of depletion of fermentative sugars, the substrate utilizable in fermentation. Additionally, it is documented that sugar addition had an effect on the sensory quality of the soured vegetables, therefore the need for such optimization (Sui et al., 2019).

Increasing the salt concentration did not result in any increase in the titratable acidity nor decrease in the pH. In their study, Ziadi et al. (2019) reported the need to optimize salt concentrations utilized in lactic acid fermentation of vegetables for pH did not significantly change with changing concentrations of the brine. On the other hand, Muchoki (2007) reported that increasing salt concentrations in the fermentation of cowpea leaves would result in decreasing pH and increasing titratable acidity. However, in the latter study it was also observed that increasing the salt concentrations above 2% (w/v) would inhibit growth of the fermentative bacteria.

The current study found that in order to produce optimally soured cowpea leaves, sugar concentration of 5% (w/v), salt concentration of 2% (w/v) and a fermentation period of 16 days have to be observed. Kasangi et al. (2010) utilized fermentable sugars to the tune of 3% in his optimized trails, however, the attained titratable acidity of 0.6% is lower than the optimal points obtained in this study. This was also a demerit that was realizable in the study by Muchoki (2007), whereby the target 1.5% for the titratable acidity was not met. Jagannath et al. (2012) explains these occurring phenomena in vegetable fermentation by elucidating the occurrence of osmotic stress with increasing levels of the fermentation parameters, salt and sugar concentrations; and depletion of the substrate utilizable over lengthened period of fermentation.

### 5.4.3 Biochemical characterization of fermentative bacteria involved in the production of soured cowpea leaves

The attained acidity in the optimally fermented leaves falls below the threshold for classification of high acid foods of pH less than 4.6 (Cunningham, 2009). The high acidity realizable in the optimally fermented product depictive of more improved microbial activity than the spontaneous process. The major fermentative bacteria associated with the production of soured vegetables products include *Lactobacillus acidophilus*, *Lactobacillus fermentum*, *Lactococcus lactis*, *Leuconostoc mesenteroides* and *Lactobacillus plantarum* (Wafula et al., 2016). Similar LAB isolates were found to dominate the fermentation of cowpea leaves. In the event of slow release of sugar, Zhao et al. (2019) reported a slow transition of homofermentation to heterofermentation; domination of homofermenters in the process is evident. The fermentation in spontaneous process was originally dominated by the homofermenter (*L. lactis)* before the obligate heterofermenter (*L. brevis* and genus *Leuconostoc*) dominated the intermediate stage. With the addition of sugar, the transition to heterofermentation is faster, hence the domination of *L. brevis* of the onset process is due to this. The importance of the heterofermentation is its ability to induce antibacterial properties in the food and its largely influential improvement in the sensory quality of the product. Moon et al. (2018) reported that the starter culture of heterofermenter, *Leuconostoc citreum* of the genus *Leuconostoc*, improved the sensory quality of the fermented Kimchi relative to the spontaneously fermented one. Additionally, the heterofermenters produce acetaldehyde, diacetyle and hydrogen peroxide which provide antimicrobial and antifungal properties, on top of improving the sensory and textural properties of the product (Ashaolu and Reale, 2020).

*L. plantarum* is a facultative homofermenter, implying that it largely produces lactic acid as the product of fermentation; however, it can also degrade pentoses ($C_5$ Sugars) such as the xylose to produce lactic acid, acetic acid and alcohol. Both in spontaneous and optimized fermentation, the process was predominated by *L. plantarum* in the final stage of fermentation (Ashaolu and Reale, 2020). Dominance of the facultative homofermenter, *L. plantarum*, was for a longer period in spontaneous fermentation than in optimized process. The microbe has displayed capacity to metabolize both hexose and pentose sugars; this catabolic flexibility has contributed to its dominance in food fermentation processes (Filannino et al., 2014). The microorganism has been found to improve the antioxidant activity of fermented vegetables while minimizing deterioration of microbial quality. There is however need to investigate the possibility of any antagonism between *L. plantarum* and the dominant LAB cultures in the fermentation processes.

## 5.5 Conclusion

The optimization of the fermentation process of cowpea leaves in this study found that sugar and salt had to be added as ingredients and the period of fermentation observed at 16 days. From this study, cowpea leaves products were acidified (high acid food) with a low pH of 3.8 and titratable acidity of 1.22%. The optimization induced changes to the microbial profile of the fermentation process of the vegetables. The dominant LAB cultures were found to change in the onset stage of fermentation of cowpea leaves. The domination of the *L. plantarum* was also found to be limited in the optimized process. The limitation of the current study was that the antagonism between the cultures was not investigated, and further recommendation is to have this evaluated for potential development of symbiotic starter cultures. Further research is also recommended to establish the sensory profiling and improvements occurring in the optimally fermented product in comparison to the spontaneously fermented leaves. This study contributes to the prospect of commercialization and standardization of quality and production process of fermented cowpea leaves for it provides inputs towards improving the low-cost processing techniques currently being utilized among smallholder groups and households.

# CHAPTER SIX: COMPARATIVE CHARACTERIZATION OF TREND AND PATTERNS OF PHYSICO-CHEMICAL ATTRIBUTES OF OPTIMALLY AND TRADITIONAL PROCESSED COWPEA LEAVES


## Abstract

Whereas dehydration techniques serve as alternative avenues of enhancing the availability of cowpea leaves, the physico-chemical quality of the products is an area of investigation that studies have focused on. This study used statistical techniques of principal component analysis for comparative mapping of the trends and patterns of the retention and degradation of physico-chemical quality of both locally and optimally processed cowpea leaves. The study evaluated dehydrated cowpea leaves of different processing techniques from farmer groups and those optimally processed using modern techniques for nutritional composition, phytochemical compounds and colour changes. Sun-drying techniques that excluded blanching had the least content of beta-carotene and ascorbic acid of 2.65±0.95 and 21.80±1.24 mg/100g dwb accompanied with the most significant ($p<0.001$) deterioration of colour (7.74±3.49) than techniques that included. Whereas the antinutrients declined, the difference did not significantly differ ($p>0.05$) based on preservation techniques. With factor analysis determining optimal nutritional quality for cowpea leaves as 8 weeks after emergence, sun-drying had the highest loss of beta-carotene and ascorbic acid, 66.7-80.1% and 53.7%-58.3, respectively ($p<0.001$), whereas mineral leaching, reduction of antinutrients and colour changes was more pronounced in dehydration techniques incorporating fermentation as pretreatment. For the low-cost traditional preservation techniques, preservation of minerals resulted in aggravated losses of beta-carotene and ascorbic acid whereas in the mechanized techniques this was not the case. In concluding that the mechanized techniques have a better combination of attenuating losses of micronutrients, the

study recommends that in promoting the utilization of the traditional preservation techniques, low-cost processes like steam blanching can help improve nutrient quality of the product.

## 6.1 Introduction

The vast utilization of cowpea leaves in sub-Saharan Africa (SSA) for food and nutrition security has been attributed to its rich nutritional composition and its thriving in a variety of agro-ecological zones (Horn and Shimelis, 2020; Kirigia et al., 2018). Of the 14.4 million hectares global production area of the crop, 85.1% is in the western Africa according to FAOSTAT (2021); about 7.8% of this global production area is in eastern Africa. The crop has a dual purpose of utilization, for its grains and vegetables, which has made it popular among many communities in SSA (Kebede and Bekeko, 2020). Moreover, the vegetable is rich in phytochemicals with health promoting properties that has aided the continued push for their utilization; including among the urban communities (Kirakou et al., 2017; Kirigia et al., 2018). Additional utilization that have been exploited for cowpea leaves is for fodder (Enyiukwu et al., 2018a; Owade et al., 2020a). Its relative importance in the agriculture sector is due to its high productivity and stability, tolerance to environmental stress, economic viability and low environmental impact coupled with capacity to promote environmental conservation (Carneiro da Silva et al., 2019). Additionally, the crop has production flexibility to permit its production in mono and mixed cropping (Njonjo et al., 2019).

In Kenya, the coastal areas are among the regions with the highest production and consumption of the vegetable (Owade et al., 2020a); thus the vegetable forming a major component of their diet. This vegetable constitute one of the most consumed African leafy vegetables in the country (Horticultural Crops Directorate, 2016). However, seasonal availability of the crop often constrains its extended utilization in households. Reliance on the fresh forms often expose the communities to shortage of such vegetables especially in areas where there is much reliance on subsistent production (Owade et al., 2020b). Communities in the arid and semi-arid lands (ASALs) of the country often incorporate traditional preservation techniques in order to enhance their utilization of the vegetable (Owade et al., 2020b). Traditional preservation of the vegetables range from sun-drying techniques, hurdle technology of blanching or cooking and drying and fermentation (Muchoki, 2007). Over a quarter of the households in coastal areas were found to be reliant on the traditional processed vegetables to overcome the shortage occasioned by seasonal availability (Owade et al., 2020b). The nutritional quality of these products differs based on the technique utilized in the processing. Whereas Kirakou et al. (2017) recommended blanching and fast drying techniques including solar drying for use in processing of cowpea leaves due to its maximum nutrient retention, Owade et al. (2020b) established that sun-drying, a more affordable technique, is the most utilized in the cowpea leaves value addition among the coastal arid and semi-arid lands (ASALs). Okello et al. (2015) reported that consumers attached no additional economic advantage, and this was adduced to product quality, pointing to a gap that needs evaluation. However, it is not sufficient enough to be dismissive of these technologies as less efficient ways of availing the vegetables for consumption despite the limited practice among communities.

This research contributes towards the promotion of the adoption of value addition techniques among producing households to enhance the all-season availability of the vegetable. The dominance of women in the cowpea leaves value chain (Kirakou et al., 2017), makes it a feasible avenue for economic empowerment of the most vulnerable in the community. The current study sought to establish the trends and patterns in the retention and degradation of physico-chemical attributes in value added cowpea leaves subjected to either optimal and traditional processing techniques, providing an upgrade of existing knowledge of the physico-chemical quality of processed vegetables. The mapping and patterns developed using statistical techniques in this study is the first of its kind that provides a comparative evaluation of local food processing and modernized techniques. The study will shape nutrition information that is disseminated in nutrition interventions that promote value addition practices especially in resource constrained settings in SSA.

## 6.2 Materials and Methods

### 6.2.1 Study design

A comparative study on the patterns on nutrient retention in processed leaves was conducted on vegetables that had been processed using traditional and optimal techniques. The study was undertaken in two phases, a cross-sectional survey and an experimental study. In the first phase, a cross-sectional survey was conducted among farmer groups processing the two study areas of Kitui and Taita Taveta Counties, described in **Section 3.2.1**. The second phase experimental study designs in the evaluation of optimal processing dehydration techniques of cowpea leaves.

### 6.2.2 Phase I

#### 6.2.2.1 Sample collection and preparation

A total of 30 samples of dehydrated cowpea leaves were obtained from six farmer groups in Taita Taveta and Kitui Counties who practiced value addition practices for cowpea leaves. The samples were collected based on the processing techniques done; including fresh, shredded sundried, unshredded sundried; blanched sundried; and shadow-dried. Samples were collected based on the batches available during the week-long study in the two areas. All the samples were collected for the month of May for Taita Taveta County and October for Kitui County, 2020, when the first harvesting of the leaves was done. The collected samples, each 2 kg, were put in air tight sterile polythene bags and placed in cooler boxes, -10 $^{o}$C, for transportation to the University of Nairobi Laboratories for analysis. The limitation in the study is the farmers were reliant on landrace varieties, thus could not distinctively identify the varieties planted. Exhaustive sampling was used as the practice is not widely done in the two counties (Owade et al., 2020b). The 30 samples were subjected to compositing where ~200g obtained from each batch were mixed in a plastic tub based on similarity of processing technique and similar farmer group in order to minimize the effect of extraneous outliers due to individual variations in sample types. A total of twelve composites were obtained and evaluated for colour changes before being frozen awaiting nutrient analysis.

### 6.2.3 Phase II

#### 6.2.3.1 Experimental designs

This study utilized a combination of two experimental designs: the full factorial arrangement in the evaluation of the optimal maturity stage for harvesting of the cowpea leaves and the completely randomized block experimental study in the evaluation of the optimal processing of cowpea leaves. In the full factorial experiment, the experimental factors were period of maturity and the variety of the cowpeas. On the other hand, in the completely randomized study, the experimental factor was the processing technique.

#### 6.2.3.2 Evaluation of optimal stage of maturity for harvesting of cowpea leaves

**a. Experimental arrangement**

Two different varieties of cowpeas, Machakos 66 (M66- a dual purpose variety) and Kunde Mboga (predominantly for the leafy vegetables) were subjected to evaluation of their maturity indices; nutritional quality. In order to eliminate the effect of extraneous factors such as gradient of the soil and seasonal variation, blocking was done. The planting was done in two different seasons (April to August) and September to August) in three different blocks at the University of Nairobi Field Station. The spacing of the plants was 60 cm by 30 cm as determined by Muniu (2017). The three top leaves in every branch in a plant for each of the different varieties were harvested at intervals of four weeks after emergence (WAE), transported to the laboratory and stored at -20 $^{o}$C awaiting analysis for nutritional quality and antinutrient content. Blocking was done in the field to take care of difference in soil gradient.

**b. Study site**

The study site was located the Field station located at the College of Agriculture and Veterinary Sciences, the University of Nairobi, Nairobi County. The field is located West of Nairobi County along the latitudes 1˚ 15´ S, the longitudes 36˚ 44´E and an altitude of 1820 m above sea level (Kirakou, 2014). The area has an annual rainfall of 1060 mm which has a bimodal distribution with long rains between March and May and short rains between October and December (Esilaba et al., 2013; Muthama et al., 2008). The temperature ranges from 13.7 and 24 $^{o}$C. The soils of the area are deep well-drained, dark reddish brown to dark brown (Kirakou, 2014).

#### 6.2.3.3 Evaluation of optimal dehydration of cowpea leaves

Optimal processing techniques for cowpea leaves have a higher retention of the physico-chemical quality when hurdle technology is used (Owade et al., 2020a). The study employed a completely randomized experimental design with the investigative factor being the processing technique coopting the hurdle technology (a pretreatment and dehydration technique). Kunde Mboga variety of cowpea leaves were harvested at optimal maturity, washed and reduced in size and divided into two batches. The first batch of the vegetables (15kg) was steam blanched (temperature of 100 °C) for 3 minutes followed by immersion in ice cold water as established in the desktop review Owade et al. (2020a) and divided into six equal parts. Two parts each were dried using oven drier (temperature of 55 °C for 6 hours), solar drier (temperatures averaging 50 °C for 8 hours) for and the sun (for two days). The drying of the vegetables targetting a moisture content below 15%. The second batch was divided into four equal parts of 2.5kg and sugar and salt added to each portion at 5% and 2%, respectively according to optimization studies conducted by Owade et al. (2021). The fermented vegetables were subjected to oven and solar drying till a moisture content of below 15% was attained. The dried vegetables were evaluated for colour changes then stored at -20 $^{o}$C awaiting evaluation of nutrient and antinutrient composition.

### 6.2.4 Analysis of physico-chemical attributes of processed cowpea leaves

#### 6.2.4.1 Determination of proximate composition

The proximate composition was determined as moisture, crude fact, crude ash, crude fiber and crude protein contents in duplicates as per the methods 950.46, 960.39, 920.153, 962.09 and 955.05 of AOAC (2005), respectively. The carbohydrate content on the other hand was determined using the difference method as per the procedure described by Greenfield and Southgate (2003). The energy values of the traditionally preserved cowpea leaves were determined by multiplying the protein, carbohydrate and fat contents (g/100g) by 4, 4 and 9, respectively, and separately adding the values for each sample.

#### 6.2.4.2 Determination of ascorbic acid content

Ascorbic acid content was determined in duplicates as per the official method 967.21-1968 of the AOAC (2010). Standardization of the dicholorophenolindophenol (DCPIP) reagent was done by it titrating it thrice with 2ml of standard ascorbic acid solution (0.02% in 5% metaphosphoric acid). The titration was done till distinct rose-pink color persists for >5 s appeared. A blank of 5%

metaphosphoric acid was also titrated thrice. To a 10 g sample of the dehydrated vegetable, 60ml of 5% metaphosphoric acid was added and filtered through a glasswool into a 100ml volumetric flask. This was made to volume and 10 ml put into a 100 ml conical flask and titrated against DCPIP. The titre of the dye was determined as per Equation 6.1. The amount of ascorbic acid in the dried vegetables was determined as per Equation 6.2.

$$Titre\ (F) = \frac{n}{b-a}$$ **Equation 6.1**

where *n* was the mg of ascorbic acid per ml of titrated standard solution in this case was $\frac{mg\ of\ ascorbic\ acid \times 2}{50}$, *a* was the titre of the standard used and *b* was the titre of the blank.

$$ascorbic\ acid\ (mg\ g^{-1}) = x - c \times \frac{f}{e} \times \frac{v}{y}$$ **Equation 6.2**

where $x$ was the titre volume used for the sample, *c* was the titre used for the blank, $f$ was the mg of ascorbic acid equivalent to 1ml of DCPIP solution, *e* was the assayed volume (2 ml), *v* was the volume of the initial assay solution (10 ml) and *y* was the volume of sample aliquote (10 ml).

#### 6.2.4.3 Determination of beta-carotene content

Beta carotene was determined calorimetrically using the spectrophotometry method adopted through modification of the methods described by Biswas et al. (2011).

*Preparation of a standard curve:* A stock solution of beta-carotene (5% purity, Sigma Aldrich) was dissolved in acetone to make a concentration of 1mg/ml. The stock solution was used to make working solution of 32, 16, 8, 4, 2, 1, 0.025, 0.125, 0.062, 0.03 and 0 µg/ml. A standard curve was generated in a UV-VIS spectrophotometer (Hitachi U-2900, Tokyo, Japan). The concentration was expressed in mg/ml. All standards were protected from the light by covering with aluminium foil.

*Sample preparation:* Dried samples of the vegetables (1 g) was mixed with 5 ml chilled acetone and left at 4°C for 15 minutes with occasional shaking, votexed at high speed for 10 minutes and centrifuged at 1370x *g* for 10 minutes. The supernatant was collected in a tube and the extraction repeated until a clear supernatant with no colouration was obtained. The supernatant was filled to volume of 50 ml. The supernatant was passed through a Whatman paper No 42 and the absorbance read at 450 nm. The concentration of beta-carotene was calculated as per Equation 6.3.

$$b = \frac{C \times V}{M}$$ **Equation 6.3**

where *b* is the beta carotene in mg/g, *C* is the concentration determined as per the calibration curve, *V* is the volume of the extract in ml and *M* is the weight of sample used in extraction.

#### 6.2.4.4 Determination of mineral content

The mineral (calcium, zinc, iron and sodium) contents was determined in duplicates using atomic absorption spectrometer as per the AOAC (2005) method 2005.08. A 2 g sample of cowpea leaves was ashed at 550 $^{o}$C, followed by boiling in 10ml 20% hydrochloric acid in a beaker. The boiled was filtered into 100ml standard flask and then read using atomic absorption spectrometry (Buck Scientific 210 VGP, USA).

#### 6.2.4.5 Determination of oxalate content

The oxalate content of the preserved cowpea leaves was determined in duplicate as per the procedures by AOAC (2005) method. About 1 g of preserved cowpea leaves samples was weighed into 100 ml conical flask. To it, 75 ml of 3 mol/l of $H_2SO_4$ was added and the solution stirred using a magnetic stirrer. The solution was filtered through Whatman filter paper no. 1 and the filtrate collected in a 250 ml conical flask. From this sample filtrate, 25 ml of it was titrated against hot (80-90 $^{o}$C) 0.1N $KMnO_4$ solution, with a persistent faint pink colour (30 seconds) indicating the end point. The oxalate content was calculated as 1 ml of 0.1 N of $KMnO_4$ is equivalent to 0.006303 g of oxalate.

#### 6.2.4.6 Determination of nitrate content

Nitrate content of the preserved cowpea leaves cowpea vegetable samples was determined in duplicate by modification of procedures described by Gaya and Alimi (2006). Samples of the vegetable was ground using a mortar and pestle and to 10 g of the ground samples, 70 ml distilled water followed with 2.5 ml 4% NaOH was added. The mixture was heated at 80 $^oC$ for 25 minutes with occasional shaking during heating. Thereafter, the resultant solution was filtered into a 100 ml volumetric flask through a fluted filter paper and made to mark with distilled water to form mixture 2. About 4 ml of mixture 2 was pipetted into an ice-cold test tube followed by addition of 1 ml of 1% $Ag_2SO_4$, 7 ml of 98% $H_2SO_4$ and 1ml 5% phenol solution to form mixture 3 that was left to stand in the dark for 20 minutes while occasionally shaking. Mixture 3 was transferred into a 50 ml separating funnel and toluene added (mixture 4) and further shaking for 5-10 minutes to mix. The upper phase of mixture 4 (organic phase) was retained while the aqueous phase was discarded. The organic phase was washed twice with 10 ml distilled water and each time the aqueous phase was discarded. The organic phase was extracted further by addition of 10 ml 10% $Na_2CO_3$ and shaken for a minute. The extract was collected in a test tube. The absorbance was read at 407 nm. Standard curves were generated by varying the concentrations of sulphuric acid, $Na_2CO_3$, Phenol and reaction time of standard nitrogen nitrate solution. The quantity of nitrates was calculated as per Equation 6.4.

$$Nitrate = \frac{C \times S}{W \times F}$$ **Equation 6.4**

where *C* is the concentration is the concentration of the nitrates in the samples as per the calibration curve, *S* is the volume of filtrate used to read the absorbance, *W* is the weight of slurry used while *F* is the total volume of the filtrate.

#### 6.2.4.7 Determination of total phenolic compounds

The flavonoid content of the preserved samples of cowpea leaves was determined using the Folin-Ciocalteu l procedure that was adopted through modification of the methods described by Abong' et al. (2020). A 5 g sample of the vegetables was subjected extraction by adding 5ml of methanol followed by twenty-four-hour extraction at 25°C. The extract was centrifuged at 3226× *g* for 10 min and the supernatant obtained was used to determine total phenolic content. To an aliquote of 1ml of methanolic extract in a 10ml of volumetric flask, 2.5 ml of tenfold dilution of Folin-Ciocalteu reagent (1:10 dilution with distilled water) followed by 2ml of 7.5% (w/v) sodium carbonate solution. The mixture was topped to volume and incubated at 45 °C for 15 minutes. The samples were read against a standard calibration curve of gallic acid monohydrate prepared by obtaining 0.25, 0.5, 1.0, 1.5 and 2.0 mg/ml followed by similar treatment as the methanolic extracts. The calibration curve of the standard was in mg/ml with an $R^2$ of 0.995. Distilled water was used as the blank. The samples were read at 765 nm using UV-VIS spectrophotometer (Hitachi U-2900, Tokyo, Japan) and the total phenolic content expressed as mg per Gallic Acid Equivalent (GAE) per gram as per Equation 6.5.

$$P = \frac{C \times V}{M}$$ **Equation 6.5**

Where $P$ is the total phenolic content in mg/g, $C$ is the concentration determined as per the calibration curve, $V$ is the volume of the extract in ml and $M$ is the weight of sample used in extraction.

#### 6.2.4.8 Determination of flavonoid contents

The flavonoid content of the samples was determined using the aluminum chloride colorimetric procedure by modifying the method described by Abong' et al. (2020). A standard calibration curve was generated using catechin solution. From a stock solution of 100 µg/ml (w/v of methanol) of catechin, aliquots of 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 ml were obtained and transferred into five 10ml volumetric flasks containing 4 ml of water, followed by addition of sodium nitrite and left to rest for five minutes. After the five minutes, 0.3 ml of 10% (w/v) aluminium chloride was added and allowed to rest further for six minutes. To the rested mixture, 2 ml 1 N sodium hydroxide was added and filled to volume. The standard curve was calibrated in mg/ml with $R^2$ of 0.995 obtained when read from a UV/VIS spectrophotometer (Hitachi 2900, Tokyo, Japan). The methanolic extract obtained as per the extraction procedures for determining total phenolics, was subjected to treatment similar to catechin standards. The concentration of total flavonoids was determined in milligrams of catechin equivalents per gram (mg. CE. g-1) as per Equation 6.6.

$$F = \frac{C \times V}{M}$$ **Equation 6.6**

where $F$ is the total flavonoid content in mg/g, $C$ is the concentration determined as per the calibration curve, $V$ is the volume of the extract in ml and $M$ is the weight of sample used in extraction.

#### 6.2.4.9 Determination of anti-oxidant activity

The anti-oxidant activity of the preserved cowpea leaves was determined using the 2, 2 diphenyl-1-picrylhydrazyl (DPPH) procedure by modifying the methods described by Abong' et al. (2020). Methanolic extract of preserved samples of cowpea leaves were prepared by mixing 0.25 g of sample with 10 ml of 80% (v/v) of methanol, with overnight extraction in a shaker. About 1 ml of the methanolic extract, standard Trolox solutions (0, 5, 10, 25 and 50 µg/ml) and blank was pipetted into boiling tubes and 0.002% of DPPH (prepared using absolute methanol) was added to each. The mixture was shaken briefly and read immediately upon addition of DPPH at 515 nm (Hitachi U-2900 spectrophotometer). A standard calibration curve of Trolox was used to calculate the anti-oxidant activity of the preserved cowpea leaves in mg Trolox Equivalents (TE) per 100 g dry weight.

### 6.2.5 Determination of colour changes

The L*, a*,b* and chroma and Hue angles of the formulated soup mixes were determined as per the procedures described by the manufacturer (PCE Instruments, 2014). Using the CSCQ3 software, the Hue, Chroma and ΔE were calculated basing on the Equation 6.7-6.9. The value of L* represented the lightness of the vegetable samples (more positive value have lighter colour intensity), the value a* value represented the measure of redness (positive), greyness (zero) or greenness (negative), and the value b* value represented the measure of yellowness (positive), greyness (zero) or blueness (negative).

$$\text{Hue angle (Ho)} = \arctan(b/a) \text{ (for } +a \text{ and } +b \text{ values)}$$ **Equation 6.7**

$$\text{Hue angle (Ho)} = \arctan(b/a) + 180 \text{ (for } -a \text{ and } +b \text{ values or for } -a \text{ and } -b \text{ values)}$$

**Equation 6.8**

$$\text{Chroma angle } (C^{o}) = \sqrt{a^2 + b^2} \qquad \textbf{Equation 6.7}$$

$$\Delta E = \sqrt{(a_1^* + a_2^*)^2 + (b_1^* + b_2^*)^2 + (L_1^* + L_2^*)^2} \qquad \textbf{Equation 6.9}$$

### 6.2.6 Statistical analysis

Statistical analysis of the data was done using the R language for programming version 4.0.3 (R Core Team, 2019). One way analysis of variance (ANOVA) was used test for mean differences induced by the different processing techniques on the physico-chemical quality of cowpea leaves. For means that were significantly different ($p<0.05$), Tukey's Honest Significant Difference (HSD) in the Agricolae Package was used to separate them. Principle component analysis was used to map the patterns of nutrient retention in the various samples. The data for optimization of the maturity stage of cowpea leaves was analyzed using two-way ANOVA. The Akaike's Information Criterion (AIC) of the AICmodav package was used to select the model that best explains the variation of the nutritional composition of the cowpea leaves grown and the Tukey's HSD of the Agricolae Package used to separate means of different investigative factors.

## 6.3 Results

### 6.3.1 Physico-chemical qualities of traditional processed cowpea leaves

Significant ($p<0.05$) variation in proximate composition existed with cowpea leaves that combined blanching and solar drying (Table 6.1). Whereas the crude fat content (4.3 ± 0.3 g/100 g dry weight) was high in blanched and sun-dried leaves than the fresh and other preserved samples, there was a decline in the crude ash content ($p<0.05$). The lower crude ash content is pronounced with significantly ($p<0.05$) lower mineral iron and calcium content in the blanched and sun-dried leaves (Table 6.2). In overall, the utilization of artisanal traditional processing for the preservation resulted in significant loss ($p<0.05$) of micronutrients. Whereas the anti-oxidant activities of the preserved samples significantly ($p<0.001$) decreased with the application of traditional preservation techniques, the anti-nutrient content in the vegetables still remained invariably high (Table 6.3). Moreover, degradation in colour also occurred with, a significantly higher deviation ($p<0.001$) occurring in preservation techniques that did not include blanching as a pre-treatment (Table 6.4). The colour coordinates for b*, a* and Chroma and Hue angles were significantly different from the fresh vegetables.

**Table 6.1: Proximate composition of traditional preserved cowpea leaves (per 100g/dmb)**

| Processing technique | Moisture (g) | Crude protein (g) | Crude fat (g) | Crude fibre (g) | Crude ash (g) | Carbohydrates (g) | Energy values (Kcal) |
|---|---|---|---|---|---|---|---|
| S1 | 10.3±0.3$^{b}$ | 33.3±3.0$^{a}$ | 4.3±0.3$^{a}$ | 15.9±2.3$^{a}$ | 8.2±1.0$^{b}$ | 51.7±4.4$^{a}$ | 371.2±7.9$^{a}$ |
| S2 | 87.0±0.6$^{a}$ | 31.0±0.4$^{ab}$ | 2.9±0.4$^{b}$ | 15.5±0.5$^{a}$ | 14.1±0.4$^{a}$ | 47.8±0.9$^{b}$ | 341.0±2.0$^{c}$ |
| S3 | 10.6±0.3$^{b}$ | 27.6±1.1$^{b}$ | 1.9±0.5$^{c}$ | 15.1±0.7$^{a}$ | 15.0±1.2$^{a}$ | 52.3±2.2$^{a}$ | 336.7±8.3$^{bc}$ |
| S4 | 11.0±0.5$^{b}$ | 29.8±1.0$^{c}$ | 1.9±0.2$^{c}$ | 14.5±2.3$^{a}$ | 13.4±0.5$^{a}$ | 52.8±2.6$^{a}$ | 347.4±9.9$^{b}$ |
| %CV | 109.1 | 15.3 | 104.6 | 15.5 | 19.3 | 8.0 | 5.1 |
| HSD | 29.6 | 1.78 | 3.02 | 14.6 | 4.3 | 1.55 | 6.49 |
| p-value | <0.001 | <0.001 | <0.001 | 0.050 | <0.001 | <0.001 | <0.001 |

The values are mean ± sd of duplicates. Values with different letters in the superscript are statistically different. S1- Blanched sundried, S2- Fresh leaves, S3- Shadow dried and S4- Unblanched sundried. All the variables are in dry matter basis except for moisture content.

