THE EFFECTS OF PHYSICAL PROPERTIES OF COMMON BEAN (*Phaseolus vulgaris L.)* VARIETIES ON SOAKING AND COOKING TIME.

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Declaration by the Candidate

I understand that plagiarism is an offence and therefore I declare that this thesis report is my original work and has not been presented to any other institution for any other award.

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Dedication

To my husband Robert S.Ndungu and my children Joel K. Syanda and Jackyline M. Syanda for your support and encouragement.

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List of Abbreviation and Acronyms

AEZ	–	Agro- Ecological Zone
ANF	–	Anti- Nutritional Factors
ANOVA	-	Analysis of Variance
CIAT	-	International Centre for Tropical Agriculture
CRD	–	Complete Random Design
CULTI AF	–	Cultivate African Farmers
GMD	–	Geometric Mean Diameter
DWB	–	Dry weight Basis
FAO	-	Food and Agricultural Organization of the United Nation
GMC	–	Grain moisture Content
I/O	–	Input/output
KALRO	–	Kenya Agricultural and Livestock Organizations
LAC	-	Latin America and Caribbean
LSD	–	Least Significant Difference
MBC	–	Mattson Bean Cooker
MI	-	Weight of soaked beans
MO	-	Weight of dry beans
PABRA	–	Pan-African Bean Research Alliance
PEM	–	Protein Energy Malnutrition
PI	–	Principal Investigator
PV	–	Processing Value
SSA	–	Sub-Saharan Africa

Abstract

Cookability of common bean is constrained by hardness which results to extend cooking times, low widespread consumption, and high cost of cooking fuel, the consequence of this is malnutrition due to nutritional deficiencies and food insecurity. A study was conducted in the seed Laboratory of Kenya Agricultural and Livestock Research Institute (KALRO)-Katumani to investigate the effects of physical properties of eleven bean varieties (GLPX92, KATX69, EMBEAN118, WAIRIMU, EMBEAN14, GLP2, KATX56, KATB9, KATRAM, KATB1 and KATSW-13) in relation to soaking and cooking time in a complete randomized design replicated three times. Bean samples for long and short rains 2016 that were stored for 5 and 8months respectively were evaluated for the effect of water imbibition in relation to cooking time, effect of water imbibition in relation to grain hardness and differences in physical properties and their effects on cooking time. After retrieval from the storage, the samples were size graded manually, weighed and randomly picked 50 grains from each variety which were divided into two groups of 25 and 6 grains for use in cooking and grain hardness respectively. These were weighed and rinsed with distilled water before soaking at varying soaking times of 0, 3, 6, 12 and 24 hours. All the collected data was subjected to analysis of variance (ANOVA) using SAS (version 9.1.3) to detect differences between treatments. Mean separation for significant treatments were carried out using Fisher's protected least significant difference test at $p \leq 0.05$ level and correlation between physical properties (length, width and thickness), hardness, water imbibition and cooking time were determined. The results showed that, the overall water imbibition and cooking time for KATB1 and KATSW-13 imbibed the highest amount of water and also cooked significantly faster than other varieties in both the seasons' whileKATX69andGLPX92took significantly longest time to cook in both the seasons respectively. In terms of hardness, in short rains, KATX69 had the hardest seed coat whileKATSW-13 had the softest. In long rains KATRAM was the hardest while EMBEAN118was softest. Physical properties (length, width and thickness) were significantly higher for short rains than for long rains 2016. In short rains, EMBEAN118 and KATSW-13 had significantly ($p \leq 0.05$) recorded both the highest length and lowest thickness respectively. The width didn't have significant difference among the varieties. For long rains, GLP2 and KATRAM had the highest and lowest lengthrespectively.The width of KATX56 was highest and EMBEAN14 the lowest. KATSW-13 had the highest thickness while KATRAM had lowest. The physical properties of beans affected the cooking time significantly in both the seasons which could be linked to the permeability of the seed coat that influences water imbibition in individual beans. The study recommends breeding of bean varieties with less permeable seed coat which could aid in faster cooking as this would save cost on fuel and time.

Key Words: *Hardness*; cooking time; water imbibition; physical properties; *Phaseolus vulgaris*

CHAPTER ONE

1.0 Introduction

1.1 Consumption and quality use of beans

Common beans (*Phaseolus vulgaris L.*) are the world's most important source of food supply, especially in developing countries, in terms of food energy as well as nutrients (Namugwanya *et al.,* 2014). They are vital for nutrition security and are considered as a cost-effective option for improving the diets of low-income consumers in developing countries. Sub-Saharan Africa has the highest proportion of people living in extreme poverty and highest per capita pulse consumption in the world (Larochelle *et al.,* 2016). Though per capita consumption depends on the consumer preferences which is normally as high as 66kg/capita/year in some parts of western Kenya, the annual per capita consumption always varies with each producing and consuming country and more so among the low income people who cannot afford to buy nutritious foods such as meat and fish (Fetahu *et al.,* 2013).Common beans are consumed after cooking both in the form of whole seeds and decorticated splits in various types of food (Fernandes *et al.,* 2010).

1.2Utilization of beans

As food, beans are consumed either green or dry and are often combined with such energy sources as maize to make the most common food in schools called '*Githeri'* due to their high nutritional quality in terms of percentage protein that is important complement to these starchy foods and the high mineral content of the beans, especially iron and zinc, which are also advantageous in regions where there is a high prevalence of micronutrient deficiencies such as iron deficiency anemia (Kimatu *et al.,* 2014). The beans can also be mixed with other cereals like rice and corn flour and they can as well be eaten as side dish or whole meal or as sandwich or can make sauces. They are important food crops for simultaneously achieving the following sustainable objectives: -economic importance through reducing poverty, improving human health and nutrition hence contributing to the alleviation of malnutrition among resource poor farmers and enhancing ecosystem resilience (Nedumaran *et al.,* 2015).

1.3*Phaseolus vulgaris L.*

Among the pulses, *Phaseolus vulgaris L*. are the most produced and consumed crop and is a major staple food for the majority of households in Eastern and Southern Africa where yearly bean consumption is as high as in Latin America (Kimatu *et al.*, 2014). They, thus, offer a tremendous high content of proteins, vitamins, complex carbohydrates and minerals (Gathu *et al.,* 2012, de Barros and Prudencio, (2016). They are also well adapted to different climatic conditions and so can be grown in any environment (Larochelle *et al.,* 2014). In Kenyabeans ranks the second most important staple crop after maize where it is grown by over 95% of farmers, providing over 65% of the protein and 35% of the caloric intake (Kinyanjui *et al.,* 2015). The acceptance of beans by consumers is based on the attributes such as texture, seed size, taste and cooking quality (Firatligil-Durmus *et al.,* 2010).

1.4 Hindrances to Beans Consumption

The consumption of beans is affected due to negative characteristics such as grain hardness (hard-to-cook) phenomenon. Beans with this hardness defect are characterized by extended cooking times and high fuel consumption and is less acceptable to the consumer (Zhang *et al.,* 2013) especially in nations where fuel wood for cooking is often expensive and scarce. The production of common beans is characterized by a large variety of beans of different cooking properties where the cooking properties are dependent on several factors that include the seed size, variety, storage time and conditions, precooking treatments as well as cooking methods (Ramaekers *et al.,* 2013). Beans have bioactive compounds such as flavonoids (anthocyanins and proanthocyanidins) and phenolic acids (mainly ferulic, caffeic, synaptic and garlic acids) that are mostly found in seed coat (Ramirez Jimenez *et al.,* 2015,Padhi *et al.,* 2017). Some of them contribute to flatulence production in consumers while others reduce the availability of nutrients and cause growth inhibition (Moreno-Jiménez *et al.,* 2015).

