SELECTION FOR DROUGHT TOLERANCE, DISEASE RESISTANCE, CANNING AND NUTRITIONAL QUALITY IN DRY BEANS(*Phaseolus vulgaris* L.)

By

AHMED OMAR WARSAME

B.Sc. Crop Science (Hons), University of Gadarif, Sudan

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Declaration

I hereby declare that this is my own original work and that it has not been presented for any award of a degree in any other university or Institute of higher learning.

Signed.........................Date..

Warsame Ahmed Omar

This thesis is submitted with our approval as supervisors:

Signed .... Date ....

Prof.Paul M. Kimani

Department of Plant Science and Crop Protection

University of Nairobi

Signed..................................... Date..

Prof. EdwardG. Karuri

Department of Food Science, Nutrition and Technology

University of Nairobi

Dedication

I dedicate this thesis to: my beloved parents, Mumina and Omar; my two children, Salim and Ruweydah, and my entire family for their love and support.

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is the most important legume crop in eastern and central Africa. The crop is low yielding and underutilized due to several factors such as biotic and abiotic stresses and poor seed quality attributes. Therefore, breeders must consider production and utilization constraints when developing new bean varieties. Bean growers want bean varieties to be high yielding and tolerant to production constraints such as drought and diseases. Bean consumers want beans that cook fast and have good sensory qualities. Processors of beans are constrained by the consumer preferences, but they also want beans to meet specific processing standards. In addition, to contribute in fight against micronutrient malnutrition among poor population, new bean varieties should have high nutritional quality. This research was therefore undertaken to identify bean cultivars of different grain types with superior agronomic performance, good culinary, canning and nutritional quality from the available germplasm.

Field trials were conducted for two seasons during long-rain 2012 and short-rain 2012/2013. In the first season, 427 lines from seven market classes and local check varieties were planted at Kabete and Thika under irrigated and rainfed conditions in asplit plot design. Selections from the first season were evaluated under rainfed conditions in four sites including Kabete, Nakuru, Thika and Tigoni using 5x5 lattice design. Data on days to flowering, days to maturity, reaction to major diseases under field conditions and grain yield were recorded. Water regimes and site significantly affected days to flowering and maturing of the genotypes. Genotypes matured earliest in Thika and latest in Tigoni. In both seasons, local varieties KATB9, KATB1, GLPx92, GLP1004 and Miezi Mbili were early maturing compared to test lines. During the first season, Kabete experienced severe disease breakout. Anthracnose was the most severe with 24% of the genotypes succumbing to the disease (7-9 score). Red mottled and speckled sugar lines were

affected the most by the disease with over 40% of the genotypes succumbing to the disease. Nearly all local varieties succumbed to the disease. Results showed that Thika site had drier conditions and rainfed plots had 30% less yield compared to irrigated plots. At Kabete, effect of water regime was concealed by the diseases which infected severely the genotypes under both treatments. Lines which performed well under both rainfed and irrigated treatmentsat Thika were selected for drought tolerance during the first season. Most of the local check varieties were low yielding and very susceptible to diseases under different conditions. Mexican142 was the best check in terms of yield and reaction to diseases.

One hundred fifty lines were selected and evaluated for cooking time, water absorption and hard-shell defect to identify lines combining good agronomic and culinary traits that are suitable for household preparation and food processing industry. The most agronomically superior variety, Mexican142, was used as control. Mattson bean cooker was used to determine cooking time. Results showed that around 30 lines from different market classes were fast-cooking (<35 minutes), had high water absorptioncapacity (>90%) and zero percent hard-shell defect. Lines combining good agronomic and, fast cooking time, high water absorption and zero hard shell defect traits included: BCB11-324 (Red mottled), BCB11-158 and BCB11-196 (Red kidney), BCB11-386 and BCB11-414 (Speckled sugar), BCB11-108 and BCB11-94 (navy bean), BCB11-184 (small red), BCB11-448, BCB11-274 and BCB11-508 (pinto and carioca) and BCB11-263 from mixed colour market class.

Based on results from the first season and visual selections during second season, 29 lines from different market classes were selected for canning quality evaluation to identify lines combining superior agronomic traits and processing qualities. Mexican142 was used as control. Beans were canned in brine. Sensory quality evaluation was done by panelists in two food processing factories. Results showed that lines BCB11-182 (small red), BCB11-108 (navy) BCB11-98 (navy), BCB11-162 (red kidney) and BCB11-324 (red mottled) had better canning and sensory qualities than Mexican142, and met the requirements of both processors and consumers.

Iron and zinc concentration analysis was done on grain of 31 advanced lines selected during short-rain season and 18 lines from biofort nursery which was previously bred for high iron and zinc. The red mottled line BCB11-145 had the highest iron concentration (136 ppm). However, this line had long cooking time and high percentage of hard-shell seeds (16%). In general, results showed that lines bred for high iron and zinc had higher concentration of these nutrients.

Selected lines were ranked using critical weighting factors which included yield, cooking time, hard-shell defect, hydration coefficient and overall acceptability (sensory). Lines BCB11-108 (navy), BCB11-62 (navy),BCB11-344 (small red),BCB11-324 (red mottled),BCB11-80 (navy) and BCB11-303 (speckled sugar) were the best 6 lines in that order.Mexican142 was ranked 15th out of 30 genotypes. Therefore, the crop improvement strategy deployed in this study showed that significant improvement in beans can be made by selection from the available genetic variation.

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Chapter 1

Introduction

1.1. Background information

Dry bean (*Phaseolus vulgaris* L.) is a crop of considerable importance in the world as a grain legume and vegetable (Singh, 1999). For more than 300 million people, an inexpensive bowl of beans is the centerpiece of their daily diet (HarvestPlus, 2006). It is a perfect food and contains over 25% of protein and is one of the best non-meat sources of iron, providing 23-30% of daily-recommended levels from a single serving (Schwarz *et al.,* 1996). Beans provide dietary proteins that play an essential role in human nutrition by complementing other foodsthat are primarily sources of carbohydrates and are an important source of phosphorus, magnesium, manganese, and in lesser degree, zinc, copper and calcium (Broughton *et al.*, 2003).

Bean production is concentrated in the developing world. Eighty six percent of worldwide production of dry bean is from developing countries (Gepts *et al.*, 2008). Most dry bean is grown by source-poor farmers in Latin America and Africa. Accounting for nearly half of the global output, Latin America is the most important bean-producing region with 8 million hectares used for bean production (CIAT, 2001).In Africa, more than 5 million hectares are cultivated with dry beans and annual production of 4 million metric tons (Jackson *et al.,* 2012). The crop is cultivated mainly by women for subsistence and the market. In this continent, most bean production is found in the eastern region where it plays a paramount role in human nutrition and market economies throughout rural and urban areas of Eastern Africa (Pachico, 1989). This region has the highest bean production in Africa at 2.9million tons per annum (Jackson *et al.*, 2012).

Common bean is consumed in many forms around the world. In traditional households, dry beans are cooked, fried, or baked to be in soups, eaten as vegetables, or combined with other protein foods to make a main dish (Siddiq and Uebersax, 2012). In urban areas, value added canned beans provide a major formforconsumptionof this crop. This is due to trends of urbanization which is associated with changing eating habits, with preference for fast cooking foods due to rising costs of cooking fuels. Canned bean products are recognized for convenience and distinctive flavor while providing excellent consumer value (Uebersax, 2006). In addition, canned products are considered safe and reduce the risk of food borne illnesses (Floros *et al.*, 2010).

In eastern Africa region, productivity of beans is threatened by biotic (diseases and insects) and abiotic stresses especially low soil fertility and frequent droughts (Wortmann *et al.*,1998; Kimani *et al.*, 2005) on the one hand. On the other hand, seed quality traits related to culinary and canning quality are of utmost importance for the utilization of common beans. Substantial health benefits of beans in reducing micronutrient malnutrition among poor households have been reported (Cichy *et al.*, 2009; Nchimbi-Msolla and Tryphone, 2010).

1.2. Problem statement

In Africa, over 200 million people in sub-Saharan Africa depend on dry bean (*Phaseolus vulgaris* L.) as a primary staple food. However, production is declining due to a number of biotic, abiotic and socio-economic constraints (Kambewa, 1997).In bean producing areas of eastern and southern Africa, drought is one of the most devastating abiotic constraints. Worldwide, about 60% of the bean crop is grown under the risk of either intermittent or terminal drought (White and Singh, 1991; Thung and Rao, 1999). In bean producing areas of Africa, drought is endemic and more than 390,000 tons of beans are lost to drought annually (Wortmann *et al.,* 1998; Amede et al., 2004). With global climate change threatening to exacerbate the drought problem especially in Sub-Saharan Africa, food and nutritional insecurity is likely to increase.Diseases are most severe biotic constraint to productivity of dry beans in eastern Africa. The major diseases that occur in farmers' field include angular leaf spot, anthracnose, root rots, and common bacterial blight (Wortmann *et al.,* 1998; Kimani et al., 2005). The first three fungal diseases can cause yield loss up to 80%, 90% and 70% respectively under favorable conditions (Schwartz *et al.,* 1981; Otsyula *et al.,* 2003).

Culinary quality such as cooking time is critical for the utilization of dry beans due to its long-cooking nature (Iyer *et al.,* 1980; Miles and Sonde, 2004; Elia, 2003). Bean cooking time can vary from 1½ hour to 8 hours depending on variety (Miles and Sonde, 2004).This has implication on time, cost and energy requirements of preparing dry bean food. In Kenya, traditional bean varieties need 2 to 3 hours to cook (Kimani *et al.,* 2005). On the other hand, due to rapid urbanization and high costs of cooking fuel, the consumption of canned beans,especially in urban areas in the region, is increasing. However, the available canning bean varieties such as Mexican142 are low yielding, highly susceptible to rust, angular leaf spot, common bacterial blight and drought (Kimani *et al.,* 2005).This results in inadequate and irregular supply for the processors. Frequently, the dry beans supplied to processing industry do not meet required canning standards (Kimani *et al.,* 2013).

Millions of poor people in Africa suffer from micronutrient malnutrition, especially iron and zinc (Newton et al., 2011). Several strategies have been proposed to deal with micronutrient malnutrition problem. However, the success of these intervention approaches has had weaknesses, either in terms of sustainability, cost- effectiveness or coverage (Ruel and Bouis, 1998; Kimani, 2005; Qaim *et al.*, 2007; White and Broadley, 2009). Therefore, development of crop cultivar rich in micronutrients has been suggested (Qaim *et al.*,2007; Ruel and Bouis, 1998). Due to wide spread cultivation of dry beans and existence of genetic variation for iron and zinc concentrations, it has been suggested that development of agronomically superior bean cultivars with high iron and zinc concentrations will aid in reducing micronutrient malnutrition (HarvestPlus, 2006; Kimani, 2005).

Considering these challenges facing production of dry beans and the increasing importance of beans in terms of food and nutrition security, it would be necessary to adopt a crop improvement approach which incorporates improvement for agronomic traits such as drought tolerance, disease resistance, and end-user needs (acceptable grain type, good culinary, canning and nutritional quality). Development of dry bean varieties that combine these traits would probably improve food security and economic situation of the poor communities in the region.