**Table 6.2: Micronutrient composition of traditional preserved cowpea leaves (mg/100g dry matter basis)**

| Processing technique | Beta-carotene | Vitamin C | Zinc | Iron | Calcium | Sodium |
|---|---|---|---|---|---|---|
| S1 | 4.13±1.96$^{ab}$ | 27.99±7.06$^{b}$ | 2.27±0.92$^{a}$ | 15.18±6.11$^{b}$ | 36.30±6.31$^{b}$ | 16.60±5.89$^{b}$ |
| S2 | 8.40±8.17$^{a}$ | 90.56±33.57$^{a}$ | 5.59±4.53$^{a}$ | 75.93±18.80$^{a}$ | 51.34±3.12$^{a}$ | 75.84±19.52$^{a}$ |
| S3 | 3.55±0.57$^{ab}$ | 66.92±11.41$^{a}$ | 2.06±1.89$^{a}$ | 21.79±5.77$^{b}$ | 38.73±6.97$^{b}$ | 16.42±1.53$^{b}$ |
| S4 | 2.65±0.95$^{a}$ | 21.80±1.24$^{b}$ | 3.31±0.77$^{a}$ | 32.94±7.84$^{b}$ | 36.78±6.18$^{b}$ | 16.68±1.67$^{b}$ |
| %CV | 78.8 | 30.2 | 58.2 | 71.7 | 15.6 | 61.2 |
| HSD | 4.46 | 55.6 | 3.29 | 34.2 | 10.1 | 30.2 |
| p-value | 0.032 | <0.001 | 0.294 | <0.001 | 0.003 | 0.034 |

The values are mean ± sd of duplicates. Values with different superscripts in the same column are statistically different. S1- Blanched sundried, S2- Fresh leaves, S3- Shadow dried and S4- Unblanched sundried.

**Table 6.3: Anti-nutrient content and anti-oxidant activity of traditional preserved cowpea leaves (mg/100 g dry matter basis)**

| Processing technique | Nitrates (mg) | Oxalates (mg) | Total phenolics (mg GAE) | Flavonoids (mg CE) | Anti-oxidant activity (mg TE) |
|---|---|---|---|---|---|
| S1 | 509.02±138.55[b] | 151.90±25.73[b] | 20.75±2.64[a] | 4.45±2.17[ab] | 21.90±12.16[b] |
| S2 | 731.19±73.48[a] | 142.86±29.83[b] | 23.10±9.91[a] | 7.78±1.67[a] | 45.01±1.55[a] |
| S3 | 389.96±11.72[c] | 141.62±28.99[b] | 17.02±1.19[a] | 1.92±0.11[b] | 3.25± 2.67[b] |
| S4 | 495.26±245.62[bc] | 191.85±21.63[a] | 25.69±2.73[a] | 6.39±2.69[ab] | 20.40± 6.17[b] |
| %CV | 20.2 | 15.3 | 20.5 | 46.8 | 44.9 |
| HSD | 177.7 | 35.8 | 21.9 | 5.73 | 23.0 |
| p-value | <0.001 | <0.001 | 0.092 | 0.016 | <0.001 |

The values are mean ± sd of duplicates. Values with different superscripts in the same column are statistically different. S1- Blanched sundried, S2- Fresh leaves, S3- Shadow dried and S4- Unblanched sundried.

**Table 6.4: Colour changes of traditional preserved cowpea leaves**

| Processing technique | L | A | B | C | H | ΔE |
|---|---|---|---|---|---|---|
| S1 | 43.10±1.39[ab] | -1.23±0.32[c] | 7.00±1.28[ab] | 7.11±1.26[ab] | 100.19±3.06[a] | 3.33±0.90[b] |
| S2 | 40.77±3.55[b] | 0.36±0.36[a] | 2.47±1.70[b] | 2.53±1.69[b] | 80.82±12.42[b] | Na |
| S3 | 45.11±3.52[a] | -1.10±0.23[c] | 8.47±2.78[ab] | 8.54±2.78[ab] | 97.60±1.42[a] | 5.39±3.41[ab] |
| S4 | 47.82±3.52[a] | -0.72±0.59[b] | 9.67±2.18[a] | 9.72±2.12[a] | 95.06±4.78[a] | 7.74±3.49[a] |
| %CV | 6.06 | 60.5 | 22.1% | 21.6 | 9.49 | 66.1 |
| HSD | 4.2 | 0.37 | 6.7 | 6.8 | 10.1 | 2.4 |
| p-value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

The values are mean ± sd of duplicates. Values with different superscripts in the same column are statistically different. S1- Blanched sundried, S2- Fresh leaves, S3- Shadow dried and S4- Unblanched sundried.

### 6.3.2 Physico-chemical qualities of optimally processed cowpea leaves

#### 6.3.2.1 Optimization of stage of maturity for harvesting cowpea leaves

Using the WSSplot, the optimal number of clusters was determined as three for the classification of the nutritional and anti-nutrient contents of cowpea leaves harvested at different maturity stages. Cluster one had the optimal content of protein and micronutrients (Table 6.5). Whereas, seasonal variation had no difference in loading in the different clusters, variety of cowpea leaves and the stage of maturity of leaves differed in loading amongst the three clusters. Kunde Mboga variety and cowpea leaves harvested at eight weeks after emergence had the highest loading in cluster one (Table 6.6). In choosing the most optimal period of harvesting, the cluster with the highest number of positive values for the normalized means of protein and micronutrient contents and the highest number of negative values of the antinutrient contents was selected, cluster two met this criterion (Table 6.7).

**Table 6.5: Normalized means of clustered nutrient and antinutrient composition of cowpea leaves harvested at different maturity stages**

| Chemical composition | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| Moisture content (g) | 0.86 | 0.26 | -0.83 |
| Crude protein (g) | 0.47 | 0.28 | -0.65 |
| Crude ash (g) | 1.36 | -0.43 | -0.03 |
| Crude fat (g) | -0.72 | 0.62 | -0.57 |
| Crude fiber (g) | 2.02 | -0.46 | -0.32 |
| Carbohydrate (g) | -1.33 | 0.49 | -0.08 |
| Beta-carotene (mg) | 0.18 | 0.75 | -1.22 |
| Ascorbic acid (mg) | 0.07 | -0.34 | 0.47 |
| Nitrates (mg) | -0.24 | -0.42 | 0.75 |
| Oxalates (mg) | -1.15 | 0.58 | -0.29 |
| Total phenolics (mg) | 1.43 | -0.24 | -0.35 |
| Flavonoids (mg) | 1.06 | -0.02 | -0.49 |
| Zinc (mg) | 1.96 | 0.62 | -0.05 |
| Iron (mg) | 1.30 | 0.10 | -0.49 |
| Sodium (mg) | 0.63 | 0.44 | -0.98 |
| Calcium (mg) | 2.08 | -0.44 | -0.39 |
| Total Anti-oxidant (mg TE) | -0.57 | 0.85 | -1.00 |

**Table 6.6: Loading of independent variables for optimization of stage of maturity of cowpea leaves in clusters**

| **Independent variables** | | **Clusters** | | |
|---|---|---|---|---|
| | | **1** | **2** | **3** |
| Seasons | Season 1 | 50 | 50 | 50 |
| | Season 2 | 50 | 50 | 50 |
| Stage of maturity (WEA) | 4 | 50 | 33 | 0 |
| | 8 | 0 | 67 | 0 |
| | 12 | 50 | 0 | 100 |
| Variety | Machakos 66 | 100 | 33 | 0 |
| | Kunde Mboga | 0 | 67 | 100 |

**Table 6.7: AIC model selection criterion for independent factors affecting nutrient and antinutrient composition of cowpea leaves harvested at different maturity stages**

| **Response variables** | **Delta values for model prediction (AIC weight %)** | | | | |
|---|---|---|---|---|---|
| | **Model _1** | **Model_2** | **Model_3** | **Model_4** | **Model_5** |
| Moisture content | 5.9(5) | 0.0(92) | 8(2) | 7.9(2) | 15.8(0) |
| Crude protein | 2.4(17) | 0.0(55) | 4.9(5) | 1.69(23) | 17.3(0) |
| Crude fat | 0(65) | 7.5(2) | 12.0(0) | 1.4(33) | 17.5(0) |
| Crude ash | 5.78(0) | 0.1(47) | 0.8(3 | 0.0(47) | 0.9(3) |
| Crude fiber | 6.9(2) | 6.0(4) | 7.5(2) | 2.6(20) | 0.0(73) |
| Beta-carotene | 3.1(18) | 0.0(82) | 21.9(0) | 20.8(0) | 20.6(0) |
| Ascorbic acid | 5.7(0.0) | 0.0(43) | 1.1(25) | 0.7(30) | 21.6(0) |
| Zinc | 11.6(0) | 11.2(0) | 13.05(0) | 7.52(2) | 0.0(97) |
| Iron | 5.7(0.02) | 0.7(35) | 5.8(0) | 0.0(65) | 3.0(0) |
| Sodium | 0.0(87) | 9.4(1) | 66.7(0) | 64.6(0) | 4.0(12) |
| Calcium | 0.(92) | 13.1(0) | 19.6(0) | 6.6(3) | 6.2(5) |
| Total phenolics | 0(1) | 58.1(0) | 61.6(0) | 22.1(0) | 9.0(1) |
| Flavonoids | 0.0(56) | 31.4(0) | 32.9(0) | 0.47(44) | 16.4(0) |
| Nitrates | 2.9(11) | 8.6(1) | 10.6(0) | 0.0(89) | 12.1(0) |
| Oxalates | 6.0(1) | 0(65) | 2.9(15) | 2.8(16) | 23.4(0) |
| Anti-oxidant activity | 5.4(3) | 0.0(44) | 1.08(24) | 0.42(33) | 16.4(0) |

Independent variable for Model_1 is the main effect of type of variety, season and period of harvesting in weeks after emergence; Model_2 is main effect of type of variety; Model_3 is main effect of season; Model_4 is main effect of period of harvesting in weeks after emergence; and Model_5 is interaction factors of type of variety, season and period of harvesting in weeks after emergence.

Seasonal variation had no significant (p<0.05) effect on the nutrient and antinutrient composition of the cowpea leaves. With increasing longevity of the period for harvesting of the cowpea leaves, the crude fiber of the leaves increased whereas the protein content decreased (Figure 6.1). The Kunde mboga variety of cowpea leaves had the highest content of crude fiber, crude protein and moisture as shown in Figure 6.2. The interaction of the factors, did not significantly (p>0.05) affect the proximate composition of the cowpea leaves save for crude fiber content. Whereas at 4 and 8 WAE, the crude fiber content in Machakos 66 was higher, at 12 WAE the fiber content in Kunde Mboga variety was higher (p<0.05), see Figure 6.3.

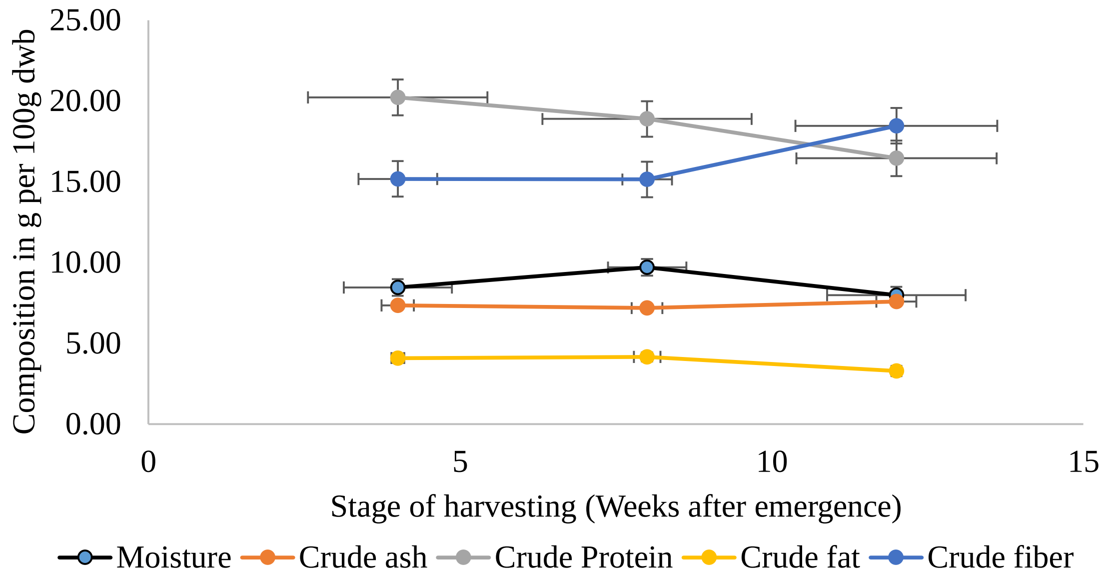


**Figure 6.1: Effect of stage of harvesting on the proximate composition of cowpea leaves.** Moisture is in fresh weight basis.

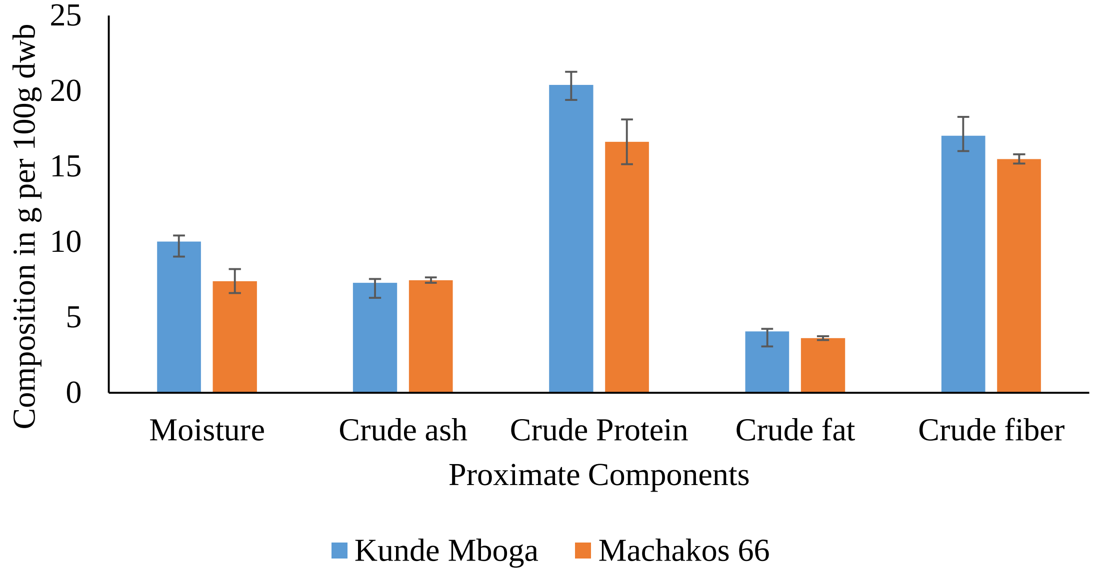


**Figure 6.2: Effect of variety on the proximate composition of the leaves. The bars indicate standard error of the means.**

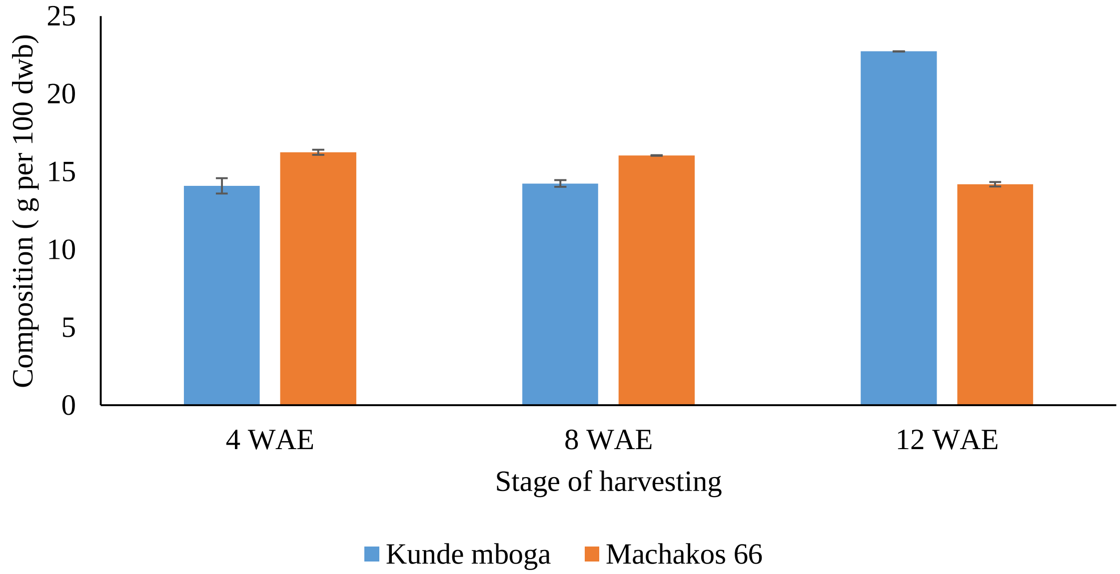


**Figure 6.3: Effect of the interaction between crop variety and the stage of harvesting (weeks after emergence) on the crude fiber content of the leaves. The bars indicate standard error of the means.**

The beta-carotene, sodium and calcium contents were significantly ($p<0.001$) higher in the Kunde Mboga variety than the Machakos 66 (Table 6.8). Beta-carotene was significantly ($p<0.001$) higher in cowpea leaves harvested at 8 WAE than both at 4 and 12 WAE. Zinc and calcium contents increased with increasing stage of harvesting in WAE, whereas sodium content decreased ($p<0.05$). Flavonoids and total phenolics contents were significantly ($p<0.05$) higher in Kunde Mboga variety than the Machakos 66, see Table 6.9. With increasing period of harvesting stage, the total phenolics and flavonoids content in the leaves significantly ($p<0.001$) increased, whereas the nitrate contents decreased. Interaction of the main effects did not significantly ($p<0.05$) affect the micronutrient nor the antinutrient contents of the leaves except for the zinc content. The zinc content in the leaves harvested from Machakos 66 decreased over lengthened period of stage of harvesting whereas that in Kunde Mboga variety increased (Figure 6.4).

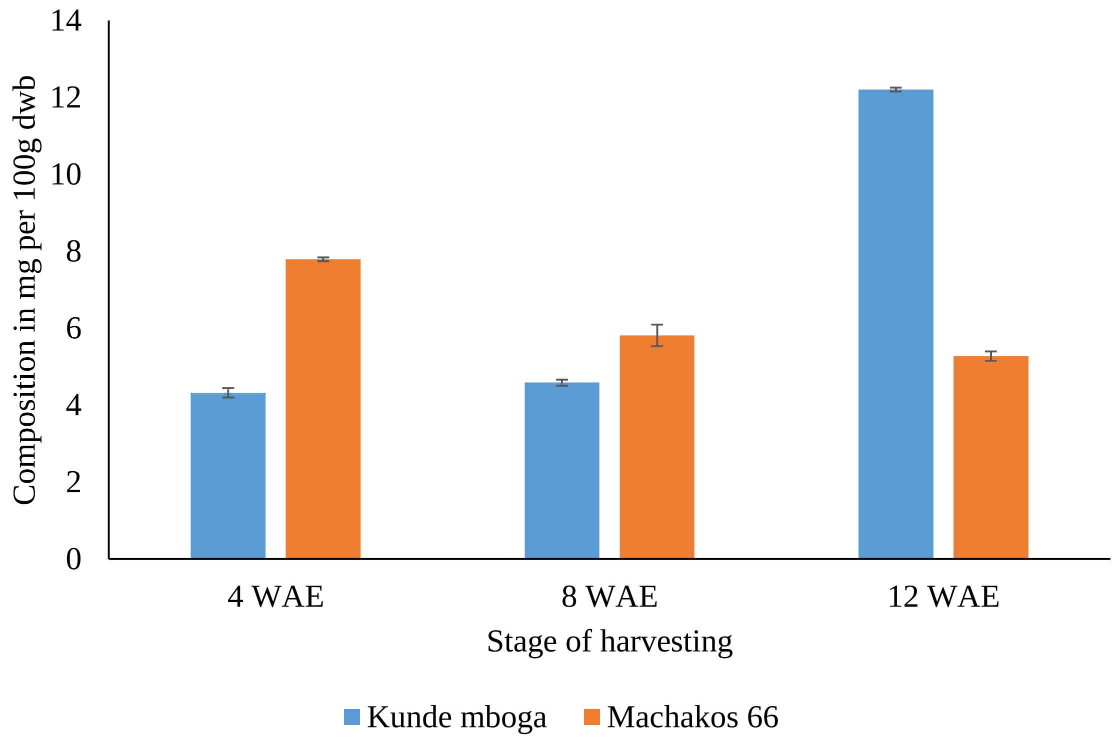


**Figure 6.4: Effect of the interaction between crop variety and the stage of harvesting (weeks after emergence) on the zinc content of the leaves. The bars indicate standard error of the means.**

**Table 6.8: Main effect crop variety and stage of harvesting on the micronutrient content of cowpea leaves**

| Independent variable | | Micronutrient (per 100 g dwb) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Beta carotene (mg) | Ascorbic acid (mg) | Zinc (mg) | Iron (mg) | Sodium (mg) | Calcium (mg) |
| Crop variety | Kunde mboga | $17.81 \pm 1.06^{Aa}$ | $64.02 \pm 57.63^{Aa}$ | $7.04 \pm 3.83^{Aa}$ | $26.79 \pm 10.68^{Aa}$ | $58.74 \pm 10.59^{Aa}$ | $40.95 \pm 30.84^{Aa}$ |
| | Machakos 66 | $14.78 \pm 1.49^{Ab}$ | $82.37 \pm 24.54^{Aa}$ | $6.29 \pm 1.30^{Aa}$ | $27.30 \pm 10.35^{Aa}$ | $12.21 \pm 3.59^{Ab}$ | $16.67 \pm 8.77^{Ab}$ |
| %CV | | 7.93 | 60.5 | 42.9 | 38.9 | 22.3 | 78.7 |
| HSD | | 1.09 | 37.5 | 2.42 | 8.9 | 6.7 | 19.1 |
| p-value | | <0.001 | 0.321 | 0.53 | 0.906 | <0.001 | 0.016 |
| Stage of harvesting (WEA) | 4 | $16.04 \pm 1.85^{Bb}$ | $89.01 \pm 53.99^{Ba}$ | $6.06 \pm 1.89^{Bab}$ | $23.62 \pm 6.80^{Ba}$ | $42.79 \pm 1.81^{Ba}$ | $15.51 \pm 6.34^{Bb}$ |
| | 8 | $17.84 \pm 1.36^{Ba}$ | $55.42 \pm 8.51^{Ba}$ | $5.20 \pm 1.01^{Bb}$ | $29.81 \pm 9.27^{Ba}$ | $33.56 \pm 0.36^{Bb}$ | $15.98 \pm 5.05^{Bb}$ |
| | 12 | $15.00 \pm 1.76^{Bb}$ | $75.15 \pm 5.55^{Ba}$ | $8.74 \pm 3.72^{Ba}$ | $27.71 \pm 13.89^{Ba}$ | $30.07 \pm 2.97^{Bb}$ | $54.93 \pm 9.74^{Ba}$ |
| %CV | | 7.93 | 60.5 | 42.9 | 38.9 | 22.3 | 78.7 |
| HSD | | 1.56 | 56.6 | 3.4 | 13.4 | 7.4 | 19.6 |
| p-value | | <0.001 | 0.544 | 0.058 | 0.450 | <0.001 | <0.001 |

The values represent mean ± sd. Values with similar uppercase letters followed by a different lowercase letter in the superscript are statistically different.

**Table 6.9: Main effect of crop variety and stage of harvesting on the anti-nutrient and antioxidant contents of cowpea leaves (per 100 g dwb)**

| Independent variables | | Antinutrient content and antioxidant activity per 100g dry matter basis | | | | |
|---|---|---|---|---|---|---|
| | | **Nitrates (mg)** | **Oxalates (mg)** | **Total phenolics (mg GAE)** | **Flavonoids (mg CE)** | **Total anti-oxidant activity (µM TE)** |
| Crop variety | Kunde mboga | 278.71±5.78$^{Aa}$ | 1.74±0.65$^{Aa}$ | 26.08±5.83$^{Aa}$ | 8.16±5.07$^{Aa}$ | 26.40±8.94$^{Aa}$ |
| | Machakos 66 | 429.30±72.94$^{Aa}$ | 2.16±0.60$^{Aa}$ | 15.66±1.57$^{Ab}$ | 5.90±4.05$^{Ab}$ | 21.19±5.49$^{Aa}$ |
| %CV | | 59.8 | 32.6 | 17.8 | 30.6 | 53.6 |
| HSD | | 179.8 | 0.54 | 3.2 | 1.8 | 10.8 |
| p-value | | 0.096 | 0.115 | <0.001 | 0.02 | 0.329 |
| Stage of harvesting (WEA) | 4 | 621.79±134.42$^{Ba}$ | 1.58±0.20$^{Aa}$ | 4.04±2.08$^{Ac}$ | 0.90±0.15$^{Bb}$ | 21.22±5.73$^{Ba}$ |
| | 8 | 206.24±35.22$^{Bb}$ | 2.79±0.20$^{Aa}$ | 23.15±8.58$^{Ab}$ | 9.73±1.77$^{Ba}$ | 33.94±8.90$^{Ba}$ |
| | 12 | 234.00±59.71$^{Bb}$ | 1.49±0.30$^{Aa}$ | 35.42±6.90$^{Aa}$ | 10.47±1.58$^{Ba}$ | 16.21±2.88$^{Ba}$ |
| %CV | | 59.8 | 32.6 | 17.8 | 30.6 | 53.6 |
| HSD | | 266.9 | 0.80 | 4.7 | 2.7 | 16.1 |
| p-value | | 0.001 | 0.770 | <0.001 | <0.001 | 0.441 |

The values represent mean ± sd. Values with similar uppercase letters followed by a different lowercase letter along the same column in the superscript are statistically different.

### 6.3.2.2 Nutrient composition of optimally processed cowpea leaves

Whereas the fermented dehydrated vegetables had significantly ($p<0.001$) increased contents of the crude ash, the blanched dehydrated vegetables had minimal reduction in the crude ash content as compared to the fresh leaves (Table 6.10). The fibre contents in the fermented dehydrated significantly ($p<0.001$) declined whereas the moisture content significantly ($p<0.001$) increased. Oven-drying techniques achieved the least content for moisture of all the dehydration techniques ($p<0.001$).

**Table 6.10: Proximate composition of optimally dried cowpea leaves (per 100 g dwb)**

| Processing technique | Moisture (g) | Crude protein (g) | Crude fat (g) | Crude fibre (g) | Crude ash (g) | Carbohydrates (g) | Energy value (kcal) |
|---|---|---|---|---|---|---|---|
| A | $5.4±0.2^{e}$ | $16.5±0.5^{c}$ | $4.0±0.1^{cd}$ | $14.6±0.1^{d}$ | $8.7±0.0^{c}$ | $55.4±0.5^{a}$ | $326.77±0.12^{b}$ |
| B | $6.8±0.8^{d}$ | $14.3±0.2^{d}$ | $4.0±0.0^{de}$ | $20.4±0.4^{b}$ | $6.1±0.1^{d}$ | $55.0±0.4^{ab}$ | $313.58±0.85^{c}$ |
| C | $6.5±0.5^{d}$ | $20.1±0.2^{a}$ | $4.7±0.5^{bc}$ | $17.4±0.8^{c}$ | $6.3±0.1^{d}$ | $52.1±1.3^{c}$ | $329.14±1.05^{a}$ |
| D | $6.6±0.2^{d}$ | $17.6±0.1^{b}$ | $3.7±0.1^{de}$ | $13.7±0.0^{e}$ | $16.1±0.2^{b}$ | $48.9±0.0^{d}$ | $299.71±0.82^{e}$ |
| E | $10.9±0.3^{c}$ | $11.4±0.3^{e}$ | $4.9±0.0^{b}$ | $12.6±0.0^{f}$ | $18.1±0.0^{a}$ | $53.0±0.1^{bc}$ | $301.99±0.10^{e}$ |
| F | $13.1±0.2^{b}$ | $15.8±0.2^{c}$ | $5.8±0.4^{a}$ | $14.5±0.5^{de}$ | $16.1±0.5^{b}$ | $47.5±1.3^{d}$ | $306.16±1.51^{d}$ |
| G | $87.3±0.1^{a}$ | $20.7±0.7^{a}$ | $3.4±0.2^{e}$ | $22.7±0.1^{a}$ | $8.4±0.3^{c}$ | $45.0±0.9^{e}$ | $292.57±0.07^{f}$ |
| %CV | 16.9 | 18.4 | 47.2 | 19.1 | 17.0 | 1.6 | 26.7 |
| HSD | 0.92 | 0.85 | 0.57 | 0.86 | 0.54 | 2.3 | 2.3 |
| p-value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

The values are mean ± sd of duplicates. Values with different superscript along the same column are statistically different. A-Blanched oven-dried, B-Blanched sundried, C-Blanched Solar-dried, D-Fermented oven-dried, E-Fermented sundried, F-Fermented Solar-dried and G-Fresh leaves. Moisture content is not in dry weight basis (dwb).