Cooking is the main method for eliminating the anti-nutritional factors in beans to ensure acceptable consumption quality and those that require long cooking times are less convenient, more energy consuming hence less desirable to processors and consumers (Wiesinger *et al.*,2016, Jogihalli *et al.*,2017). However, many farmers fail to get uniform cooking quality even after cooking freshly harvested bean varieties simply because of type of water and differences in bean preparation which are generally labor and time intensive and certainly unsuitable for urban settings where time is very often a major constraint (Namugwanya *et al.*,2014*)*. Studies have shown that, bean genotypes are mostly evaluated for agronomic performance but are not systematically assessed for physical properties and Cookability (Siqueira *et al.*,2016). Cookability can be defined as the cooking time required for beans to reach cooked texture that is considered acceptable to consumers (Sofi *et al.*, 2011).

1.5 Bean physical properties versus cookability

Cooking quality may be affected by cultivar, seed characteristics, composition of seeds, growing location and environment (dos Santos Siqueira *et al.*,2013), however, it causes some physiological changes such as gelatinization of starch, denaturation of protein, solubilization of some polysaccharides, softening and breakdown of the middle lamella; a cementing material found in the cotyledon (Brennan *et al.*, 2013). Physical properties, such as seed size and weight, seed coat and cotyledon characteristics can influence bean cooking quality (Pirhayati *et al.*,2011). Information regarding the physical properties is very important in the design of equipment for harvesting, transporting, cleaning, separating, and packaging, storing and processing it into different foods (Sasikala *et al.*, 2011, Siah *et al.*,2014). Attempts to minimize these physical beans hindrances include; prior to cooking, the beans are soaked in water for hours in order to soften them, reduce anti-nutritional substances, reduce cooking time and the cost of cooking fuel to improve the nutritional quality (Silochi *et al.*,2016).The loss in cooking quality is associated with the development of hardness in stored dry beans that are mostly preserved in dry storage at ambient temperature to maintain year-round supply of this important protein food source (Hernández-Delgado *et al.*, 2015*)*. Additionally, the long cooking time of some bean varieties discourage use especially in urban settings where time is often a major constraint (Anozie *et al.*, 2007, Mavromatis *et al.*, 2012, Namugwanya *et al.*,2014). Consumers concerned with convenience in preparation, will reject beans that need extended cooking time. Studies have shown that beans cook well when fleshly harvested but certain successive factors affect cooking quality such as storage, cultivar, seed characteristics, and composition of seeds, growing location and environmental condition (Correa *et al.*, 2010). The breeding of common bean for grain characteristics that cook faster is of great importance to bean consumer's and so breeders who aim at developing varieties with faster cooking time and market acceptability for both the packaging industry and consumer preferences meet the objectives of these consumers (Brennan *et al.*, 2013). According to Alam *et al*, *(*2016) the beans that have a thinner outer skin are more easily hydrated during soaking, which in turn presents shorter cooking time, as the water favors the transfer of heat to the inside of the beans, facilitating the cooking quality.

1.6 Water soaking and imbibition in beans

Soaking of beans is an important process because it involves the absorption of water by cell wall and macro-molecules like proteins and polysaccharides (Hilhorst *et al.,* 2010, Yang *et al.,* 2010, Raes *et al.,* 2014). During imbibition process the seed swell rapidly and changes in size and shape (Ross *et al.,* 2010, Stolárik *et al.,* 2015, Mwami *et al.,* 2017). The imbibed water activates enzymes and facilitates metabolism of the stored starch and protein in seed (Rajjou *et al.*,2012, Gómez-Maqueo *et al.,* 2016) and thus, water imbibition is the most important event for ensuring seed coat permeability of water in cooking and energy generation for the commencement of faster cooking and supply of nutrients (Ilse de Jager *et al.,* 2013). During the process of water uptake, the cell wall enlarges and seed coat becomes softened allowing oxygen diffusion for seed respiration. The amount of water to be imbibed for faster cooking depends on the genotype and species. Like for example water imbibed by soybeanisabout 50% water and for maize is around 34% (Zanella-Díaz *et al.*,2014).Previous studies show that common dry beans from different growing seasons may affect cooking time due to interference in environmental conditions in the physiological quality and the change in the integrity of the seed coat with subsequent changes in regard to water absorption capacity and cooking time (Perina *et al.,* 2014).

Therefore, the purpose of this study was to evaluate the effects of physical properties in relation to soaking and cooking time of common bean varieties. However this study shall not include studieson longer storage periods and with other varieties to determine whether reduction in time is being experienced through soaking. The eleven bean varieties in this study, represents some of the economically food security promising varieties of beans for dry areas and were evaluated because they have not been tested for the grain hardness and cooking time as it is known that beans are susceptible to hardening phenomenon during their shelf life which leads them to acquire extended cooking time (Zamindar *et al.,* 2013).

1.7 Statement of the problem

Malnutrition is a major problem in the semi-arid areas of Kenya especially with the poor farmers. Beans may presents a cheap source of ameliorating the problem. However, common beans are susceptible to poor cookability caused by hardening (hard-to-cook) phenomenon during their shelf life, which precludes availability of nutrients and lengthen cooking time (Zhang *et al.,* 2013) resulting in lowering the bean quality (Zamindar *et al.*, 2013). Defective cooked bean grain, and limited cooking fuel and firewood are already undermining the consumption and purchase of the common beans. This fact is a reflection of changing dietary habits of the population, and especially to the time required for cooking common beans (Siqueira *et al.,* 2013). Although beans provide many nutrients that make their consumption advantageous (Petry *et al.,* 2015), they have been passed over by the less nutritious foods, or foods with faster cooking times and also precooked foods. Therefore, there is need to enhance the usability of this crop, in order to improve its widespread consumption, by addressing bean hardness, moisture content and cooking time.

1.8 Justification

Cooking time is the primary quality characteristic of edible dry beans, and factors that influence the cooking time of commercially grown cultivars, and of experimental lines need to be investigated. Thus, cooking of beans consumes a lot of energy where energy is a major issue in developing nations where beans are largely consumed. Reducing carbon footprints through reduced cooking time is a strong ecological rationale to be used as a trait while developing or breeding varieties. In fact, the most energy demanding process in the whole bean processing is probably cooking of beans.

Studies show that bean genotypes are mostly evaluated for agronomic performance but are not systematically assessed for cookability (Siqueira *et al.,* 2014). Processors demand good Cookability because this is essential for efficient processing of the bean products (Namugwanya *et al.,* 2014). A large number of studies have been undertaken in different parts of the world to assess the effects of physical properties in relation to soaking and cooking time which reported higher cooking times and which prompted such a study to be done.

A Study conducted by Zamindar *et al, (*2013) showed that cooking time was significantly reduced by soaking time. Another related study by Correa *et al,* (2010) observed that soaking allows the bean to hydrate water resulting in better heat transfer through the bean and therefore presenting shorter cooking time.

1.9 Objectives

1.9.1 Main Objective

Determine the effects of physical properties (length, width, hardness and thickness) of bean varietieson soaking and cooking time.

1.9.2 Specific Objectives

1. To evaluate the effect of soaking on the cookability of eleven different bean varieties.
2. To evaluate the effect of soaking time on the hardness of eleven bean varieties
3. To determine the effectsof beanphysical propertieson the cooking time of eleven bean varieties
4. To determine the effects of cooking on water imbibed at different soaking times on eleven bean varieties by season
5. To correlate bean physical properties with water imbibition and cooking time of eleven bean varieties by one season.

1.9.3 Hypotheses

H_0:There is no significant effect of soaking on the cookability of eleven different bean varieties.

H_0: There is no significant effect of soaking time on hardness of eleven bean varieties.

H_0:There are no significant effects of bean physical properties on cooking time of eleven bean varieties

H_0: There are no significant effects of cooking on water imbibed at different soaking times by eleven bean varieties by season.

H_0:There are no significant correlations between bean physical properties with water imbibition and cooking time of eleven bean varieties by season.

CHAPTER TWO

2.0Literature Review

2.1 Effects of water imbibition on the cooking time

At physiological maturity bean seeds usually have 50% grain moisture content but as they dry the moisture content drops to 13-15% (Kimatu *et al.*, 2014). The chemical changes in the product during post-harvest storage can damage the grain including seed hardening, hard shell, hard to-cook effect, moisture absorption, mould growth, seed discoloration, flavor and odour.