The Bean Research Program of the University of Nairobi holdsconsiderable germplasm of common bean, including advanced lines from different market class, which have been selected for droughttolerance. However, they have not been evaluated for their agronomic performance under different environments, and also culinary, canning and nutritional quality. This study, therefore, aimed to identify bean lines that combine superior agronomic performance,and culinary, canningand nutritional quality from this germplasm in order to contribute to the national and regional efforts to reduce food insecurity, enhance commercialization of dry beans, and improve nutrition and economic status of poor farmers in drought-prone areas in East Africa.

1.3. Objectives

The main objective of this study wasto identify dry bean genotypes with superior agronomic traits, culinary, canning and nutritional quality in order to contribute to reduction of food and nutrition insecurity and enhance commercializationand utilization of dry beans in drought-prone areas of east Africa.

Specific objectives:

1. To evaluate and select advanced bean lines for drought tolerance, disease resistance and other agronomic traits.
2. To evaluate the advanced lines for cooking time, water absorption and hard-shell seeds.
3. To determine canning and sensory quality of the most agronomically superior bean lines.
4. To determine grain iron and zinc concentrations in selected advanced bean lines.

1.4. Study hypotheses

1. There is no genetic variability among the advanced bean lines for drought tolerance and agronomic potential.
2. There is no genetic variation for cooking time, water absorption and hard-shell seeds among the dry bean lines.
3. There is no genetic variation for canning and sensory quality among the dry bean lines.
4. There is no genetic variation for grain iron and zinc concentration among the advanced bean lines.

1.5.Conceptual framework

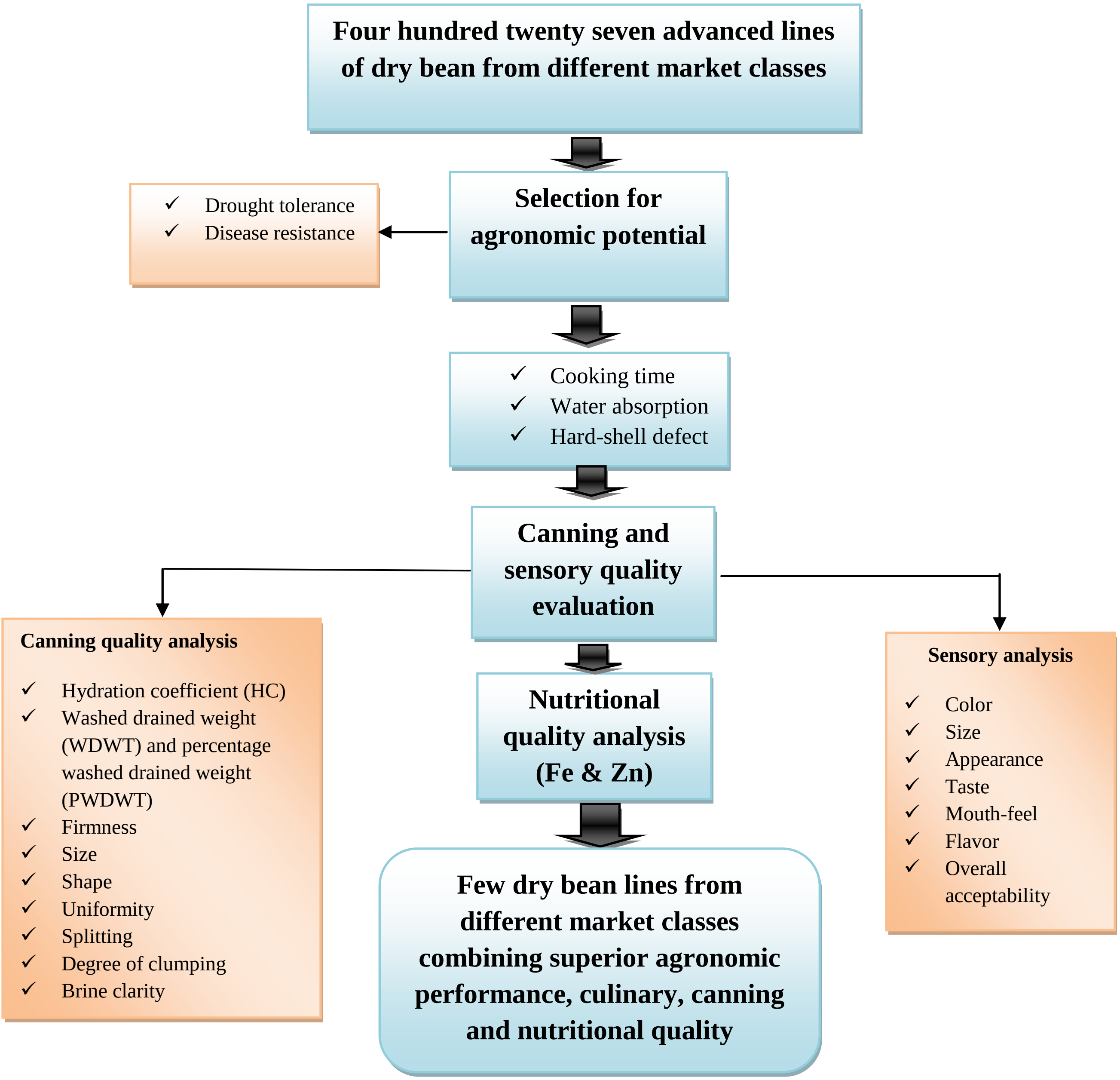

Figure 1.1: Framework of the study.

Chapter 2

Literature Review

2.1. Introduction

Common bean or dry bean, (*Phaseolus vulgaris*, L.) is a member of the family Leguminosae, tribe Phaseoleae, subfamily Papilionoideae.The genus *Phaseolus* contains four other domesticated and cultivated species and over 50 wild species. Other cultivated species are: *P.coccineus* (runner bean), *P.dumosus* (Year bean), *P.acutifolius* (Tepary bean) and *P.lunatus* (Lima bean) (McClean *et al.,* 2004; Kelly *et al*., 2012). Common beans evolved over 7000 years in highland regions of Mexico and Andean South America (Gepts and Debouck, 1991; Graham and Ranalli, 1997).During this period, evolutionary forces (mutation, selection, migration, and genetic drift) have acted on the common bean plant, which have shaped the morphological, physiological, and genetic characteristics of present-day common bean cultivars (Gepts and Debouck, 1991). Based on archeological, morphological, agronomic and seed protein evidence, common beans has been separated into two major gene pools: Middle American and Andean South American, which could be further divided into six races. Three races originated in Middle America (races Durango, Jalisco, and Mesoamerica) and three in Andean South America (races Chile, Nueva Granada, and Peru) (Singh*et al.*, 1991).

Dry bean is a true diploid with 22 chromosomes (2n=2x=22). It has genome size of 450–650 Mbp/haploid (Broughton*et al.,* 2003). It is herbaceous annual crop with determinate or indeterminate growth habit. Flowers are borne in auxiliary and terminal racemes and have ten stamens and a single multi-ovuled ovary which is predominantly self-fertilized, and develops into a straight or slightly curved pod (Graham and Ranalli, 1997).Mature pods contain five to eight seeds and considerable variation exists in size, shape, and color ofpods and seeds (Miklas and Singh, 2007). Physiological maturity in common bean seeds is achieved after around 60-65 days from planting amongst those early bush types or extend to 200 days after planting amongst climbing varieties used in cooler upland elevations (Graham and Ranalli, 1997). Crop yields can range from less than 500 kg ha^{-1}in parts of Latin America and Africa to as much as 5000 kg ha^{-1}under experimental conditions (Graham and Ranalli, 1997).

2.2. Production and utilization of dry beans

The world production of dry beans in 2010 was estimated to be 23.2 million tons with area of production of more than 28 million hectares (Siddiq and Uebersax, 2012). Latin America is the largest producer of dry beans with Brazil being the leading country (Broughton et al., 2003). In Africa, dry bean production is estimated to be more than 4 million tons with annual cultivated area of more than 5.8 million hectares (Jackson *et al*., 2012) with Uganda, Kenya and Tanzania being the leading countries (Katungi *et al.*, 2009). In both regions, resource-poor farmers with very few inputs grow beans primarily on small-scale and marginal farms (Broughton *et al.*, 2003). In Latin America, the highest per capita consumption of dry bean was found to be 24 kg yr^{-1}in some parts of Bolivia, while in Africa it reaches up to 66 kg yr^{-1} in Kisii, Kenya (Broughton *et al.,* 2003). Globally, dry bean tradehas developed an international market that exceeds 2.5 million tons. The largest exporters are China and Myanmar, followed by USA, Argentina, and Canada (Broughton *et al.,* 2003;Katungi *et al.,* 2009).

In Africa, dry seeds of beans are traditionallycooked fried, or bakedto be in soups, eaten as vegetables, or combined with other protein foods to make a main dish. Household cooking of beans associated with excessive expenditure of time and fuel isthe most popular form of consumption of dry beans (Jackson *et al*., 2012). In industrialized regions, dry-bean-based products include: packaged dry beans, canned beans, pre-cooked bean products, extruded and pasta-type products, specialized food ingredients, quick-cooking beans, and frozen beans (Uebersax, 2006; Siddiq and Uebersax, 2012). In Africa, several traditional dishes are prepared from the grain (Katungi *et al.*, 2009) while young leaves, immature pods are used as vegetables (Jackson *et al.*, 2012).

Based on consumer preferences, beans are classified into market classes based on seed size, shape and color (Kelly *et al.*, 2012). According to Buruchara *et al.* (2011) and Wortmann *et al.* (1998), preferences for bean varieties in Africa are extremely diverse among farmers, traders, processors and consumers. Common bean market classes in the continent include: red mottled, large red kidneys, small and medium red, navy, large white kidney, sugars, brown, yellow, tan, cream, pinto, carioca, purples and blacks.

Figure 2.1: Different dry bean market classes in Eastern Africa.

2.3. Dry bean production constraints in eastern Africa

In the world, production of dry bean is constrained by different factors. These include: Diseases, insects, drought and soil fertility (Broughton*et al.,* 2003; Graham and Ranalli, 1997). Kimani *et al.,* (2005) summarized the major problems faced by bean producers in eastern Africa as those associated with: (a) production, (b) seed delivery systems, (c) marketing, and (4) agricultural research and extension.

In eastern Africa, drought and diseases are ranked in the top of production constraints (Kimani*et al.*, 2005). As much as 60% of bean production in the developing world occurs under conditions of significant drought stress (Graham and Ranalli, 1997). According to Palmer (1965), and Porton and Nicholds (1994) drought can be defined as a condition of insufficient moisture caused by a deficit in precipitation over some time period. Water deficit in the soil leads to a series of morphological, physiological, biochemical and molecular changes in plants, which adversely affect their growth and productivity (Lisar *et al.,* 2012). The effects depend on the severity and duration of the stress, the growth stage at which stress is imposed, and the genotype of the plant (Kramer, 1983).

Plants employ morphological, physiological and biochemical mechanisms to tolerate effects of droughts. White and Singh (1991) defined drought tolerance as all characteristics which permit greater yields under soil moisture deficits. These mechanisms include: short phenology-drought escape, root growth (Turner *et al.*, 2000; Prasad *et al*., 2008), stomatal closure(Ludlow, 1980), osmotic adjustment(Ludlow and Muchow, 1990), increased accumulation of organic compounds under drought stress such as proline protein(Ashraf and Iram, 2005; Raggio and Raggio, 2006; Güler *et al.*,2012) and abscisic acid (ABA)(Gebeyehu, *et al.*, 2010; Abass and Mohamed, 2011).