Use of sun-drying techniques significantly ($p<0.001$) reduced the beta-carotene (66.7-80.1%) and ascorbic acid contents (53.7-58.3%), see Table 6.11. Hurdle technology combining fermentation and sun-drying had the least retention of beta-carotene (19.8%) and ascorbic acid (41.7%). Combining dehydration techniques with fermentation resulted in reduction in iron and zinc contents in the vegetables as compared to those combining dehydration with blanching. On the other hand, the sodium content of all the dehydrated leaves combining fermentation as a pretreatment were relatively high, more than even the fresh vegetables ($p<0.001$).

Incorporating fermentation in the processing of dehydrated cowpea leaves, significantly ($p<0.001$) reduced the antinutrient contents of the leaves (Table 6.12). The nitrates followed by the oxalates had the highest decline when fermentation techniques were incorporated in the processing. The changes on the quality attributes due to the use of hurdle technology in processing also resulted in physical changes in product quality. Whereas all dehydration techniques induced deterioration of the colour of the preserved samples, sun-dried samples processed through hurdle technology had the highest deviation ($p<0.001$), see Table 6.13.

**Table 6.11: Micronutrient composition of optimally processed cowpea leaves (mg/100 g dwb)**

| Processing technique | Beta-carotene | Ascorbic acid | Zinc | Iron | Calcium | Sodium |
|---|---|---|---|---|---|---|
| A | $22.65\pm0.06^{a}$ | $136.00\pm1.88^{b}$ | $8.90\pm2.42^{b}$ | $17.07\pm3.31^{ab}$ | $14.12\pm4.00^{b}$ | $19.95\pm4.00^{c}$ |
| B | $7.34\pm0.03^{f}$ | $76.83\pm0.60^{c}$ | $6.54\pm0.28^{bc}$ | $25.99\pm8.44^{a}$ | $19.84\pm2.06^{b}$ | $15.81\pm2.06^{c}$ |
| C | $16.80\pm0.05^{c}$ | $51.06\pm0.19^{e}$ | $13.91\pm0.86^{a}$ | $23.03\pm10.58^{ab}$ | $19.75\pm2.19^{b}$ | $15.85\pm2.19^{c}$ |
| D | $13.41\pm0.00^{e}$ | $38.82\pm0.06^{f}$ | $2.20\pm0.63^{de}$ | $8.17\pm4.09^{b}$ | $19.08\pm1.55^{b}$ | $102.12\pm1.55^{a}$ |
| E | $4.38\pm0.11^{g}$ | $69.27\pm0.87^{d}$ | $1.35\pm0.37^{e}$ | $14.15\pm3.50^{ab}$ | $17.15\pm3.50^{b}$ | $87.51\pm3.50^{a}$ |
| F | $15.21\pm0.07^{d}$ | $75.46\pm0.85^{c}$ | $5.26\pm1.12^{cd}$ | $9.07\pm2.69^{b}$ | $16.38\pm2.14^{b}$ | $94.52\pm5.14^{a}$ |
| G | $22.06\pm0.04^{b}$ | $165.97\pm0.11^{a}$ | $13.51\pm1.34^{a}$ | $22.65\pm0.52^{ab}$ | $46.29\pm4.72^{a}$ | $27.90\pm4.72^{c}$ |
| %CV | 41.1 | 69.7 | 64.2 | 84.4 | 30.3 | 55.5 |
| HSD | 0.1666 | 2.46 | 3.37 | 16.0 | 9.91 | 20.2 |
| p-value | <0.001 | <0.001 | <0.001 | 0.009 | <0.001 | <0.001 |

The values are mean ± sd of duplicates. Values with different superscript along the same column are statistically different. A-Blanched oven-dried, B-Blanched sundried, C-Blanched Solar-dried, D-Fermented oven-dried, E-Fermented sundried, F-Fermented Solar-dried and G-Fresh leaves.

#### 6.3.2.3 Colour changes and phytochemical composition of optimally dried cowpea leaves

All the optimally processed leaves were green except for the fermented vegetables that had discolouration of the green colour, a positive value for L* (Table 6.13). The largest deviation in colour existed in the sundried vegetables ($\Delta E=22.0$, $p<0.001$).

**Table 6.12: Anti-nutrient and phytochemical content of optimally processed cowpea leaves (100 g dwb)**

| Processing technique | Nitrates (mg) | Oxalates (mg) | Total phenolics (mg GAE) | Flavonoids (mg CE) | Anti-oxidant activity (mg TE) |
|---|---|---|---|---|---|
| A | 232.89±31.40$^{c}$ | 274.85±8.78$^{a}$ | 43.36±6.30$^{ab}$ | 9.78±0.25$^{ab}$ | 37.18±3.12$^{a}$ |
| B | 303.31±22.63$^{b}$ | 106.44±1.07$^{d}$ | 44.96±2.20$^{ab}$ | 9.38±0.08$^{ab}$ | 36.09±1.98$^{a}$ |
| C | 218.40±3.48$^{c}$ | 215.73±3.82$^{b}$ | 44.69±2.72$^{ab}$ | 10.31±0.32$^{a}$ | 36.07±0.94$^{a}$ |
| D | 180.54±38.74$^{c}$ | 128.04±7.76$^{cd}$ | 36.13±0.08$^{bc}$ | 8.27±0.83$^{b}$ | 38.08±0.63$^{a}$ |
| E | 181.60±4.83$^{c}$ | 116.55±15.37$^{cd}$ | 28.93±5.06$^{c}$ | 9.83±0.57$^{ab}$ | 44.10±8.31$^{a}$ |
| F | 181.60±4.83$^{c}$ | 137.12±4.88$^{c}$ | 31.71±0.12$^{c}$ | 9.00±1.01$^{ab}$ | 34.66±4.36$^{a}$ |
| G | 760.00±34.29$^{a}$ | 217.92±6.60$^{b}$ | 48.42±5.35$^{a}$ | 9.97±0.01$^{ab}$ | 38.86±0.91$^{a}$ |
| %CV | 36.4 | 72.5 | 80.4 | 5.9 | 26.3 |
| HSD | 68.5 | 22.5 | 10.9 | 1.6 | 22.4 |
| p-value | <0.001 | <0.001 | <0.001 | 0.010 | 0.840 |

The values are mean ± sd of duplicates. The values are mean ± sd of duplicates. Values with different superscripts in the same column are statistically different. A-Blanched oven-dried, B-Blanched sundried, C-Blanched Solar-dried, D-Fermented oven-dried, E-Fermented sundried, F-Fermented Solar-dried and G-Fresh leaves.

**Table 6.13: Colour changes of optimally processed cowpea leaves**

| Processing technique | L* | a* | b* | C | H | ΔE |
|---|---|---|---|---|---|---|
| A | 39.28±3.21$^{ab}$ | -2.54±0.02$^{c}$ | 7.12±0.03$^{a}$ | 7.56±0.03$^{ab}$ | 109.60±0.09$^{a}$ | 16.62±1.95$^{b}$ |
| B | 37.77±3.46$^{b}$ | -0.11±0.14$^{bc}$ | 1.93±0.70$^{a}$ | 1.94±0.71$^{b}$ | 92.53±2.73$^{cd}$ | 22.05±1.49$^{a}$ |
| C | 38.35±0.03$^{b}$ | -0.25±0.40$^{bc}$ | 3.30±1.37$^{a}$ | 3.33±1.34$^{b}$ | 96.33±7.63$^{bc}$ | 20.48±0.92$^{a}$ |
| D | 50.13±6.17$^{a}$ | 0.80±0.35$^{ab}$ | 6.16±0.34$^{a}$ | 6.22±0.29$^{ab}$ | 82.51±3.58$^{d}$ | 15.35±0.27$^{b}$ |
| E | 37.77±3.46$^{b}$ | -0.11±0.14$^{bc}$ | 1.93±0.70$^{a}$ | 1.94±0.71$^{b}$ | 92.53±2.73$^{cd}$ | 22.05±1.49$^{a}$ |
| F | 50.13±6.17$^{a}$ | 0.80±0.35$^{ab}$ | 6.16±0.34$^{a}$ | 6.22±0.29$^{ab}$ | 82.51±3.58$^{d}$ | 15.35±0.27$^{b}$ |
| G | 26.94±2.38$^{b}$ | -3.84±3.06$^{a}$ | -10.22±5.64$^{b}$ | 11.06±6.04$^{a}$ | 105.70±0.02$^{ab}$ | NA |
| %CV | 40.1 | 42.3 | 95.4 | 43.4 | 73.4 | 66.8 |
| HSD | 11.35 | 3.30 | 6.2 | 6.1 | 10.47 | 3.40 |
| p-value | <0.001 | <0.001 | <0.001 | 0.003 | <0.001 | <0.001 |

The values are mean ± sd of duplicates. The values are mean ± sd of duplicates. Values with different superscripts in the same column are statistically different. A-Blanched oven-dried, B-Blanched sundried, C-Blanched Solar-dried, D-Fermented oven-dried, E-Fermented sundried, F-Fermented Solar-dried and G-Fresh leaves. Fresh vegetables were the control.

### 6.3.3 Comparative characterization of retention of physico-chemical quality of optimally and traditional processed cowpea leaves

The correlation maps generated through principal component analysis for nutrient composition of locally processed cowpea leaves showed that with limited retention of beta-carotene content, the anti-oxidant activity and crude protein content also deteriorate (Figure 6.5). Additionally, utilization of techniques that improved the retention of the minerals (sodium, calcium, zinc and iron), aggravated the losses for antioxidant activity and beta-carotene. Similarly, the optimally processed cowpea leaves had higher retention of crude protein with improving retention of beta-carotene (Figure 6.6). The loss of the minerals was not aggravated with the use of processing techniques that improved the retention of beta-carotene.

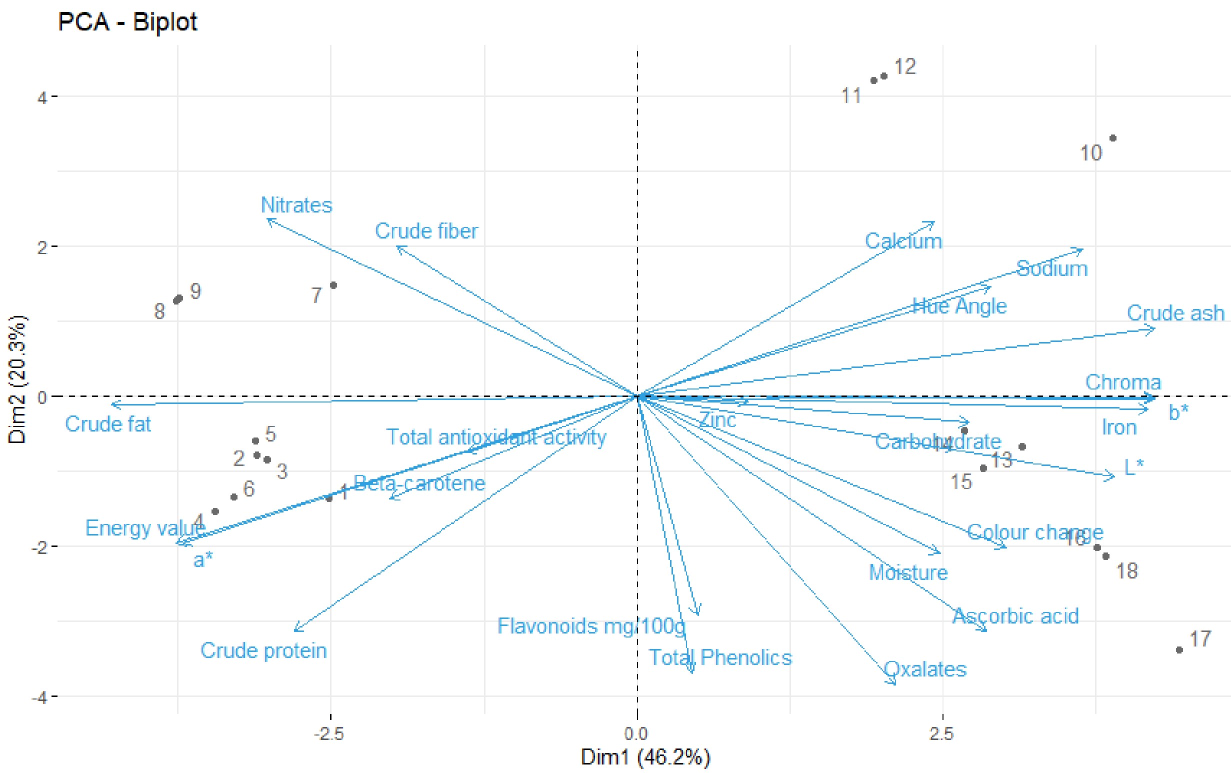


**Figure 6.5: Principle component analysis of physico-chemical quality of locally processed cowpea leaves**

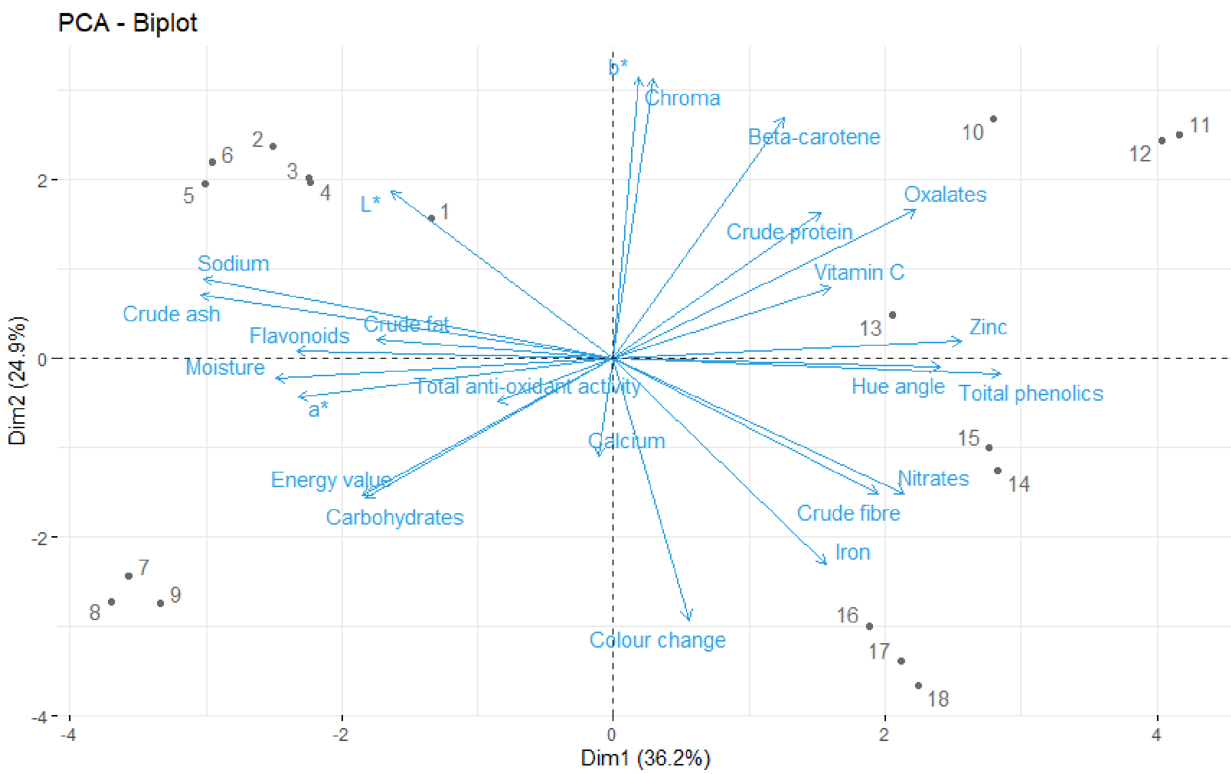


**Figure 6.6: Principal component analysis of nutrient retention and trends in optimally processed cowpea leaves**

## 6.4 Discussion

### 6.4.1 Physico-chemical qualities of traditional processed cowpea leaves

Whereas the Kenyan standard for dehydrated vegetables stipulate that moisture content for finished products be maintained at below 8% (KEBS, 2018), dried samples utilized and consumed in the communities have higher moisture levels as established in this study. However, some specific standards including for dehydrated products in similar categorization have had moisture levels revised to be permitted up to 15% (East African Community, 2018). The moisture content established in this study was within the range for documented studies by Owade et al. (2020a). It is imperative to maintain moisture below the 15% in order to prevent quality deterioration occasioned by microbial growth due to less optimal moisture contents (Chitrakar et al., 2018). Hag et al. (2020) established a critical limit of ≤14% for the growth of microorganisms in dehydrated African leafy vegetables. A review for various studies by Owade et al. (2020a) established that dehydration has minimal impact on the crude fat, fibre, protein and ash of cowpea leaves. Results from this study are in agreement, however, crude ash had some minimal decline due top leaching of minerals as hot water blanching is the technique that was used in the processing of the vegetables. The leaching of minerals explains the decline in the sodium, iron and zinc contents in the blanched dehydrated vegetables. In her study that corroborates the findings in the current study, Chikwendu et al (2014) increasingly higher losses in iron, calcium and sodium with blanched and sundried cowpea leaves.

The significant losses established in sundried leaves have been adduced to photo-oxidation activity catalyzed by UV-radiation (Ndawula et al., 2004). Additionally, exposure to factors such as heat that induces drying and oxygen also accelerates the oxidation both beta-carotene and ascorbic acid (Patricia D Oulai et al., 2015). Without blanching, Ndawula et al. (2004) established that the losses are aggravated. Principally, the oxidation of the two micronutrients, beta-carotene and ascorbic acid, are a pointer towards deterioration of other anti-oxidants and colour due to oxidation, with the trend increasing in the unblanched dried vegetables. However, incorporation of blanching has been adjudged to improve retention of colour with almost similar attributes to fresh products when cooked (Natabirwa et al., 2016; Nyambaka and Ryley, 2004). Moreover, blanching attenuates oxidation of the anti-oxidants thus improving the activity thereof (Kessy et al., 2016).

### 6.4.2 Optimization of the nutrient composition of harvested cowpea leaves

Promotion of cowpea leaves in food security initiative hinges on its rich micronutrient and phytochemical composition (Enyiukwu et al., 2018a). Optimizing the period of maturity for cowpea leaves focuses on high retention of micronutrients whereas the anti-nutrient content be minimized in content. In this study, with increasing period of growth, the cultivated vegetables accumulated more antinutrients, whereas the trend does not occur in exact similarity with the micronutrients and protein content. Kirigia et al. (2018) in his study found that for Tumaini variety (dual purpose variety), the secondary metabolites of total phenolics increased with increasing period of maturity. He however reported, a decline in the flavonoid content with increasing period of maturity coupled with variation of micronutrient content based on variety differences. This study established Kunde Mboga variety as having a richer nutritional profile for use for vegetable availability as compared to M66. With increasing period of maturity, the fiber content in cowpea leaves has been reported to increase progressively (Ohler et al., 1996). Therefore, more mature leaves tend to be tougher for consumption as vegetables (Bulyaba and Lenssen, 2019).

### 6.4.3 Physico-chemical qualities of optimally processed cowpea leaves

The use of hurdle technology (combination of two preservation techniques) in the processing of cowpea leaves seeks to minimize on the quality losses in the vegetables while improving the desirable product attributes such as sensory and textural properties (Ndawula et al., 2004; Owade et al., 2020a). Whereas fermented dehydrated products resulted in declining antinutrients, micronutrients such as beta-carotene, ascorbic acid, zinc and calcium and crude fiber decreased, the crude ash increased. In optimizing the fermentation process of cowpea leaves that were employed in this study, Owade et al. (2021) added salt (sodium chloride) at the proportion of 2% (w/w), explaining the increase in crude ash. Oboh and Madojemu (2016) in evaluating the impact of incorporating salting in dehydration processes for enhanced preservation, established that beta-carotene, ascorbic acid, zinc and iron contents decreases whereas sodium, calcium and moisture contents were relatively higher. The fermentation process with the vegetables submerged was undertaken for sixteen days, which provided more time for leaching of minerals. The resulting changes in the crude fiber content can be explained by findings by Nyman (1995) that lactic acid fermentation reduced the soluble dietary fiber. The moisture levels attained by the blanched dehydrated leaves met the stipulated legislative requirement in the Kenyan Standard of below 8% (KEBS, 2018). In contrast to the techniques utilized by the local communities in blanching the vegetables, the optimal processing employed steam blanching to minimize nutrient leaching. However, leaching of the minerals in fermentation process was still noticeable, for the process took 16 days. Sun-drying as a dehydration technique in optimal processing still had the pronounced disadvantage of more pronounced degradation of beta-carotene, vitamin C and colour than other techniques. This is a proof of the less preference of sun-drying as a technique of maximizing product quality and minimizing deterioration of dehydrated vegetables.

#### 6.4.4 Comparative characterization of retention of physico-chemical quality of optimally and traditional processed cowpea leaves

The complementary effort in hurdle technology in preservation of cowpea leaves, should seek to improve the retention of the micronutrient contents, whereas minimizing deterioration of physical properties such as colour changes. Essentially, dehydrated vegetables should have closer similarity to the fresh vegetables when cooked in order to enhance consumer acceptability of these preserved forms. In finding the acceptability of blanched solar dried leaves as the highest in the evaluation of the impact of preservation techniques on sensory attributes, deterioration of textural properties and colour was minimized by Natabirwa et al. (2016). Artisanal techniques that employ the use of sun-drying dehydration techniques excluding blanching as a pretreatment, results in alteration both in textural and colour properties (Nyembe, 2015). Blanching has been found to attenuate deterioration of anti-oxidants and colour, thus the exclusion has the demerit of product deterioration. Moreover, the use of the hot-water blanching as in the case of traditional processing has the disadvantage of leaching of minerals as compared to steam blanching used in mechanized techniques (Kirakou et al., 2017). Limited leaching of minerals coupled with attenuation of labile nutrients such as bet-carotene improve the nutrient retention.

## 6.5 Conclusion

This study concludes that the mix of techniques utilized in traditional preservation of cowpea leaves lack the balance in the trends of retention of essential nutrients in the products. The incorporation of mechanized techniques introduces a balance and attenuates losses of these essential micronutrients. Even so, this may not be sufficient enough to be dismissive of the traditional processing techniques as a means of improving vegetable availability in the households for the vegetables still had significant amounts of beta-carotene, zinc and iron some of the micronutrients whose deficiencies are prevalent in Africa. This study thus recommends that initiatives promoting the utilization of similar traditional techniques of preservation evaluated in this study, should co-opt some of the low-cost pretreatments such as steam blanching and fermentation in order to improve the nutritional quality of the products.

# CHAPTER SEVEN: A BENEFIT-COST ANALYSIS APPROACH FOR DETERMINATION OF OPTIMAL PROCESSING OF MICRONUTRIENT-ENRICHED COWPEA LEAVES SOUP MIXES


**Abstract**

In dissemination and adoption of postharvest processing technologies of food products, cost-effective techniques are usually recommended. Due to the limited value addition practices of cowpea leaves, Fruits and Vegetables for All Seasons Project undertook a study to bridge the gap of seasonality in the availability of the vegetable in arid and semi-arid lands (ASALs) of Kenya through production of cowpea leaves soup mix. However, the adoption of these techniques has an economic perspective that guides the decision-making. This study utilized a two-step methodology of the linear programming using Nutri-Survey and Analytic Hierarchy Process in a seven-step hierarchy for the production of optimal nutrition quality and consumer acceptability cowpea leaves soup mix. Optimal inclusion level of cowpea leaves into the soup mix was found to be 49%. With an $R^2$ of 61.36%, consistency, taste and mouthfeel were greatest determinants of the acceptability of cowpea leaves soup mixes. Blanching and solar drying only and blanching and sun-drying only were the least cost options with priority vectors of 0.08 and 0.09 (CR<0.1), respectively whereas use of mechanized processing techniques had higher maximum benefits with oven drying yielding priority vectors of 0.10-0.19, compared to local processing technique of sun-drying that had a priority vector of 0.08 (CR<0.1). The benefit-cost ratio was maximum without extrusion, with solar-drying pathway having the highest benefit-cost ratio of 1.5. The study found that the resource intensive pathways were not necessarily yielding maximum benefits. However, with the exclusion of extrusion, the benefit-cost ratio of the processes improved.

## 7.1 Introduction

In attaining food and nutrition security among the vulnerable populations, cost effective strategies have proven the most successful (Bizikova et al., 2017; Pearson-Stuttard et al., 2018). Resulting from sub-optimal nutrition, the low-income earning households have disproportionately higher incidences of nutrition-related health burdens (Mozaffarian et al., 2018). Diet diversification and food fortification programmes are some of the recommended nutrition interventions being undertaken in the resource constrained sub-Saharan African (SSA) countries. The effort in promoting such techniques is due to the cost effectiveness. Additionally, in addressing vulnerability to food and nutrition insecurity, five case scenarios are recommended: (1) increase food production; (2) reduce on farm losses; (3) achieve optimal yields; (4) reduce postharvest losses; and (5) reduce alternative uses of food such as in production of animal feed and biofuels (Denkenberger and Pearce, 2016). The recommended case scenarios differ in adoptability due to the cost implications. Moreover, the ever increasing global demand for food has further increased the demand for appropriate interventions that would deliver food of the right quality and quantity (Amit et al., 2017).

Value addition techniques are co-opted in the food systems to address postharvest losses and to improve quality, thus acceptability of produce (Njoroge et al., 2016). Value addition techniques including dehydration and fermentation form part of most important processing methods used in addressing postharvest losses in the cowpea leaves value chains (Owade et al., 2020a). These techniques differ in efficiency in improving product quality such as nutrient retention and colour retention. Okello et al. (2015), in their study established that most of the consumers attached no additional value to processed cowpea leaves. Thus, the need to develop additional cost-effective techniques that maximize positive product qualities. Artisanal techniques such as sun-drying have often been adduced as the weakest links in processing towards promoting product quality (Owade et al., 2020a). In departure from these techniques, modern food products are developed using low-cost processing technology; achieving higher product quality while minimising the deleterious effects.

Economic evaluation of production techniques is co-opted in order to guide on decision-making towards adoption of an initiative aimed at addressing existent challenges while minimizing the costs (WHO, 2011). Through Choosing Interventions that are Cost-Effective (CHOICE) project, the World Health Organization promotes the utilization of initiatives with maximum outcomes per unit cost (WHO and FAO, 2006). Processing of cowpea leaves can utilize multiple pathways with varied levels of nutrient retention and cost-implication (Ddungu et al., 2015; Okello et al., 2015; Owade et al., 2020a); there is however, need for economic evaluation of the recommended pathways in realizing the targeted benefits. Analytic hierarchy process (AHP) is a multi-criteria decision analysis (MCDA) used by decision makers, from the small-scale processors to policy-makers, in constructions and solving complex decision problems (Babalola, 2020). MCDA incorporated competing goals and outputs that are of importance in decision-making such as in the processing of cowpea leaves, the optimal nutritional quality vis-à-vis the costs of the processing are taken into consideration. Vaidya and Kumar (2006) document that in selecting the best processing pathway for powdered milk, a hierarchy development that considers weight of vectors in quantitative terms is best undertaken. The tool presents a prioritization approach that best guides the best economic approach to be taken. The current study deployed the AHP-decision making approach in documenting the best pathway for addressing the challenges of limited value addition of cowpea leaves. This study narrows down on the cowpea leaves soup mixes, an output generated from value addition studies undertaken by the Fruits and Vegetables for All Seasons Project

(FruVaSe) at the University of Nairobi, Kenya. The study provides a case for evaluation of costs and benefits for decision-making in food processing initiatives for neglected crops.

## 7.2 Material and methods

### 7.2.1 Conceptual framework

The conceptual framework of the study is as summarized in Figure 7.1. A two-stage methodology, nutrient optimization and cost-optimization were undertaken. The input variables for nutrient optimization were zinc, iron and beta carotene composition of raw ingredient of cowpea leaves, coriander leaves, tomato, onion, garlic, salt and oil and the response variable was consumer acceptability. The second stage entailed the processing of the optimized ratios of ingredients using different techniques and evaluation of a combination of criteria to make a benefit-cost decision for production of cowpea leaves soup mix.

### 7.2.2 Optimization of formulations for cowpea leaves soup mixes

Ingredient formulations of cowpea leaves soup mixes were generated using the Nutri-Survey Software (NutriSurvey, 2007). Seven different formulations of cowpea leaves soup mixes were generated with a targeted nutrient composition (fresh weight) of 0.5mg/100g beta-carotene, 4mg/100g iron and 2mg/100g zinc in order to meet the minimum set threshold for product fortification (Johnson et al., 2004; Low and Jaarsveld, 2008); with capacity to provide the nutrients capable of meeting the recommended dietary allowance (RDAs) of various segments of the population for the product is targeted for general household consumption.