Soaking allows water to be distributed among starch and protein fractions within the beans. When beans imbibe enough water, it reduces the cooking time by as much as 70%, and also breaks down the compounds in beans that cause flatulence (Limón *et al.*, 2015). Further research has indicated that if one fails to soak the beans first, a large part of the cooking time (and energy expense) is wasted while the beans rehydrate water to the point where they actually can begin to cook and soften, extending the cooking time to several hours (Stolárik *et al.*, 2015).

2.2 Nutritional factors and benefits of common beans

Dry beans provide protein, complex carbohydrates and valuable micronutrients to more than 300 million people in the tropics hence meeting more than 50% of dietary protein requirements of households in Sub Saharan Africa while green beans are most important for fibers, vitamins andminerals(Sibiko *et al.*, 2013). The merit of dry bean is mostly its high caloric value and protein content and they contain higher amount of resistant starch in comparison to cereals and tubers (Atchibri *et al.*, 2010). Thus, they are important components of a healthy diet whereby, the health-related benefits of beans include their positive effect on lowering the blood cholesterol and glucose levels because of their high dietary fiber content (Wani *et al.*, 2014). A study conducted by Romero-Arenas *et al*, (2013) pointed out that low concentrations of phytates and phenolic compounds (which are present in beans) can be protective against cancer and cardiovascular diseases. Further studies show that it has a role in reducing weight (Onakpoya *et al.*, 2011). All dry beans are good sources of lysine, indicating that dry beans could be added to lysine-deficient cereal products (Perina *et al.*, 2014). Also, fermentation of oligosaccharides present in beans may result in the production of short chain fatty acids and decrease in intestinal pH (Fernandes *et* *al.*,2010). Common beans are also a rich source of B vitamins, folate, riboflavin and valuable mineral substances like potassium, calcium, magnesium, phosphorus and iron salts (Gichangi *et al.,* 2012).

Among the valuable mineral substances, is the Iron (Fe) and zinc (Zn) where Fe is essential for preventing anemia in human being and for the proper functioning of many metabolic processes its deficiency causes anemia whose consequences are numerous and grave, While Zn is essential for adequate growth and sexual maturation and for resistance to gastro-enteric and respiratory infections, especially in children where its deficiency can lead to poor child growth, delayed maturation, poor appetite and impaired immune function (Ulloa *et al.*, 2015).

2.3 Constraints of common bean

Common bean is a major grain legume crop cultivated species from the genus *phaseolus.* Studies show that hardness in legumes is the most important factor in cooking quality characteristics and sometimes it is a problem during processing (Bayram *et al.,* 2013). However, people do not patiently prepare or process beans to the recommended level to destroy the anti-nutrients because of high and prohibitive cost of energy sources which is limited.Susceptibility of common beans acquiring hardening phenomenon is a problem and it results to defective cooked grain texture extended cooking time, presence of anti-nutrients which lowers the nutritive value and high fuel consumption which really undermines the consumption. Hardness may present additional challenges in the diets of households since human beings are vulnerable to diseases especially where low nutrients foods are involved hence malnutrition and poverty may become high and more severe.

Other challenges are like flatulence in human which is often as a result of ingesting foods high in raffnose, stachyose and verbascose (Winham *et al.,* 2011). Their nutritional quality is indirectly impacted by the presence of heat labile and heat-stable anti-nutritional factors (ANF) that exhibit undesirable physiological effects (Hefnawy, (2011). The ANFs are structurally different compounds broadly divided into two categories: proteins (such as lectins and protease inhibitors) and others such as phytate, tannins or proanthocyanidins, oligosaccharides, saponins and alkaloids. In general raw beans contain far higher levels of ANFs than their processed forms hence processing is necessary before the incorporation of these grains into food or animal diets (Garba *et al.*, 2013).

2.4 Hardness and moisture content test

Dry beans are widely known for their fiber, mineral and protein contents and for a long-time farmers have been testing bean hardness and seed moisture content by biting the seed with teeth or by pinching it between fingers. The results they obtained were based on the hardness or softness of the grain (Kimatu *et al.*, 2014). This traditional method is still the main method to date used by many small scale farmers apart from the salt test used to detect moisture by its extraction by osmosis. Studies show that it may not be the best practice because there can be more economical and quality benefits by harvesting the beans at higher acceptable moisture levels. Studies show that, when the grains imbibe enough water it softens the texture and hasten both the germination capacity and the cooking process thus the grains will cook evenly and completely without splitting open or losing their skin or cooking only the outer surface and leaving the middle part (Ilse de Jager *et al.*, 2013).

2.5 Preparation of beans for cooking

Quality changes in dry beans during cooking and processing are associated with their inherent physical components and chemical constituents (Brigide *et al.*, 2014). However; the health benefits of beans are associated with their processing methods. Beans should be cooked or processed before intake. The processing of legumes not only improves their flavor and palatability, but it also increases the availability of nutrients and reduces flatulence factors (raffnose oligosaccharides) (Garba *et al.*, 2013). The preparation of beans by consumers involves a soaking step to rehydrate, and a cooking step to soften the plant tissue so that it is palatable, inactivate heat-labile anti nutrients and aid in the digestion and assimilation of protein and starch. Cooking time is one of the main criteria used in evaluating bean cooking quality and long cooking times are a major constraint to wider acceptance and the use of beans (Ribeiro *et al.*, 2013). The composition of the bean variety may be influenced by its genotype, local soil composition and the season of cultivation (Rao *et al.*, 2013). These differences are due to the factor of variety. Furthermore, the texture can be influenced by location and production period, weather and storage condition (de Barros and Prudencio, 2016). The development of appropriate preparation technologies for use at the household and village level would facilitate processing and dietary availability of beans and other legumes. Valuable time could thus be devoted to more effective childcare or additional income generating activities and thus the long preparation time can be inconvenient and expend much fuel (Namugwanya *et al,* 2014).

An Automated Mattson bean cooker (MBC) (Canadian Grain Commission) developed for automatically registering and recording the time of drop of the plungers was used to determine the mean cooking time where twenty-five soaked and unsoaked beans were picked at random for cooking, weighed and then positioned in each of the 25 saddles of the rack so that the tip of each plunger rest on top of the seed. The eleven bean varieties in this study, represents some of the promising varieties of beans for food security used in dry areas and were evaluated because they have not been tested for the grain hardness and cooking time as it is known that beans are susceptible to hardening phenomenon during their shelf life which leads them to acquire extended cooking time (Santos *et al.,* 2016). Consumers concerned with convenience in preparation, will reject beans that need extended cooking time.

2.6 Post harvest handling

Typically, dry beans are harvested in the mature, dry stage and stored until processed. The chemical changes in the product during post-harvest storage can damage the grain including seed hardening, hard shell, hard to-cook effect, moisture absorption, mould growth, seed discoloration, flavor and odour (Siqueira *et al.,* 2014). At physiological maturity bean seeds usually have 50% grain moisture content but as they dry the moisture content drops to 13-15 % Vasudeva and Vishwanathan,(2010). Studies in the bean grain, however, revealed that the bean moisture content does not directly affect its quality but can indirectly affect quantity since grain can be spoiled at high moisture content. Fungi and some insects like weevils require moisture and certain temperatures to grow (Kimatu *et al.,* 2014). Studies also show that bean grain needs careful moisture analysis in storage management strategies by carefully balancing the weight value economics and minimizing post-harvest risks so as to achieve maximum benefits from grains (Zamindar *et al.,* 2013). The morphological variation in seed characters includes differences in seed size and shape. Studies show that the seed shape is an important trait in plant identification and classification and it has agronomic importance because it reflects genetic, physiological, and ecological components which affects yield, quality, and market price (Barros *et al.,* 2016).

2.7 Bean physical properties (length, width and thickness)

The study of the chemical and physical characteristics of the bean varieties is important because, they influence the bean culinary properties and the consumer's preferred bean of choice (de Barros and Prudencio, 2016). The consumer preference refers to visual appearance as the primary criterion (Castro-Rosas *et al.*,2013).