Although morphological, physiological, and biochemical traits related to drought tolerance in dry beans have been studied, Ramirez-Vallejo and Kelly (1998) concluded that no single trait contributed exclusively to the improvementof drought tolerance, nor could one trait be selectedsolely to improve the performance of common beanunder drought. For this reason, and the fact that the ultimate interest of growers is the yield, it has been suggested that the direct measurement of seed yield is the most practical way to screen for drought tolerancein dry beans (Acosta-Gallegos and Adams, 1991; Kelly *et al.,* 1998;White and Singh, 1991; Terán and Singh, 2002).

Diseases are the second most important production constraint of bean productivity in Africa. Major diseases of beans that occur in farmers' fields in Africa: angular leaf spot (*Phaeiosariopsis griseola*), anthracnose (*Colletotrichum lindemuthianum*) root rot (*Pythium spp*.) and common bacterial blight (*Xanthomonascampestris*pv. *phaseoli*) (Kimani *et al*., 2005). Other bean diseases include rust, halo blight and bean common mosaic virus (BCMV) (Beebe and Pastor-Corales, 1991).

Angular leaf spot can cause up to 80% yield losses under severe conditions of infection (Schwartz *et al*., 1981), while anthracnose can cause up to 90% under favourable climatic conditions. In eastern Africa, angular leaf spot and anthracnose cause yield loss of 281,300 and 247,400 ton/year respectively (Wortmann *et al*., 1998).Root rot has been reported to cause yield loss up to 70% in commercial bean cultivars in Rwanda and Kenya (Otsyula *et al*., 2003). Genetic resistance to pathogens is well studied in dry beans. Since more than one disease can occur in the farmers' field, selection for multiple resistances to major disease is considered the most practical and sustainable strategy for disease management in dry beans.

2.3.1.Dry bean improvement for drought tolerance in eastern Africa

Drought is ranked as major constraint to bean production in Kenya, Ethiopia, parts of south western Uganda, northern and central Tanzania, South Africa, southern Rwanda, Sudan, Angola, central plateau of Madagascar and south east DR Congo(Kimani and Beebe, 2003).

In eastern African region, although screening dry bean genotypes for drought resistance dates to mid-1970s, not much progress has been made by scientists in identifying drought resistant bean genotypes (Amede *et al.,* 2004). However, selection in stress environments has resulted in improved performance. In Kenya, in 1980s four lines with moderate drought tolerance were identified (Van Rheenen*et al.,* 1984). These included GLP 1004, GLP x 1127, and GLP x 92 GLP100 and GLPX-92. In a subsequent effort at Katumani (Kenya),four new dry bean varieties, KAT B1, KAT B9, KAT x56 and KAT 69 were released in the late 1990's and early 2000's. KAT B1 is yellow seeded; KATB9 is a medium red; KAT56 is a large red kidney, and KAT69 is a large red mottled.A regional initiative known as BIWADA (Bean improvement for water deficit areas in Africa) was started in 1999. Several lines with farmer preferred attributes were selected from BIWADA nursery in Katumani and Thika.

Drought tolerant small-seeded lines that out-yielded the local checks were identified in Kenya (Kimani and Beebe, 2003). They include SEA 16, SEA 20, SEA 23, RAB 608, RAB 618, RAB 636 and INIB 35. However, those lines were lacking marketable grain types and were suggested to be utilized as sources for drought tolerance in breeding drought tolerant marketable bean cultivars.

2.3.2. Dry bean improvement for multiple diseaseresistance in eastern Africa

Since 2000 dry bean breeding programs in eastern Africa adopted market-led strategy to improve new cultivars targeting particular markets (CIAT, 2001). Dry bean breeding for multiple disease resistance in eastern Africa involved in collection of germplasm materials comprising segregating populations, advanced breeding lines, development of segregating populations from simple and multiple crosses and introductions from CIAT and regional germplasm collections (Kimani *et al.,* 2008).

Among large-seeded types, around 15 red mottled varieties with multiple resistances to angular leaf spot, anthracnose, BCMV, halo blight and common bacterial blight were released in six eastern African countries between 2003 and 2008 (Kimani *et al.,* 2008). During the same period, 12 red kidney bean varieties with multiple resistances to ALS, anthracnose, BCMNV, BCMV, halo blight and CBB was released in eastern Africa countries (D.R. Congo, Ethiopia, Kenya, Madagascar, Rwanda, Tanzania, and Uganda.)(Kimani *et al.*, 2008). Also 8 new speckled sugar varieties were released in Kenya, Uganda, Ethiopia and D.R.Congo (west) between 2003 and 2008. Among small and medium seeded types, 8 small red varieties with multiple resistances to ALS, halo blight and rust were released in Ethiopia, Kenya and Madagascar between 2003 and 2008. Eighteen varieties of other colors such as brown, tan and yellow with multiple resistance to diseases were released in five eastern African countries (Kimani *et al.*, 2008).

2.4. Dry bean processing

The processing of bean-based foods in Africa has traditionally been done at home by women. Consumers in rural and majority of lower-income classes in urban areas consume beans as boiled grains while canned bean products are consumed by the higher-income classes (Jackson et al., 2012). However, given the trends of urbanization in the region, demand for canned beans is expected to increase.

2.4.1. Cooking time in dry bean

Long cooking time is a well-known problem in dry bean which is responsible for under utilization of the crop (Elia *et al.,* 1997; Garcia *et al.,* 2012). Cooking time is one of the quality variables of beans in the market worldwide because the cooking process consumes fuel and time (Maryanna Maryange *et al.,* 2010).Adverse storage conditions such as high temperatures and high relative humidity (%RH) are the most cited cause for deterioration of cooking quality of legumes (Stanley, 1992; Berrios *et al.* 1999; Balameze *et al.* 2008). Such storage conditions promote seed hardness which leads to impermeability of the seed coat to water or inability of cotyledon to be hydrated during cooking (Nasar-Abbas *et al.* 2008). Studies on dry bean cooking time reveal huge variation for this trait which varies from 19.5 to more than 80 minutes (Shimelis and Rakshit, 2005; Elia, 2003; Maryanna Maryange *et al.,* 2010; Shellie and Hosfield, 1991).

Genetic control of cooking time in common beans has been reported to be oligogenic (controlled by few major genes) (Garcia *et al.,* 2012).Elia (2003) reported an importantadditive genetic variance for cooking time in beans and heritability of up to 0.91 was reported by Elia *et al.* (1997). Further study on QTL mapping revealed six significant QTLs which explained 11.54 to 21.63% of phenotypic variation in the cooking time (Garcia *et al.,* 2012).

2.4.2. Canning dry bean

Canning is the heat sterilization process during which all living organisms in food are killed, to assure that no residual organisms could grow in the can (van Loggerenberg, 2004). The bean canning process has two important steps, soaking and sterilization. Soaking bean before filling in cans help in removing foreign material, facilitate cleaning, filling through uniform expansion, ensure product tenderness and to improve colour (Uebersax *et al.,* 1987). Sterilization helps in destroying all spores of *Clostridium botulinum* and to prevent the spoilage of the product by heat-resistant, non-pathogenic organisms (van Loggerenberg, 2004).

2.4.2.1. Canning quality of dry beans

According to Hosfield *et al.,* (2000) and van Loggerenberg (2004), most important traits related to processing quality of dry beans include: cooking time, water uptake (WU), hydration coefficient (HC), washed drained weight (WDWT), percentage washed drained weight (PWDWT), splits, texture, clumps, percent solids, visual appearance (VA), size and colour.

Cooking time in beans is a very important market trait worldwide because the cooking process consumes fuel and time (Maryanna Maryange*et al.,* 2010). In bean processing, since the cost of fuel consumed during cooking process will be part of the final cost of the product, fast-cooking varieties are preferred. WU is important in bean canning, as a larger quantity of beans is necessary to fill a certain can volume, when the WU ratio is low (van Loggerenberg, 2004).Washed drained weight (WDWT) is the measurement used by processors to indicate the swelling capacity and water entrainment of beans (Hosfield, 1991) and is direct measure of processor yield. Texture of canned beans was found to correlate with acceptability of the product (Mkanda, 2007). Sensory analysis of cooked beans showed that consumers preferred soft beans while rejected too soft or hard beans (Mkanda, 2007). Size and colour are among the properties of beans that consumers have specific preferences about. Consumers reject bean cultivars that lack preferred combinations of seed color, size and shape (Kelly*et al.,* 1998). Other sensory quality attributes like VA, splitting and clumping are important for consumer preferences of beans. They determine the general suitability of beans for commercial processing (van Loggerenberg, 2004).

2.4.2.2. Dry bean improvement for canning quality in eastern Africa

In eastern Africa, production of dry bean for canning industry started in 1937. The first activities to improve canning quality of dry beans in the regionwere reported in Tanzania (Leakey, 1970). According to Macartney, (1966) the early efforts were focused on (a) selection for seed quality traits such as soakability, size, shape and flavor. (b) Agronomic traits such as resistance to rust, growth habit, earliness, non-shattering during drying and yield potential. Soakability and percentage of hard-shell seeds were the first criteria used to screen for canning quality. According to Leakey (1970), from a germplasm collection and selecting program between 1955-1959, one of the most popular canning bean variety in eastern Africa was identified, Mexican142, and released in 1961. In Ethiopia, a breeding program of dry beans (1972-1978) identified Mexican142, which originated from Tanzania, as preferred variety for export, probably for its excellent canning quality (Abebe, 1989). After more than 50 years of its release, the Mexican142 variety is considered the “ruling variety” which dominates production of canning beans in the region. This is despite reports that it is susceptible to rust, anthracnose, common bacterial blight and drought (Kimani *et al.,* 2005). This indicates that limited work has been done so far in the region to improve new canning beans with good canning quality and superior agronomic traits.

2.5. Micronutrient malnutrition

Micronutrients,like iron and zinc, are essential elementsneeded in small amounts for adequate human nutrition (Blair *et al.,* 2008). The term ‘hidden hunger’ has been used to describe themicronutrient malnutrition inherent in human diets that areadequate in calories (carbohydrates, protein, andfat) but lack vitamins and/or mineral elements like iron and zinc (Qaim *et al.*, 2007; White and Broadley, 2009; Aizat *et al.*, 2011).

Iron and zinc deficiency is widespread in the world. About 3.7 billion people are deficient in iron (Welch, 2002), and 49% of the human population is at risk for inadequate zinc in their diets (Brown *et al.*, 2001).

Iron is a vital element in oxygen-binding moleculessuch as hemoglobin and myoglobin, and its deficiencycan lead to anemia and chronic cognition problems (White and Broadley, 2009). Iron deficiency causes reduction of physical working capacity, negatively influences the normal defense systems against infections.It has negative influence on behavior of children such as attention, memory, and learning(FAO and WHO, 2004). The economic impact of iron deficiency on individual productivity, and subsequently on country economy, has been quantified by Horton and Ross (2003). Based on data from 10 developing countries, they found that the median value of annual physical productivity losses due to iron deficiency is around $2.32 per capita.

Zinc is an important micronutrient that is used inmore than 300 eukaryotic enzymes (FAO and WHO, 2004). Zinc deficiency causes growth retardation, delayed sexual and bone maturation, skin lesions, diarrhoea, alopecia, impaired appetite, increased susceptibility to infections mediated via defects in the immune system, and the appearance of behavioral changes (Hambidge, 1987).