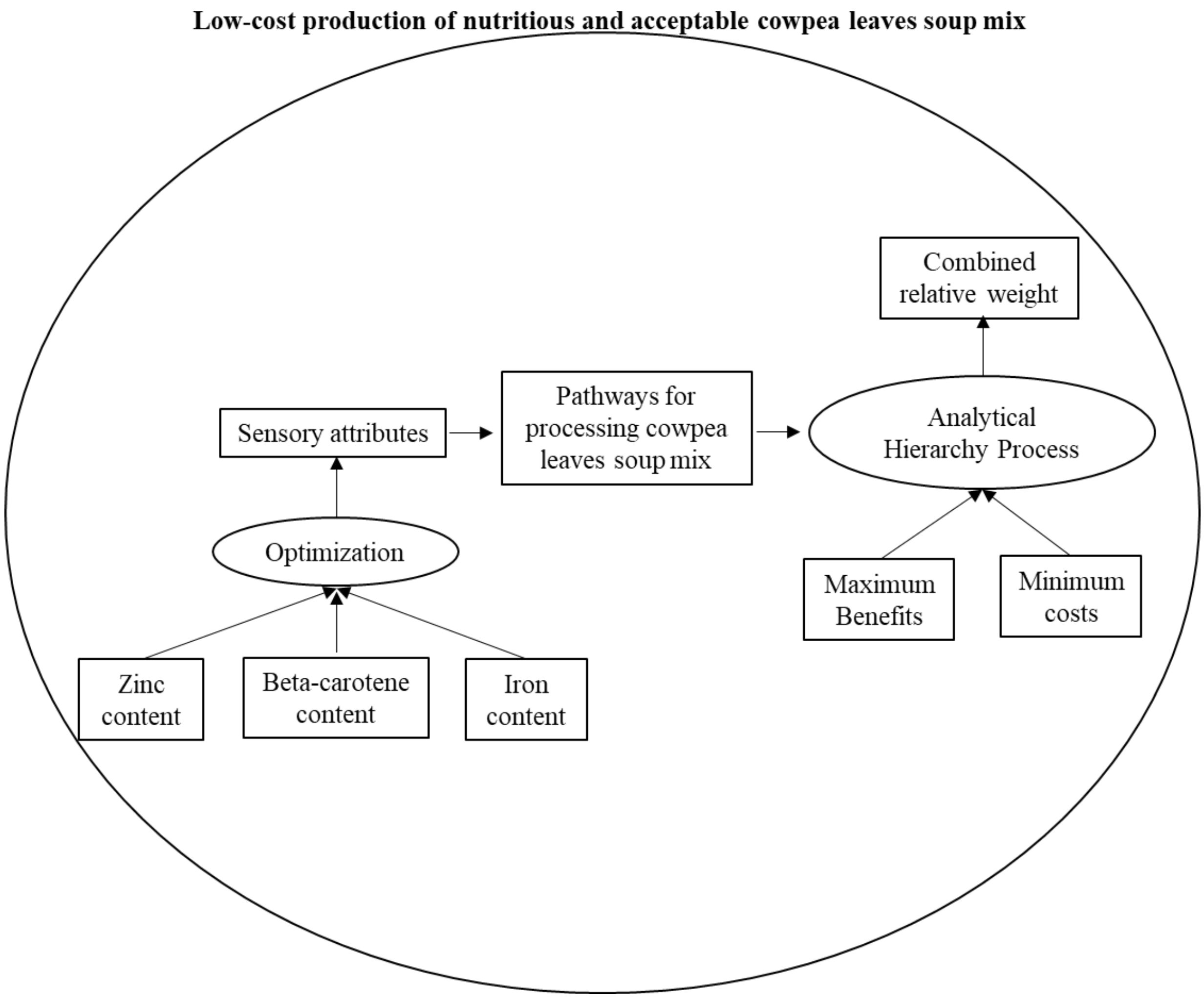


**Figure 7.1: Conceptual framework of the study**

Sensory analysis of the cooked formulations was done to establish the most optimal product formulation based on consumer acceptability. An untrained sensory panel of 32 respondents from the College of Agriculture and Veterinary Sciences, University of Nairobi comprising a mix of students and staff was used. The panellists were aged between 20 and 50 years, with the females comprising 43.75% and the males 56.25%. The formulated soup mixes were first mixed with cold water (ratio of 1:9, respectively) stirred to form consistent paste before heating to boil for the extruded whereas the non-extruded were boiled further for 5 minutes. Each of the seven different formulations of the soup mix was served hot to the panellists in a counter-current sequence for each successive panellist. A nine-point hedonic scale, ranging from 1-dislike extremely to 9-like extremely, was used to assess the attributes of each formulation; the attributes were colour, appearance, mouthfeel, texture/consistency, aroma and overall acceptability. Sensory evaluation was done in a well-lit room and the soup of about 30 ml served hot in white dish. Once the panellist had sampled one formulation, cleansing of the palate with water was done before the next sampling.

### 7.2.3 Analytical Hierarchy Process

The AHP was undertaken in a seven-step hierarchy recommended by Saaty and Vargas (2012) as shown in Figure 7.2. The decision making hierarchy has its basis on relative weights that analyse alternatives (pathways) using pairwise comparison to generate the best case scenario for cost minimization and maximization of benefits (Babalola, 2020). The priority alternative (pathway/vector) is determined based on the combined relative weights of all criteria and options (Equation 7.1).

$$AW = \boldsymbol{\lambda}_{max} W \qquad \textbf{Equation 7.1}$$

where *A* is the comparison matrix, W is the priority vectors $\boldsymbol{\lambda}_{max}$ is the principal eigen value.

Each and every decision-making criterion is subjected to evaluation based on consistency ratio (CR, shown in Equation 7.2 with computation of consistency index as shown in Equation 7.3), and thus avoid reliance on a single decision.

$$CR = \frac{CI}{RI} \qquad \textbf{Equation 7.2}$$

$$CI = \frac{\boldsymbol{\lambda}_{max} - n}{n-1} \qquad \textbf{Equation 7.3}$$

where CI is the consistency index, n is the size of the comparison matrix, RI is the random consistency index for the $n^{th}$ row generated by random pairwise comparison for a criterion.

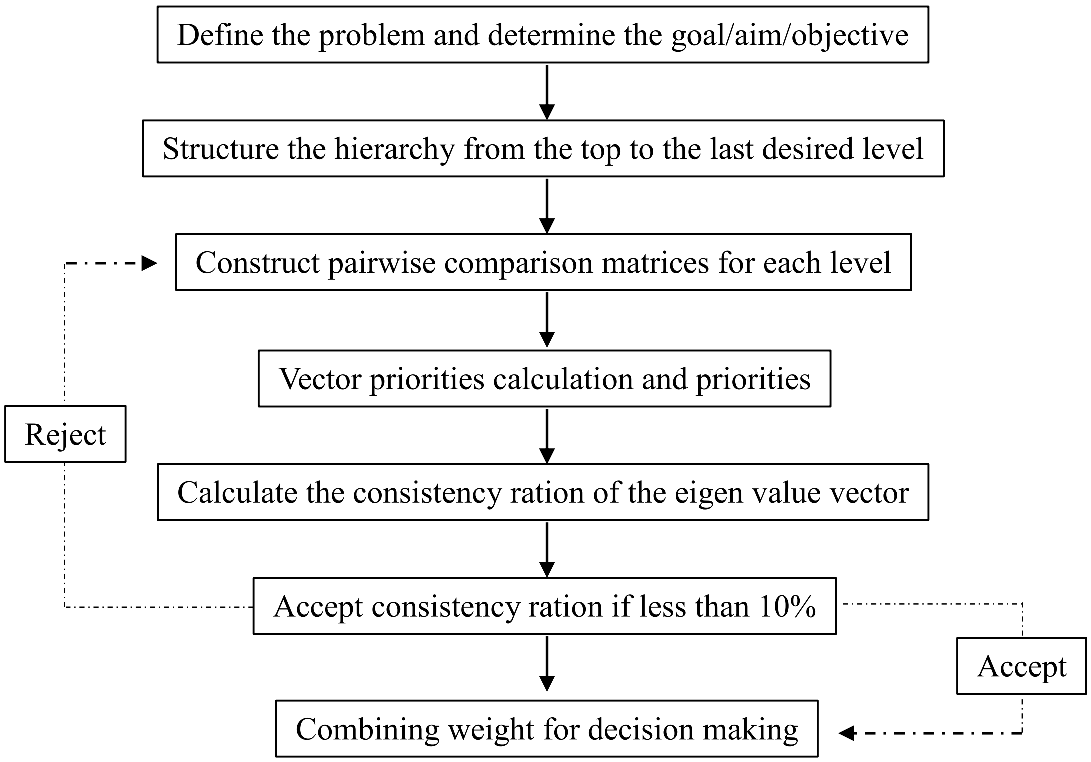


**Figure 7.2: The step-wise analytical hierarchy process.** Adapted from Saaty and Vargas (2012).

1. *Choosing alternative pathways for processing of cowpea leaves soup mix*

The most optimal ingredient ration was adopted for use in the case scenario setting for the production of cowpea leaves soup mixes using different process flows. The adopted case scenarios was adopted from a scoping study conducted by Owade et al. (2019) coupled with nutrient retention patterns established by authors (2020, unpublished data). Seven different scenarios were selected for evaluation in the processing of cowpea leaves soup mix. Optimal fermentation was achieved as per the study by Owade et al. (2021). The initial benefits and costs of each pathway are calculated before being computed into one hierarchy.

2. *Step 1: Definition and determination of the goal*

This study had the ultimate aim of achieving minimum cost of processing of cowpea leaves soup mix while maximizing on the nutrient retention and consumer acceptability of the product. Higher retention of the nutrients due to lower in-process losses during the processing of cowpea leaves and higher consumer acceptability were used to define the most optimal best practice in production of cowpea leaves soup mixes.

3. *Step 2: Identification and classification of criterion and alternative/pathways*

The identified pathways of processing of cowpea leaves were used to inform the objectives of the hierarchy setting.  From the identified seven different pathways based on nutrient retention trends as determined in Chapter Six: blanching and oven-drying combine with extrusion, blanching and oven drying only, blanching and solar-drying combined with extrusion, blanching and solar drying only, fermenting and oven-drying combined with extrusion, fermenting and oven-drying only and blanching and sun-drying only; cost analysis was done for the cost of energy, water, labour, raw material and fixed assets with a computation in United States Dollars (USD), see Figure 7.4. The derivative benefits were classified into beta-carotene, iron and zinc content, time saved and overall consumer acceptability (Figure 7.5). The quantitative ideal concept of quality for beta-carotene, iron, zinc, time saved and overall acceptability was obtained from a study by authors (2020, unpublished data).

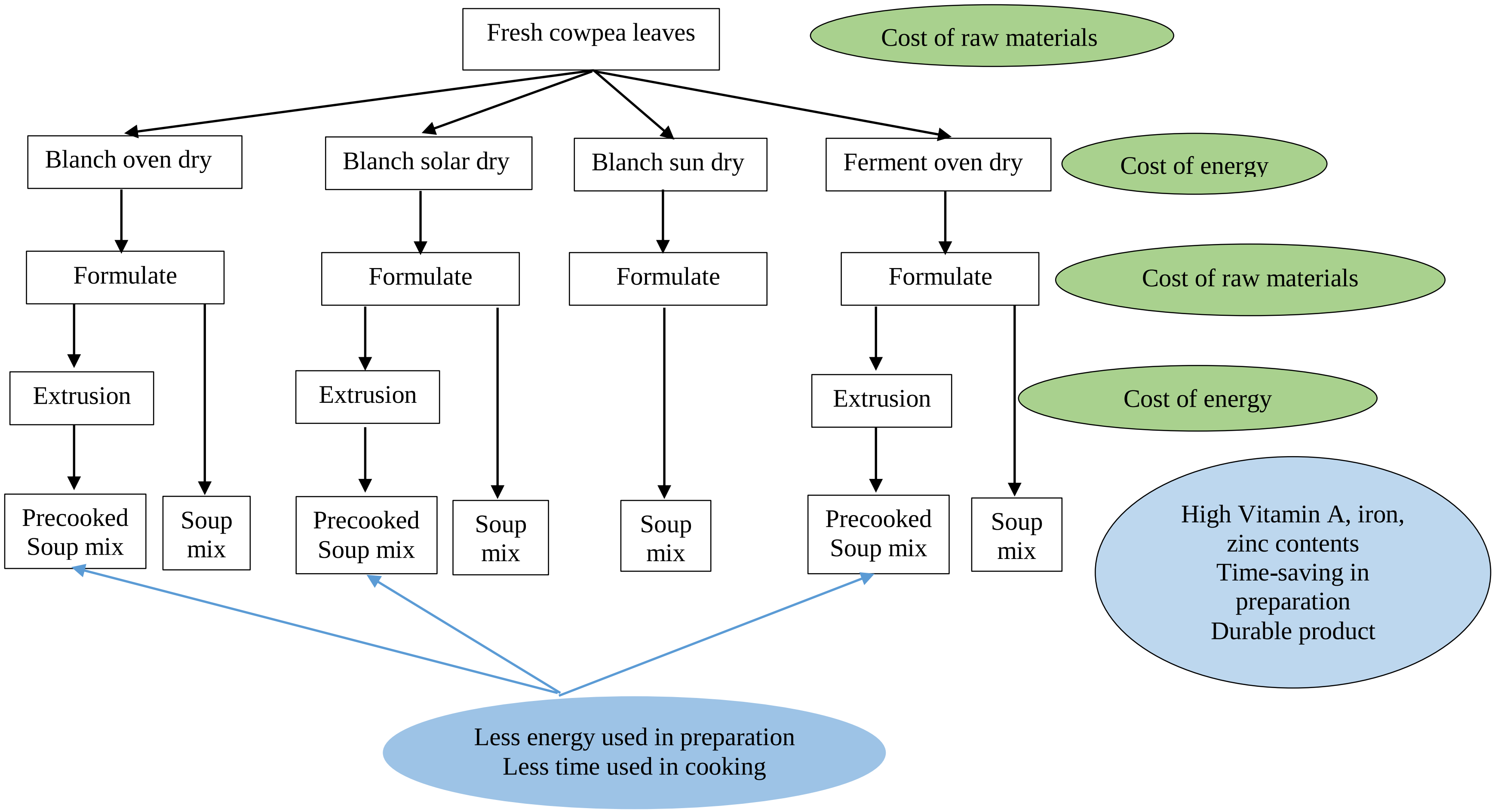


**Figure 7.3: Case-scenarios for the processing of cowpea leaves soup mix**

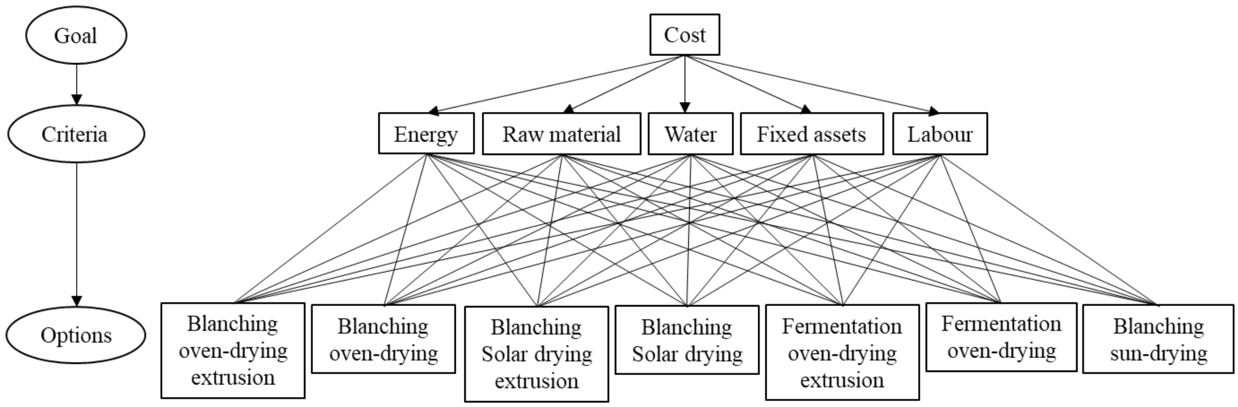


**Figure 7.4: Hierarchy structure for cost analysis**

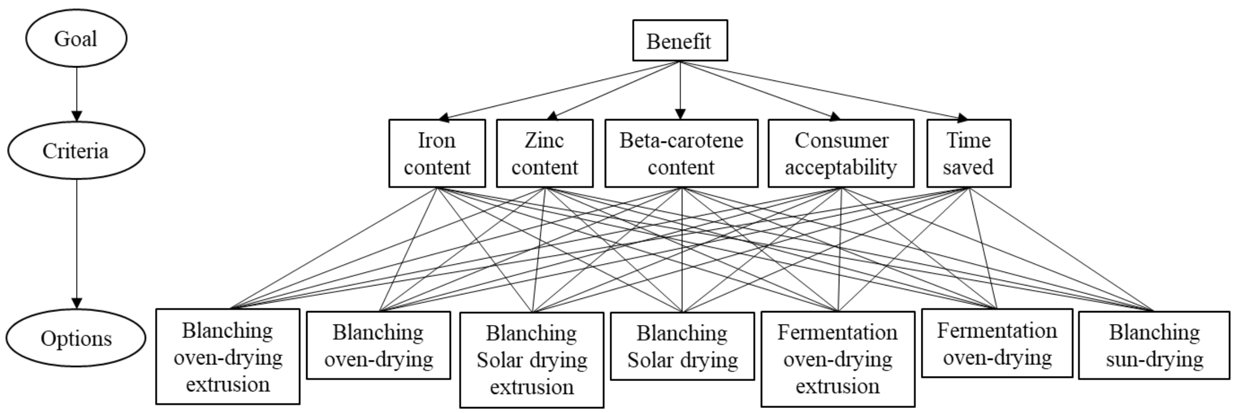


**Figure 7.5: Hierarchy structure of benefits analysis**

The cost of production of the soup mix was calculated as shown in Equation 7.4.

$$Total\ production\ cost = Variable\ costs + Fixed\ costs$$ **Equation 7.4**

The cost analysis of the cowpea leaves soup mixes subjected to various processing techniques, was done by calculating the total variable costs as described by Katanga and Haruna (2015), Equation 7.5, see Table 7.1. The variable costs incorporated cost of raw materials, energy and water used and packaging.

$$Total\ variable\ costs = cost\ of\ all\ inputs\ (ingredients)\ used\ in\ production$$

**Equation 7.5**

In calculating the fixed costs of the products, the consumption of fixed capital approach was used as shown in Equation 7.6 (FAO, 2016).

$$f(x) = p(x) - p_1(x) = D = \frac{1}{T} \qquad \textbf{Equation 7.6}$$

where *f(x)* is the fixed cost of an asset for production of a unit of product, $p(x) - p_1(x)$ denotes the change in price of a product in a given period of production (in this case the transformation was done to daily production), D is depreciation and T is the product life.

**Table 7.1: Description of cost components**

| **Cost component** | **Description** |
|---|---|
| Raw materials | Costs calculated from dried cowpea leaves $0.3, Starch $1, Dried coriander $10, Dried onions $25, Dried Garlic $33, Salt $0.3, Tomato $40 and Sugar $1.25 per kg, oil $1.5 per litre and packaging material $0.03 |
| Labour | Daily wage rate of $15 |
| Water | Calculated at $0.64 per $m^3$ |
| Energy | Calculated at $0.15 per kilowatt per hour |
| Fixed costs | Extruder (Emerson Industrial Automation, UK) at $2000, Blender (Krups, Germany) $200, Oven drier (Innotech, Australia) at $500, Electric Cooker (GE Consumer and Industrial, USA) at $660 and Solar Drier at $2,000 with an assumption of estimated life of 26 years for machinery as per Erumban (2008). |

Daily production rate of cowpea leaves for soup mix was set at 10kg except for sun drying which was 5kg.

4. *Step 3: Pairwise comparison*

In ranking of the attributes, Saaty's nine-point rating scale (Table 7.2) and the concept of ideal alternative recommended by García et al. (2010) was used in the current study in order to overcome the challenges of the reliance on the qualitative aspects only. The quantitative ratios were generated for each individual benefit whereas the comparative ranking of the components of cost was done qualitatively. In ranking the benefits of the products, the quantitative scale established in a study by Petrescu et al. (2020) on processed food products was used whereas the costs were quantitatively ranked on a nine-point scale based on their proportion in the overall production costs.

**Table 7.2: Saaty's numeric scoring scale**

| Numeric intensity | Saaty's pairwise comparison scale |
|---|---|
| 9 | Extremely favoured |
| 8 | Very strongly to extremely |
| 7 | Very strongly favoured |
| 6 | Strongly to very strongly |
| 5 | Strongly |
| 4 | Moderately to strongly |
| 3 | Moderately favoured |
| 2 | Equally to moderately |
| 1 | Equally favoured |

Adapted from Saaty (1987).

5. *Step 4: Calculation of vector priorities*

The vector priorities were calculated using the mean of normalized values approach (Ishizaka and Lusti, 2006). Summation of all ratios in a column was done as shown in Equation 7.7 for column *j*.

$$\sum_{i=1}^{n} \frac{p_1}{p_j} = \frac{p_1}{p_j} + \frac{p_2}{p_j} + \ldots + \frac{p_n}{p_j} \qquad \textbf{Equation 7.7}$$

where *p* is the ratio (qualitative or quantitative) of a benefit or cost, *i* is an alternative and ranges from 1 to n and $p_j$ is the cumulative mean of the ratios.

Normalization of the values was done as shown in Equation 7.8.

$$\frac{\frac{p_1}{p_j}}{\frac{\sum_{i=1}^{n} p_i}{p_j}} = \frac{p_1}{p_j} \cdot \frac{p_j}{\sum_{i=1}^{n} p_1} = \frac{p_i}{\sum_{i=1}^{n} p_1} \qquad \textbf{Equation 7.8}$$

The priority vector for *i* was therefore determined as shown in Equation 7.9.

$$\frac{p_i}{\sum_{i=1}^{n} p_i} = \frac{n.p_i}{\sum_{i=1}^{n} p_i} \cdot \frac{1}{n} = \left[\frac{p_1}{\sum_{i=1}^{n} p_i} + \ldots + \frac{p_i}{\sum_{i=1}^{n} p_i}\right] \cdot \frac{1}{n} \qquad \textbf{Equation 7.9}$$

6. *Step 5: Calculation of consistency ratio*

Consistency ratio is generated by dividing the consistency index by the random indices (Table 7.3).

**Table 7.3: Random indices for calculating consistency ratio**

| **n** | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 | 1.56 | 1.58 | 1.59 |

Adapted from Lin et al. (2013).

7. *Step 6: Acceptance of consistency ratio*

Consistency was defined by CR of less than 0.1 (<10%) as posited by Saaty (Saaty, 1989; Vargas, 1990). If an alternative A has CR greater than 0.1, it is an indication that the matrix falls beyond the tolerance levels and the ratio scale needs to be relooked.

8. *Step 7: Decision making*

A benefit-cost ratio was obtained with the maximum being the best pathway for production and the least being the worst case pathway (Ramlan and Qiang, 2014). Sensitivity analysis of the optimal solution was undertaken through variation of the ratios based on the standard deviations of the metrics.

## 7.3 Statistical analysis

The analysis of the sensory data was done using the Agricolae, Caret, Pls and TidyVerse Packages of the R language for Computing Software (R Core Team, 2019). The sensory data was first subjected to analysis of variance (ANOVA) test with the panellists as fixed factor and the samples as experimental factor to evaluate the mean differences in the scores of the sensory attributes. Means that were statistically different ($p<0.05$) were separated using Tukey's Honest Significant Difference (HSD) test. Principle component analysis was used to generate orthogonal principal components, reduce multi-collinearity in the generated independent variables, used to establish the linear model predicting the acceptability of the product. The data was first divided into training (80%) and test (20%) datasets using the Caret Package. The training dataset was utilised in generating the principal component regression linear model, and the validation of the model done on the test dataset. Microsoft office excel 2013 was used to compute the pairwise comparisons, consistency ratios, priority vectors and the benefit cost ratios for the AHP.

## 7.4 Results

### 7.4.1 Optimal ingredient formulation of cowpea leaves soup mixes

Seven different formulations of cowpea leaves soup mix were obtained from the nutrient composition optimization study (Table 7.4). The colour, consistency, taste, mouthfeel and overall acceptability significantly ($p<0.01$) differed among the seven different formulations (Table 7.5). Incorporating cowpea leaves at the proportion of 49% produced the most optimal product. Six principal components explained variation in the sensory attributes. All the six sensory parameters had a positive correlation with the overall acceptability of the formulations (Figure 7.6). Consistency, taste, mouthfeel and overall acceptability had the highest loading in the first principal component as shown in Table 7.6. The generated linear model explained 57.88% of the variation in the overall acceptability. The first principal component explained 57.36% of the variance in the overall acceptability and a beta-coefficient of 1.59 (Figure 7.7). Thereby consistency, taste and mouthfeel are the greatest determinants of product acceptability. Validation of the model on the test dataset showed that the model accounted for 61.36% of variation in the acceptability of the soup mixes with the root mean square error equaling to 0.91.

**Table 7.4: Formulation of cowpea leaves soup mixes**

| Ingredient | Formulations (% ingredients) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** | **F7** |
| Corn starch | 22.5 | 22 | 17 | 27 | 12 | 7 | 2 |
| Cowpea leaves | 53.5 | 55 | 60 | 49 | 65 | 70 | 75 |
| Tomato | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Onions | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Vegetable oil | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Coriander | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Salt | 3 | 2 | 2 | 3 | 2 | 2 | 2 |
| Garlic | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

**Table 7.5: Sensory profile of optimized formulation of cowpea leaves soup mixes**

| Formulation | Sensory Attributes | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Colour** | **Consistency** | **Taste** | **Mouthfeel** | **Aroma** | **Long-lasting taste** | **Overall Acceptability** |
| F1 | 5.4±1.2$^{ab}$ | 5.9±1.2$^{a}$ | 5.3±1.7$^{ab}$ | 4.9±1.5$^{abc}$ | 5.1±1.6$^{a}$ | 4.7±1.3$^{a}$ | 5.3±1.5$^{a}$ |
| F2 | 5.5±0.9$^{ab}$ | 5.3±1.7$^{ab}$ | 5.3±1.7$^{ab}$ | 5.1±1.5$^{ab}$ | 5.1±1.5$^{a}$ | 4.8±1.5$^{a}$ | 5.2±1.4$^{a}$ |
| F3 | 5.5±1.1$^{ab}$ | 5.2±1.2$^{ab}$ | 5.1±1.3$^{abc}$ | 5.0±1.1$^{abc}$ | 5.0±1.3$^{a}$ | 4.6±1.5$^{a}$ | 4.9±1.4$^{ab}$ |
| F4 | 5.9±0.9$^{a}$ | 5.8±1.2$^{a}$ | 5.5±1.4$^{a}$ | 5.4±1.5$^{a}$ | 5.3±1.5$^{a}$ | 5.1±1.5$^{a}$ | 5.4±1.6$^{a}$ |
| F5 | 5.1±1.4$^{ab}$ | 4.7±1.7$^{bc}$ | 4.0±1.9$^{c}$ | 4.3±1.8$^{bc}$ | 5.0±1.9$^{a}$ | 4.4±1.8$^{a}$ | 4.4±1.6$^{ab}$ |
| F6 | 5.2±1.3$^{ab}$ | 4.6±1.6$^{bc}$ | 4.5±1.7$^{abc}$ | 4.4±1.8$^{abc}$ | 5.1±1.3$^{a}$ | 4.3±1.7$^{a}$ | 4.3±1.4$^{ab}$ |
| F7 | 4.6±1.9$^{b}$ | 3.6±2.2$^{c}$ | 4.2±1.9$^{bc}$ | 3.9±1.8$^{c}$ | 4.7±1.7$^{a}$ | 4.4±1.3$^{a}$ | 4.1±1.9$^{c}$ |
| HSD | 0.89 | 1.12 | 1.16 | 1.1 | 1.1 | 1.0 | 1.1 |
| %CV | 23.3 | 31.0 | 33.1 | 32.7 | 29.1 | 30.7 | 31.5 |
| p-value | 0.003 | <0.001 | <0.001 | <0.001 | 0.81 | 0.226 | <0.001 |

**Table 7.6: Loading of individual sensory attributes of formulated cowpea leaves soup mixes on the seven principal components**

| Sensory attributes | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 |
|---|---|---|---|---|---|---|---|
| Colour | 0.28 | 0.26 | 0.17 | 0.40 | 0.25 | 0.78 | 0.02 |
| Consistency | 0.39 | 0.76 | 0.25 | -0.33 | 0.08 | -0.31 | 0.01 |
| Taste | 0.44 | -0.11 | -0.51 | 0.29 | 0.40 | -0.30 | 0.44 |
| Mouthfeel | 0.43 | -0.16 | -0.33 | -0.14 | 0.09 | 0.04 | -0.81 |
| Aroma | 0.33 | -0.43 | 0.72 | 0.26 | 0.12 | -0.30 | -0.08 |
| Long lasting taste | 0.36 | -0.36 | 0.06 | -0.69 | -0.06 | 0.34 | 0.37 |
| Overall acceptability | 0.39 | 0.05 | -0.10 | 0.29 | -0.86 | -0.01 | 0.09 |

PC-Principal Component

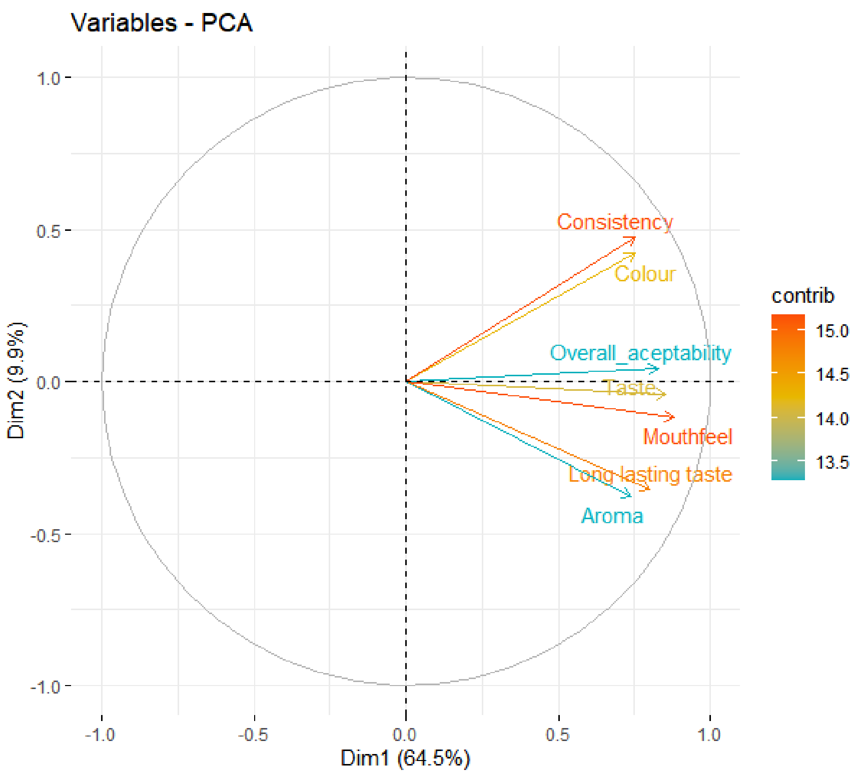


**Figure 7.6: Principal component analysis plot of sensory attributes of formulated cowpea leaves soup mixes**

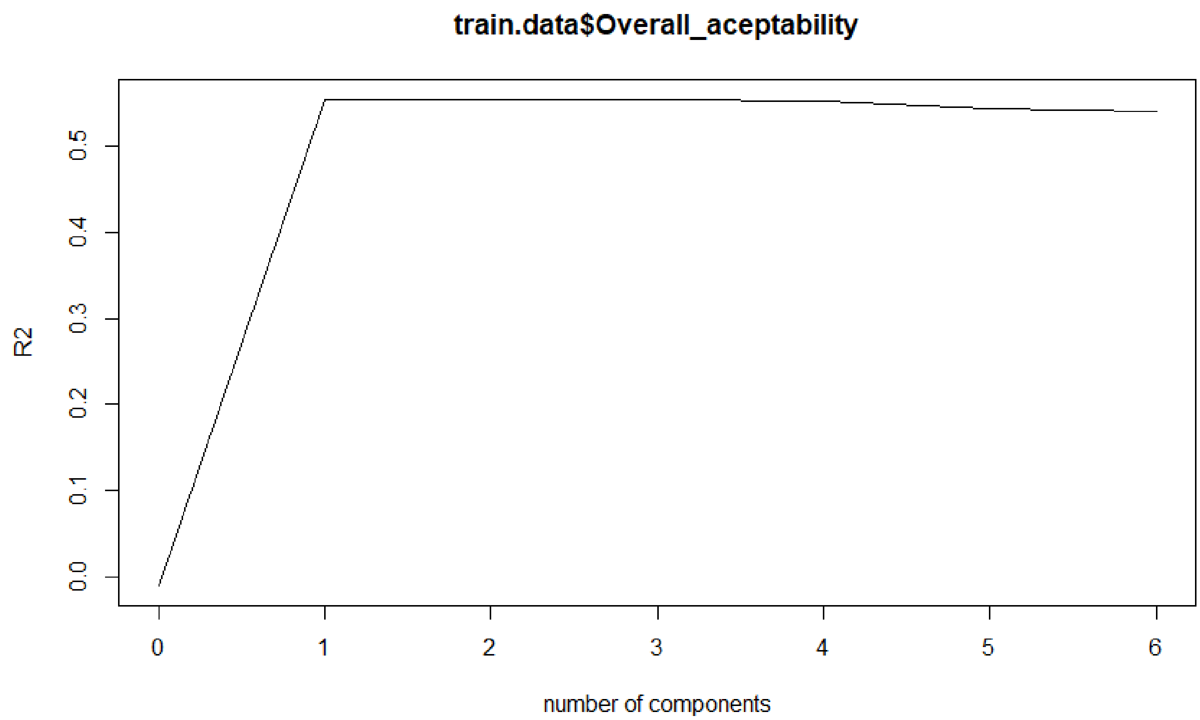


**Figure 7.7: Explained variance of acceptability of cowpea leaves soup mixes by the predictors**

## 7.5 Optimization of cost of production of cowpea leaves soup mixes

*Pairwise comparison matrices*

Pairwise comparison matrix of the benefits showed that time-saved, consumer acceptability and beta carotene content were the most preferred criterion in ranking of the benefits with a consistency ration <0.1 (Table 7.7). In terms of consumer acceptability and ease of preparation, the pathways showed no major differences in preference. The benefit of high iron, zinc and beta-carotene was maximized in oven-drying techniques (CR<0.1), see Table 7.8. The benefits were maximized in blanched oven-drying techniques Table 7.9.