Although all the bean varieties contain similar major components (protein, fat, carbohydrates and minerals), each of them has a unique physical profile that affect their functional foods like when cooking and processing. Physical properties such as size, thickness and weight as well as seed coat and cotyledon characteristics, influence the bean cooking quality. Physical properties information of bean seed as well is very important in the design of equipment for harvesting transporting cleaning packaging storing and processing into different foods (Wani *et al.*, 2014).

CHAPTER THREE

2.0 Materials and Methods

3.1 Description of the site

The bean varieties used in this study were obtained from Kenya Agricultural and Livestock Research Organization,Katumani,MachakosCounty, Kenya, located at latitude $11^0$35'S: longitude $37^0$14'E, and 1560masl. The Centre experiences a semi- tropical climate described as AEZ IV with a bi-modal pattern of rainfall which on average receive 200-400mm and the temperatures range between 13.7^0C to 24.7^0C (GoK, 2013).

3.2Seed Preparation

Eleven (11) whole bean grains from each of the season (Short & Long rains 2016) were retrieved from the store and were sorted by hand using a sieve of 2mm size to remove excessively dirty materials for example: extremely small beans and broken ones, small stones, split seeds and defective seed coat. 100 seed weight was taken and the beans were cleaned and size-graded manually and categorized as follows: the ones which weighed between 20-30grams were grouped as small, between 31-40grams were grouped as Medium and between 41-50grams were grouped as big. The bean varieties were selected based on the field records from the previous seasons which showed the characteristics of each variety and its yield stability over a range of conditions (biotic and a biotic stresses). The beans were then rinsed with distilled water to eliminate insecticide before soaking and cooking. The grains were soaked in a container measuring 8cm high, a diameter of 9.5 cm and a capacity of 1000ml with distilled water at varying soaking times of 0 (zero) as the control, 3, 6, 12 and 24 hrs. The length (L), width (W) and thickness (T) were measured following perpendicular directions before and after soaking where ten representative measurements were taken from each variety of the two seasons. The bean hardness test was determined using whole single grain and the measurements were done before and after soaking to measure the hardness of beans where an average of ten representative measurements were recorded from each of the 11 bean varieties of the two seasons.

Cooking time was monitored using an automated Mattson Cooker (MBC) to get the mean cooking time (CT) of beans. Twenty five (25) grains from each of the eleven bean varieties of the two seasons were positioned on the 25 reservoir like perorated saddles on the MBC that hold the grains. The vertical plunger on the MBC was placed on the surface of the grain, where it penetrated the grain after it sufficiently became soft and cooked. The cooking of the beans was proceeded by immersing MBC in a beaker with boiling water (98^{o}C) over a hotplate. Cooking time was recorded as the time in minutes needed to penetrate 50% of the beans; conventionally adopted as the falling time of the 13th plunger on the beans. All the above measurements were replicated three times.

3.3 Experimental procedures

3.3.1 Determining physical properties

Sorting out of seeds was done manually by hand, 100 seeds were weighed usinga sensitive weighing balance (6kg). The length, width and thickness measurementswere done by use of Vaniercalipers reading to 0.01mm following perpendicular directions (Figure 2). An average of ten representative measurements wererecorded. These were used to evaluate the geometric mean diameter of the seeds using the relationship given by Adejumo and Abayomi (2012) as: Dg = (LWT) 1/3. Where; GMD = geometric mean diameter; L = length; W = width; T = thickness. The degree of sphericity of the various varieties of beans were determined using the equation; φ = GMD /L= (LWT) 1/3L. Where; φ = degree of sphericity; GMD= geometric mean diameter; L = length; W = width; T = thickness.

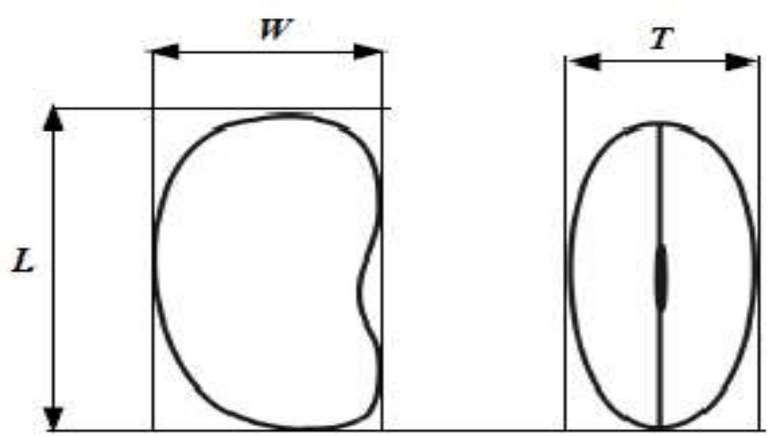

Figure 1: The various components of bean seed measured in this study

3.3.2Determining percentagemoisture content

Ten bean grains from each variety were picked at random to obtain averages of the percent grain moisture contents using GMK-303RS moisture meter calibrated to measure bean grain moisture content 12.5 - 19.7% with an accuracy of ±0.5% to obtain an average data in nine repetitions. Ten grainsfrom each variety were picked randomly after a thorough mixing. The grains were crushed inside the grain moisture meter and readings recorded. The process was repeated three times for different bean grains from each variety and the averages of percentage Moisture content were recorded for analysis.

3.3.3 Determining water absorption

Twenty five (25) grains from each of the eleven bean varieties were picked at random to measure water uptake as per procedure by (Laurent *et al.*,2010) where each of these 25 grains from each variety was soaked in 80ml of distilled water in a beaker and maintained at room temperature (25^{0}C). The soaking times were 0, 3, 6, 12 and 24 hrs. After soaking for each period, the seeds were removed from water and drained for 2 minutes and the amount of water absorbed by beans measured by weighing samples before and after soaking. The water absorption value was expressed as a percentage of water absorption and was calculated as gains of water absorption per 100g of beans (dwb) using the formula by Laurent *et al.* (2010). The weight gains were then calculated as the percentage of the difference between the measured weight at a given time and the original weight. That is percentage water absorption = **M1- M0/M0*100**

Where M1 = weight of soaked beans

M0 = weight of dry *beans*.

3.3.4 Determiningseed hardness test

Ten (10) bean grains from each of the eleven variety of the two seasons were again picked at random to measure bean grain hardness. This was done by use of crust hardness meter and by using a whole bean grain before and after soaking to obtain averages of hardness in beans. The crust hardness meter has a constant speed of 20mm/sec after compression. All measurements were recorded and repeated to achieve average hardness in beans for each variety.

3.3.5 Determining beans cooking time

Twenty five (25) grains from each of the eleven bean varieties from the two seasons were also picked at random to determine cooking time. This was done by use of an automated Mattson cooker which has a cooking rack that consists of a dish with 25 seed size openings or holes with reservoir-like perforated saddles each of which holds grains and 25 plungers or pins calibrated to specific weights of 90g which terminates in a stainless steel probe of 1mm in diameter (Wang *et al.*, 2005). During cooking time, the bean varieties were subjected to soaking in distilled water (ratio 1:5 beans to water) at varying soaking times (0, 3, 6, 12 and 24 hrs.). The twenty five (25) grains were held in the perforated like wells with their corresponding pins resting on top of each grain. The cooking was preceded by immersing MBC in a beaker with boiling water (78-80^{0}c) over a hotplate. The 25 grains from each bean variety were maintained in boiling water until the pin dropped through the seeds. Cooking time was recorded as the time in minutes, versus the number of penetrations where the running time was recorded immediately when the grains were placed in boiling water. The 50% cooked point was indicated by plungers dropping and penetrating individual bean seeds after reaching the percentage cooking time in minutes.

3.4An Automatedbean Mattson cooker

This is an electronically controlled system with a digital input/output (I/O) card, which allows 25 channels to be monitored simultaneously, a circuit designed for connecting the 25 switches and the interface box, the main components of the custom-made printed circuit board assembly that included a copper-clad printed circuit board, 25 mechanical switches and a support plate on which the printed circuit board was Mounted, a custom-made actuator that actuated the mechanical switches. In the circuit associated with the 25 switches, the position of the plunger was translated into the input signal level of the I/O card.(Wani *et al*, (2013) a logic level of zero was indicating that the switch was OFF and this time the plunger was located in high position. While a logic level of one was indicating that the switch was ON,and again this time the plunger was dropped down as shown in Plate1 below.