2.5.1. Biofortificationof crop plants

Different interventions have been used to deal with micronutrient malnutrition. Common interventions include mineral supplementation, food fortification and food diversification. However, the success of these intervention approaches in the less developed world has had weaknesses either in terms of sustainability, cost or coverage (Ruel and Bouis, 1998; Kimani, 2005; Qaim *et al.*,2007; White and Broadley, 2009).

According to Ruel and Bouis, (1998) plant breeding holds a great promise for making a significant, sustainable, low-cost contribution to the reduction of micronutrient deficiencies in humans. Nestel *et al.*, (2006) defined biofortification as the development of micronutrient-dense staple crops using the best traditional breeding practices and modern biotechnology. They summarized the merits of biofortification approach as: (a) it capitalizes on the regular dailyintake of a consistent and large amount of food staples by allfamily members (b) after the one-time investment to develop micronutrient-rich seeds, they fortify themselves and recurrent costs are low (c) highly sustainable; improved varieties will continue to be grown and consumed year after year (d) provides a feasible means of reaching under-nourished populations in relatively remote rural areas.

Agronomically, Ruel and Bouis, (1998), Rengel and Graham, (1995) suggested agronomic advantages to growing micronutrient-rich crops, including (a) improved disease resistance in plants which results in a decrease for the need of fungicides; and (b) greaterseedling vigor that is associated with higher plant yields. In addition, Wu *et al.*, (2005) reported that iron concentration in seed coats limit the process of excessive softening, and thus maintain the integrity of the seed coat during the canningprocess.

2.5.2. Biofortification of dry bean

The idea of breeding micronutrient-dense seeds was first initiated in early1990s by members of the Consultative Groupon International Agricultural Research (CGIAR)scientists(Ruel and Bouis, 1998). The initiative concentrated on enhancing content of major nutrients (iron, zinc, and vitamin A) in the food crops of wheat, maize, rice, dry bean,and cassava. The first stage in biofortification research is screening forgenetic variability in concentrations of micronutrients in the crops. In dry bean, studies by Beebe *et al.*, (2000) at CIAT evaluated core collection of over 1000 accessions of dry bean and they found that concentration of Fe ranged from 34-89 µg g^{-1} Fe (average= 55 µg g^{-1} Fe) and Zn concentration ranged from 21-54 µg g^{-1} Zn (average=35 µg g^{-1} Zn). Other study by Kimani *et al.* (2006) reported a significant variation of iron and zinc concentrations among dry bean in Africa. The observed genetic variations in the available germplasm collections suggested the potential to develop dry bean varieties with two to three times higher content of Fe and Zinc (*Cichy et al.*, 2009; Nchimbi-Msolla and Tryphone, 2010).

Breeding for increased micronutrient concentrations in seeds was found not to cause a negative effect on the yield. Moreover, positive correlation between the Fe and Zn concentrations in the leaves and seeds of common beans has been found.This suggests that genetic factors that increase Fe concentration are co-segregating with genetic factors that increase Zn concentration (Beebe *et al.*, 2000; Nchimbi-Msolla and Tryphone, 2010; Cichy *et al.*, 2009). Inheritance of iron and zinc in common bean seeds is controlled multigenically (Blair *et al.*, 2008). The QTLs for these minerals have been found to co-localize on three linkage groups (Cichy *et al.*, 2009). The discovery of QTLs can facilitate marker-assisted selection to breed new varieties of common bean with commercial seed types along with higher micronutrient concentration (Blair *et al.*, 2008).

2.5.3.Dry beanimprovement for nutritional quality in eastern Africa

In eastern Africa,breeding dry bean for higher iron and zinc content was initiated in 2001. According to CIAT (2007) the strategy for micronutrient-dense beans in the region included: (a) characterization of the variation of grain iron and zinc concentration, (b) identify potential parents for further breeding work, (c) identify lines which could be fast-tracked as mineral dense lines for cultivation by farmers in regions with severe Fe and Zn malnutrition.

According to Kimani *et al.* (2007), the most notable program of biofortification in the region involved incollection of 2849 germplasm accessions from nine countries in East and Central Africa which were screened for nutritional quality. Results showed that iron concentration varied from 40 to over 100 mg kg^{-1} and zinc concentration varied from 18 to over 50 mg kg^{-1} . Thirty-eight micronutrient-rich bean lines were selected at the University of Nairobi and were evaluated for their agronomic potential and acceptability to farmers in preliminary yield trials in Burundi and Madagascar, and in advanced yield trials in Rwanda, Ethiopia, Uganda, Kenya, Tanzania and DR Congo (Kimani *et al.*, 2007). The most promising lines included: (a) climbers: VCB 81013, VCB 81012, Kiangara, G59/1-2 and AND 10, (b) bush lines: Maharagi Soja, Ngwinurare, AND 620, VNB 81010, MLB 40-89A, MLB 49-89A, PVA 8, Nain de Kyondo, Gofta and Kirundo) (Kimani et al., 2007).

2.6. Summary of existing knowledge and gaps

It has been reported that drought and diseases are the major constraints of dry bean production in eastern Africa (Amede et al., 2004; Kimani et al, 2005; Wortmann et al. 1998). Several bean varieties with drought tolerance have been identified in the region (Kimani *et al.*, 2003) but have undesired grain types. Dry bean varieties with resistance to major diseases were also reported (Kimani et al., 2008). However, most of the literature available deals with one problem at time. There is lack of integrated strategy to select against more than one stress factor.

Household utilization of dry bean is limited by long-cooking time (Elia et al., 1997; Garcia et al., 2012). In Kenya, most available varieties are long-cooking (2-3 hours) (Kimani et al., 2005). On the other hand, dry bean processing industry is faced by shortage of raw bean material. This is due to dependence on a single variety, Mexican142, which was released for canning purposes in the 1960s (Leakey, 1970) and has been reported to be susceptible to diseases and drought (Kimani et al., 2005). In addition, nutritional quality of dry beans has become a breeding objective due potential of the crop in reducing micronutrient malnutrition (Beebe *et al.*, 2000; Kimani *et al.*, 2006). Bean varieties that combine tolerance to major stresses and, good culinary, canning and nutritional quality have not been reported in the region.

Available literature shows existence of genetic diversity in dry beans for drought tolerance (Singh, 1995; Singh *et al.*,2001; Terán and Singh, 2002), disease resistance (Singh et al., 1998; Wagara and Kimani, 2007), culinaryquality (Miles and Sonde,2004;Corrêa et al., 2010; Elia, 2003) canning quality related traits (Gathu *et al*, 2012; WU *et al*, 2005, Hosfield *et al,* 2000; Mekonnen, 2012), iron and zinc concentrations (Beebe *et al.*, 2000; Kimani *et al.*, 2006).However, the available literature shows that there is no coordinated strategy to select bean varieties that combinedesired agronomic traits, culinary, canning and nutritional quality from the available germplasm in the region. If some trait(s) are not captured due to limited genetic variation, such strategy would facilitate incorporation of the lacking trait(s) in later stages.

Chapter 3

Selection for drought tolerance and disease resistance in dry bean lines

Abstract

In Africa and other parts of the world, dry bean production is constrained by biotic and abiotic stresses. Over 60% of bean production occuring under drought conditions which cause yield losses of up to 60% depending on the severity, time and duration of the stress. Biotic stresses such as diseases and insects cause significant yield and quality losses. In eastern and central Africa, angular leaf spot, anthracnose and bean common mosaic virus (BCMV) are the most important diseases. It has been reported that the existing bean varieties are low yielding and susceptible to production stresses. Therefore, it is important to develop new bean varieties of different market classes which are tolerant to major production constraints to meet both producer and consumer requirements. The objective of this study was to select for drought tolerance and disease resistance in advanced bean lines of seven market classes grown under different environments. During 2012 long-rain season, 427 advanced lines that were previously selected under drought conditions and the local varieties were grown in Kabete and Thika under irrigated and rainfed conditions using split plot design. Grain yield under drought stress was used as the main selection criterion for drought tolerance. Data was collected on duration to flowering, reaction to major diseases, days to maturity and grain yield. Results showed that due to drier conditions in Thika site, rainfed plots had 30% less yield compared to irrigated plots. Kabete experienced severe outbreak of diseases probably due to the wetter and cooler conditions. Anthracnose was the most severe disease with 24% of the test lines were destroyed by the disease. In red mottled and speckled sugar market classes, 46.4% and 40.9% of the test lines were highly susceptible to anthracnose. Based on results from both sites, 157 lines from the seven market classes that performed better than most local checks were selected and planted with the local varieties in the 2012/2013 short-rain season at four sites under rainfed conditions. The performance of the selected lines under different environments indicated that selection of dry bean lines under drought conditions and disease pressures had aided in the identification of agronomically superior lines from the available germplasm.

Key words: market classes, advanced lines, anthracnose, yield

3.1. Introduction

Stabilizing bean yields under adverse production conditions is a major objective in plant breeding. Bean production is constrained by different abiotic and biotic stresses (Kimani et al., 2005; Wortmann *et al*., 1998). Among abiotic stresses, drought is the most important with 60% of bean production in the developing world occurs under conditions of significant drought stress (Graham and Ranalli, 1997). In dry beans, drought reduces plant size, days to physiological maturity and grain yield (Teran and Singh, 2002). Seed yield is the most important economic trait in beans; hence the grain production is considered the most reliable criterion in selecting for drought tolerance (Acosta-Gallegos and Adams, 1991; Kelly *et al.*, 1998;White and Singh, 1991). In addition, stability of the performance of selected bean lines under various production conditions is considered an important trait during selection for yield (Mekbib, 2003). Diseases are considered the most important biotic stresses limiting dry bean production. Among major diseases of beans that occur in farmers' fields in Africa: angular leaf spot, anthracnose, root rot (*Pythium spp*.), common bacterial blight,rust, halo blight and bean common mosaic virus (BCMV) (Kimani *et al*., 2005; Beebe and Pastor-Corales, 1991).

Considering the increasing demand for beans and the wide range of bean type preferences among bean consumers in the region (Buruchara et al., 2011), development of dry bean varieties which combine tolerance to major production stresses and superior grain quality traits will contribute to increased production and commercialization of dry beans in drought-prone areas of eastern Africa. Therefore, the objective of this study was to identify agronomically superior lines from advanced dry bean lines of different market classes that were previously selected under drought conditions.

3.2. Materials and Methods

3.2.1. Plant Materials

Four hundred and twenty seven (427) advanced dry bean lines from seven market classes and local commercial varieties were used in this study (Table 3.1). The advanced lines were obtained from the University of Nairobi Bean Research Program. The study lines were selected under severe early season, intermittent and terminal drought conditions at Kabete and Thika in 2007, 2008 and 2009. The large number of lines was chosen to broaden genetic base of the study material and increase chances of capturing the combination of the desired traits.

Table 3.1: List of advanced dry bean lines used in the study

Market class	Number of entries	Local check varieties
Red mottled	69	KAT69,GLP2 and Kenya Umoja
Red kidneys	53	KAT56 and GLP-24
Speckled sugars	44	Miezi Mbili
Navy bean	119	Mexican142
Small reds	43	GLP585, ,KATB9, SER16, Tio Canella, SEA15
Pintos and cariocas	43	GLPX92 and GLP1004
Mixed colors	56	KATB1, GLPX92, GLP585, SER76
Total	427	

GLP varieties were released in 1980s with intermediate tolerance to drought(van Rheenen *et al.* 1984). KAT varieties were released in mid 1990s and early 2000 for their good marketable grain types and suitability for drought prone areas in eastern Kenya. Mexican142 is a white navy variety released in 1961 for its excellent canning quality (Leakey, 1970),and it is widely grown in the region. CIAT lines, Tio canella, SER16, SER76, and SEA15 were included for their known reaction to drought conditions (CIAT, 2003).