**Table 7.7: Pairwise comparison of benefits of pathways**

| Options | Iron content | Beta carotene content | Zinc content | Consumer acceptability | Time saved | Priority vector |
|---|---|---|---|---|---|---|
| Iron content | 1.00 | 0.71 | 1.00 | 0.65 | 1.06 | 0.17 |
| Beta carotene content | 1.40 | 1.00 | 1.40 | 0.91 | 1.48 | 0.24 |
| Zinc content | 1.00 | 0.71 | 1.00 | 0.65 | 1.06 | 0.17 |
| Consumer acceptability | 1.54 | 1.10 | 1.54 | 1.00 | 1.32 | 0.25 |
| Time saved | 0.94 | 0.67 | 0.94 | 0.76 | 1.00 | 0.17 |

**$\lambda_{max}$=5.00, CI=-0.001, CR=-0.0.001**

**Table 7.8: Pairwise comparison for alternatives for each benefit**

| Options | Project | | | | | | | Priority |
|---|---|---|---|---|---|---|---|---|
| | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | |
| **Iron content ($\lambda_{max}$=7, CI=-0.0, CR=-0.0.00)** | | | | | | | | |
| P1 | 1.00 | 0.59 | 0.85 | 0.76 | 0.49 | 1.30 | 0.92 | 0.11 |
| P2 | 1.71 | 1.00 | 1.46 | 1.29 | 0.83 | 2.23 | 1.57 | 0.19 |
| P3 | 1.17 | 0.69 | 1.00 | 0.89 | 0.57 | 1.53 | 1.08 | 0.13 |
| P4 | 1.32 | 0.77 | 1.13 | 1.00 | 0.65 | 1.72 | 1.21 | 0.15 |
| P5 | 2.05 | 1.20 | 1.74 | 1.55 | 1.00 | 2.67 | 1.88 | 0.22 |
| P6 | 0.77 | 0.45 | 0.65 | 0.58 | 0.37 | 1.00 | 0.70 | 0.08 |
| P7 | 1.09 | 0.64 | 0.93 | 0.83 | 0.53 | 1.42 | 1.00 | 0.12 |
| **Beta-carotene content ($\lambda_{max}$=7, CI=-0.0, CR=-0.0.00)** | | | | | | | | |
| P1 | 1.00 | 1.71 | 3.56 | 4.49 | 5.86 | 5.50 | 3.21 | 0.36 |
| P2 | 0.58 | 1.00 | 2.08 | 2.63 | 3.43 | 3.22 | 1.88 | 0.21 |
| P3 | 0.28 | 0.48 | 1.00 | 1.26 | 1.65 | 1.54 | 0.90 | 0.10 |
| P4 | 0.22 | 0.38 | 0.79 | 1.00 | 1.30 | 1.22 | 0.71 | 0.08 |
| P5 | 0.17 | 0.29 | 0.61 | 0.77 | 1.00 | 0.94 | 0.55 | 0.06 |
| P6 | 0.18 | 0.31 | 0.65 | 0.82 | 1.07 | 1.00 | 0.58 | 0.07 |
| P7 | 0.31 | 0.53 | 1.11 | 1.40 | 1.83 | 1.71 | 1.00 | 0.11 |
| **Zinc content ($\lambda_{max}$=7, CI=-0.0, CR=-0.0.00)** | | | | | | | | |
| P1 | 1.00 | 0.69 | 1.02 | 1.13 | 1.23 | 9.09 | 1.65 | 0.17 |
| P2 | 1.46 | 1.00 | 1.49 | 1.65 | 1.79 | 13.26 | 2.40 | 0.25 |
| P3 | 0.98 | 0.67 | 1.00 | 1.10 | 1.20 | 8.90 | 1.61 | 0.17 |
| P4 | 0.89 | 0.61 | 0.91 | 1.00 | 1.09 | 8.06 | 1.46 | 0.15 |
| P5 | 0.81 | 0.56 | 0.83 | 0.92 | 1.00 | 7.41 | 1.34 | 0.14 |
| P6 | 0.11 | 0.08 | 0.11 | 0.12 | 0.14 | 1.00 | 0.18 | 0.02 |
| P7 | 0.61 | 0.42 | 0.62 | 0.68 | 0.74 | 5.52 | 1.00 | 0.10 |
| **Consumer acceptability ($\lambda_{max}$=7, CI=-0.0, CR=-0.0.00)** | | | | | | | | |
| P1 | 1.00 | 0.83 | 0.90 | 0.91 | 0.95 | 0.81 | 1.13 | 0.16 |
| P2 | 1.21 | 1.00 | 1.10 | 1.11 | 1.15 | 0.98 | 1.37 | 0.13 |
| P3 | 1.11 | 0.91 | 1.00 | 1.01 | 1.05 | 0.90 | 1.25 | 0.16 |
| P4 | 1.09 | 0.90 | 0.99 | 1.00 | 1.04 | 0.89 | 1.24 | 0.13 |
| P5 | 1.05 | 0.87 | 0.95 | 0.96 | 1.00 | 0.85 | 1.19 | 0.16 |
| P6 | 1.23 | 1.02 | 1.11 | 1.13 | 1.17 | 1.00 | 1.40 | 0.13 |
| P7 | 0.88 | 0.73 | 0.80 | 0.81 | 0.84 | 0.72 | 1.00 | 0.13 |
| **Time-saved ($\lambda_{max}$=7, CI=-0.0, CR=-0.0.00)** | | | | | | | | |
| P1 | 1.00 | 1.25 | 1.00 | 1.25 | 1.00 | 1.25 | 1.25 | 0.16 |
| P2 | 0.80 | 1.00 | 0.80 | 1.00 | 0.80 | 1.00 | 1.00 | 0.13 |
| P3 | 1.00 | 1.25 | 1.00 | 1.25 | 1.00 | 1.25 | 1.25 | 0.16 |
| P4 | 0.80 | 1.00 | 0.80 | 1.00 | 0.80 | 1.00 | 1.00 | 0.13 |
| P5 | 1.00 | 1.25 | 1.00 | 1.25 | 1.00 | 1.25 | 1.25 | 0.16 |
| P6 | 0.80 | 1.00 | 0.80 | 1.00 | 0.80 | 1.00 | 1.00 | 0.13 |
| P7 | 0.80 | 1.00 | 0.80 | 1.00 | 0.80 | 1.00 | 1.00 | 0.13 |

P1-blanching and oven-drying combine with extrusion; P2-blanching and oven drying only; P3-blanching and solar-drying combined with extrusion; P4-blanching and solar drying only; P5-fermenting and oven-drying combined with extrusion; P6-fermenting and oven-drying only; and P7-blanching and sun-drying only

**Table 7.9: Synthesis of benefits for prioritization of pathways**

| Alternatives | Iron content | Beta carotene content | Zinc content | Consumer acceptability | Time saved | Overall priority | Idealized priorities |
|---|---|---|---|---|---|---|---|
| P1 | 0.02 | 0.09 | 0.03 | 0.03 | 0.03 | 0.19 | 1.00 |
| P2 | 0.03 | 0.05 | 0.04 | 0.04 | 0.02 | 0.19 | 0.96 |
| P3 | 0.02 | 0.02 | 0.03 | 0.04 | 0.03 | 0.14 | 0.71 |
| P4 | 0.02 | 0.02 | 0.03 | 0.04 | 0.02 | 0.13 | 0.66 |
| P5 | 0.04 | 0.01 | 0.02 | 0.03 | -0.03 | 0.08 | 0.43 |
| P6 | 0.01 | 0.02 | 0.00 | 0.04 | 0.02 | 0.10 | 0.49 |
| P7 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.12 | 0.60 |

P1-blanching and oven-drying combine with extrusion; P2-blanching and oven drying only; P3-blanching and solar-drying combined with extrusion; P4-blanching and solar drying only; P5-fermenting and oven-drying combined with extrusion; P6-fermenting and oven-drying only; and P7-blanching and sun-drying only.

As the objective of the cost analysis was to rank the pathways based on their costliness, the ranking rated the pathways from the most costly to the least costly. The comparison matrix for the cost components had CR of <0.1 thus the scales used were consistent (Table 7.11). The pathway that combined extrusion, fermentation and oven-drying was the most costly (Table 7.12), with the least costly being combining blanching and solar drying. Sun-drying and solar drying without extrusion had less than half the costs incurred by the pathway combining extrusion, fermentation and oven drying (Figure 7.8).

**Table 7.10: Pairwise matrix for costs of alternatives**

| Options | Energy | Water | Raw material | Labour | Fixed costs | Priority vector |
|---|---|---|---|---|---|---|
| Energy | 1.00 | 2.00 | 2.00 | 2.00 | 0.11 | 0.19 |
| Water | 0.50 | 1.00 | 0.25 | 0.33 | 0.26 | 0.05 |
| Raw material | 0.50 | 4.00 | 1.00 | 9.00 | 9.00 | 0.41 |
| Labour | 0.50 | 3.00 | 0.11 | 1.00 | 0.28 | 0.08 |
| Fixed costs | 9.00 | 3.82 | 0.11 | 3.60 | 1.00 | 0.28 |

**$\lambda_{max}$=5.00, CI=-0.00, CR=-0.00**

**Table 7.11: Pairwise comparison matrix of the alternatives for each cost component**

| Options | Project | | | | | | | Priority |
|---|---|---|---|---|---|---|---|---|
| | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | |
| **Cost of raw material ($\lambda_{max}$=7.00, CI=-0.00, CR=-0.0.00)** | | | | | | | | |
| P1 | 1.00 | 1.08 | 0.86 | 1.08 | 0.68 | 1.16 | 1.22 | 0.14 |
| P2 | 0.92 | 1.00 | 0.79 | 1.00 | 0.63 | 1.07 | 1.12 | 0.13 |
| P3 | 1.17 | 1.27 | 1.00 | 1.27 | 0.79 | 1.35 | 1.42 | 0.16 |
| P4 | 0.92 | 1.00 | 0.79 | 1.00 | 0.63 | 1.07 | 1.12 | 0.13 |
| P5 | 1.47 | 1.60 | 1.26 | 1.60 | 1.00 | 1.71 | 1.79 | 0.21 |
| P6 | 0.86 | 0.94 | 0.74 | 0.94 | 0.59 | 1.00 | 1.05 | 0.12 |
| P7 | 0.82 | 0.89 | 0.70 | 0.89 | 0.56 | 0.95 | 1.00 | 0.11 |
| **Cost of energy ($\lambda_{max}$=7.07, CI=-0.01, CR=-0.0.01)** | | | | | | | | |
| P1 | 1.00 | 1.12 | 2.56 | 3.53 | 1.00 | 1.12 | 3.53 | 0.21 |
| P2 | 0.89 | 1.00 | 2.28 | 3.15 | 0.89 | 1.00 | 3.15 | 0.19 |
| P3 | 0.39 | 0.44 | 1.00 | 1.38 | 0.39 | 0.44 | 1.38 | 0.08 |
| P4 | 0.28 | 0.32 | 0.73 | 1.00 | 0.28 | 0.32 | 1.00 | 0.06 |
| P5 | 1.00 | 1.12 | 2.56 | 3.53 | 1.00 | 1.12 | 3.53 | 0.21 |
| P6 | 0.89 | 1.00 | 2.28 | 3.15 | 0.89 | 1.00 | 3.15 | 0.19 |
| P7 | 0.28 | 0.32 | 0.73 | 1.00 | 0.28 | 0.32 | 1.00 | 0.06 |
| **Cost of water ($\lambda_{max}$=7.07, CI=-0.008, CR=-0.0.011)** | | | | | | | | |
| P1 | 1.00 | 1.32 | 0.96 | 1.33 | 1.14 | 1.11 | 1.00 | 0.16 |
| P2 | 0.76 | 1.00 | 0.77 | 1.00 | 0.66 | 1.15 | 1.12 | 0.13 |
| P3 | 1.04 | 1.30 | 1.00 | 1.38 | 1.18 | 1.16 | 1.05 | 0.16 |
| P4 | 0.75 | 1.00 | 0.72 | 1.00 | 0.86 | 0.84 | 0.76 | 0.12 |
| P5 | 0.88 | 1.52 | 0.84 | 1.17 | 1.00 | 1.75 | 1.70 | 0.17 |
| P6 | 0.90 | 0.87 | 0.86 | 1.19 | 0.57 | 1.00 | 0.90 | 0.12 |
| P7 | 1.00 | 0.89 | 0.96 | 1.32 | 0.59 | 1.11 | 1.00 | 0.14 |
| **Cost of labour ($\lambda_{max}$=7.06, CI=-0.009, CR=-0.0.007)** | | | | | | | | |
| P1 | 1.00 | 1.67 | 1.00 | 1.67 | 0.83 | 1.00 | 0.83 | 0.15 |
| P2 | 0.60 | 1.00 | 0.57 | 1.00 | 0.65 | 0.44 | 0.34 | 0.08 |
| P3 | 1.00 | 1.76 | 1.00 | 1.76 | 1.15 | 0.77 | 0.59 | 0.15 |
| P4 | 0.60 | 1.00 | 0.57 | 1.00 | 0.50 | 0.60 | 0.50 | 0.09 |
| P5 | 1.20 | 1.53 | 0.87 | 2.00 | 1.00 | 1.20 | 1.00 | 0.17 |
| P6 | 1.00 | 2.28 | 1.30 | 1.67 | 0.83 | 1.00 | 0.77 | 0.16 |
| P7 | 1.20 | 2.96 | 1.68 | 2.00 | 1.00 | 1.30 | 1.00 | 0.20 |
| **Cost of fixed assets ($\lambda_{max}$=7.27, CI=-0.045, CR=-0.0.033)** | | | | | | | | |
| P1 | 1.00 | 2.47 | 0.69 | 1.17 | 1.00 | 2.47 | 3.91 | 0.19 |
| P2 | 0.40 | 1.00 | 0.28 | 0.48 | 0.40 | 1.00 | 1.58 | 0.08 |
| P3 | 1.45 | 3.57 | 1.00 | 1.70 | 1.45 | 3.57 | 5.65 | 0.27 |
| P4 | 0.85 | 2.10 | 0.59 | 1.00 | 0.85 | 2.10 | 3.33 | 0.16 |
| P5 | 1.00 | 2.47 | 0.69 | 1.17 | 1.00 | 2.47 | 3.91 | 0.19 |
| P6 | 0.40 | 1.00 | 0.28 | 0.48 | 0.40 | 1.00 | 1.58 | 0.08 |
| P7 | 0.26 | 0.63 | 0.18 | 0.30 | 0.26 | 0.63 | 1.00 | 0.05 |

P1-blanching and oven-drying combine with extrusion; P2-blanching and oven drying only; P3-blanching and solar-drying combined with extrusion; P4-blanching and solar drying only; P5-fermenting and oven-drying combined with extrusion; P6-fermenting and oven-drying only; and P7-blanching and sun-drying only

**Table 7.12: Synthesis of the costs for prioritization**

| Alternatives | Energy | Water | Raw material | Labour | Fixed costs | Overall priority | Idealized priorities |
|---|---|---|---|---|---|---|---|
| P1 | 0.13 | 0.02 | 0.01 | 0.02 | 0.01 | 0.19 | 0.96 |
| P2 | 0.12 | 0.02 | 0.01 | 0.01 | 0.01 | 0.16 | 0.79 |
| P3 | 0.05 | 0.02 | 0.01 | 0.02 | 0.02 | 0.12 | 0.60 |
| P4 | 0.04 | 0.02 | 0.01 | 0.01 | 0.01 | 0.08 | 0.41 |
| P5 | 0.13 | 0.02 | 0.01 | 0.02 | 0.01 | 0.20 | 1.00 |
| P6 | 0.12 | 0.02 | 0.01 | 0.02 | 0.01 | 0.16 | 0.82 |
| P7 | 0.04 | 0.02 | 0.01 | 0.02 | 0.00 | 0.09 | 0.44 |

P1-blanching and oven-drying combine with extrusion; P2-blanching and oven drying only; P3-blanching and solar-drying combined with extrusion; P4-blanching and solar drying only; P5-fermenting and oven-drying combined with extrusion; P6-fermenting and oven-drying only; and P7-blanching and sun-drying only

*Benefit-cost analysis*

The pathway of blanched solar drying was the most cost efficient with a benefit cost-ratio of (1.55) with the pathway combining fermentation, oven-drying and extrusion being the least cost efficient with a benefit cost ration of 0.4 (Figure 7.8).

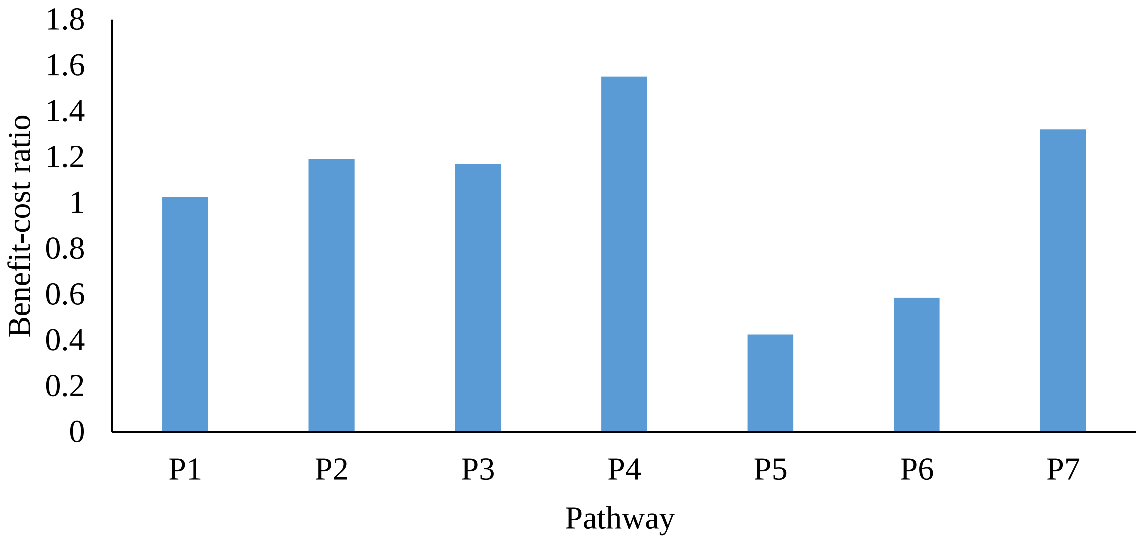


**Figure 7.8: Benefit-cost ratio of pathways for processing cowpea leaves soup mixes.** P1-blanching and oven-drying combine with extrusion; P2-blanching and oven drying only; P3-blanching and solar-drying combined with extrusion; P4-blanching and solar drying only; P5-fermenting and oven-drying combined with extrusion; P6-fermenting and oven-drying only; and P7-blanching and sun-drying only.

*Sensitivity analysis*

Sensitivity analysis was undertaken by deviating the mean of an attribute of the costs by its specific standard deviation. In the first case, deviation of means above the overall mean was done by adding the standard deviation whereas those below, the standard deviation was subtracted in order to attain the highest possible variation for the benefit cost. In the second scenario, the means that were above the overall mean had standard deviation subtracted from them whereas those below the standard deviation was added in order to obtain the least possible deviation in benefit-cost ratio. Case-scenario A showed increase in the benefit-cost ratio whereas in case scenario B, the artisanal techniques showed an increase in benefit cost ratio (Figure 7.9). The pairwise comparison in the two case-scenarios attained a CR of $<0.1$.

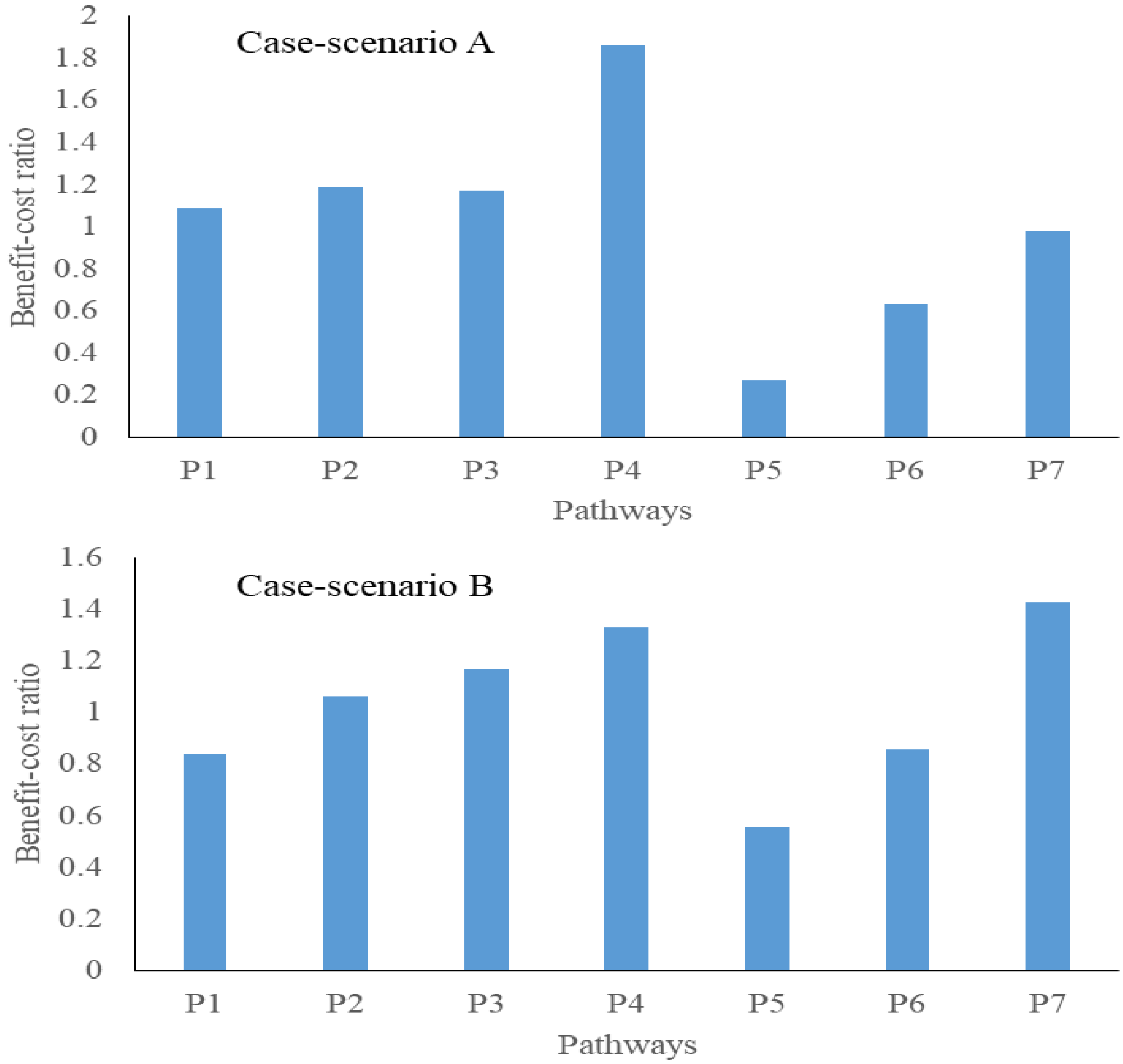


**Figure 7.9: Sensitivity analysis of changes to the benefit-cost ratio.** Scenario A, values above the average mean were increased by addition of standard deviation whereas those below the standard deviation was subtracted. In scenario B, the values above the mean were reduced by subtracting the mean whereas those below the standard deviation was added. P1-blanching and oven-drying combine with extrusion; P2-blanching and oven drying only; P3-blanching and solar-drying combined with extrusion; P4-blanching and solar drying only; P5-fermenting and oven-

drying combined with extrusion; P6-fermenting and oven-drying only; and P7-blanching and sun-drying only.

## 7.6 Discussion

### 7.6.1 Optimization of ingredient formulations

The current findings showed that the optimal level of inclusion of cowpea leaves in the soup mix was 49%, with levels higher than this showing lower consumer acceptability. This is explained by the reducing consistency which is induced in the product by the addition of starch, a thickening agent (Alcázar-Alay and Meireles, 2015). Starch has inherent thickening property that improves product acceptability of soups (Dhiman et al., 2017), however, this trend has an optimal point at which with increasing proportion of starch the product acceptability decline (Bothma et al., 2020). In the development of food preferences, textural properties is one of the factors that have significant influences (Jeltem et al., 2015). Similarly, the present study established that consistency and mouthfeel, textural properties, influenced the overall consumer acceptability of the developed soup mixes. Whereas, the optimization of the product focused on ameliorating the nutritional quality, determination of the optimal ingredient formulation level was guided by acceptability of the product. In their study, Mohajan et al. (2018) incorporated starch to levels as high as 68%, higher than in the current study, however this study explored limited use of optimization models for targeted levels of nutrient requirements. In optimizing for the functional and sensory qualities of vegetable-based soup mixes in another study, Yatnatti and Vijayalakshmi (2018) incorporated starch at similar levels with the current study. Optimization studies are undertaken to balance the functional and sensory properties of the soup in order to avoid detrimental quality attributes such as nutrient composition due to unbalanced ingredients (Manhivi et al., 2020). In mapping the sensory attributes to the consumer acceptability of the soup mixes, this study found that all the six attributes were contributors towards acceptance of the soup mixes. This implies that the functional properties were subject to the incorporation of cowpea leaves in the soup mixes. Increasing the vegetables beyond 49% of the ingredient formulation, resulted in declining levels of acceptability. The Kenyan and Tanzanian Standards for the soups permit such levels of inclusion (>40% for one ingredient) if and only if in labelling the product the dominant raw material will be stated (KEBS, 2012; TBS, 2020).