Plate1: Mattson Cooker with Cooking rank with plungers dropped down indicating the switch was on**.** *(Photo by Josephine Syanda)*

3.5 Treatments

The experiment was conducted using a complete randomized design (CRD) with three replications. The treatments were eleven improved bean varieties, that are drought tolerant and micronutrient dense (Karanja *et al.*, 2011) which included: GLPX92, KATX69, EMBEAN118, WAIRIMU, EMBEAN14, GLP2, KATX56,KATB9, KATRAM, KATB1, and KATSW-13 (Plate 2 below) to study the effects of physical properties in relation to varying soaking times (0, 3, 6, 12 and 24 hrs.) and on cooking time.

1 2 3 4 5 6 7 8 9 10 11

Plate 2: The bean varieties used in this Research: 1 (KATSW-13), 2 (WAIRIMU), 3 (EMBEAN118), 4 (KATB9), 5 (EMBEAN14), 6 (KATB1), 7 (KATX69), 8 (GLP2), 9 (KATRAM), 10 (KATX56), 11 (GLPX92).*(Photo by Josephine Syanda)*

3.6 Data collection

Data collected was 100 grain wt., physical properties (length, width, and thickness), water absorbed at varying soaking times, bean grain hardness, cooking time.

3.7Statistical analysis

The collected data was subjected to Analysis of Variance (ANOVA) using SAS: 9.1.3. Differences between the treatments at ($p \leq 0.05$) were considered significant and the treatment means were separated using Fisher's protected Least significant difference test (LSD) at $p \leq 0.05$ level.

CHAPTER FOUR

4.0 Results

4.1: The effect of soakingon cookability of eleven different bean varieties

In both the short and long rains 2016, the bean varieties varied significantly ($p \leq 0.05$) in cooking time in respect to soaking time (Table 4.1). Cooking time decreased significantly with increased soaking time. Overall KATB1 took the shortest time to cook which was notsignificantly different from KATSW-13 while GLPX92 took longest time to cook. In the short rains the times taken by EMBEAN118, KATX56, GLP2 EMBEAN14, KATX69 and GLPX92 were not significantly different from each other but were longer than those taken by KATSW-13 and KATB1 followed by WAIRIMU and KATB9 which were also not significantly different from each other; KATRAM took the longest time to cook for long rains followed by KATX56 and WAIRIMU which were not significantly different. At 3 hour soaking, the cooking time for short rains, started changing in respect to soaking time where KATX56 took the shortest time to cook but was not significantly different from EMBEAN14 and KATSW-13. Similarly, KATX69, EMBEAN118, WAIRIMU and GLPX92 were also not significantly different and the same was true for KATB9 and GLP2. At 6 hours, KATB1 took the shortest time to cook in both the short and long rains while GLPX92 and KATX69 took longer time to cook respectively. At 12 hours in both the short and long rains, KATB1 and KATSW-13 took the shortest time to cook which were not significantly different from GLP2, EMBEAN14, and KATX56; KATB9 and WAIRIMU; KATRAM and EMBEAN118 were also not significantly different and GLPX92 and KATX69 took longest time to cook respectively. Similarly, for long rains; KATSW-13 was not significantly different from KATB1, EMBEAN118 and WAIRIMU; followed by KATX56, GLP2, KATRAM and EMBEAN14 were also not significantly different. At 24 hours, KATB1 and KATSW-13 took the shortest time to cook in both the short and long rains, while KATX69 took the longest cooking time to cook. In short rains KATX56, EMBEAN14, EMBEAN118, WAIRIMU and KATRAM were not significantly different from each other; followed by KATB9 and GLPX92 while for long rains, KATB1 was not significantly different from WAIRIMU, EMBEAN118 and KATSW-13 while KATX56, GLP2, KATRAM, KATB9 and EMBEAN14 were also not significantly different; followed by GLPX92.

Table 4.1 Effects of soakingon cookability (minutes) of eleven different bean varieties

	Short rains 2016 Soaking time						Long rains 2016 soaking time					
Variety	**0hr**	**3hr**	**6hr**	**12hr**	**24hr**	**Mean**	**0hr**	**3hr**	**6hr**	**12hr**	**24hr**	**Mean**
GLPx92	111.87Ac	96.95Bb	90.60Ba	80.16Ca	56.11Db	**88.54a**	108.34Aa	76.18Ba	46.43Db	37.28Db	30.04Ea	**59.65b**
Katx69	109.09Ac	82.78Bc	72.93Cb	72.59Cb	65.00Dc	**80.48b**	99.53Ab	72.11Ba	56.37Ca	47.54Da	34.26Da	**61.96a**
Embean118	105.81Ac	90.06Ab	61.54Cb	57.12Dc	35.07Ed	**69.92c**	97.43Ab	60.65Cb	38.17Dc	29.44De	20.93Ec	**49.32c**
Wairimu	115.04Ab	92.38Ab	61.58Cb	51.98Ed	38.34Ed	**71.86c**	85.63Ac	52.16Cc	35.39Dc	29.48De	20.05Ec	**44.54d**
Embean14	108.59Ac	68.68Bd	61.16Cb	41.38Ee	33.43Ed	**62.65d**	96.71Ab	51.97Ba	39.71Cc	35.87Cc	27.84Db	**50.42c**
GLP2	107.28Ac	88.71Bc	47.50Dc	40.06Ee	31.58e	**63.03d**	96.22Ab	54.82Cc	43.52Db	32.66Dc	24.26Eb	**50.30c**
Katx56	107.13Ac	67.39Bd	48.68Dc	42.81Ee	33.03Ed	**59.81d**	85.35Ac	54.45Cc	43.52Cb	31.22Dd	22.90Eb	**47.49d**
KatB9	121.17Ab	85.35Bc	63.71Cb	48.88Dd	45.27Dc	**72.88c**	97.76Ab	62.03Bb	45.24Cb	38.02Cb	27.44Db	**54.10b**
Katram	145.00Aa	100.95Aa	63.18Bb	57.03Cc	40.19Dd	**81.27b**	107.27Aa	64.79Cb	46.66Db	34.90Dc	25.93Eb	**55.91b**
KatB1	97.80Ad	88.04Bc	45.16Dc	28.03Ef	21.76Ee	**56.16d**	68.74Ae	52.74Cc	29.40Dd	26.88De	16.96Ec	**38.94d**
Katsw-13	88.76Ae	71.57Cd	57.31Db	38.60Ee	26.02e	**56.45d**	77.36Ad	45.77Dd	30.26Dd	24.61De	21.62Ec	**39.92d**
LSD columns	6.97						**5.86**					
LSD in Rows	11.25						**10.50**					

Cooking time means in the same row followed by the same upper case letters (A,B….E) or in the same column followed by the same lower case letters (a, b, c,….f) are not significantly ($p<0.05$) different (Fisher's least significant difference test).

4.2 Effects of soaking time on bean hardness in Newton (N) of eleven bean varieties

Differences in hardness of beans were observed within the two seasons (Table 4.2). Hardness reduced with increased soaking time. Overall for short and long rains, KATX69 and KATRAM were the hardest and the softest were KATSW-13 and KATB1 respectively. For short rains at zero and 3 hours GLPX92 was the hardest followed by KATX69;KATX56 was not significantly different from KATB9, while KATRAM, EMBEAN118 and WAIRIMU were not significantly different from each other; KATSW-13; GPL2 and EMBEAN14 were also not significantly different; KATB1 was the softest. At 3 hours, GLPX92 was the hardest followed by KATX69, KATRAM; KATB9, KATX56 and WAIRIMU were not significantly different, followed by EMBEAN14; EMBEAN118 and GLP2 were also not significantly different; KATB1 andKATSW-13 were the softest. At 6 hour soaking KATRAM was the hardest followed by KATX69, which was not significantly different from EMBEAN118, GLPX92 and GLP2; EMBEAN14, KATB9 and KATX56 were also not significantly different from each other, followed by WAIRIMU; KATB1 was not significantly different from KATSW-13 and were the softest. At 12 hour soaking, KATX69 was the hardest followed by EMBEAN14 which was not significantly different from KATB9, followed by KATRAM; GLP2, WAIRIMU, EMBEAN118 and GLPX92 were not significantly different from each other; KATB1, KATX56 and KATSW-13 which was the softest. At 24 hour soaking, EMBEAN14 was the hardest; KATB9 was not significantly different from KATRAM; followed by KATX69, GLP2; EMBEAN118, GLPX92 and WAIRIMU were not significantly different from each other; KATX56 and KATB1 were not significantly different; KATSW-13 was the softest.