3.2.2. Trial sites

During 2012 long rain season, experiments were conducted in Kabete Field Station and at KARI-Thika. The Tigoni and Nakuru sites were included during 2012/2013 short rain season.

3.2.2.1. Kabete Field station

Kabete Field Station of the University of Nairobilies at an altitude of 1840 meters above sea level and on latitude 1°15' S and longitude 36° 44' E (Google Maps, 2013). It falls under agro-ecological zone UM3 (upper midland).The areahas a bimodal rainfall pattern with peaks in April andNovember. The annual rainfall is around 1000 mm which is received during long rains (March to May) and short rains (October to December) seasons every year. The site has maximum and minimum mean temperatures of 24.3° and 13.7° C, respectively. The soils are very deep, well-drained, dark reddish, deep friable clay type resistant to erosion (Michieka, 1977).

3.2.2.2. Thika

KARI-ThikaResearch Station falls under agro-ecological zone UM3 (upper midland)(Jaetzold et al., 2009). It lies at an altitude of 1520 m above sea level and on latitude of 00 59’ S and longitude37 04’ E (Google Maps, 2013). It experiences bimodal pattern of rainfall with an annual mean of 900 mm (Jaetzold et al., 2009). The mean annual maximum and minimum temperatures are 25.1 and 13.7 °C, respectively (Ndegwa et al., 2009). Soils are well drained, extremely deep, dusky red to dark reddish brown, friable clay (Jaetzold et al., 2009).

3.2.2.3. Tigoni

KARI-Tigoniresearch station falls under the lower highland (LH1) agro-ecological zone (Jaetzold et al., 2009). It is located on altitude of 2131 meters above sea level, and latitude of 1°15' Sand longitude 23° 46' E (Google Maps, 2013). The average annual rainfall is around 1400 mm annually. The soil type is humic Nitosol. Soils are well drained, extremely deep, dusky red to dark reddish brown, friable clay, with an acid humic topsoil (Jaetzoldet al., 2009).

3.2.2.4. Nakuru

The experiment was carried out in a farmer's farm inKabatini area of Bahati constituency, Nakuru North District in Nakuru County. The area falls under lower highland (LH3) agro-ecological zone(Jaetzoldet al., 2009).The field area locates on latitude of 0° 12'S and longitude of 36° 10' with altitude of 2070 masl (Google Maps, 2013). The average annual rainfall is about 1000-1200 mm. The mean annual maximum and minimum temperatures are 22.6 and 9.1 respectively(Jaetzold et al., 2009).The soil of the location is classified as vitric Andosols. Soils are well drained moderately deep to deep, brown to dark brown, very loam to sandy clay loam(Jaetzold et al., 2009).

3.2.3. Experimental design, treatments and crop husbandry

In first season, drought tolerance screening experiments in Thika and Kabete were laid out in split plot design with three replications. Main plots were irrigated and rainfed treatments and the test lines were the subplots. Irrigated treatments received supplementary irrigation from the flowering period to physiological maturity while rainfed treatments did not receive any irrigation water during the same period. A plot consisted of single 3 m row with 50 cm spacing between rows and 10 cm within rows with one seed per hill. In the second season, advanced lines selected in the first season and control varieties were planted in 5x5 lattice design under rainfed conditions at four locations. A plot consisted of two 3 m rows with 30 plants each making a total of 60 plants. Experiments were replicated three times.

The land of the experiments was ploughed and harrowed so as to achieve a moderate tilth in seed bed. Diamonium phosphate (18-46-0) fertilizer was applied at rate of around 150 kg/ha and thoroughly mixed with the soil. At seedling stage, plants were sprayed with dimethoate 40% EC at rate of 30 ml per 20 liter for the control of the bean fly. The fields were kept relatively clean of weeds throughout the growing seasons. Supplementary irrigation was provided using overhead sprinklers in Kabete Field Station and KARI-Thika Research Station during the first season.

3.2.4. Data collection

Data on plant growth habit, reaction to diseases, days to flowering, days to physiological maturity and grain yield were recorded using standard system for the evaluation of bean germplasm described by Van Schoonhoven and Pastor-Corrales, (1987). Growth habit was determined by observing determinate/indeterminate habit, stem strength and presence or absence of guides. Disease scoring was done from flowering to pod filling stages using a nine point severity scale (1-9), where a score of 1-3 was considered resistant, 4-6 intermediate resistance and 7-9 as susceptible. In first season, the test lines were screened for their reaction to infection by angular leaf spot, anthracnose, common bacterial blight and root rot. Kabete location was considered optimum for this purpose because it had wetter conditions compared to Thika. In the second season, diseases like rust and bean mosaic virus were included in screening criteria. Days to flowering were recorded as number of days from planting to when approximately 50% plants in a plot had at least one opened flower. Days to physiological maturity were recorded as the actual number of days from planting to when approximately 50% of plants in a plot had at least one dry pod. Yield was determined by counting and harvesting all the plants in a plot and taking the weight of the dry grains.

3.2.5. Data analysis

All data were subjected to analysis of variance in GenStat software (v.13, VSN, UK, 2010) with locations, treatments and genotypes as factors and the measurements as variables. Fisher's least significant difference was used for mean separation.

3.3. Results

3.3.1. Weather

Weather data was obtained from Kabete weather station of Kenya Meteorological Department. Kabete received a total of about 650 mm of rain during the first season of the study (2012 long rain season). The mean maximum and minimum temperatures were 22.7° C and 12.7° C respectively. Thika had 476.7 mm of rain during the same season and had mean maximum and minimum temperatures of 24.9° C and 14.4° C (Appendix 21). Due to expected drier conditions at Thika, experiments in this site focused on drought evaluation, while Kabete experiments addressed other agronomic traits such as disease resistance due to the wetter climate conditions and disease infestation. However, Kabete also experienced severe terminal drought (Fig 3.1). In the second season, 2012/2013 short-season, Kabete received highest rainfall (779.4) which was even higher than the long-rain season. This was followed by Thika (469.6 mm) and Nakuru (405.2 mm) (Appendix 22). The highest temperatures were recorded in Thika (26.6° C) compared to Nakuru (24.3) and Kabete (23.7).The coolest site was Tigoni with maximum mean temperatures of 19.2° C.

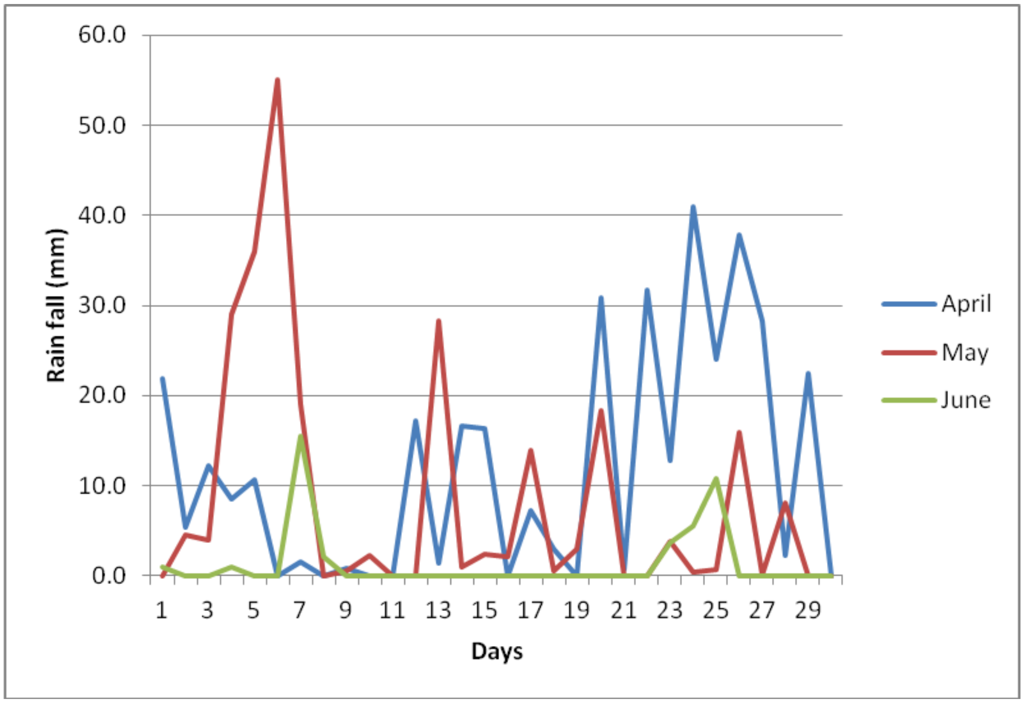

Figure 3.1: Rainfall distribution during 2012 long rain season in Kabete.

3.3.2. Days to 50% flowering

Days to 50% flowering varied significantly among advanced lines in the seven market classes due to site ($p<0.05$), genotypes (<0.01) and there were interactions among site and genotypes. In the first season, bean lines from seven market classes flowered in 42 and 47 days at Thika and Kabete respectively. Among market classes, the shortest days to flowering was recorded in speckled sugar lines (41 days on average) and navy beans the latest to flower (46 days on average) (Appendices 1 to 7). Days to flowering of selected advanced lines in seven market classes grown in the second season was longest at Tigoni (55 day on average) compared to Kabete and Thika with average of 43 and 41 respectively (Table 3.2 to 3.8).

Among red mottled market class, early flowering lines in the first season included BCB11-354,BCB11-378 andBCB11-147 (40 days). The latest lines were BCB11-155, BCB11-345 and BCB11-513 which took 47 to 48 days to flower. The earliest check variety (Kenya Umoja) flowered in 43 days (Appendix 1). Among selections from this market class grown in season two, BCB11-305, BCB11-464 and BCB11-433 were the earliest (43 days on average) while BCB11-145,BCB11-345 and BCB11-334 were the latest to flower (49 to 51 days). The earliest check (Kenya Umoja) flowered in 45 days (Table 3.2).

Among red kidney market class, the minimum days to flower in the first season was recorded for BCB11-276, BCB11-397 andBCB11-503 with 41 days each, while late flowering lines included BCB11-468,BCB11-489 and BCB11-492 (48 to 49days on average). The earliest check (GLP-24) took 45 days to flower (Appendix 2). Among selected lines grown in season two, the earliest lines of this market class included BCB11-325 (43 days) and BCB11-342 (44 days), while BCB11-468 and BCB11-500 were the latest with 49 days each. The earliest check took 44 daysto flower (Table 3.3).

Advanced lines in speckled sugar market class showed the shortest days to flowering across sites and seasons. In the first season, days to flowering of nearly 50% of the lines ranged between 38 and 40 days. Miezi Mbili, the check variety, flowered in 41 days (Appendix 3). Among speckled sugar lines grown in season two, the earliest were BCB11-516, BCB11-530 whilethe latest were BCB11-303 (49 days) and BCB11-507 (50 days). The check variety (Miezi Mbili) took 44 day to flower (Table 3.4).