## 7.7 Minimization approach for cost of production

The current study undertook separate evaluation of costs and benefits prior to combining the weights to evaluate the least cost and maximum benefits as performed in similar study by Babalola (2020). However, in the study, the concept of ideal alternative that improves on the accuracy of the values was less explored thus the consistency ratios obtained for the pairwise matrices were higher (>0.06) than those obtained in our study. The nine-point scaling suffers the demerit of less accuracy of the pairwise matrices due to the use of the qualitative components in the generation of the scales (Benítez et al., 2011). Babalola (2020) in his study established that the least cost pathways did not necessarily attract maximum benefits, similarly in the present study the least cost option was the local processing to yield the soup mixes, however, the maximum benefits were realizable using the in the pathway combining extrusion, oven-drying and blanching pathway. The benefit analysis undertook to identify the processing pathway that provided the highest benefits including consumer acceptability, iron, zinc and beta-carotene content and ease of preparation whereas on the other hand the cost analysis identified which of the seven pathways cost the least to develop a soup mix from cowpea leaves.

Incorporation of highly mechanized processing techniques improved the benefits derived from the processed product, however, it attracted increasing costs too. The emergence of solar-drying, a technique that incorporates the use of renewable energy as the pathway with the maximum cost-benefit ratio is explained by the minimal variable costs that come with it compared to oven-drying and sun-drying such as sun-drying attracts higher labour costs and low retention of beta-carotene due to photo-oxidation (Çiftçioğlu et al., 2020; Ndawula et al., 2004). The major demerit of the low-cost artisanal techniques, is the low retention of the nutrients.

Whereas some of the assumptions made in this study may vary from product to product especially on the ranking of costs and benefits as revealed by the sensitivity analysis, the study provides a justification for the need of a shift from the artisanal food processing techniques to the mechanized ones especially for initiatives seeking to address micronutrient deficiencies in the vulnerable communities. Additionally, in this study, the criteria for both cost and benefits were limited to five, within the recommended maximum of seven (Russo and Camanho, 2015); however, in instances where additional criteria would be identified, the final cost-benefit ratio would fluctuate. The need for this limitation was to improve the accuracy of the pairwise comparison matrices that were generated (Ishizaka, 2012). In cases of more than seven levels, Hanine et al. (2016) introduced sub-criteria through introducing extra hierarchies in the steps while minimizing on the probability of increasing the error in the calculation of weights through pairwise comparison matrix.

## 7.8 Conclusion

The two stage-optimization study achieved the minimal production costs necessary to process cowpea leaves soup mixes rich in micronutrients which are major limiting nutrients in the diet of most communities in the arid and semi-arid lands. Whereas, processing techniques with little demand of mechanization would seem more feasible for adoption among resource-constrained communities, this study proves that mechanized techniques have a higher value for money invested than the artisanal techniques. Additionally, the study establishes that the low-cost processing pathways provide minimal benefits thus provide limited advantage in terms of product quality amelioration. It is therefore recommended that a shift from the artisanal processing is necessary for the realization of the maximum benefits from the derived product. In instances where the interest would be on health outcomes including reduction in the micronutrient deficiencies, this study would recommend the undertaking of cost effectiveness analysis. The approach explored in this study is recommended in evidence-based decision-making for dissemination approaches of the processing technologies for cowpea leaves soup mixes and other initiatives in SSA dealing with orphaned and neglected crops such as the ALVs can be informed by it.

# CHAPTER EIGHT: EVALUATION OF THE PHYSICO-CHEMICAL QUALITY, ACCEPTABILITY, SHELF-STABILITY OF SOUP MIXES INCORPORATING COWPEA LEAVES AS DOMINANT RAW MATERIAL


## Abstract

Product development and value addition approaches are deployed in the value chains of neglected crops to increase commercialization and ameliorate product quality. The current study evaluates the functional attributes sensory, keeping and nutritional qualities of novel product developed from cowpea leaves processed using different resource intensive techniques. A comparative study evaluated low-cost and intermediate and highly mechanized processing techniques. The nutrient, antinutrient composition and anti-oxidant activity of the low-cost processed soup mixes were comparatively similar to those processed through mechanized techniques ($p<0.05$). However, in incorporating fermentation as a pre-treatment in the mechanized techniques significantly ($p<0.001$) reduced the nitrate, beta carotene and ascorbic acid contents. The low-cost processing achieved similar functional properties as the intermediate mechanized techniques. The product consistency was significantly ($p<0.001$) lower (508.03-635.75 g/sec) whereas the bulk density was higher (0.63-0.78g/ml) in the extruded soup mixes than the non-extruded and low-cost processed. Incorporating fermentation as a pre-treatment in the mechanized processing yielded an acidic product (pH of 3.91-4.32). The shelf-life and sensory qualities of the low-cost processed soup mixes were significantly ($p<0.001$) lower than those processed through mechanized techniques. Packaging in aluminium pouches comparatively extended the shelf-life of the soup mixes beyond 7 months. In as much as the low-cost processing yielded comparatively similar products in terms of the nutritional quality and functional properties, the sensory and keeping qualities were lower.

It is therefore recommended that in processing of the cowpea leaves soup mixes, the resource-intensive mechanized techniques be incorporated for optimal product quality.

## 8.1 Introduction

In response to the emerging challenges and market demands, through product development food scientists often come up with superior quality products at minimal costs and efficient processing in furtherance of product diversification and commercialization (Tiedemann et al., 2020). At the household level, traditional food processing techniques which tend to be artisanal are utilized in order to enhance the wholesomeness and the stability in storage of the food products (Habwe and Walingo, 2008). Inappropriate processing techniques have deleterious effects on the product quality rather than amelioration. At the household level, cost-effective techniques are recommended for the processing and quality amelioration of especially the perishable foods (Kansiime et al., 2018). However, with use of less optimal processing techniques, the developed product has limited consumer acceptability. The less exploitation of these processing techniques may also result in less derivative benefits by the communities from the available foods (Akinola et al., 2020).

Green leafy vegetables like the cowpea leaves are highly perishable and in order to enhance their utilization and consumption, product diversification has been attained through product development (Jethwani et al., 2015; Kasangi et al., 2010). There is massive utilization of the cowpea leaves vegetables during glut especially in the food and nutrition insecurity hotspots of the arid and semi-arid lands, however there is a massive decline during the off-season due to unavailability of the vegetable (Owade et al., 2020b). Due to the nutrient rich property of cowpea leaves (Dakora and Belane, 2019; Owade et al., 2020a), some recommendations towards promotion of food and nutrition security advocate for its utilization in diet diversification in order to address the prevalent micronutrient deficiencies among the low income households (Enyiukwu et al., 2018a; Vilakati et al., 2016). The arising challenge of seasonal availability of the vegetable in such cases become a deterrent of the enhanced utilization of the vegetable. Moreover, seasons of glut has high postharvest losses of the vegetables that occasion economic losses to the farmers. In the commercialization of indigenous crops like cowpea leaves, efforts seek to increase commercial opportunities for local farmers, lower production costs, improve the nutritive quality of the diet of local households and provide feasible alternative cultural viable products for the local communities Vilakati et al. (2016).

In their study, Okello et al. (2015), reported major gaps in the quality of processed cowpea leaves products resulting in low willingness to pay among the targeted consumers. Whereas, practices like sun-drying are deemed affordable and adaptable among the resource-constrained households, it has massive deleterious effects on the nutritional composition (Owade et al., 2020a). It is also notable that sun-drying induces quality deterioration in textural properties of the vegetables (Okello et al., 2015). In another study, Muchoki et al. (2010) reported that fermentation has the advantage over other techniques in terms of reducing the anti-nutrient content of cowpea leaves. The combination of processing techniques, hurdle technology, has been found to be more efficient than single preservation techniques in improving g product quality (Owade et al., 2020a). Whereas there is need to address the seasonal production of cowpea leaves through value addition, the development and evaluation of quality of cowpea leaves soup mix is meant to achieve product diversification that presents the additional advantage towards commercialization of cowpea leaves products. The product under evaluation in this study is novel and has not been subjected to quality evaluation in any known study. This study utilizes techniques identified through a scoping study in the area (Owade et al., 2020b), against optimal techniques that are documented in literature (Owade et al., 2020a), in developing a novel product of cowpea leaves soup mix.

## 8.2 Material and methods

### 8.2.1 Experimental design

A comparative study on the physico-chemical, sensory and keeping qualities of soup mixes based on intensity of mechanization for the formulation of cowpea leaves soup mixes was undertaken. The resource intensity of the processing techniques was divided into traditional processing which was a low-cost technique that is utilizable in the households that are resource constrained in the arid and semi-arid lands (ASAL) with high production quantities of the vegetables as determined in Chapter Three and Four; intermediate mechanized techniques that produced cowpea leaves using technologies yielding optimal retention of product quality as determined in Chapter Seven; and the highly mechanized techniques that included extrusion process to yield an instant soup mix as determined in Chapter Seven. For the physico-chemical and sensory qualities, the study used completely randomized study design with the technique of processing as a factor. In evaluating the keeping quality, a full factorial experiment investigating period of storage, processing technique and type of packaging as factors was deployed.

### 8.2.2 Formulation of cowpea leaves soup mixes

The cowpea leaves were harvested from the Field Station farm, University of Nairobi at eight weeks after emergence. Coriander leaves, tomatoes, garlic, tomato, starch, whole maize flour and onions were bought from the local market. The cowpea leaves soup mixes were prepared through modification of the recipes by Abeysinghe and Illeperuma (2006) and Gandhi et al. (2017). Formulation of cowpea leaves soup mixes was done from blanched leaves that were dehydrated using solar and oven driers as techniques that had highest micronutrient retention; fermented leaves that were oven dried as a technique with reduced antinutrient content; and sun-drying as a low-cost processing technique. Formulation of the soups was done as illustrated in Figure 8.1**Error! Reference source not found.** with incorporation of coriander, onion, and tomato and garlic powder obtained from dehydration techniques utilized for the specific cowpea leaves incorporated.

#### 8.2.2.1 Dehydration of the raw ingredients

The cowpea onion, tomato, garlic, and cowpea and coriander leaves were dried using the solar, oven and sun-drying techniques. The cowpea and coriander leaves were first steam-blanched (100 °C) for three minutes and cooled in ice-cold water before dehydration. In drying the vegetables, all the raw ingredients were divided in seven batches in duplicates except for cowpea leaves that had six batches. Two batches were dried in oven drier cowpea leaves (temperature of 55 °C for 6 hours) and three for the other raw ingredients, two in solar drier (temperatures averaging 50 °C for 8 hours) for all ingredients and one on the sun for 2 days. The targeted moisture content of <15% was set as the threshold. In order to yield soured cowpea leaves, two different batches of cowpea leaves were subjected to fermentation as per the procedures described in our earlier study covered in Chapter Five (Owade et al., 2021). Both batches of fermented vegetables were oven-dried with a targeted moisture content of <15%. The dehydrated ingredients and leaves are ground into powder and sieved through 250 µm pore sieves.

#### 8.2.2.2 Extrusion of the formulated soup mixes

A batch of blanched oven-dried, blanched solar dried and fermented oven-dried was used in formulation of the soup mixes, as illustrated in Figure 8.1. Direct extrusion of formulated soup mixes was done by first pre-mixing the soup mix with water at a ratio of 10:1 (w/v) and subjected to a single screw extruder (TechnoChem, USA) set at extrusion temperature of 160 °C, screw speed of 800rpm. The extrudates were dried to realize moisture contents of <15%, ground into powder using a blender and sieved through a 250 µm pore sieves.

### 8.2.3 Determination of physico-chemical quality of cowpea leaves soup mix

Nutritional composition in terms of proximate composition, beta-carotene, ascorbic acid, sodium, zinc, iron and calcium and antinutrients and phytochemical determination was done as per the procedures described in Section 6.2.4. Colour changes was determined as per the procedures described in Section 6.2.5.

#### 8.2.3.1 Analysis of texture

*Sample preparation:* The soup mix was mixed with water at the ratio of (1:9) to make 500ml, and heated to boil for the extruded samples and the non-extruded a further boiling of 5 minutes was done. The soups were allowed to cool to 30 ml and the texture profile analyzed for each in duplicate.

*Sample analysis:* Texture analysis of the samples was done as per the procedures described by Onyango et al. (2020). The soups that were cooled to 30 ± 0.5 °C were evaluated for texture profile in terms of cohesiveness, consistency, firmness and work of cohesion (index of viscosity) using TA.XT-plus Texture Analyser (Stable Micro Systems, Surrey, UK). The TA settings were set at mode of measurement: force; load cell: 50 kg; height calibration: 60 mm; disc diameter: 45 mm; pretest speed: 1.0 mm/s; test-speed: 1 mm/s; trigger force: 10 g; post-test speed: 10 mm/s; data acquisition rate: 200 pps; penetration distance: 30 mm.

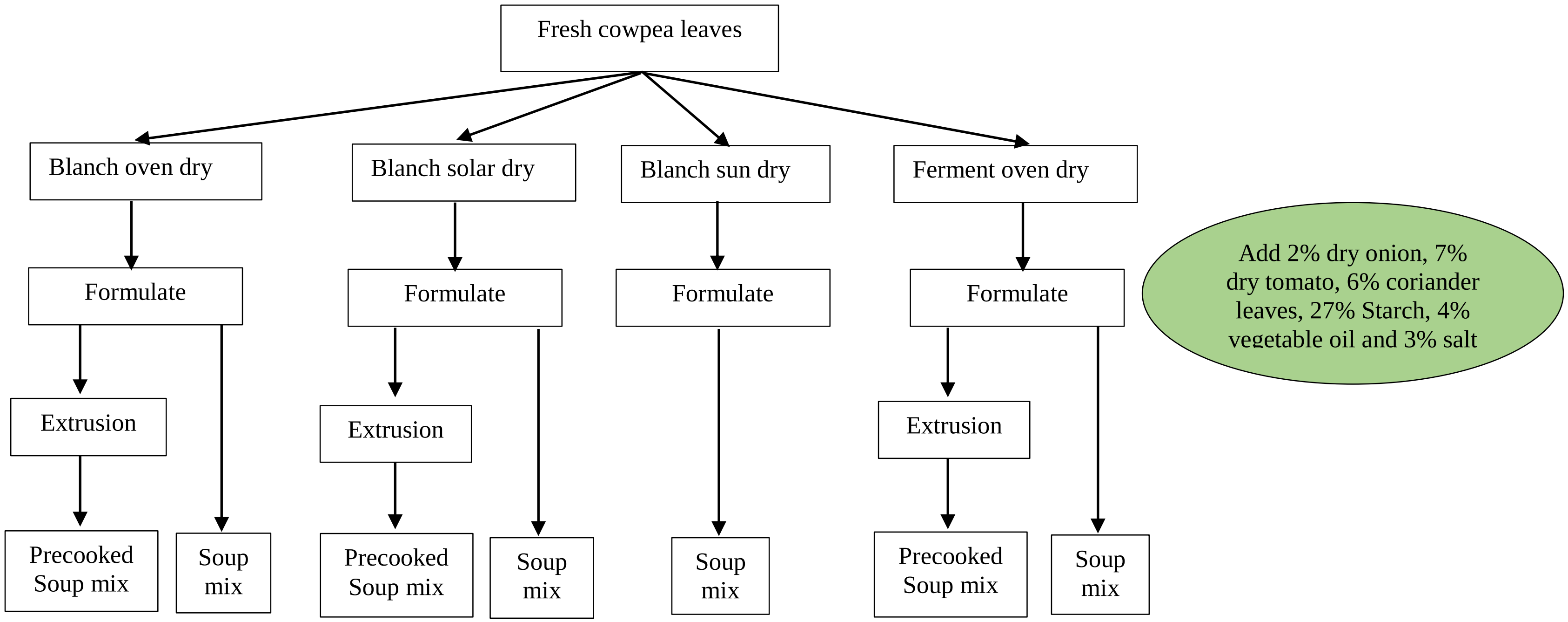


**Figure 8.1: Processing of cowpea leaves soup mixes**

#### 8.2.3.2 Determination of water absorption

Water absorption of the cowpea leaves soup mixes was determined in duplicate as described by Bamidele *et al.* (2015) and Lin and Zayas (1987). A 2 g sample of cowpea leaf instant soup mix was transferred into 50 ml centrifuge tube and the weight determined ($W_1$). To this, 30 ml hot distilled water (70 $^oC$) was added to wash down the soup mix on the sides of the tube and mixing done for 30 minutes. The mixture was allowed to stand for 10 minutes while the powder adhering to the surface is scrubbed down to prevent them from drying. Additional 10 ml of hot distilled water to wash off any water adhering to the stirring rod was added. The suspension was centrifuged further 25 minutes at 1165x $g$ at 50 $^oC$, the tube cooled and weighed ($W_2$). Water absorption was determined as follows and expressed in grams of water retained per gram of sample (Equation 8.1).

$$Water\ absorption = \frac{W_2 - W_1}{Weight\ of\ the\ sample\ (g)} \qquad \textbf{Equation 8.1}$$

#### 8.2.3.3 Determination of bulk density

The bulk density of the soup mix was determined in duplicate as per the method described by Bamidele *et al.* (2015). A sample of instant soup mix (10 g) was weighed into a 25 ml graduated cylinder. The cylinder was tapped 10 times against the palm and the volume occupied determined. The bulk density was expressed as grams per volume occupied by the sample.

#### 8.2.3.4 Determination of swelling capacity

The swelling capacity of the soup mix was determined in duplicate by the method described by Bamidele *et al.* (2015) and Lin and Zayas (1987). A sample (2 g) was weighed in a centrifugation tube and the weight determined ($W_2$). The sample was dispersed in 40 ml distilled water followed by heating at 70 $^oC$ for 30 minutes in a water bath. Centrifugation of the mixture was done at 598 x g (2300 rpm) for 30 minutes. The supernatant from the centrifuged mixture was decanted off and the residue dried at 50ºC for 25 minutes. The centrifuge tube was finally weighed ($W_2$). The swelling capacity was expressed as grams per gram of the sample (Equation 8.2).

$$Swelling\ capacity = \frac{W_2 - W_1}{Weight\ of\ the\ sample\ (g)}$$ **Equation 8.2**

### 8.2.4 Sensory evaluation of cowpea leaves soup mix

Sensory profile of the cowpea leaves soup mixes was evaluated using descriptors used is a similar study by Kim et al. (2010). The sensory panelists constituted a farmer group comprising of ten men and 22 women who are involved in cowpea leaves value addition. A vegetable soup mix purchased from local supermarket was used in training the farmers on sensory evaluation and translation of the used descriptors into local language of Swahili. The sensory evaluation was done in the midmorning whereby successive panelist were given the samples which were given three random codes in a counter-current flow. The soups prepared as explained in Section 8.3.2.1 were served hot in 30 ml quantities. The panelists scored the descriptors of each sample using nine-point hedonic scale (1-Extremely dislike to 9-Extremely like). Upon sampling each formulation, the panelist cleansed the palate with water.

### 8.2.5 Evaluation of the shelf-life of cowpea leaves soup mix

Samples subjected to low-cost processing, the most preferred extruded samples and overall preferred soup mix were subjected to accelerated shelf-life with a targeted period of storage of nine months determined as per Arrhenius Model shown in Equation 8.3 (Troncoso and Zúñiga, 2013). Samples of soup mixes packaged in three different packages including brown laminated kraft paper of 5 cm by 6 cm size; 5 cm by 6 cm aluminium pouches of 200 microns; and transparent plastic packages of 100 ml were stored at 55 °C.

$$\text{Accelerated Aging Time (AAT)} = \frac{Desired\ Real\ time\ (RT)}{Q_{10}^{\frac{T_{AA}-T_{RT}}{10}}}$$ **Equation 8.3**

where $Q_{10}$ is the rate of reaction usually determined as 2, $T_{AA}$ is the accelerated temperature (55 °C) and $T_{RT}$ is the room temperature (23 °C).

Sampling was done after every three days corresponding to real time life of one month and analyzed for colour changes, moisture content, peroxide value, free fatty acids, total viable counts and yeast and moulds. Yeast and mould and total viable counts were determined as per the procedures in 42-50-01 and 42-11-01 of AACC (2000), respectively. Serial dilutions were prepared and plated on potato dextrose agar for yeast and moulds and plate count agar for total viable counts. The plated yeast and mould inoculum was incubated at for 30$^{o}$C for 72 hours whereas the total viable count plated at 35 $^{o}$C for 24 hours. The colonies were enumerated using colony count technique with microbial counts expressed in log cfu $g^{-1}$.

The peroxide value was determined using the titration method as per method 965.33 of AOAC (2000). To a 5 g sample of soup mix, 30ml of acetic-chloroform mixture (3:2) was added followed by 0.5 ml of saturated potassium iodide.  This was kept in the dark for a minute with occasional and 1% starch solution added upon removal. The mixture was titrated against 0.001 N sodium thiosulphate and peroxide value calculated in mEq/100g as shown in Equation 8.4.

$$Peroxide\ value = \frac{T \times N \times 10}{weight\ of\ sample}$$ **Equation 8.4**

where *T* is the titre volume used for the sample corrected with a blank and N is the normality of sodium thiosulphate.

The free fatty acid of the soup mixes was determined using the titration method ISO 660:1996 (ISO, 1996). Hot ethyl alcohol (diethyl ether and alcohol mixed at 1:1 ratio) rectified with phenolphthalein indicator was used in extraction of the free fatty acids. The mixture was boiled and titrated against 0.1 N sodium hydroxide solution. The free fatty acids was calculated as per Equation 8.5.

$$Free\ fatty\ acids\ (\%\ weight) = \frac{28.2 \times V \times N}{weight\ of\ sample} \qquad \textbf{Equation 8.5}$$

where $V$ is the titre volume of sodium hydroxide used corrected with a blank and $N$ is normality of the sodium hydroxide.

### 8.2.6 Statistical analysis

The data were analysed in the R language for statistical computing software (R Core Team, 2019). The physico-chemical and sensory quality data was first analysed using analysis of variance (ANOVA) to test for significant differences in the mean levels of composition of the various samples. Means that were statistically different ($p<0.05$) were separated using the Tukey's Honest Significant Difference (HSD) of the Agricolae package. Variation of data for each attribute was evaluated by determining the co-efficient of variation. Since the data for the keeping quality was organized in a full factorial, evaluation of the models explaining variation in the microbial and chemical attributes was done using the Akaike Information Criteria of the AICmodav package. Both two way and one way ANOVA were evaluated in order to determine model selection. The Tukey's Honest Significant Difference (HSD) of the Agricolae package was used to separate means that were statistically different.

## 8.3 Results

### 8.3.1 Nutritional and antinutrient contents of cowpea leaves soup mixes

Proximate composition of the formulated soup mixes significantly ($p<0.01$) differed based on the type of dehydrated cowpea leaves incorporated (Table 8.1). The low-cost processing of the soup mixes had comparatively similar proximate composition as the formulated soup mixes processed using mechanized techniques except for ash content ($p<0.001$). The ash content was highest (14.91-16.49%) in soup mixes in which fermented leaves were incorporated ($p<0.001$). The crude fat and crude protein significantly ($p<0.01$) reduced when mechanized techniques incorporated extrusion. Whereas the of beta-carotene content in the low-cost processed soup mix were comparatively similar to those processed through mechanized techniques, the ascorbic acid was significantly lower ($p<0.001$) in the former than the latter (Table 8.2). Extrusion process had significant ($p>0.05$) effect on the beta-carotene and ascorbic acid of soup mixes. The zinc, iron, sodium and calcium contents of the soup mixes processed using the low-cost techniques were comparatively similar to those processed using mechanized techniques ($p<0.001$). Incorporation of the optimally fermented cowpea leaves in the formulation of soup mixes, significantly ($p<0.001$) increased the sodium content while lowering the calcium and zinc contents.

Phytochemical and antinutrient composition of the low-cost processed soup mixes were similar to the soup mixes processed through mechanized techniques except for those that incorporated fermented vegetables ($p<0.05$), see Table 8.3. Soup mixes in which fermented vegetables were incorporated had significantly ($p<0.05$) lower nitrate, total phenolic and flavonoid contents. Anti-oxidant activity was highest (57.97±17.49 mg/100 g TE) in non-extruded samples of soup mix in which oven-dried vegetables was incorporated ($p<0.01$).

### 8.3.2 Functional properties of cowpea leaves soup mixes

Extruded samples of the soup mixes had significantly ($p<0.001$) higher bulk density (0.63 ± 0.03 to 0.78 ± 0.03 g/ml) than the non-extruded (0.51 ± 0.04 to 0.54 ± 0.01 g/ml). On the other hand, the water absorption and swelling capacity had no significant ($p>0.05$) differences among the different formulation of soup mixes (Table 8.4). With extrusion, the soups formulated from the soup mixes decreased in viscosity evidenced by low firmness, consistency and cohesiveness. Whereas the fermented soup mixes had the lowest pH (3.91 ± 0.06 to 4.32 ± 0.03), hurdle technology combining extrusion with dehydration diminished the titratable acidity ($p<0.001$). Low-cost processed soup mixes had comparatively similar functional properties as the soup mixes processed through mechanized techniques.

Formulation of the soup mixes resulted in transformation of the product from the greenish colour of the dominant raw material to red in the soup mixes (Table 8.5). The low-cost processed soup mix and those in which fermented leaves were incorporated had the highest redness index (+a*), $p<0.001$. The yellowishness (+b*), lightness (L*) and hue and Chroma angles significantly ($p<0.001$) decreased when low-cost technique or fermented leaves were incorporated in processing the soup mixes. Incorporating blanched oven-dried leaves rather than the blanched solar-dried, blanched sun-dried or fermented oven-dried resulted in the least deviation in colour from the raw vegetables ($p<0.001$).

**Table 8.1: Proximate composition of formulated soup mixes (g per 100 g)**

| Formulations | Moisture (g) | Crude protein (g) | Crude fat (g) | Crude fibre (g) | Crude ash (g) | Carbohydrates (g) | Energy value |
|---|---|---|---|---|---|---|---|
| F1*** | 7.69±0.27$^{c}$ | 19.32±0.57$^{d}$ | 6.86±1.74$^{c}$ | 10.29±3.41$^{a}$ | 14.74±0.44$^{b}$ | 48.79±2.44$^{a}$ | 334.20±22.86$^{b}$ |
| F2** | 9.59±0.36$^{b}$ | 22.09±0.26$^{c}$ | 13.76±1.97$^{ab}$ | 10.59±0.61$^{a}$ | 14.49±0.28$^{b}$ | 39.06±2.39$^{cd}$ | 368.50±8.24$^{ab}$ |
| F3*** | 8.00±0.77$^{c}$ | 18.19±0.82$^{d}$ | 9.92±3.16$^{bc}$ | 6.77±0.87$^{b}$ | 13.91±0.34$^{c}$ | 51.21±1.85$^{a}$ | 366.90±17.80$^{ab}$ |
| F4** | 8.15±0.85$^{c}$ | 18.46±1.00$^{d}$ | 12.73±4.75$^{abc}$ | 8.67±0.38$^{ab}$ | 13.93±0.34$^{c}$ | 46.20±5.39$^{ab}$ | 373.20±25.16$^{a}$ |
| F5* | 10.08±0.33$^{b}$ | 23.81±0.11$^{b}$ | 10.16±0.35$^{bc}$ | 9.51±0.27$^{ab}$ | 8.50±0.29$^{d}$ | 48.02±0.32$^{ab}$ | 378.80±3.99$^{a}$ |
| F6*** | 10.46±0.30$^{b}$ | 23.00±0.35$^{bc}$ | 11.85±3.60$^{abc}$ | 8.03±0.22$^{ab}$ | 14.91±0.25$^{b}$ | 42.21±3.49$^{bc}$ | 367.50±17.57$^{ab}$ |
| F7** | 10.00±0.23$^{a}$ | 26.26±0.15$^{a}$ | 16.48±0.25$^{a}$ | 8.46±0.35$^{ab}$ | 16.49±0.28$^{a}$ | 34.64±0.73$^{d}$ | 391.90±1.26$^{a}$ |
| %CV | 31.6 | 61.9 | 45.2 | 22.2 | 40.2 | 44.2 | 42.8 |
| HSD | 1.20 | 1.29 | 6.29 | 3.14 | 0.74 | 6.56 | 37.53 |
| p-value | <0.001 | <0.001 | 0.002 | 0.005 | <0.001 | <0.001 | 0.004 |

All values are in dry weight basis except for moisture content. F1- Blanched oven dried extruded, F2- Blanched oven dried non-extruded, F3- Blanched solar dried extruded, F4- Blanched solar dried non-extruded, F5- Blanched sun dried non-extruded, F6- Fermented oven dried extruded and F7- Fermented oven dried non-extruded. Values (mean ± sd) with different superscripts along the same column are significantly different. All values are in dry weight basis except for moisture. The techniques of processing the soup mix are: *Low-cost (artisanal/sun-drying) technique, **intermediate mechanized technique and ***highly mechanized (extrusion added) technique.