In long rains, KATX69 was the hardest at zero soaking followed by KATB9, KATRAM, EMBEAN118 and GLPX92 which were not significantly different from each other; KATX56 and KATSW-13; EMBEAN14 and WAIRIMU; GLP2 and KATB1 were also not significantly different and were the softest. At 3 hours, KATB9 was the hardest; KATRAM and GLPX92 were not significantly different; KATX56, WAIRIMU and EMBEAN14 were also not significantly different; KATX69 and GLP2 were not different; KATB1 and KATSW-13 were the softest. At 6 hours, KATX69 was the hardest; EMBEAN14, GLP2 and KATRAM were not significantly different. KATX56, KATB9 and KATB1 were also not significantly different; KATSW-13 and

EMBEAN118 was not significantly different and were the softest. At 12 hours, GLP2 and EMBEAN14 were not significantly different and were the hardest.

Table 4.2 Effects of soaking time on the hardness (Newton) of eleven different bean varieties

	Short rains Soaking time						Long rains soaking time					
Variety	**0hr**	**3hr**	**6hr**	**12hr**	**24hr**	**Mean**	**0hr**	**3hr**	**6hr**	**12hr**	**24hr**	**Mean**
GLPx92	32.06Aa	27.55Aa	18.89Bd	13.45Cd	8.28Ce	**20.05b**	28.17Ab	22.17Bb	15.83Cc	9.17Db	6.72Da	**16.41a**
Katx69	31.39Aa	26.34Ab	20.00Bb	17.28Ca	9.56Dc	**20.91a**	29.94Aa	20.56Bd	18.55Ca	6.84Cd	5.17Cc	**16.21a**
Embean118	28.61Ac	22.28Af	19.33Bc	13.50Cd	8.39Ce	**18.42c**	28.17Ab	18.39Be	10.95Cf	6.84Dd	5.39Dc	**13.95c**
Wairimu	28.56Ac	24.89Ad	14.67Bf	13.61Cd	8.06Ce	**17.96d**	21.11Ad	20.89Bc	13.45Cd	7.72Dc	4.72Dc	**13.58c**
Embean14	25.55Ae	23.22Be	18.56Bd	15.44Cb	10.33Ca	**18.62c**	21.95Ad	20.89Ac	17.94Bb	9.44Ca	4.83Dc	**15.01b**
GLP2	25.78Ae	20.67Bg	18.61Bd	13.94Cd	9.00Cd	**17.6d**	20.56Be	19.77Ad	17.50Bb	9.77Ca	5.17Cc	**14.55b**
Katx56	30.67Ab	25.17Bd	15.06Ce	11.61Df	7.44Df	**17.90d**	27.55Ac	21.50Bc	12.89Ce	5.95Dd	5.11Dc	**14.6b**
KatB9	30.67Ab	25.50Ad	16.61Be	15.06Bb	9.89Cb	**19.55b**	28.39Ab	24.72Ba	12.61Ce	7.39Dc	6.72Da	**15.97a**
Katram	29.11Ac	25.55Bc	20.50Ba	14.55Cc	9.78Cb	**19.90b**	28.22Ab	22.72Bb	17.44Bb	8.33Cb	6.39Cb	**16.62a**
KatB1	23.06Af	17.28Eh	13.66Cg	12.56Ce	7.44Cf	**15.29e**	20.06Ae	16.61Bf	12.44Be	6.78Cd	4.50Cc	**12.08d**
Katsw-13	27.17Ae	16.94Bh	12.61Bg	7.18Cg	5.83Cg	**14.55f**	26.72Ac	14.78Bg	11.67Cf	6.72Dd	4.61Dc	**13.0d**
LSD Along	**0.71**						**0.93**					
LSD Across	**5.38**						**5.33**					

Hardness means in the same row followed by the same upper case letters (A, B, C….E) or in the same column followed by the same lower case letters (a, b, c,…..g) not significantly ($p<0.05$) different (Fisher's least significant difference test)

4.3Effects of bean physical properties (mm) on the cooking time of eleven bean varieties

Different levels of length, width and thickness were observed in seed samples of two seasons. In short rains 2016, the greatest difference ($p \leq 0.05$) occurred between the length of EMBEAN118 which recorded the highest length followed by GLP2, KATX56, KATX69, KATRAM followed by WAIRIMU followed by GLPX92 followed by KATB9 which was not different from KATB1 followed by KATSW-13 which recorded the lowest length. The width differed but was not significantly different from each other where the highest was KATB1 followed by KATB9 followed by KATRAM followed by GLP2 followed by EMBEAN118 which was not different from EMBEAN14 followed by GLPX92 which was not different from KATX69 followed by KATSW-13 followed by WAIRIMU which recorded the lowest width. The greatest thickness occurred in EMBEAN118 followed by KATB9 which was not different from KATB1 followed by GLP2 followed by GLPX92 followed by KATX69 followed by KATRAM followed by KATX69 followed by EMBEAN14 followed by KATX56 followed by WAIRIMU followed by KATSW-13 which recorded the lowest thickness.

In long rains 2016, the length of varieties varied significantly ($p \leq 0.05$). GLP2 recorded the highest length followed by GLPX92 which was not different from KATB1 followed by WAIRIMU followed by KAX56 followed by KATX69 followed by EMBEANS118 which was not different from EMBEAN14 followed by KATB9 followed by KATSW-13 followed by KATRAM which recorded the lowest length. The greatest width recorded was KATX56 followed by KATX69 which was not different from KATSW-13 followed by GLPX92 followed by WAIRIMU followed by followed by EMBEAN118 followed by KATB9 followed by GLP2 followed by KATRAM followed by KATB1 followed by EMBEAN14 which recorded the lowest width. The highest thickness recorded was KATSW-13 followed by KATX69 followed by EMBEAN118 followed by KATB9 followed by WAIRIMU which was not different from GLP2 and KATX56 followed by GLPX92 followed by EMBEAN14 which was not different from KATB1 followed by KATRAM which recorded the lowest thickness.

Table 4.3 The effects of physical properties in mm on the cooking time of eleven bean varieties (short and long rains 2016)

	Short rains			**Long rains**		
Variety	Length	Width	Thickness	Length	Width	Thickness
GLPx92	11.9c	5.3d	7.1b	15.2a	5.0b	6.2e
Kaxt69	14.8b	5.3d	6.7c	14.4a	5.4b	7.1b
Embean118	16.2a	5.5d	7.7a	12.3b	4.8c	6.9c
Wairimu	12.1c	4.1g	5.6f	15.1a	4.9c	6.3d
Embean14	15.1b	5.5d	6.5d	12.3b	3.7d	5.6f
GLP2	15.5a	5.7c	7.2a	17.3a	4.4d	6.3d
Kat x56	15.2b	5.1e	6.0e	14.7a	5.8a	6.3d
KatB9	11.3c	6.3a	7.3a	11.3b	4.5d	6.4d
Katram	13.7b	6.1b	7.0b	8.4d	4.3d	5.3g
KatB1	11.3c	6.7a	7.3a	15.2a	4.1d	5.6f
Katsw-13	8.0d	4.5f	5.3g	10.4b	5.4b	7.2a
Means	13.19	5.45	6.68	13.33	4.74	6.28
C.V	6.74	4.55	4.62	30.10	23.33	19.09
LSD	0.20	0.13	0.90	0.23	0.10	0.12

Physical properties means in the same row followed by the same upper case letters (A, B, C, ….E) or in the same column followed by the same lower case letters (a, b, c, ….g) are not significantly ($p<0.05$) different (Fisher's least significant difference test).