The advanced lines in navy market class took longest to flower across sites and seasons. However, there were significant differences among the lines within this market class. In the first season, the earliest lines included BCB11-475, BCB11-70,BCB11-18 and BCB11-56 which took 43 days each, whileBCB11-23 and BCB11-66were the latest to flower (50 days). The check, Mexican142, flowered in 50 days (Appendix 4). Among selected navy lines planted in season two, early flowering lines included BCB11-47 and BCB11-55 with 45 days each, while late flowering lines included BCB11-108 and BCB11-98 with 50 days each.Mexican142 flowered in 49 days on average (Table 3.5).

Among small red market class, the earliest lines were BCB11-399, BCB11- 197 and the local check KATB9. These lines reached 50% flowering in 41 days. Late flowering lines in the first season included BCB11-529, BCB11-189 and BCB11-436 (Appendix 5). Among small red selections grown in season two, KATB9, the local check was the earliest to flower (43 days), followed by BCB11-399 and BCB11- 197 with 45 days each. BCB11-184 and BCB11-331 took the longest duration to flower in this market class (Table 3.6).

Among pinto and carioca advanced lines evaluated in the first season, BCB11-372 was the earliest (41 days on average) followed by GLP1004 and GLPx92, local checks, BCB11-486 and BCB11-254 which flowered in 42 days on average. Late flowering lines included BCB11-284 (50 days) and BCB11-508 (51 days) (Appendix 6). Among selected lines fromm pinto and carioca market class, BCB11-372 and BCB11-254 were the earliest, and BCB11-508 and BCB11-512 were the latest flowering during the second season (Table 3.7).

Among mixed colours lines, KATB1 (local check) was the earliest across seasons and sites. Other early flowering genotypes included GLPx92, BCB11-359 and BCB11-493 (Appendix 7, Table 3.8).

Table3.2 Days to flowering of red mottled lines grown at Kabete, Tigoni and Thika during 2012/2013 short-rain season

.

Line	Kabete	Tigoni	Thika	Mean
BCB11-305	40.7	50.0	38.7	43.1
BCB11-464	42.7	48.7	38.3	43.2
BCB11-433	41.7	50.7	38.0	43.4
BCB11-523	41.7	50.3	39.0	43.7
BCB11-290	42.0	50.0	39.3	43.8
BCB11-400	43.3	50.3	40.7	44.8
BCB11-470	43.3	52.7	40.7	45.6
BCB11-130	43.0	54.7	40.3	46.0
BCB11-347	43.7	54.7	40.0	46.1
BCB11-132	44.3	55.3	40.0	46.6
BCB11-133	42.3	55.7	42.3	46.8
BCB11-144	42.0	55.0	43.3	46.8
BCB11-413	45.0	55.0	40.3	46.8
BCB11-314	43.3	55.3	42.7	47.1
BCB11-135	43.0	54.7	45.0	47.6
BCB11-142	45.0	55.0	42.7	47.6
BCB11-143	45.3	55.7	42.3	47.8
BCB11-445	45.0	54.7	44.3	48.0
BCB11-324	43.3	55.0	46.3	48.2
BCB11-145	45.7	58.0	42.3	48.7
BCB11-345	46.7	58.0	42.7	49.1
BCB11-334	46.3	59.0	46.7	50.7
Kenya Umoja	41.7	53.3	40.0	45.0
KAT69	45.3	53.7	39.3	46.1
GLP2	44.7	54.3	41.0	46.7
Mean	43.6	54.0	41.5	46.4
CV(%)	2.1			
LSD $_{0.05}$ **:** Lines=0.9, Site= 0.3, Lines x Site= 1.6				

Table 3.3: Days to flowering of red kidney lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

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Line	Kabete	Tigoni	Thika	Mean
BCB11-325	40.7	50.0	38.0	42.9
BCB11-342	43.7	49.0	38.0	43.6
BCB11-503	41.0	51.0	38.7	43.6
BCB11-162	40.7	50.3	42.7	44.6
BCB11-174	40.7	54.7	39.3	44.9
BCB11-175	41.0	54.0	39.7	44.9
BCB11-173	42.3	53.0	40.0	45.1
BCB11-285	43.0	53.0	39.3	45.1
BCB11-327	41.7	54.7	39.3	45.2
BCB11-196	42.0	55.3	39.3	45.6
BCB11-522	42.7	54.3	40.0	45.7
BCB11-168	43.0	54.7	42.0	46.6
BCB11-176	45.7	54.3	40.0	46.7
BCB11-166	42.3	55.3	43.7	47.1
BCB11-492	44.7	55.7	41.0	47.1
BCB11-163	43.3	54.7	43.7	47.2
BCB11-171	42.7	54.7	44.3	47.2
BCB11-509	44.3	55.0	42.7	47.3
BCB11-337	42.7	54.7	45.0	47.4
BCB11-158	42.7	55.0	45.3	47.7
BCB11-159	42.7	55.3	45.0	47.7
BCB11-468	45.7	58.0	43.3	49.0
BCB11-500	45.3	57.7	44.0	49.0
GLP-24	42.3	51.0	39.3	44.2
KAT56	44.7	56.0	43.3	48.0
Mean	42.9	54.1	41.5	46.1
CV (%)	2.0			
LSD $_{0.05}$ **:** Lines=0.9, Site= 0.3, Lines x Site= 1.5				

Table 3.4: Days to flowering of speckled sugar lines grown in Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-516	39.3	48.3	36.7	41.4
BCB11-530	39.3	48.0	37.0	41.4
BCB11-390	40.0	49.0	37.3	42.1
BCB11-498	40.3	49.0	37.0	42.1
BCB11-501	40.0	51.7	37.3	43.0
BCB11-382	40.3	52.3	38.0	43.6
BCB11-414	41.3	51.7	37.7	43.6
BCB11-209	41.7	53.7	36.3	43.9
BCB11-386	42.7	53.3	37.3	44.4
BCB11-393	42.3	54.3	37.0	44.6
BCB11-380	43.3	54.0	39.3	45.6
BCB11-267	43.7	54.7	39.7	46.0
BCB11-421	42.7	56.0	39.7	46.1
BCB11-217	43.0	55.7	40.0	46.2
BCB11-336	43.0	56.0	40.3	46.4
BCB11-495	43.0	55.0	41.3	46.4
BCB11-204	43.0	56.7	41.7	47.1
BCB11-377	46.3	55.0	41.0	47.4
BCB11-467	44.0	55.3	43.0	47.4
BCB11-269	44.7	57.0	43.0	48.2
BCB11-282	46.0	57.3	42.7	48.7
BCB11-443	46.7	57.3	42.0	48.7
BCB11-303	45.0	57.0	45.7	49.2
BCB11-507	44.7	57.7	46.7	49.7
Miezi Mbili	40.7	51.7	38.7	43.7
Mean	42.7	53.9	39.9	45.5
CV%	2.2			
LSD $_{0.05}$: Lines=0.9, Site= 0.3, Lines x Site= 1.6				

Table 3.5: Days to flowering of navy lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-47	40.7	53.7	40.0	44.8
BCB11-55	41.3	53.7	39.3	44.8
BCB11-75	41.7	53.7	40.0	45.1
BCB11-69	41.3	54.3	40.0	45.2
BCB11-58	42.3	54.0	40.0	45.4
BCB11-94	42.3	54.3	40.0	45.6
BCB11-35	41.7	55.7	40.0	45.8
BCB11-49	42.3	54.3	42.7	46.4
BCB11-9	42.7	55.0	41.7	46.4
BCB11-476	43.3	55.3	41.0	46.6
BCB11-52	42.7	54.7	43.0	46.8
BCB11-33	43.7	55.3	41.7	46.9
BCB11-62	44.7	54.7	41.7	47.0
BCB11-48	43.0	55.7	43.3	47.3
BCB11-355	45.3	55.7	42.0	47.7
BCB11-87	44.3	56.3	42.3	47.7
BCB11-14	44.0	57.3	43.3	48.2
BCB11-34	46.3	55.3	43.7	48.4
BCB11-30	46.7	56.3	43.0	48.7
BCB11-80	46.7	57.0	42.3	48.7
BCB11-40	46.0	57.3	43.3	48.9
BCB11-10	46.7	57.7	43.0	49.1
BCB11-108	49.0	57.3	43.7	50.0
BCB11-98	47.7	59.0	43.7	50.1
Mexican142	47.3	57.0	43.7	49.3
Mean	44.1	55.6	41.9	47.2
CV(%)	2.5			
LSD $_{0.05}$: Lines=1.1, Site= 0.4, Lines x Site= 1.9				

Table 3.6: Days to flowering of small red lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-197	41.3	54.0	39.3	44.9
BCB11-399	40.7	55.3	40.3	45.4
BCB11-362	43.0	53.3	40.7	45.7
BCB11-195	42.7	54.0	41.0	45.9
BCB11-199	43.0	54.3	40.7	46.0
BCB11-202	43.0	53.3	41.7	46.0
BCB11-182	43.3	54.0	41.0	46.1
BCB11-194	42.3	54.3	41.7	46.1
BCB11-437	43.0	54.7	41.3	46.3
BCB11-443	43.7	55.0	41.0	46.6
BCB11-366	43.3	55.3	41.7	46.8
BCB11-517	43.7	55.0	41.7	46.8
BCB11-191	43.3	56.7	40.7	46.9
BCB11-401	43.0	56.0	41.7	46.9
BCB11-280	43.7	56.7	40.7	47.0
BCB11-245	44.3	55.3	41.7	47.1
BCB11-323	43.0	56.3	42.0	47.1
BCB11-192	43.0	55.7	43.7	47.4
BCB11-193	44.0	57.7	41.0	47.6
BCB11-344	44.3	58.7	42.0	48.3
BCB11-184	44.3	58.3	42.7	48.4
BCB11-331	46.0	57.0	43.3	48.8
KATB9	40.0	50.7	38.7	43.1
GLP585	42.3	56.0	41.7	46.7
Tio Canella	44.7	57.0	43.3	48.3
Mean	43.2	55.4	41.4	46.7
CV(%)	2.2			
LSD $_{0.05}$: Lines=1.0, Site= 0.3, Lines x Site= 1.7				

Table 3.7: Days to flowering of pinto and carioca lines grown in Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-372	38.3	48.7	36.0	41.0
BCB11-254	40.0	47.0	38.0	41.7
BCB11-426	39.0	48.0	38.7	41.9
BCB11-392	41.0	49.3	38.0	42.8
BCB11-232	41.0	54.7	40.3	45.3
BCB11-231	41.7	55.0	40.3	45.7
BCB11-448	42.7	54.3	40.3	45.8
BCB11-233	41.7	55.0	41.0	45.9
BCB11-274	43.0	55.3	40.3	46.2
BCB11-234	43.0	55.0	41.0	46.3
BCB11-524	44.3	56.0	41.7	47.3
BCB11-338	44.3	57.3	41.0	47.6
BCB11-236	43.7	57.0	42.3	47.7
BCB11-383	45.7	56.7	40.7	47.7
BCB11-235	44.0	58.0	41.7	47.9
BCB11-271	44.3	58.0	42.7	48.3
BCB11-297	45.3	56.7	43.3	48.4
BCB11-425	45.3	57.3	42.7	48.4
BCB11-515	45.3	57.0	43.0	48.4
BCB11-428	45.3	57.7	43.3	48.8
BCB11-293	45.3	57.7	43.7	48.9
BCB11-508	47.0	57.7	43.0	49.2
BCB11-512	47.3	58.0	43.0	49.4
GLP1004	40.7	50.7	38.0	43.1
GLPx92	40.3	48.0	38.7	42.3
Mean	43.2	54.6	40.9	46.2
CV(%)	1.8			
LSD $_{0.05}$: Lines=0.9, Site= 0.3, Lines x Site= 1.4				