**Table 8.2: Micronutrient composition of formulated soup mixes (mg/100 g dry weight basis)**

| Formulations | Beta carotene | Ascorbic acid | Zinc | Iron | Sodium | Calcium |
|---|---|---|---|---|---|---|
| F1*** | 9.24±0.12[ab] | 23.63±8.69[bc] | 9.54±1.16[ab] | 18.96±4.27[a] | 1496.10±11.41[c] | 43.20±0.06[ab] |
| F2** | 15.80±3.37[a] | 33.12±1.10[ab] | 13.92±3.91[a] | 32.36±16.13[a] | 1578.26±126.79[bc] | 35.45±7.38[abc] |
| F3*** | 3.52±0.72[b] | 35.07±2.43[a] | 9.34±1.20[ab] | 22.24±4.25[a] | 1462.50±9.16[c] | 35.22±4.02[abc] |
| F4** | 4.44±1.79[ab] | 36.84±6.50[a] | 8.45±2.86[ab] | 25.05±24.97[a] | 1633.24±36.39[ab] | 47.19±3.57[a] |
| F5* | 4.92±0.29[ab] | 12.47±3.12[d] | 5.79±0.81[bc] | 20.67±6.64[a] | 1562.84±49.42[bc] | 34.34±4.54[abc] |
| F6*** | 2.70±0.45[b] | 11.67±1.53[d] | 7.77±4.12[b] | 38.80±3.68[a] | 1542.21±62.49[bc] | 29.96±0.98[bc] |
| F7** | 2.87±0.33[b] | 16.01±0.49[cd] | 1.05±0.49[c] | 14.54±4.47[a] | 1746.61±2.18[a] | 28.21±1.09[c] |
| %CV | 82.3 | 18.3 | 31.5 | 48.4 | 3.7 | 17.4 |
| HSD | 11.7 | 10.1 | 5.8 | 27.4 | 134.5 | 14.5 |
| p-value | 0.015 | <0.001 | <0.001 | 0.12 | <0.001 | 0.003 |

F1- Blanched oven dried extruded, F2- Blanched oven dried non-extruded, F3- Blanched solar dried extruded, F4- Blanched solar dried non-extruded, F5- Blanched sun dried non-extruded, F6- Fermented oven dried extruded and F7- Fermented oven dried non-extruded. Values (mean ± sd) with different superscripts in the same column are statistically different The techniques of processing the soup mix are: *Low-cost (artisanal/sun-drying) technique, **intermediate mechanized technique and ***highly mechanized (extrusion added) technique.

**Table 8.3: Anti-nutrient content and anti-oxidant activity of formulated soup mixes (per 100 g dry weight basis)**

| Formulations | Nitrates (mg) | Oxalates (mg) | Total phenolics (mg GAE) | Flavonoids (mg CE) | Anti-oxidant activity (mg TE) |
|---|---|---|---|---|---|
| F1*** | $0.19\pm0.02^{ab}$ | $0.90\pm0.10^{a}$ | $9.58\pm1.36^{a}$ | $1.80\pm0.01^{b}$ | $41.51\pm13.23^{ab}$ |
| F2** | $0.60\pm0.55^{a}$ | $1.03\pm0.50^{a}$ | $10.94\pm1.30^{a}$ | $2.64\pm0.17^{ab}$ | $57.97\pm17.49^{a}$ |
| F3*** | $0.14\pm0.01^{ab}$ | $1.11\pm0.08^{a}$ | $10.19\pm1.98^{a}$ | $2.14\pm0.41^{ab}$ | $29.10\pm6.51^{b}$ |
| F4** | $0.13\pm0.03^{ab}$ | $1.54\pm0.19^{a}$ | $11.91\pm1.17^{a}$ | $2.78\pm0.11^{a}$ | $41.17\pm6.13^{ab}$ |
| F5* | $0.21\pm0.02^{ab}$ | $1.25\pm0.11^{a}$ | $9.69\pm1.91^{a}$ | $2.00\pm0.88^{ab}$ | $26.15\pm3.88^{b}$ |
| F6*** | $0.03\pm0.01^{b}$ | $1.17\pm0.46^{a}$ | $4.00\pm0.01^{b}$ | $0.81\pm0.02^{c}$ | $29.52\pm8.69^{b}$ |
| F7** | $0.01\pm0.00^{b}$ | $1.06\pm0.01^{a}$ | $3.08\pm0.54^{b}$ | $0.68\pm0.05^{c}$ | $29.12\pm3.04^{b}$ |
| %CV | 0.48 | 23.8 | 15.9 | 19.1 | 26.7 |
| HSD | 95.6 | 0.63 | 3.1 | 0.86 | 22.3 |
| p-value | 0.023 | 0.078 | <0.001 | <0.001 | 0.002 |

F1- Blanched oven dried extruded, F2- Blanched oven dried non-extruded, F3- Blanched solar dried extruded, F4- Blanched solar dried non-extruded, F5- Blanched sun dried non-extruded, F6- Fermented oven dried extruded and F7- Fermented oven dried non-extruded. Values (mean ±sd) with different superscripts in the same column are statistically different. The techniques of processing the soup mix are: *Low-cost (artisanal/sun-drying) technique, **intermediate mechanized technique and ***highly mechanized (extrusion added) technique.

**Table 8.4: Functional properties of formulated soup mixes**

| Sample | Water absorption capacity (g/g) | Bulk density (g/ml) | Swelling capacity (g/g) | pH | Titratable acidity (%) | Firmness (g Force) | Consistency (g/sec) | Cohesiveness (g Force) | Work of Cohesion (g/sec) |
|---|---|---|---|---|---|---|---|---|---|
| F1*** | 2.40±0.62[a] | 0.78±0.03[a] | 3.41±1.06[a] | 5.40±0.06[c] | 1.59±0.06[b] | 22.88±3.12[b] | 508.03±85.77[b] | -18.64±1.77[a] | -10.73±14.02[a] |
| F2** | 1.96±0.10[a] | 0.52±0.05[c] | 4.09±0.18[a] | 5.55±0.04[ab] | 1.48±0.17[b] | 59.14±1.62[ab] | 1562.45±46.98[ab] | -63.55±2.78[abc] | -140.28±6.48[abc] |
| F3*** | 3.02±0.76[a] | 0.63±0.03[b] | 3.70±1.91[a] | 5.56±0.03[ab] | 1.72±0.19[b] | 27.55±5.93[b] | 635.75±167.62[b] | -25.32±7.63[ab] | -41.96±29.58[a] |
| F4** | 1.35±0.08[a] | 0.54±0.02[c] | 3.79±1.84[a] | 5.59±0.02[a] | 1.37±0.18[b] | 84.56±38.99[a] | 2210.95±236.53[a] | -96.96±54.38[c] | -211.36±112.69[c] |
| F5* | 2.85±2.25[a] | 0.54±0.01[c] | 2.77±0.08[a] | 5.50±0.02[b] | 1.79±0.23[b] | 38.31±6.92[ab] | 948.14±188.12[ab] | -31.13±8.78[abc] | -59.45±28.21[ab] |
| F6*** | 2.70±0.01[a] | 0.64±0.04[b] | 3.16±0.27[a] | 4.32±0.03[d] | 1.50±0.41[b] | 23.46±0.37[b] | 533.68±13.60[b] | -17.18±0.05[a] | -9.58±0.74[a] |
| F7** | 2.17±0.33[a] | 0.51±0.04[c] | 3.67±0.24[a] | 3.91±0.06[e] | 4.84±0.22[a] | 81.61±42.48[a] | 2022.02±226.22[a] | -92.70±58.87[bc] | -189.61±114.94[bc] |
| %CV | 39.9 | 5.32 | 30.9 | 0.78 | 11.24 | 45.8 | 46.6 | 62.0 | 66.5 |
| HSD | 2.15 | 0.07 | 2.50 | 0.09 | 0.52 | 50.8 | 1288.87 | 70.4 | 144.9 |
| p-value | 0.221 | <0.001 | 0.683 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 |

F1- Blanched oven dried extruded, F2- Blanched oven dried non-extruded, F3- Blanched solar dried extruded, F4- Blanched solar dried non-extruded, F5- Blanched sun dried non-extruded, F6- Fermented oven dried extruded and F7- Fermented oven dried non-extruded. Values (mean ±sd) with different superscripts in the same column are statistically different. The techniques of processing the soup mix are: *Low-cost (artisanal/sun-drying) technique, **intermediate mechanized technique and ***highly mechanized (extrusion added) technique.

**Table 8.5: Colour changes in formulated soup mixes**

| Sample | L* | a* | b* | C* | h* | ΔE* |
|---|---|---|---|---|---|---|
| F1*** | 55.62±1.86[a] | 1.25±0.85[c] | 17.33±1.30[a] | 17.39±1.24[a] | 85.71±3.07[a] | 3.53±2.13[b] |
| F2** | 57.10±1.39[a] | 1.44±0.73[c] | 15.42±1.94[ab] | 15.51±1.85[ab] | 84.35±3.69[a] | 3.76±2.27[b] |
| F3*** | 50.97±1.91[ab] | 1.54±0.65[c] | 13.95±2.11[bc] | 14.04±2.14[bc] | 83.78±2.11[a] | 9.15±2.69[ab] |
| F4** | 52.09±6.46[abc] | 1.66±0.59[bc] | 15.86±1.26[ab] | 15.96±1.21[ab] | 83.95±2.59[a] | 7.79±5.63[ab] |
| F5* | 49.94±1.72[abc] | 2.89±0.16[ab] | 11.73±0.38[cd] | 12.08±0.40[cd] | 76.17±0.37[b] | 11.28±1.44[a] |
| F6*** | 47.72±2.92[c] | 4.01±0.42[a] | 10.16±0.43[d] | 10.92±0.53[d] | 68.51±1.42[c] | 14.18±2.05[a] |
| F7** | 47.76±2.07[c] | 3.87±0.39[a] | 11.15±1.01[cd] | 11.81±1.01[cd] | 70.81±1.84[bc] | 13.50±1.63[a] |
| %CV | 5.97 | 24.4 | 3.11 | 9.56 | 3.01 | 31.8 |
| HSD | 7.09 | 1.33 | 9.92 | 3.07 | 5.47 | 6.19 |
| p-value | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

F1- Blanched oven dried extruded, F2- Blanched oven dried non-extruded, F3- Blanched solar dried extruded, F4- Blanched solar dried non-extruded, F5- Blanched sun dried non-extruded, F6- Fermented oven dried extruded and F7- Fermented oven dried non-extruded. Values (mean ±sd) with different superscripts in the same column are statistically different. The techniques of processing the soup mix are: *Low-cost (artisanal/sun-drying) technique, **intermediate mechanized technique and ***highly mechanized (extrusion added) technique.

### 8.3.3 Sensory quality of cowpea leaves soup mixes

The liking of the colour, grainy and cowpea leaf odour, bitterness, oiliness and long-lasting taste of the soup mixes did not significantly (p>0.05) differ based on the technique of processing used

(Table 8.6). Incorporating the fermented dehydrated leaves rather than the blanched leaves gave significantly ($p<0.01$) higher liking of the saltiness and fermentation odour with scores of 6.6-8.6 and 5.2-5.5, respectively, compared to scores of <6.3 and <5.1, respectively, in the latter. Highly mechanized techniques that incorporated extrusion of the soup mixes resulted in significantly ($p<0.01$) lower liking (4.1-4.9) of the consistency of the soup mixes. The low-cost processed soup mix had the least acceptability compared to the soup mixes processed intermediate and highly mechanized techniques.

### 8.3.4 Keeping quality of cowpea leaves soup mixes

In defining the different models, the factors were classified as shown in Appendix 5: Part A. The interaction of factors except in the case of free fatty acids and peroxide values did not account for a large variation on the keeping qualities of the soup mixes (Table 8.7). Similarly, as single factors, period of storage and type of package did not explain the largest variation in the colour changes and microbial counts of stored samples. The yeast and mould count in all the soup mixes, after twenty one days of accelerated storage, was < 10 cfu/g after 21 days of storage. The type of package, type of soup mix, period of storage of soup mixes and the interaction factors of type of soup mix and period of storage and period of storage and type of package significantly influenced the peroxide values of stored soup mix (Appendix 5: Part B). With increasing period of storage, the peroxide values of the soup mixes increased with the samples surpassing the mark of 3 mEq/100g active oxygen ($O_2$) on the 18$^{th}$ day of accelerated storage. The independent factors of type of package, type of soup mix and period of storage of soup mixes and the interaction factors of the three significantly ($p<0.01$) affected the free fatty acids content of the stored samples (Appendix 5: Part C). By the twenty first day of storage, the soup mixes had a free fatty acid content of 1.13 g/100g. The kraft paper had the highest accumulation of the peroxide value over the period of storage compared to the plastic and aluminium packages ($p<0.05$), see Figure 8.2. The non-extruded samples and the low-cost processed had higher free fatty acid (2.8 and 1.8 g/100g) than the extruded (0.8 g/100g) over the period of storage. With increasing period of storage, the low-cost processed soup mix accumulated higher peroxide values than the extruded and the non-extruded-soup mixes (Figure 8.3). For a period of 12 days and under, all the samples notwithstanding the type of package had free fatty acid content of below (1%).

Moreover, the low-cost processed and non-extruded samples had significantly ($p<0.01$) higher peroxide values of 4.34 and 6.57 mEq $O_2$/100g, respectively, than the extruded soup mix (2.38 57 mEq $O_2$/100g). Storing of the soup mixes in plastic packages resulted in peroxide values of 3.6 ± 0.9 57 mEq $O_2$/100g for low-cost processed soup mixes on the twelfth day of accelerated storage; 2.13 ± 0.27 57 mEq $O_2$/100g for extruded samples after 21 days of storage; and 3.4 ± 0.48 57 mEq $O_2$/100g in the eighteenth day of accelerated storage of non-extruded soup mixes. On the other hand, samples stored in aluminium pouches and kraft papers had detectable levels of peroxide values only in the low-cost processed samples but below 3 57 mEq $O_2$/100g.

**Table 8.6: Sensory attributes of formulated soup mixes**

| Formulations | Colour | Cowpea leaf odour | Fermentation odour | Grainy odour | Bitterness | Saltiness | Consistency | Oiliness | Long-lasting taste | Overall acceptability |
|---|---|---|---|---|---|---|---|---|---|---|
| F1*** | 6.3±2.4$^{a}$ | 6.1±1.9$^{a}$ | 4.0±2.1$^{d}$ | 5.4±2.1$^{a}$ | 5.1±2.6$^{a}$ | 5.6±2.7$^{e}$ | 4.8±2.1$^{c}$ | 6.0±2.4$^{a}$ | 4.6±2.7$^{ab}$ | 5.7±2.7$^{a}$ |
| F2** | 5.0±2.9$^{a}$ | 5.6±1.9$^{a}$ | 4.6±2.1$^{c}$ | 5.5±2.1$^{a}$ | 5.0±2.6$^{a}$ | 6.3±2.4$^{c}$ | 5.2±3.2$^{b}$ | 5.8±2.7$^{a}$ | 4.9±2.9$^{ab}$ | 5.7±3.0$^{a}$ |
| F3*** | 6.5±2.7$^{a}$ | 5.7±2.6$^{a}$ | 4.8±1.4$^{bc}$ | 5.9±2.7$^{a}$ | 6.0±2.6$^{a}$ | 4.8±3.1$^{f}$ | 4.9±2.8$^{c}$ | 5.7±2.6$^{a}$ | 5.0±2.3$^{ab}$ | 5.2±2.6$^{b}$ |
| F4** | 5.8±2.9$^{a}$ | 5.8±2.1$^{a}$ | 4.8±1.5$^{bc}$ | 5.3±2.2$^{a}$ | 6.5±2.0$^{a}$ | 6.0±2.2$^{d}$ | 5.7±3.2$^{a}$ | 5.2±3.1$^{a}$ | 5.6±2.8$^{a}$ | 5.2±3.3$^{b}$ |
| F5* | 5.5±2.6$^{a}$ | 5.1±1.9$^{a}$ | 5.1±2.5$^{abc}$ | 5.8±2.2$^{a}$ | 5.3±2.6$^{a}$ | 5.9±2.2$^{d}$ | 5.7±3.0$^{a}$ | 4.2±1.4$^{a}$ | 4.0±1.5$^{b}$ | 4.7±2.6$^{c}$ |
| F6*** | 4.9±3.3$^{a}$ | 5.5±2.3$^{a}$ | 5.2±2.0$^{ab}$ | 6.1±2.5$^{a}$ | 5.5±2.8$^{a}$ | 6.6±2.2$^{b}$ | 4.1±2.6$^{c}$ | 5.8±2.8$^{a}$ | 4.0±2.5$^{b}$ | 5.0±3.3$^{b}$ |
| F7** | 4.6±2.4$^{a}$ | 4.9±1.9$^{a}$ | 5.5±2.3$^{a}$ | 4.5±2.5$^{a}$ | 5.2±2.2$^{a}$ | 8.6±2.1$^{a}$ | 6.0±2.7$^{a}$ | 5.5±2.8$^{a}$ | 5.6±2.6$^{a}$ | 5.8±2.9$^{a}$ |
| %CV | 49.4 | 37.6 | 41.0 | 42.4 | 44.8 | 86.1 | 52.9 | 46.2 | 50.8 | 57.1 |
| HSD | 2.09 | 1.6 | 0.50 | 1.79 | 1.90 | 0.22 | 0.31 | 2.04 | 2.00 | 0.24 |
| p-value | <0.061 | 0.294 | 0.008 | 0.184 | 0.216 | 0.002 | 0.007 | 0.818 | 0.058 | 0.009 |

F1- Blanched oven dried extruded, F2- Blanched oven dried non-extruded, F3- Blanched solar dried extruded, F4- Blanched solar dried non-extruded, F5- Blanched sun dried non-extruded, F6- Fermented oven dried extruded and F7- Fermented oven dried non-extrude. Values (mean ±sd) with different superscripts in the same column are statistically different. The techniques of processing the soup mix are: *Low-cost (artisanal/sun-drying) technique, **intermediate mechanized technique and ***highly mechanized (extrusion added) technique.

**Table 8.7: Akaike Information Criterion for selection of model explaining variation in keeping qualities**

| Models | Response variable Delta (AIC weight %) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **L*** | **a*** | **b*** | **C** | **H** | **ΔE** | **Moisture content (%)** | **Yeast and mould counts Log cfu/g** | **Total viable counts Log cfu/g** | **Free fatty acids (g/100g)** | **Peroxide value mEqu/100g** |
| Model_1 | 0.0(100) | 0.0(100) | 1.9(28) | 0.0(61) | 0.0(81) | 1.1(35) | 0. 0(96) | 0.0(94) | 0.0(80) | 28.2(0) | 84.6(0) |
| Model_2 | 20.1(0) | 32.9(0) | 0.0(70) | 0.9(39) | 26.8(0) | 0.0(61) | 6.3 (0) | 5.7(6) | 2.8(19) | 25.7(0) | 138.2(0) |
| Model_3 | 23.6(0) | 37.8(0) | 48.7(0) | 43.5(0) | 45.8(0) | 9.2(1) | 22.9(0) | 33.5(0) | 60.6(0) | 61.5(0) | 102.6(0) |
| Model_4 | 42.8(0) | 59.0(0) | 50.1(0) | 45.2(0) | 62.9(0) | 5.8(3) | 48.1(0) | 44.0(0) | 67.3(0) | 65.8(0) | 127.2(0) |
| Model_5 | 30.3(0) | 16.0(0) | 25.2(0) | 25.2(0) | 2.9(16) | 24.3(0) | 44.3(0) | 10.6(0) | 8.7(1) | 0.0(100%) | 0.0(100) |

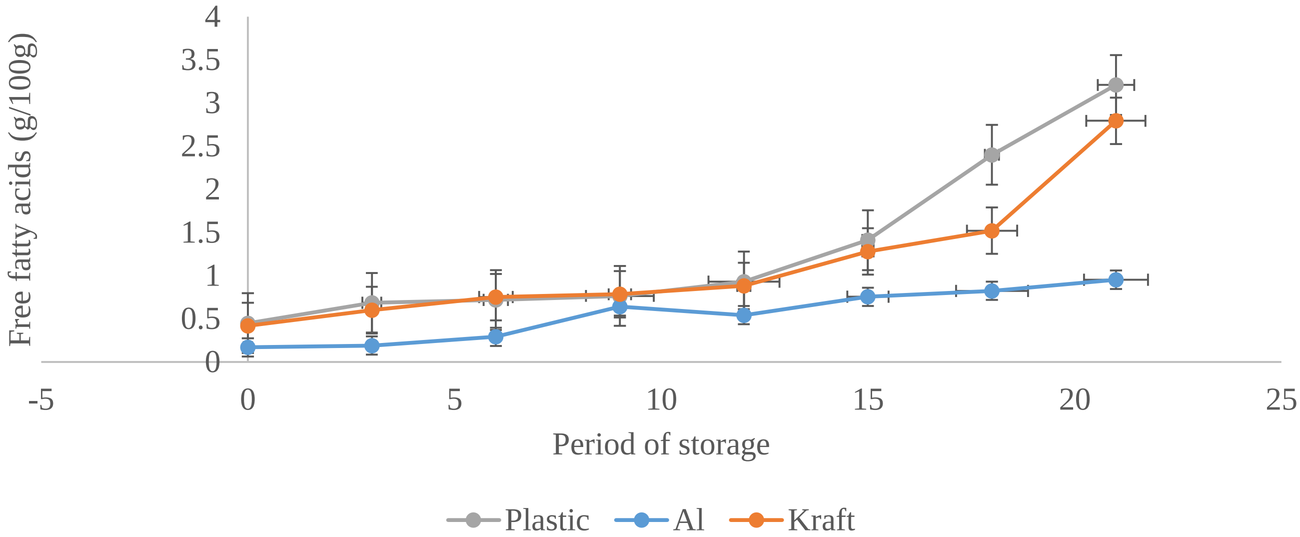


**Figure 8.2: Effect of period of storage on the free fatty acid content of cowpea leaves soup mixes packaged differently.** The error bars indicate the standard error of the mean.

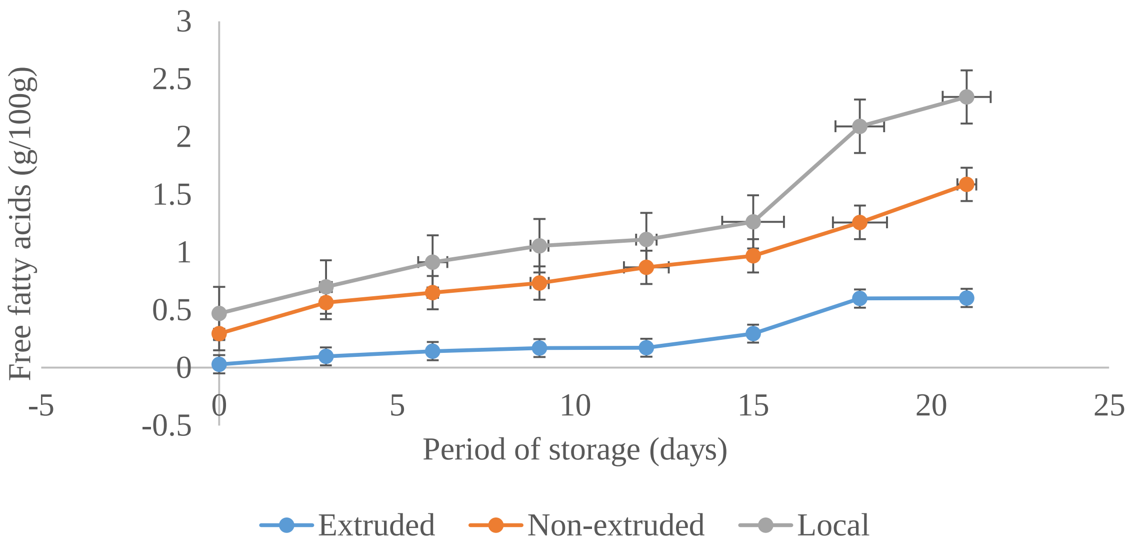


**Figure 8.3: Effect of period of storage on the free fatty acid content of different cowpea leaves soup mixes.** The error bars indicate the standard error of the mean. Extruded is the soup mix processed through highly mechanized technique; non-extruded is processed through intermediate mechanized technique and local is processed through low-cost technique.

## 8.4 Discussion

### 8.4.1 Nutritional and antinutrient contents of cowpea leaves soup mixes

Elevated levels of crude ash in the raw materials of fermented leaves as established Chapter Six, explains the higher crude ash content of soup mixes formulated from the leaves. The finding that crude ash and crude protein reduces in the extruded soup mixes is indicative of degradation of the nutrients in process. Gui et al. (2012) and Hagenimana et al. (2006) in describing similar trend established that the fats and proteins form complexes between each other and with starch during extrusion. Similarly, due to low beta carotene and ascorbic acid contents in the dehydrated leaves used as dominant raw material in the formulation, low-cost processed cowpea leaves soup mixes and mechanized processing techniques co-opting fermentation as a pre-treatment low levels of beta-carotene and ascorbic acid. Whereas in incorporating tomato and coriander leaves which are rich in beta carotene and ascorbic acid, the use of the techniques of processing of fermentation as pre-treatment and sun-drying have already been proven in the study to result in declining levels of these two micronutrients. Beta-carotene and ascorbic acid are labile nutrients that are easily oxidized when exposed to UV-radiation and thermal treatment, that the drying technique in the study utilizes (Lee et al., 2018; Sonar et al., 2019).

In order to improve the stability of these nutrients in storage, it is recommended that the moisture content be kept below 14% (Hag et al., 2020), the critical level above which most micro-organisms will begin to grow gradually. The soup mixes obtained in this study adhered to this threshold including the low-cost processing, thus aiding in improving the keeping quality of the products. Incorporating of the mechanized techniques in processing of dehydrated products of cowpea leaves has more emphasis of reducing leaching of minerals, thus the incorporation of steam-blanching instead of hot water blanching (Kirakou et al., 2017; Wickramasinghe et al., 2020). Additionally, blanching attenuates the loss of anti-oxidant activity (Nobosse et al., 2017), thus the minimal variation thus the anti-oxidant activity notwithstanding the technique of processing of the vegetables used. The positive attribute of fermentation as a pre-treatment was noticeable with reduced levels of nitrates in the soup mixes. WHO has set the acceptable daily intake of nitrates at 3.7 mg/kg body weight (Natesh N et al., 2017). The reconstituted soups of cowpea leaves, assuming a normal adult weighing 70 kg consuming a cup daily, will therefore consume 0.002 mg/kg.

### 8.4.2 Functional properties of cowpea leaves soup mixes

Fermentation induces acidity in the preserved cowpea leaves thus the low pH realizable in the soured product of the soup mix (Owade et al., 2021). The higher extrusion temperatures (70°C) utilized in the highly mechanized processing resulted in degradation of organic acids formed during the fermentation process of the leaves thus the extruded soured soup mixes had relatively low titratable acidity. Fermentation of the cowpea leaves utilization the LAB bacteria, thus yields lactic acid that has the tendency to degrade in thermal treatment (Komesu et al., 2017). Onyango et al. (2005) in undertaking product-instantization study, found that the acidity in extruded products did not change, however, this may be due to acidification of the product that was done using lactic and citric acids. In another study, Ojokoh et al. (2015) undertook fermentation after extrusion, however, this is only possible for wet products.

In his study, Mesquita et al. (2013) related the increasing bulk density for extruded products to expansion of the extrudates. This explains the increased bulk density in highly mechanized processed soup mixes. Moreover, Poliszko et al. (2019) relates that the reduction in the consistency of extrudates is due to dextrinization of starch. Singha et al. (2018) in his study posits that with increasing extrusion temperature, the viscosity of the extrudates would decline. However, the use of similar conditions of parameters in the extrusion of the products in our study makes it difficult to elucidate the exact impact of extrusion conditions on the textural properties of the product.

The formulated soup mixes were transformed in colour from greenish to yellowish which is as a result of the incorporation of the starch source and other ingredients which have positive values of the a* coordinate. Deviation in the colour properties of the low-cost processed soup mixes from the utilized dominant raw material varied from mechanized techniques that did not incorporate fermentation as a pre-treatment. Whereas, blanching techniques that have been found to attenuate colour degradation in dehydrated products through control of oxidation (Mulokozi and Svanberg, 2003; Nyambaka and Ryley, 2004), oxidation would still possibly occur in fermented products and photo-oxidation induces deterioration of coloured pigments. Ntsamo et al. (2020) explains the declining lightness in fermented products to be resulting from the breaking of the cell wall thus release of cell pigments and the continued occurrence of enzymic browning.

### 8.4.3 Sensory quality of cowpea leaves soup mixes

The most preferred soup mix had the highest preference for saltiness, consistency and fermentation odour. Fermentation induces sourness in the fermented vegetables (Swain et al., 2014); an attribute that has been reported by Breslin (1996) that it has complementary effect with saltiness with increasing the intensity of each other at moderate concentrations. In evaluating the impact of intensity of saltiness on the acceptability of vegetable soups, Hayabuchi et al. (2020) established that product liking increased with increasing intensity of saltiness. With the preparation of soups from the soup mixes, the concentration of the salt in the soups stands at 0.3%. In their study that evaluated acceptability of soups, Leong et al. (2016) established that incorporating salt at 0.2 to 0.4% generated acceptable product. The similarity in the overall acceptability of the various formulations of the cowpea leaves soup mixes except for the locally processed can be explained by similarity in the liking of textural properties such as consistency of the soup; for the textural properties constitute one of the single-most attributes determining acceptability of soup mixes (Bothma et al., 2020).

### 8.4.4 Keeping quality of cowpea leaves soup mixes

The Kenya standard for dehydrated soups and broths stipulate yeast and mould and total viable counts of each below 10 CFU/g (KEBS, 2012); a threshold that a product stored for over six month in this study adhered to. The Tanzanian standard has a lower threshold for the yeast and mould counts (nil) in comparison to the Kenyan standard (TBS, 2020). In terms of adequacy of different packaging material, the Kenyan standard stipulate that the soup mixes must be packaged in opaque packages, whereas the Tanzanian standard permit the transparent packages. This study determined that the microbial quality of the stored product was not influenced by the type of package used. Chemical constituents of free fatty acids and peroxide values, resulting from the degradation of the added vegetable fat increased with storage and compromised the safety of the product at a given stage of storage. The safe levels of peroxide values in instant foods have been determined to be 30 mEq/kg, 3 mEq/100g (Gotoh and Wada, 2006). Safety of foods is also indicated by a threshold of below 1% for free fatty acids (Barden, 2014). Free fatty acid and peroxide values are indicators of oxidative rancidity of food; indication of breakdown of the vegetable oil in the food (Frega et al., 1999). It is recommended that in evaluation of lipid peroxides, higher accelerated temperatures (>65 °C) are not used for the trend of accumulation of the lipid peroxides and free fatty acids become unpredictable (Ragnarsson and Labuza, 1977). The occurring oxidation in the soup mixes explains the colour changes noted with increasing period of storage.