4.4 Effects of cooking time on water imbibition at different soaking times oneleven bean varieties by season

Water imbition by the beans increased with increased soaking time (Table 4.4). Water imbibition ability of bean varieties varied significantly ($p \leq 0.05$) among the bean varieties. On average, in both the seasons (short and long rains 2016), KATB1 and KATSW-13 significantly ($p \leq 0.05$) imbibed the highest amount of water. For short rains 2016, KATX56 was followed by KATB9, KATRAM; KATX69 was not different from EMBEAN14, GLP2, GLPX92, WAIRIMU, and EMBEAN118 which were not significantly different from each other. Similarly, in long rains 2016, water imbibition rate increased with increase in time where on average KATSW-13 and KATB1 significantly imbibed the highest amount of water followed by KATX56 which was not different from KATB9 and KATRAM followed by GLP2 which was not different from.EMBEAN118, followed by KATX69 which was not significantly different from WAIRIMU, EMBEAN14, GLPX92 which imbibed the lowest amount.

Table 4.4: Effects of cooking time on water imbibition at different soaking times by eleven bean varieties by season

	Short rains2016						Long rains 2016					
	Soaking time						Soaking time					
Variety	0hr	3hr	6hr	12hr	24hr	**Mean**	0hr	3hr	6hr	12hr	24hr	**Mean**
GLPx92	0.0Aa	1.00Dd	4.33Ce	6.33Bf	11.00Ac	**4.53d**	0.0Aa	1.33De	5.00Cf	6.66Bd	8.33Ad	**4.26d**
Katx69	0.0Aa	2.00Bc	6.00Bc	7.33Ad	7.33Ag	**4.80d**	0.0Aa	2.33Bd	6.33Ac	7.66Ac	8.00Ad	**4.86d**
Emben118	0.0Aa	2.00Dc	4.00Ce	6.33Bb	9.33Ad	**4.33d**	0.0Aa	2.33Dd	5.33Ce	7.00Bd	10.00Ac	**4.93c**
Wairimu	0.0Aa	2.00Dc	6.00Bc	7.00Ae	7.33Ag	**4.47d**	0.0Aa	2.33Bd	7.00Ac	7.33Ad	7.66Ad	**4.86d**
Embean14	0.0Aa	2.13Cc	5.33Bd	6.00Ae	8.00Af	**4.63d**	0.0Aa	2.66Cd	6.33Bc	7.00Bd	8.33Ad	**4.86d**
GLP2	0.0Aa	1.33Dd	4.33Ce	6.33Bf	11.00Ac	**4.60d**	0.0Aa	2.00Df	5.33Ce	7.33Bd	11.66Ab	**5.26c**
Katx56	0.0Aa	2.00Dc	5.33Cd	9.00Ba	12.33Ab	**5.73b**	0.0Aa	2.33Cd	6.33Bc	10.66Ab	12.66Aa	**6.4b**
KatB9	0.0Aa	2.13Cc	6.00Bc	9.00Bc	10.33Ad	**5.47c**	0.0Aa	3.33Cc	6.13Bd	10.33Ab	11.33Ab	**6.22b**
Katram	0.0Aa	1.33Dd	3.00Cg	9.33Bb	12.00Ab	**5.33c**	0.0Aa	2.66Dd	4.33Cf	10.13Bb	12.33Aa	**5.89b**
KatB1	0.0Aa	4.00Ca	7.00Bb	11.00Ac	12.33Aa	**6.47a**	0.Aa	5.00Cb	8.00Bb	11.66Aa	12.66Aa	**7.46a**
Ksw13	0.0Aa	3.33Cb	8.33Ba	10.33Af	10.33Ae	**6.60a**	0.0Aa	6.00Ca	9.13Ba	11.66Aa	12.33Aa	**7.82a**
LSD	**column**	**0.67**					**0.62**					
LSD	**rows**	**1.6**					**1.7**					

Water imbibition means in the same row followed by the same upper case letters (A, B, C ….E) or in the same column followed by same lower case letters (a, b, c, …..g)are not significantly($p \leq 0.05$) different Fisher's least significant difference (LSD)

4.5 Relationships between soaking time, water imbibition and **cooking time**

There were a number of significant correlations between soaking time, water imbibed and cooking time (Table4.5). There was a positive correlation between the length of the bean grain and thickness, and width of the bean grain, seed weight, as well as between the seed weight after soaking and the weight before soaking.

Likewise, there was a highly positive correlation between cooking time and hardness of the bean grains as well as the correlation between seed weight and water imbibition as well as between seed weight and the weight after soaking and also between the seed weight and the weight before soaking. Highly positive correlation between soaking time and water imbibed as well as between soaking time and the weight after soaking as well as between water imbibed and the weight and weight after soaking as well as between water imbibed and weight before soaking and highly positive correlation between weight after soaking and weight before soaking.

There was a negative correlation between moisture content before soaking ($Mcb_4soaking$) and the length of the beans (Table 4.5). Likewise, there was also a negative correlation between hardness and the $Mcb_4soaking$, soaking time and the length of bean varieties, soaking time and cooking time, soaking time and hardness water imbibibition, weight after soaking and weight before soaking, weight after soaking and cooking time weight after soaking and hardness.

Table 4.5: Correlation between soaking time, water imbibed, cooking time and hardness for one season

Prop	Length	MC $b_4$soaking	Thickness	Cooking Time	Hardness	Soaking time	Water imbibed	Wt after soaking	Wt b4soaking
Length	1								
MC b_4 soaking	-0.1125	1							
Thickness	0.6240**	0.0286	1						
Cooking Time	0.0673	0.0085	-0.0571	1					
Hardness	0.1100	-0.0232	-0.0289	0.8278**	1				
Soaking time	-0.0185	-0.0116	0.0473	-0.7546**	-0.8667**	1			
Water imbibed	0.1480	-0.0134	0.1769	-0.7858	-0.8227**	0.8643**	1		
Wt after soaking	0.3603**	-0.1290	0.2719	-0.5884	-0.5599**	0.6662**	0.8662**	1	
Wt b4 soaking	0.4840**	0.4840**	0.2665*	0.0339	0.1460	0.0000	0.1877	0.6533**	1

CHAPTER FIVE

5.0 Discussions

5.1 The effects of soaking times on cookability of different bean varieties for two seasons

The cooking time of eleven bean varieties were determined by use of MBC which showed different cooking times at different varying soaking times. KATB1 and KATSW-13 significantly took the same and shortest time while GLPX92 took the longest time to cook during the short rains and KATRAM took the longest time during long rains. Normally, personal observation from farmers and other bean consumers show that older beans are drier than fresh beans and usually take longer time to cook (Castro-Rosas *et al* 2016). Therefore a bean variety like KATRAM that takes longer time to cook implies that it is very poor in imbibing water.This was supported by our results as shown in 4.1 where its states that the overall for short and long rains, KATX69 and KATRAM were the hardest while the softest bean varieties were KATSW-13 and KATB1 respectively. Confirming why KATB1 took the shortest time. This trend is similar to earlier studies conducted by Mwami *et al,* (2017) who attributed differences in water absorption in different bean varieties to also differences in biochemical structure of seed coat of different bean varieties which hinders the penetration of water even without the seed coat. The study also concurs with another study conducted by Vishwanathan, (2010) who attributed differences in water imbibition by different bean varieties to differences in concentrations of hemicelluloses and pentoses in the seed coat of individual bean varieties.