Table 3.8: Days to flowering of mixed colour lines grown in Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-488	41.0	52.7	38.0	43.9
BCB11-359	42.0	54.0	39.0	45.0
BCB11-493	41.0	54.7	39.3	45.0
BCB11-273	41.7	53.7	40.0	45.1
BCB11-310	42.7	53.3	41.0	45.7
BCB11-348	43.3	56.0	41.0	46.8
BCB11-248	44.7	55.0	42.3	47.3
BCB11-326	43.0	57.0	42.7	47.6
BCB11-253	44.7	56.0	42.3	47.7
BCB11-318	43.7	56.7	42.7	47.7
BCB11-469	44.0	55.7	43.7	47.8
BCB11-230	43.3	57.0	44.0	48.1
BCB11-219	48.0	55.0	41.7	48.2
BCB11-229	45.3	58.3	42.7	48.8
BCB11-502	45.3	57.7	43.3	48.8
BCB11-263	45.7	57.7	43.3	48.9
BCB11-459	45.3	57.3	44.0	48.9
BCB11-301	46.0	57.3	43.7	49.0
BCB11-313	50.7	57.7	43.3	50.6
KATB1	38.7	48.7	37.0	41.4
GLPX92	40.7	48.7	38.7	42.7
SEA15	42.0	53.7	40.7	45.4
SER16	42.3	54.3	40.0	45.6
GLP585	42.7	56.0	40.0	46.2
SER76	44.3	56.0	42.0	47.4
Mean	43.7	55.2	41.5	46.8
CV (%)	1.8			

LSD $_{0.05}$: Line=0.8, Site=0.3, Line x Site= 1.4

3.3.3. Days to physiological maturity

Days to physiological maturity of genotypes in all the seven market classes varied significantly due to site ($p<0.01$), water regime ($p<0.001$) and genotypes ($p<0.001$). There were also significant genotypes by treatment (water regime) interactions in the first season trials. The mean number of days to physiological maturity of genotypes under irrigated and rainfed treatments in the first season was 100 and 97 days in Kabete and 88 and 80 in Thika respectively. Irrigation affected significantly the physiological maturity of most genotypes across market classes with a 9% and 3% shorter period to maturity recorded under rainfed treatments at Thika and Kabete respectively (appendix 8 to 14). Days to physiological maturity of selected advanced lines in seven market classes grown in the second season were the longest in Tigoni (105 day on average) compared to Kabete (86 days) and Thika (79 days) (Table 3.9 to 3.15). In both seasons, speckled sugar was observed to mature earliest while navy lines matured latest compared to other market classes.

Significant differences in days to physiological maturity were observed among advanced lines in the seven market classes in both seasons. Among red mottled lines, days to physiological maturity ranged from 87 to 97 days on average in the first season with BCB11-305 and BCB11-147 being the earliest lines (87 days on average). The earliest check, Kenya Umoja, matured in 89 days on average (Appendix 8). Lines such as BCB11-290, BCB11-464 and BCB11-305 were early maturing (87 days) among selections grown in the second season (Table 3.9). Advanced red kidney lines had days to physiological maturity ranging between 85 to 97 days on average, with most lines maturing in more than 90 days on average (Appendix 9). In season two, red kidney lines matured in 91 days on average. The early maturing lines included BCB11-325 (87 days) and BCB11-342 (89 days) while late maturing genotypes includedBCB11-492, BCB11-468, GLP-24 and KAT56 with92 days each (Table 3.10). Among speckled sugar market class, days to maturity ranged between 86 and 98 on average in the first season. Lines BCB11-456, BCB11-530 and BCB11-421 (86 days) were the earliest. Latest maturing lines such as BCB11-282 and BCB11-443 took 98 days to mature (Appendix 10). In the second season, lines took between 84 to 94 days to mature. Lines BCB11-516, BCB11-498 and BCB11-530 were the earliest while BCB11-282 and BCB11-377 were the latest maturing lines. Miezi Mbili, the local check, took 86 days on average to mature (Table 3.11). In the first season, days to maturity of navy lines ranged from 86 to 98 days with BCB11-97, BCB11-79 andBCB11-35 (86) being the earliest. Late maturing lines included BCB11-20 and BCB11-92 (98 days) (Appendix 11). In the second season, most navy lines matured in between 89 to 93 days. The earliest line matured in 88 days and the latest in 95 days (Table 3.12). Mexican142, the local check, was among the latest maturing genotypes in both seasons.

The mean days to maturity of small red lines varied from 87 to 95 days in the first season. The local check KATB9 was the earliest (86 days) followed by BCB11-194 and BCB11-399 (Appendix 12). In the second season, BCB11-197, KATB9 and GLP585 (87 days) were early maturing compared to BCB11-245 (92 days) and BCB11-331 (95 days) (Table 3.13). Advanced lines of pinto and carioca market class had days to maturity between 86 to 99 days in the first season. BCB11-254 and BCB11-341 (86 days) were early maturing compared to BCB11-289 and BCB11-508 that took 98 days to mature. The earliest check (GLPx92) matured in 88 days (Appendix 13). In the second season, BCB11-372 (85 days), GLPx92 (86 days) and BCB11-392 (86 days) matured earliest compared to BCB11-92 (92 days) and BCB11-508 (93 days)(Table 3.14). The mean days to maturity of mixed colour lines varied from 86 to 97 days in the first season. The local check KATB1 (84) was earlier than all other lines, followed by BCB11-359 and BCB11-493 (Appendix 12). In the second season, KATB1 (86 days), BCB11-359 (87 days) and BCB11-273 (87 days) were early maturing compared to BCB11-301 (93 days) and BCB11-230 (94 days) (Table 3.15).

Table 3.9: Days to physiological maturity of red mottled lines grown at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-290	81.0	102.0	75.3	86.1
BCB11-464	84.3	101.7	75.3	87.1
BCB11-305	80.0	101.0	81.0	87.3
BCB11-523	84.0	102.3	76.3	87.6
BCB11-400	88.0	102.0	75.7	88.6
BCB11-413	85.7	103.7	77.3	88.9
BCB11-470	83.3	103.3	80.3	89.0
BCB11-314	84.3	102.7	81.3	89.4
BCB11-347	85.3	103.3	79.7	89.4
BCB11-433	87.0	105.0	76.3	89.4
BCB11-132	85.3	102.7	81.7	89.9
BCB11-144	85.0	106.0	80.7	90.6
BCB11-133	86.7	103.3	82.0	90.7
BCB11-143	86.0	104.3	82.3	90.9
BCB11-130	86.7	105.0	81.3	91.0
BCB11-142	87.0	106.7	80.0	91.2
BCB11-324	86.7	105.0	82.0	91.2
BCB11-345	85.7	106.7	81.7	91.3
BCB11-445	86.3	106.0	83.0	91.8
BCB11-135	87.3	106.7	82.0	92.0
BCB11-145	86.7	107.3	82.3	92.1
BCB11-334	87.3	106.0	83.0	92.1
KAT69	87.0	102.7	75.3	88.3
Kenya Umoja	86.7	105.0	80.0	90.6
GLP2	86.0	106.7	81.3	91.3
Mean	85.6	104.3	79.9	89.9
CV (%)	1.4			
LSD $_{0.05}$: Lines=1.2, Site= 0.4, Lines x Site= 2.1				

Table 3.10: Days to physiological maturity of red kidney lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-325	85.0	101.7	74.7	87.1
BCB11-342	86.0	102.7	77.0	88.6
BCB11-509	86.3	104.7	75.3	88.8
BCB11-503	86.3	102.0	79.3	89.2
BCB11-285	87.7	103.3	78.3	89.8
BCB11-327	86.3	103.7	79.3	89.8
BCB11-522	88.3	104.3	77.3	90.0
BCB11-175	87.3	104.0	79.0	90.1
BCB11-176	88.3	104.7	77.7	90.2
BCB11-162	85.7	104.3	81.3	90.4
BCB11-163	86.3	104.3	80.7	90.4
BCB11-337	86.0	104.3	81.0	90.4
BCB11-171	87.0	105.3	81.0	91.1
BCB11-196	87.0	106.0	80.3	91.1
BCB11-500	87.3	104.3	81.7	91.1
BCB11-158	87.7	105.0	81.0	91.2
BCB11-168	86.7	106.3	80.7	91.2
BCB11-174	86.3	106.7	81.0	91.3
BCB11-159	87.3	105.3	81.7	91.4
BCB11-166	87.7	105.3	81.3	91.4
BCB11-173	87.3	105.7	81.3	91.4
BCB11-492	88.0	108.0	78.7	91.6
BCB11-468	88.3	105.7	81.0	91.7
GLP-24	86.7	106.7	81.3	91.6
KAT56	87.7	107.7	81.0	92.1
Mean	87.0	104.9	79.7	90.5
CV (%)	1.1			
LSD $_{0.05}$: Lines=0.9, Site= 0.3, Lines x Site= 1.6				

Table 3.11: Days to physiological maturity of speckled sugar lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-516	80.0	100.0	73.3	84.4
BCB11-498	81.3	101.3	73.0	85.2
BCB11-530	82.3	101.0	73.0	85.4
BCB11-390	82.7	101.3	73.3	85.8
BCB11-382	83.3	101.7	73.7	86.2
BCB11-501	82.0	103.3	74.0	86.4
BCB11-267	83.0	102.3	77.7	87.7
BCB11-421	82.7	104.0	77.3	88.0
BCB11-386	87.0	102.0	76.0	88.3
BCB11-336	84.3	104.3	77.0	88.6
BCB11-380	85.7	102.7	77.3	88.6
BCB11-414	85.7	101.3	79.0	88.7
BCB11-209	85.7	105.3	76.7	89.2
BCB11-495	83.3	105.0	80.3	89.6
BCB11-393	87.3	103.7	78.3	89.8
BCB11-204	87.3	104.0	81.0	90.8
BCB11-217	87.3	106.3	79.0	90.9
BCB11-467	87.0	106.3	82.0	91.8
BCB11-303	87.7	107.0	81.3	92.0
BCB11-507	88.3	108.7	81.0	92.7
BCB11-443	89.7	109.0	80.7	93.1
BCB11-269	90.3	108.7	81.0	93.3
BCB11-282	91.0	109.0	82.7	94.2
BCB11-377	89.0	105.3	89.0	94.4
Miezi Mbili	83.3	100.0	74.7	86.0
Mean	85.5	104.1	78.1	89.2
CV (%)	11.0			
LSD $_{0.05}$: Lines=1.0, Site= 0.3, Lines x Site= 1.7				