Packaging in aluminium pouches delays lipid oxidation, thus the lengthened product shelf-life (Cyprian et al., 2017). Aluminium pouches provide the vacuum environment by sealing the oxygen that is needed to generate lipid peroxides. The kraft paper and plastic packages showed less shelf-life for keeping of the soup mixes of five months compared to those that were stored in aluminium pouches that could keep for over seven months. Oxidation of the added oil is thus one of the single-most factors that would limit the shelf-life of cowpea leaves soup mixes, with storage in kraft paper and plastic container permitting more oxidation and formation of lipid peroxides (Sra et al., 2014).

Low-cost processing technique in this case substituted the starch, a commercial product, with whole maize flour which is the dominant starch source utilizable from the cowpea producing households as established in a study by Owade et al. (2020).

## 8.5 Conclusion

The utilization of low-cost processing technique comparatively yields soup mixes of similar physico-chemical quality as soup mixes that are processed using mechanized techniques. On the other hand, the limitation, is recognizable in the sensory and keeping qualities. The utilization of mechanized techniques yields products of better sensory and keeping qualities. Whereas the low-cost component presents advantages in cost, with similar advantages to the mechanized techniques in terms of physico-chemical quality, the keeping and sensory quality may serve as a deterrent to the dissemination and adoption of such approaches. The implication of this study is in shaping the dissemination approaches for the developed technologies that would lay emphasis on the uptake of the mechanized technologies for the processing of the soup mixes rather than the low-cost techniques.

# GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

## 9.1 General discussion

In promoting food and nutrition security among households, cost effectiveness is a major consideration for the cost of such initiative is a major determinant of the capacity of the households and producing farmers to adopt the technology (WHO and FAO, 2006). Product quality is evaluated in its categories of safety and nutritional, sensory and keeping qualities and functional properties (Petrescu et al., 2020). Cowpea leaves face the demerit of loss of textural, aesthetic, nutritional and sensory quality in processing with low-cost techniques of processing such as sun-drying without blanching aggravating the losses (Chikwendu et al., 2014; Kirakou et al., 2017; Okello et al., 2015). Hurdle technology and incorporation of mechanized processing rather than the low-cost processing provided advantages in terms of quality amelioration. The cost implication of adopting these highly mechanized technologies on evaluation revealed the long-term investment in solar-drying still assured low-cost options. The highly mechanized processing provided minimal advantages over the low-cost processing, and this is adduced to the incorporation of hurdle technology to overcome the challenges associated with the use of a single preservation technique.

With the existence of cowpea leaves dehydration techniques amongst the communities, though limited practice of the same still exist (Owade et al., 2020b), options mechanized processing are complementary and improvement on the existing practices. This study also provide a case promotion of hurdle technology even with the low-cost processing in order to attain quality amelioration of the value-added cowpea leaves. This study cannot overemphasize the potential avenues for utilization of cowpea value added products as food vehicles for micronutrients which are limiting in the diets in SSA (Ferguson et al., 2015; Fraval et al., 2019). However, it should not just be assumed that gaps in value addition entail all that occasion the limited utilization and seasonal availability of cowpea leaves. The constraints in production and marketing constituted challenges that would require a multi-stakeholder approach in addressing in order to promote the uptake and the commercialization of the vegetable.

The Fruits and Vegetable for All Seasons (FruVaSe) research project that the present study forms part of has a strong component of promotion of value addition approaches for the cowpea leaves value chain. In undertaking the study, FruVaSe has partnered with the County Government of the two study areas, Kitui and Taita Taveta Counties, in order to address seasonality in the availability of cowpea leaves among producing households. The immediate implication of this study is in the selection of value addition approaches for dissemination for the resource-constrained households in these ASALs. Moreover, the study has far-reaching impact on other related value chains of the ALVs that are faced with similar constraints limiting their utilization. In yielding the soup mixes for commercialization, instantization of the product attracts additional costs without necessarily adding advantages to the product quality attributes. For the low-cost processing, this mechanized technique does not necessarily improve the benefits thus in promotion of these technologies for resource-constrained settings, a justification for overlooking such technology has been provided by this study.

## 9.2 General conclusions

From this study, low-cost processing techniques including sun-drying were the most practiced among the households growing cowpea leaves in the ASALs. However, there was increasing reliance of fresh leaves as the principal source of nutrition over the preserved forms. This has left the households exposed to scarcity of the vegetables in the off-season, with limited adoption of value addition practices aggravating the shortage.

In undertaking the optimization of fermentation of cowpea leaves, the study concluded that addition of salt and sugar provided feasible parameters for improvement of the fermentation process. This technique can possibly serve as an alternative to blanching in the pre-treatment of dehydrated leaves.

Whereas, the traditional dried cowpea leaves were easily available and utilized in the ASAL areas, the retention trends of physico-chemical quality were poorer compared to the optimally dehydrated vegetables. The inclusion of either blanching or fermentation improved the retention of colour, labile nutrients in form of beta-carotene and vitamin C and minerals that are often lost to leaching.

This study also established that the artisanal processing techniques in the form of sun-drying presented the least-cost option in processing cowpea leaves soup mixes; however, the minimal derivative benefits including low nutrient retention and limited consumer acceptability that would constrain its extended utilization.

Use of the solar-drying without extrusion technique presented most cost-efficient pathway for processing of the soup mix. Moreover, the major demerit of the low-cost option was on its sensory acceptability, nutritional quality and keeping quality. However, this technique would still serve as complementary and at times as alternative to the highly mechanized techniques especially in the resource-constrained ASAL areas.

## 9.3 General recommendations

The techniques evaluated in this study show potential for use both at the industrial and the household level. The low-cost techniques are recommended for uptake among the households in resource-constrained settings. Moreover, the developed product of cowpea leaves soup mix presents a stable food vehicle that can be generated using the cost-efficient techniques established in this study. In order to enhance the commercial viability and product value addition, the marketing component needs to be enhanced in order to address the limited commercialization adduced to products of cowpea leaves. A gap in the commercialization needs both action from the policy-makers end and value chain actors too.

Whereas the developed product was found feasible for utilization and use among households due to the high level of micronutrients, this study had the limitation of not evaluating an intervention study promoting the use of the cowpea leaves soup mixes in improving the micronutrient status of the population in the ASAL areas. This is a research gap, that is feasible for possible exploration in order to promote commercialization and intake of the developed products and cowpea leaves in general.

On the end of farmers of cowpea leaves, this study provides a case for transitioning to and increased adoption of value addition practices for the vegetable. Without intake of the value-added products, the utilization of the vegetables among the producing households would still remain low. The dissemination of these technologies should therefore target the farmers without ignoring the processors for uptake in order to increase the value addition practices in the value chain.

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## APPENDICES

## APPENDIX 1: RESPONDENTS QUESTIONNAIRE

The aim of this study is to assess the current trends and constraints in the utilization of cowpea leaves and the traditional preservation and processing techniques and processed products of cowpea leaves in Kenya. Your honest responses will be used for this research purpose only and shall be treated with utmost confidentiality. Your cooperation and participation is highly appreciated.

Thank you for accepting to take part in this study.

**Date the form was filled (dd/mm/yyyy)** __/__/____

**Altitude**___________________ **Latitude**________________________

**Longitude**______________________

**Introduction**

1. **Respondents details**

| Name of household head | Name of interviewer | Name of respondent |
|---|---|---|
| | | |

2. **Location**

| County | Sub-County | Ward | Village |
|---|---|---|---|
| | | | |

**Section A: Socio-demographic and Economic characteristics (List each household member)**

| No | Names | Gender<br>1-Male<br>2-Female | Age (yrs) | Relationship to household head<br>1=Husband<br>2=Wife<br>3=Child<br>4=Brother<br>5=Sister<br>6=In-law<br>7=Farther<br>8=Mother<br>10=Others (specify) | Level of education<br>1=Never went to school<br>2=In primary<br>3=Completed primary<br>4=In secondary<br>5=Completed secondary<br>6=University and Tertiary<br>7=Dropped out of any of the above levels | Occupation<br>1=Salaried employment<br>2=Farmer<br>3=Trading and other informal businesses<br>4=Casual labour<br>5=Unemployed<br>6=Student |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |

3. Who decides the food to be bought for the family?
   1-Mother 2-Father 3-Wife 4-Husband 5-Any other, specify…………………………..

4. What is the average monthly income of the family?
   KES………………………………………………..
5. Do you consume cowpeas leaves for vegetables?
   1-Yes 2-No

6. Where do you source the cowpea leaves for your consumption?
   1-Own farm 2-Purchase from roadside vendors 3-Purchase from the market

**SECTION B: PRODUCTION PRACTICES OF COWPEA LEAVES, if involved in production of cowpea leaves**

7. Which is the most cultivated crop cultivated in this area?

1-Cereals such as maize, sorghum and millet

2-Pulses such as beans, green grams

3-Vegetables such as leafy vegetables, tomatoes and onions

4-Root crops such as cassava and sweetpotatoes

5-Fruit crops such as mangoes, oranges

7.1. Which are the most cultivated leafy vegetables in this area (base it on yield)? List three most cultivated.

1-Cabbages 2-Kales

3-traditional vegetables such as cowpea leaves (specify)

4. Others, specify

7.2. Are cowpea leaves a major produce from your farm?

1-Yes 2-No

7.3. If Yes, what is the performance compared to other leafy vegetables that you grow?

1-Gives more yields

2-Is more drought resistant

3-Is more resistant against pests and diseases

4-don’t grow other leafy vegetables

5-others

8. I would love to know the cowpea varieties you plant, the cropping system you use, the major produce from each variety and, the main purpose of production.

| Cowpea variety | Cropping system<br>1=monocropping<br>2=intercropping | Major produce<br>1=leaves<br>2=grains<br>3=both | Main purpose<br>1=sale<br>2=own consumption<br>3=both at equal share (50:50) | If for sale, who sells the produce?<br>1=man<br>2=woman<br>3=both |
|---|---|---|---|---|
| | | | | |
| | | | | |

9. Which varieties of cowpea do you plant? Please list

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

9.1. Which of the above do you prefer most?

..........................................................................................................................

Reason………………………………………………………………………………

9.2. Is the preference the same across all seasons?

1-Yes 2-No

Reason………………………………………………………………………………

9.3. Are there landrace varieties that are preferred for their leaves by farmers or are marketable in the area?

| Variety | Reason |
|---|---|
| ……………………… | ………………………………………….. |
| ……………………… | …………………………………………. |

9.4. Are there traditional varieties which were preferred for their leaves that are no longer planted in the area?

| Variety | Reason |
|---|---|
| …………………… | ……………………………………………. |
| ..………………… | …………………………………………. |

10. How many cropping seasons do you plant cowpea leaves in a year?

…………………………………

10.1. What production quantity do you obtain in a season?

…………………………………………..kg

10.2. In case you plant in more than one season, please specify the season with the most and the one with the least production quantities?

Season (from month to month) Production quantity

Best ……………………………………………………….kg

Least ………………………………………………………kg

10.3. How do you harvest cowpea leaves?

1-Uproot the whole plant 2-Pluck the leaves

10.4. At what time do you do the harvesting of the leaves?

1-Morning 2-Afternoon 3-Evening 4-Anytime

10.5. At what point do you begin the harvesting of leaves, at what intervals and when do you terminate the harvesting?

Initiation of harvesting ……………………… weeks after emmergence

Interval of harvesting …………………….. weeks

Termination of harvesting ………………………….. weeks

10.6. To whom do you sell your produce?

1-Consumers 2-Small scale traders (kiosks) 3-Supermarkets 4-Middle men

**SECTION C: POSTHARVEST HANDLING OF COWPEA LEAVES**

11. In which containers do you keep your produce during harvesting?

1-On a plastic sheet 2-On bare ground

3-In woven basket

12. Immediately after harvest where do you put your produce?

1-Under a shade

2- Leave them outside overnight

3-In the sun

5-Any other, specify………………

13. How do you remove the field heat from the cowpea leaves?

1-Sprinkle water 2-Leave them under shade 3-Leave them outside overnight

4-Room cooling 4-I do nothing

14. In what packaging materials do you store the cowpea leaves you harvest?

1-Sack 2-Polythene bags 3-Carton

4-Plastic containers 5-Any other, specify ……………….

15. How are your cowpea leaves produce transported to the market?

1-Truck 2-Carts 3-Human labour 4-Any other…………………..

16. How much of your produce do you lose during transportation to the market? (Provide the percentage, whether a sack or bag, of what is spoiled that was gotten from the farm before getting to the market)

1-0-10%

2-10-30%

3-30-50%

4->50%

16.1. What is the major cause for this?

1-Poor storage facilities

2-Long distance to the selling point

3-Contamination of produce

4-Any other, specify…………………

17. What are the major causes of the postharvest losses of cowpea leaves at the retail?

1-Inappropriate storage

2-Low quality of the produce such as shriveled leaves

3-Contamination of the produce by pests and other hazards

4-Any other, specify…………………………………….

18. What practice do you undertake to minimize spoilage of fresh cowpea leaves?

1-Sell immediately after sale

2-Dry the leaves

3-Any other, …………………..

4-None

19. Are there practices you have learnt from other people about how to preserve the quality of cowpea leaves that you have not yet adopted? Please list them.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

**SECTION D: UTILIZATION OF COWPEA LEAVES**

20. In what forms do you consume the cowpea vegetables?

1-Boiled 2-Fermented 3-Sun-dried 4-Blanched

4-Any other, specify……………………………………

21. How do you incorporate cowpea leaves into the diet?

1-Consumed singly as vegetables

2-Made as a composite dish with other vegetables

3-Mashed with other foods

22. How frequent in a week do you consume cowpea leaves in your household?

……………………………. days in a week

23. Which group consumes it most?

| **Members** | **Reason** |
|---|---|
| Children <5years | |
| Children > 5 years | |
| Pregnant mothers | |
| Breastfeeding mothers | |
| Old women | |
| Whole family | |
| Other: | |

24. Which other local preserved products are you aware of that have cowpea leaves incorporated?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………

25. Apart from using cowpea leaves for human consumption, what other uses do you have?

1-Livestock feed 2-Medicinal use 3-Any other, specify………………………

**SECTION E: PROCESSING AND PREPARATION OF COWPEA LEAVES**

26. What processing techniques do you apply in the preservation of cowpea leaves?
1-Sun-drying 2-Solar drying 3-Blanching

4-Fermentation

5-None 6-Any other, specify………………..

26.1. In case of sun-drying, what do you do to your cowpea leaves?
1-Sorting, washing and blanching then drying

2-Sorting and washing and drying

3-Sorting then drying

26.1.1. Do you blanch the vegetables before drying and for how long (minutes)?
…………………….minutes

26.1.2. On which surface do you dry the vegetables?
1-On the ground on the mat 2-On bare ground 3-on rocks

4-On a raised platform 5-Wiremesh

26.1.3. How long do the dried vegetables take while they are still fit for consumption?
………………………………………weeks

26.2. In case of solar-drying, what do you do to your cowpea leaves?
1-Sorting, washing and blanching then drying

2-Sorting and washing and drying

3-Sorting then drying

26.2.1. Do you blanch the vegetables before drying and for how long (minutes)?
…………………… minutes

26.2.2. On which surface do you dry the vegetables?
1-On the ground on the mat 2-On bare ground 3-on rocks

4-On a raised platform 5-Wiremesh

26.2.3. How long do the dried vegetables take while they are still fit for consumption?

………………………………………weeks

26.3. What do you like about any of these preserved vegetables?

| **Method** | **Reason for like** |
|---|---|
| Dehydrated – sun | |
| Dehydrated - solar | |
| Fermented | |
| Other | |

26.4. What do you dislike about any of these preserved vegetables?

| **Method** | **Reason for like** |
|---|---|
| Dehydrated – sun | |
| Dehydrated – solar | |
| Fermented | |
| Other | |

26.5. Are these preserved vegetables in commercial production in this area?

1-Yes 2-No

26.5.1. In which places are the preserved vegetables sold?

1-Supermarkets 2-Farmer/women group centres

3-Kiosk 4-Open market

5-Any other, specify…………………………

26.6. Would you readily consume dehydrated cowpea leaves as you would fresh ones?

1-Yes 2-No

26.7. Would you readily consume fermented cowpea leaves as you would fresh ones?

1-Yes 2-No

27. Are there products of cowpea leaves that you would love to consume that are currently not available within this place?

1-Yes 2-No

27.1. If yes, please list them.

…………………………………………………………………………………………

…………………………………………………………………………………………

28. Are you aware of any soup mixes that are vegetable based in this area?

1-Yes 2-No

28.1. Would you consume a soup mix made from cowpea leaves?

1-Yes 2-No

**SECTION F: CONSTRAINTS IN THE UTILIZATION OF COWPEA LEAVES**

**29.** What major constraints do you attribute to cowpea production and utilization in this area? (Tick as appropriate)

| **Constraint** | **Extent (1=severe 2=moderate 3=low)** |
|---|---|
| Field pest | |
| Seed scarcity | |
| Lack of land | |
| Poor yields | |
| Lack of market | |
| Poor soils | |
| Poor varieties | |
| Extension services | |
| Low prices | |
| Price fluctuations | |
| Drought | |
| Diseases | |
| Access to seed | |
| Weeds | |
| Massive spoilage | |

30. What is the weight of a bunch of cowpea leaves on sale?

30.1. What is the pricing of cowpea leaves in this area?
KES…………………………… a bunch

30.2. Is there any difference with that of preserved cowpea leaves? (Please specify the differences)

| **Method** | **Price difference in KES per bunch (Indicate less with negative sign and more with positive sign)** |
|---|---|
| Dehydrated | |
| Fermented | |

31. Rate the challenges faced in getting a market for fresh cowpea leaves produce?
1=severe 2=moderate 3=low 4=Not a challenge

31.1. Rate the challenges faced in getting a market for preserved cowpea leaves
1=severe 2=moderate 3=low 4=Not a challenge

32. Please rate the accessibility to the market as a challenge for both the dehydrated and fresh cowpea leaves?
1=severe 2=moderate 3=low 4=Not a challenge

33. In seasons of drought or scarcity of vegetables, how do you obtain the traditional vegetables for your own consumption?
    1-We buy from other places

    2-We use dehydrated/fermented vegetables

    3-We don't consume them

34. What other possible challenges would you relate to the utilization of cowpea leaves?

    ………………………………………………………………………………………………

    ………………………………………………………………………………………………

    ………………………………………………………………………………………………

35. Is there any other thing you would wish to share with us?

    ………………………………………………………………………………………………

    ………………………………………………………………………………………………

    ………………………………………………………………………………………………

**THANK YOU FOR PARTICIPATING**

## APPENDIX 2: KEY INFORMANT INTERVIEW QUESTIONNAIRE

Name_______________________________________________

Organization_______________________________________________

Position_______________________________________________

**Introduction**

This Study is being done by **OWADE JOSHUA** OMABAKA, a PhD student from the University of Nairobi, under the Fruits and Vegetables for all Seasons (FruVaSe) Project. The focus of this study is to establish trends of utilization, processing and preservation of cowpea leaves in this area. You have been referred to us as one of the resourceful people with vast knowledge of the production and/or processing of cowpea leaves in the area. We request that you take part in this study and be free to share with us the information you have on the value chain of cowpea leaves.

**Questions**

1. Before we start, please tell me your role as a stakeholder in the value chain of cowpea leaves in this area?
    a. For how long have you been in this role and what is your opinion with regard to your role, rate your importance in the value chain of cowpea leaves?
    b. Have you ever sought to increase your involvement in this value chain? Did you succeed and what do you adduce for your success/failure?
    c. Going forward, how do you seek to increase your involvement in this value-chain?
2. Please tell me the varieties of cowpeas that are best suited for harvesting cowpea leaves in the area?
    a. Which among these are local and which ones are improved varieties?
3. How is the marketability of cowpea leaves in the area and the surrounding areas? If the marketability is poor, why is this so?
    a. Which specific market areas do the people rely on to sell cowpea leaves?
    b. Are there any differences in the pricing across seasons and across the various markets? Please elaborate.

4. In terms of gender and age group who are the most involved in the value-chain of cowpea leaves? You can state while substantiating the role of each.
    a. Is there specific age group or gender that is known to be involved in value addition practices for other crops other than cowpea leaves? If there is, what encourages their participation in the value addition of that crop but not cowpea leaves?
5. Please tell us other stakeholders and the specific roles they play in the value-chain of cowpea leaves?
    a. How would you rate the success in terms of the fulfillment of their roles for each of these stakeholders?
6. With reasons, how would you rate the utilization of cowpea leaves in this area?
    a. Do you have any recommendations to any of these stakeholders that may help improve the utilization of cowpea leaves in the area?
7. What are some of the modern value-addition practices of cowpea leaves in terms of processing and preservation practiced in the area?
    a. Which specific areas is each of these practices done?
    b. What were the enabling factors that aided the adoption of these practices? (If these practices ceased, why did people abandon them?)
8. What are some of the traditional value-addition practices of cowpea leaves in terms of processing and preservation practiced in the area?
    a. Which specific areas are they done?
    b. What would you adduce to the successful practice of these techniques in this area? (If these practices ceased, why did people abandon them?)
9. Are there any women or farmer groups involved in the preservation and processing of cowpea leaves in this area?
    a. If No, any reason for this?
10. With specific examples, Are there any success stories of value addition for other crops that you would wish can be emulated for the value-chain for cowpea leaves that you know of?
11. What would you cite as the greatest impediment to value-addition of cowpea leaves in the area?
12. What are the opportunities presented for value-addition of cowpea leaves in this area?
13. What are your future plans as a stakeholder in the value chain of cowpea leaves?
14. Do you have any other comments you that you would love to share with us that we have not discussed today?

**THANK YOU FOR PARTICIPATING**

## APPENDIX 3: FOCUS GROUP DISCUSSION GUIDE

### Introduction

This Study is being done by **OWADE JOSHUA OMABAKA**, a PhD student from the University of Nairobi, under the Fruits and Vegetables for all Seasons (FruVaSe) Project. The focus group discussion has the objective of determining the challenges and opportunities that are presented by value-addition techniques such as drying and fermentation on cowpea leaves. Feel free to participate in the group as the utmost confidentiality will be upheld. Remember all answers given during the discussion are respected and all of us are free to contribute.

Please fill in the details of the participants below.

| Name | | Gender (M/F) | Age (yrs) | Marital status | Role in cowpea leaves value chain |
|---|---|---|---|---|---|
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. | | | | | |
| 7. | | | | | |
| 8. | | | | | |
| 9. | | | | | |
| 10. | | | | | |
| 11. | | | | | |
| 12. | | | | | |

1. What is your role in the value chain of cowpea leaves?
    a. Have you ever explored to increase your scope of operation the value-chain of cowpea leaves? Please elaborate with examples.
    b. Who are the greatest participants in terms of gender and age in the valu cjain of cowpea leaves? Please specify the roles played.
2. How do you relate the marketability of cowpea leaves in this area?

   a. If low, what occasions this?
3. Please tell me what are the value-addition practices such as preservation techniques and processing that you know of?
   a. Which ones among these are practiced in this area?
   b. What are the challenges and opportunities that you have seen with value-addition of cowpea leaves?
4. With reasons, how would you rate the attention cowpea leaves has received among policy makers?
   a. If poor, how can it be corrected?
5. Are there any farmer groups or community based organization that are focused in improving the production and value-addition of cowpea leaves? Please give specific examples.
   a. If Yes, what are the successes and challenges the organization has faced?
   b. If No, why is this so?
6. What are your future plans with regard to cowpea production and/or processing?
   a. Any other comment that you may have?

**THANK YOU FOR PARTICIPATING**

## APPENDIX 4: THEMES, ANCHOR CODES AND LABELS OF THE QUALITATIVE DATA COLLECTION TECHNIQUES

| Theme | Anchor codes | Labels |
|---|---|---|
| Limitations in the production and preservation of cowpea leaves | Marketing | Challenges in commercialization<br>Challenges of marketing leaves<br>Challenges in the sales<br>Challenges of producing surplus cowpea leaves<br>Cost of dried leaves and fresh<br>Fluctuation of the pricing<br>Increase sales<br>Pricing of the leaves<br>Trends of marketing<br>Measure for sale<br>Measures for sale in the market<br>Poor sales<br>Sale of dry vegetables<br>Sales of fresh vegetables<br>Scope of the work<br>Improve sales<br>Marketing of the vegetable<br>Constraints of marketing<br>Constraints of sales |
| | Value addition | Limitation for commercialization<br>Challenges in preservation<br>Opportunities for expansion<br>Challenges of preservation<br>Limitation of preservation of the leaves<br>Limitation of utilization of cowpea leaves<br>Limitation to commercialization |
| Current trends in the production and preservation of cowpeas leaves | Production | Information transfer<br>Maturity of the vegetables<br>Priority vegetables<br>Promotion for utilization<br>Constraints of preservation<br>Constraints of production<br>Harvesting of cowpea leaves<br>Intercropping farming<br>Production practices<br>Source of information to<br>Benefits of farming<br>Preference of the crop |
| | Trends in preservation | New value addition and processing<br>Preservation techniques<br>Trends in the production |

| | | |
|---|---|---|
| | | Utilization of the vegetables<br>Consumers of cowpea leaves |
| | Stakeholders in cowpea leaves value-chain | Community involvement<br>Involvement of stakeholders<br>Role in cowpea leaves value-chain<br>Involvement of farmers in value-addition<br>Stakeholder involvement in value-addition |
| Improving the production, preservation and commercialization of cowpea leaves | Improving traditional processing | Preservation of cowpea leaves<br>Drying of the vegetables<br>Processing<br>Traditional processing<br>Opportunities of increasing production<br>Preference of cowpea leaves among farmers<br>Preference of cowpea leaves varieties |
| | Gender and youth involvement | Gender involvement<br>Involvement of gender and youths<br>Involvement of the youth<br>Scope of the work |
| | Improving production of cowpea leaves | Harvesting of cowpea leaves<br>Intercropping farming<br>Production practices<br>Source of information to farmers<br>Benefits of farming<br>Preference of the crop |
| | Utilization | Consumption as soup<br>Domestic consumption<br>New novel products<br>Preservation of cowpea leaves |
| | Quality | Modern preservation of cowpea leaves |
| Policy influence on the production, preservation and utilization of cowpea leaves | Government action | Promotion of cowpea leaves |
| | Way forward | Intervention to promote the vegetable |
| | Policy intervention | Constraints of production<br>Information transfer to the farmer<br>Promotion of production of cowpea leaves |

## APPENDIX 5: STATISTICAL OUTPUT OF ANALYSIS OF DATA ON KEEPING QUALITIES

### PART A: Model selection for evaluation of keeping quality

| **Response variable** | **Models** |
|---|---|
| L*<br>a*<br>a*<br>b*<br>C*<br>h*<br>**ΔE**<br>Yeast and mould counts (log cfu/g)<br>Total viable count (log cfu/g)<br>Free fatty acids<br>Peroxide value | Model_1<-aov(response variable ~Sample + Period of storage + Type of Package)<br>Model_2<-aov(response variable ~ Sample)<br>Model_3<-aov(response variable ~ Period of storage)<br>Model_4<-aov(response variable ~ Type of Package)<br>Model_5<-aov(response variable ~ Sample* Period of storage * Type of Package) |

**PART B: Analysis of variance of the effect of period of storage, type of soup mix and type of package on free fatty acid content of cowpea leaves soup mixes**

| Source of variation | Degree of freedom | Sums of squares | Mean of sums of squares | F-Value | P-value |
|---|---|---|---|---|---|
| Type of soup mix | 2 | 140.1 | 70.1 | 27.992 | 3.95e-08 *** |
| Period of storage | 1 | 1366.4 | 1366.4 | 545.884 | < 2e-16 *** |
| Type of package | 2 | 574.9 | 287.4 | 114.834 | < 2e-16 *** |
| Type of soup mix: Period of storage | 2 | 85.7 | 42.9 | 17.121 | 5.45e-06 *** |
| Type of soup mix: Type of package | 4 | 23.4 | 5.9 | 2.341 | 0.0729 |
| Period of storage: Type of package | 2 | 720.8 | 360.4 | 143.974 | < 2e-16 *** |
| Type of soup mix: Period of storage: Type of package | 4 | 24.7 | 6.2 | 2.464 | 0.0619 |
| Residuals | 37 | 92.6 | 2.5 | | |

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

**PART C: Analysis of variance of the effect of period of storage, type of soup mix and type of package on peroxide value of cowpea leaves soup mixes**

| Source of variation | Degree of freedom | Sums of squares | Mean of sums of squares | F-Value | P-value |
|---|---|---|---|---|---|
| Type of soup mix | 2 | 637.6 | 318.8 | 81.879 | 2.58e-14 *** |
| Period of storage | 1 | 22.2 | 22.2 | 5.689 | 0.02230 * |
| Type of package | 2 | 29.4 | 14.7 | 3.776 | 0.03219 * |
| Type of soup mix: Period of storage | 2 | 3.1 | 1.6 | 0.403 | 0.67146 |
| Type of soup mix: Type of package | 4 | 282.8 | 70.7 | 18.162 | 2.48e-08 *** |
| Period of storage: Type of package | 2 | 24.4 | 12.2 | 3.140 | 0.05502 |
| Type of soup mix: Period of storage: Type of package | 4 | 74.0 | 18.5 | 4.750 | 0.00341 ** |
| Residuals | 37 | 144.1 | 3.9 | | |