5.2 Effects of soaking time on bean grain hardness in Newton's (N) of eleven bean varieties

Bean seed coats have microphyles which are small microscopic holes for allowing water to enter into the seeds. However, some water is still able to pass through the seed coat after staying in water for long time. Personal observation by farmers is that when seed are planted or cooked they become soft and become ready for germination or cooking. Our observation in this research confirmed this phenomenon, because we found out that hardness reduced with increased soaking time; but our finding also found out that a hard bean seed could have a high imbibing ability that a softer seed. For example, in long rains, KATX69 at zero soaking was the hardest followed by KATB9 but after

3 hours of soaking, KATB9 was the hardest however at KATX69 was also the hardest again. The closeness of the two varieties showed that their differences were not statistically different. But, overall, it can be reliably be concluded that a hard seed has a lower imbibition capacity. Other biological structures have been observed to reinforce the seed coat hardness, for example, it was observed that beans have bioactive compounds such as flavonoids (anthocyanins and proanthocyanidins) and phenolic acids (mainly ferulic, caffeic, synaptic and Gallic acids) that are mostly found in seed coat (Ramirez Jimenez *et al.*, 2015, Padhi *et al*., 2017). Some of the chemical are hydrophobic and hence could reduce water penetrability. Bean varieties in both the short and long rains showed significant reduction in their cooking time after increased soaking time. This could be related to differences in water imbibition ability due to differences in the nature of the seed coat.(Berrios *et al.,* 1999, Wani *et al.,* 2014) reported significant differences in cooking time of different bean varieties due to slow water uptake of beans which is directly related to the nature of the seed coat.

5.3 Variations of physical properties of common bean varieties (mm)

There is a wide variation of bean physical properties where this study has confirmed and found out that these differences are also influenced by differences in seasons. Seasons with much rain seemed to give rise to longer and thicker bean seeds. This might be linked to more growth-related genes being expressed. In short rains the length of EMBEAN118 variety was the highest. In the long rains the length of GLP2 recorded the highest length but was closely followed by GLPX92. This seemed to suggest that there are intrinsic factors which control the physical properties of beans but they are influenced by extrinsic environmental factors. However, the intrinsic factors influence the extent to which environmental enhancement can influence. Hence, it is better to select better seeds for better environments. Furthermore, this is supported by an earlier study conducted by Hu *et al*, (2013) indicating the differences in seed sizes are due to genetic differences. Similarly, studies conducted by (Oomah *et al.,* 2010, Gathu *et al.,* 2012) attributed the same differences in length, width and thickness for different bean cultivars. As reported by Barros and Prudencio (2016), the texture can be influenced by location and production period, weather and storage condition.

CHAPTER SIX

6.0 Conclusions and Recommendations

6.1Conclusions

The study evaluated eleven bean genotypes based on their physical characteristics, ability to imbibe water at varying soaking time, hardness of the seed coat, and cooking time in reference to soaking time. The study showed significant differences among the bean varieties in respect to physical characteristics, water imbibition rate, seed hardness, and cooking time. It revealed that EMBEAN118 the longest length compared to other varieties. On the aspect of ability to imbibe water at varying soaking time, KATB1 absorbed the highest amount of water in 24 hours in season one while KATSW13 imbibed the highest amount of water in season two. KATB1 took the shortest time to cook compared to other varieties

6.2 Recommendations

i. Based on findings of this study KATB1 imbibed water faster than other varieties and took the shortest time to cook and therefore can be recommended for ASALs where rainfall is scarce and tree cover is low leading to low cost of cooking fuel and also it can reach physiological maturity using little water.
ii. Further molecular work could be done to verify if there are nutrients losses after soaking of the bean varieties at varying times. This can include the analysis and correlation of the seed coat components and the size of the microphyles.
iii. The project also recommends that farmers or consumers' of beans to reconsider soaking of beans for at least 6 – 24 hours since this has shown drastic reduction of cooking time hence this could save a bit of their cooking fuel.

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Appendices

Appendix 1: Anova Table for short rains percentage water imbibed and interaction of variety and treatment levels.

Dependent Variable: water imbibed for SR 2016

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	76	2955.927273	38.893780	36.72	<.0001
Error	88	93.200000	1.059091		
Corrected Total	164	3049.127273			

R-Square	Coeff Var	Root MSE	wai Mean
0.969434	18.61897	1.029121	5.527273

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Variety	10	239.393939	23.939394	22.60	<.0001
Rep	2	3.309091	1.654545	1.56	0.2154
Variety*Rep	20	32.824242	1.641212	1.55	0.0849
Treatment	4	2463.066667	615.766667	581.41	<.0001
Variety*treatment	40	217.333333	5.433333	5.13	<.0001

Appendix 2: Anova Table for Long rains percentage water imbibed and interaction of variety and treatment levels.

Dependent Variable: water imbibed for LR2016

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	77	1796.657143	23.333210	28.83	<.0001
Error	87	70.409524	0.809305		
Corrected Total	164	1867.066667			

R-Square	Coeff Var	Root MSE	wai Mean
0.962289	20.14061	0.899614	4.466667

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Variety	10	96.442857	8.767532	10.83	<.0001
Rep	2	3.430303	1.715152	2.12	0.1263
Variety*Rep	20	19.993506	0.999675	1.24	0.2466
Treatment	4	1611.915152	402.978788	497.93	<.0001
Variety*treatment	40	64.875325	1.621883	2.00	0.0036

Appendix 3: Anova Table for short rains grain hardness in Newton and interaction of variety and treatment levels.

Dependent Variable: Grain hardness for SR 2016

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	76	8957.565680	117.862706	49.19	<.0001
Error	88	210.848827	2.396009		
Corrected Total	164	9168.414507			

R-Square	Coeff Var	Root MSE	hardness Mean
0.977003	8.490355	1.547905	18.23133

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Variety	10	655.259027	65.525903	27.35	<.0001
Rep	2	1.019478	0.509739	0.21	0.8088
Variety*Rep	20	26.226162	1.311308	0.55	0.9369
Treatment	4	7807.762622	1951.940655	814.66	<.0001
Variety*treatment	40	467.298392	11.682460	4.88	<.0001

Appendix 4: Anova Table for Long rains grain hardness in Newton and interaction of variety and treatment levels.

Dependent Variable: Grain hardness for LR2016

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	77	14479.63003	188.04714	14.91	<.0001
Error	87	1096.91996	12.60828		
Corrected Total	164	15576.54999			

R-Square	Coeff Var	Root MSE	hardness Mean
0.929579	22.61918	3.550813	15.69824

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Variety	10	338.93547	30.81232	2.44	0.0104
Rep	2	31.99576	15.99788	1.27	0.2863
Variety*Rep	20	464.17048	23.20852	1.84	0.0281
Treatment	4	12961.69245	3240.42311	257.01	<.0001
Variety*treatment	40	682.83586	17.07090	1.35	0.1211

Appendix 5: Anova Table for short rainsCooking Time and interaction of variety and treatment levels.

Dependent Variable: Cooking time for SR2016

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	76	139258.7898	1832.3525	25.42	<.0001
Error	88	6343.1330	72.0811		
Corrected Total	164	145601.9228			

R-Square	Coeff Var	Root MSE	Cooking time Mean
0.956435	12.32414	8.490056	68.88964

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Variety	10	16329.0977	1632.9098	22.65	<.0001
Rep	2	362.2047	181.1023	2.51	0.0869
Variety*Rep	20	1092.3307	54.6165	0.76	0.7551
Treatment	4	110060.4197	27515.1049	381.72	<.0001
Variety*treatment	40	11414.7369	285.3684	3.96	<.0001

Appendix 6: Anova Table for Long rains Cooking Time and interaction of variety and treatment levels.

Dependent Variable: Cooking time for LR2016

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	77	110590.0404	1436.2343	37.43	<.0001
Error	87	3338.7385	38.3763		

Corrected Total	164	113928.7789

R-Square	Coeff Var	Root MSE	Cooking time Mean
0.970695	11.99380	6.194861	51.65055

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Variety	10	5542.8317	503.8938	13.13	<.0001
Rep	2	16.2863	8.1431	0.21	0.8092
Variety*Rep	20	2880.2175	144.0109	3.75	<.0001
Treatment	4	100540.8100	25135.2025	654.97	<.0001
Variety*treatment	40	1609.8949	40.2474	1.05	0.4