Table 3.12: Days to physiological maturity of navy lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-35	82.3	104.3	76.7	87.8
BCB11-69	83.3	102.3	80.3	88.7
BCB11-75	83.0	103.0	81.0	89.0
BCB11-55	83.3	103.0	81.3	89.2
BCB11-47	83.7	104.3	80.3	89.4
BCB11-58	85.0	104.0	81.3	90.1
BCB11-49	85.0	103.7	82.7	90.4
BCB11-48	85.3	103.7	82.7	90.6
BCB11-94	86.0	104.0	81.7	90.6
BCB11-52	86.3	104.7	82.0	91.0
BCB11-9	87.3	104.7	81.7	91.2
BCB11-62	87.7	106.3	83.0	92.3
BCB11-33	88.3	107.3	82.7	92.8
BCB11-98	87.7	109.0	82.3	93.0
BCB11-14	87.7	107.3	84.3	93.1
BCB11-476	88.0	109.0	83.0	93.3
BCB11-108	88.7	107.3	84.3	93.4
BCB11-34	89.3	107.7	83.3	93.4
BCB11-355	90.3	108.3	82.7	93.8
BCB11-87	90.0	107.7	83.7	93.8
BCB11-30	89.7	109.0	83.3	94.0
BCB11-80	89.7	109.3	83.0	94.0
BCB11-40	89.3	109.0	85.0	94.4
BCB11-10	91.0	109.7	83.3	94.7
Mexican142	90.7	109.0	82.0	93.9
Mean	87.1	106.3	82.3	91.9
CV (%)	11.0			
LSD $_{0.05}$: Lines=0.9, Site= 0.3, Lines x Site= 1.6				

Table 3.13: Days to physiological maturity of small red lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-197	83.0	103.3	73.7	86.7
BCB11-191	86.3	104.0	75.3	88.6
BCB11-194	84.7	106.7	76.0	89.1
BCB11-195	84.0	106.7	76.7	89.1
BCB11-517	85.0	106.0	77.0	89.3
BCB11-199	85.7	106.3	76.7	89.6
BCB11-443	87.3	105.7	76.0	89.7
BCB11-280	85.3	107.3	76.7	89.8
BCB11-202	86.0	104.3	79.3	89.9
BCB11-184	85.0	108.3	76.7	90.0
BCB11-182	86.7	107.0	76.7	90.1
BCB11-192	86.3	104.0	80.3	90.2
BCB11-193	87.3	106.7	76.7	90.2
BCB11-344	87.0	106.7	77.3	90.3
BCB11-366	87.7	106.7	76.7	90.3
BCB11-401	85.7	105.3	80.0	90.3
BCB11-362	88.0	104.3	79.7	90.7
BCB11-437	87.3	103.7	81.0	90.7
BCB11-399	85.3	107.7	81.0	91.3
BCB11-323	88.0	106.7	80.0	91.6
BCB11-245	87.3	108.7	79.3	91.8
BCB11-331	90.3	109.7	83.7	94.6
GLP585	83.7	103.7	74.7	87.3
KATB9	83.7	102.7	75.7	87.3
Tio Canella	84.3	104.7	79.0	89.3
Mean	86.0	105.9	77.8	89.6
CV (%)	12.0			

LSD $_{0.05}$: Lines=1.0, Site= 0.4, Lines x Site= 1.8

Table 3.14: Days to physiological maturity of pinto and carioca lines grown in Kabete, Tigoni and Thika during 2012-2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-372	81.7	101.7	72.7	85.3
BCB11-392	83.7	101.3	74.0	86.3
BCB11-254	82.0	102.7	75.7	86.8
BCB11-426	84.0	102.7	76.7	87.8
BCB11-236	84.3	103.7	77.0	88.3
BCB11-338	83.7	104.3	79.3	89.1
BCB11-235	86.0	108.3	75.7	90.0
BCB11-274	85.7	107.3	77.3	90.1
BCB11-232	86.3	107.3	77.0	90.2
BCB11-515	85.7	108.3	76.7	90.2
BCB11-524	86.3	106.3	78.0	90.2
BCB11-448	88.3	106.3	76.7	90.4
BCB11-231	86.3	106.3	79.0	90.6
BCB11-234	86.7	106.3	79.7	90.9
BCB11-271	87.0	108.7	78.0	91.2
BCB11-293	87.3	109.7	77.0	91.3
BCB11-297	88.7	108.3	77.0	91.3
BCB11-512	84.0	109.7	80.7	91.4
BCB11-383	88.7	106.7	79.3	91.6
BCB11-425	87.3	108.7	79.3	91.8
BCB11-233	87.0	107.3	81.3	91.9
BCB11-428	85.3	110.0	82.0	92.4
BCB11-508	87.0	108.3	82.3	92.6
GLPx92	81.0	101.7	74.0	85.6
GLP1004	82.7	104.0	74.3	87.0
Mean	85.5	106.2	77.6	89.8
CV (%)	13.0			

LSD $_{0.05}$: Lines=1.1, Site= 0.4, Lines x Site= 1.9

Table 3.15: Days to physiological maturity of mixed colour lines grown at Kabete, Tigoni and Thika during 2012/2013 short rain season.

Line	Kabete	Tigoni	Thika	Mean
BCB11-359	82.7	103.3	75.7	87.2
BCB11-273	82.0	104.3	76.0	87.4
BCB11-493	84.0	103.7	76.3	88.0
BCB11-263	84.3	105.7	74.3	88.1
BCB11-318	83.0	104.3	77.3	88.2
BCB11-488	84.0	102.3	78.3	88.2
BCB11-310	86.3	106.0	79.3	90.6
BCB11-459	86.0	105.3	80.3	90.6
BCB11-469	85.3	107.3	79.3	90.7
BCB11-348	84.7	107.3	80.3	90.8
BCB11-248	89.0	104.3	80.7	91.3
BCB11-313	86.0	108.0	81.0	91.7
BCB11-326	86.7	106.7	82.0	91.8
BCB11-253	90.0	106.3	79.3	91.9
BCB11-229	89.7	110.0	77.3	92.3
BCB11-502	87.3	110.3	80.3	92.7
BCB11-219	90.0	107.0	83.0	93.3
BCB11-301	88.3	110.0	81.7	93.3
BCB11-230	89.0	110.3	83.0	94.1
KATB1	81.3	101.7	73.7	85.6
SEA15	81.3	102.0	75.7	86.3
SER16	83.0	104.0	76.0	87.7
SER76	84.7	102.3	76.0	87.7
GLP585	84.0	105.7	77.3	89.0
GLPx92	83.7	104.3	79.7	89.2
Mean	85.5	105.7	78.6	89.9
CV (%)	11.0			
LSD $_{0.05}$: Line=0.9, Site=0.3, Line x Site= 1.6				

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

During the first half of 2012 long rain season, Kabete field station had optimal environmental conditions for bean disease development. Reaction of the advanced lines to fungal diseases such as angular leaf spot (ALS) anthracnose (ANTH), root rot (RR) and common bacterial blight was studied. Anthracnose was the most prevalent disease with 24% of test lines succumbingto the disease (7-9 score), while 37% showed intermediate resistance (4-6 score) and 39% were resistant (1-3). Three percent of lines were severely damaged (7-9 score) by angular leaf spot, with 53% and 44% showed intermediate resistance (4-6) and resistance (1-3) respectively. Root rot and common bacterial were less severe with more than 65% of lines showed resistance (1-3) to both diseases. Across market classes, red mottled and speckled sugar lines were the most susceptible (7-9) to anthracnose with 46.4% and 40.9% of genotypes succumbing to the disease respectively (Appendix 14 and 16). This was followed by mixed colours (30.2%), pinto and carioca (23.3%). Navy and small red lines showed the least percentage of susceptible lines each with 12%. The local varieties KAT69, KATB1, KATB9, GLP585, GLP1004 and Miezi Mbili succumbed to anthracnose with scores of 7 to 9. Overall, around 107 lines showed multiple resistance (1-3 score) to the four diseases.

During the second season, advanced lines from the seven market classes that were grown in Kabete, Tigoni and Thika showed significant differences in reaction to angular leaf spot, anthracnose, root rot, common bacterial blight, rust and BCMV (bean common mosaic virus) (Table 3.16 to 3.22). Anthracnose had the highest incidence particularly in Kabete and was severe on red mottled and speckled sugar lines with 22.7% and 17% of the genotypes being susceptible (7-9 scores). Nearly all navy lines were resistant to anthracnose (1-3 score) (Table 3.19). Local checks KAT69, KATB1, KATB9, GLP2, GLP585 AND Miezi Mbili succumbed to anthracnose (7-8 score). Relatively high incidence of CBB and BCMV were observed in the second season but most lines were resistant to moderately resistant to these diseases. No root rot incidence was observed in the second season. Advanced lines from different market classes that showed high degree of resistance (1-3 score) to all major diseases prevalent under field conditions were identified. Among red mottled market class, the most outstanding lines with high levels of multiple resistance included BCB11-142, BCB11-44 and BCB11-145. Among the red kidney market class, BCB11-158, BCB11-176, BCB11-162 and BCB11-327 showed multiple resistance to all diseases. For speckled sugars, BCB11-303, BCB11-507, BCB11-204 and BCB11-467had outstanding disease resistance. Among the small and medium sized market classes, lines with multiple resistance included BCB11-108, BCB11-62, BCB11-98 and BCB11-80 among the navy lines; BCB11-182, BCB11-202 and BCB11-245among the small red lines; BCB11-271, BCB11-425 and BCB11-515 from pinto and carioca; and BCB11-263, BCB11-488, BCB11-301 and BCB11-313 from mixed colors group.

Figure 3.2: Selection for disease resistance at Kabete during 2012 long rain season. Photo A to D show disease resistant lines selected from different market classes. Note adjacent lines were devastated by the disease.

Figure 3.3: Selection for disease resistance at Kabete during 2012 long rain season. Photos E to H show disease resistant lines selected from different market classes. Note adjacent lines were devastated by the disease.

Table 3.16: Reaction of red mottled lines to five major diseases at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-130	3	3	2	5	2	2	4	3	3	3	2	3	2	2	2
BCB11-132	2	3	3	7	2	3	3	3	4	4	2	5	2	4	2
BCB11-133	2	5	4	8	2	2	5	3	3	3	3	3	2	2	2
BCB11-135	2	3	3	5	2	3	3	3	4	2	3	3	2	2	2
BCB11-142	4	2	2	3	2	2	2	3	3	4	3	4	3	2	2
BCB11-143	2	3	2	4	3	2	2	4	3	5	3	4	2	2	2
BCB11-144	3	3	4	5	2	2	4	3	2	2	3	2	2	2	2
BCB11-145	3	2	2	3	2	2	3	3	2	3	3	4	2	3	2
BCB11-290	7	3	4	3	2	2	2	4	3	5	3	5	2	6	7
BCB11-305	2	1	3	7	3	2	2	1	1	5	2	4	2	1	3
BCB11-314	2	3	3	5	3	2	4	4	3	4	3	4	5	2	3
BCB11-324	3	2	3	6	2	3	4	4	3	2	3	3	2	4	2
BCB11-334	2	2	3	6	2	2	2	3	2	2	2	3	2	2	2
BCB11-345	2	3	3	3	2	3	4	3	6	2	4	2	2	6	3
BCB11-347	2	3	4	7	2	3	4	5	5	3	4	5	2	2	2
BCB11-400	2	3	3	2	2	3	3	3	4	3	3	6	2	2	3
BCB11-413	3	4	3	3	2	2	3	5	3	3	2	4	2	2	2
BCB11-433	3	3	3	7	7	2	3	4	2	4	5	4	2	2	2
BCB11-445	5	3	3	2	3	2	2	3	4	2	4	3	2	3	2
BCB11-464	6	5	6	3	2	2	2	3	2	3	4	4	2	6	3
BCB11-470	4	4	5	3	2	2	5	3	5	3	4	3	2	3	4
BCB11-523	4	5	3	6	2	3	3	3	4	3	2	5	2	2	3
GLP2	3	4	3	7	3	2	4	5	4	3	3	4	2	2	2
KAT69	2	3	4	7	2	3	4	4	3	5	3	5	2	2	3
Kenya Umoja	4	2	3	5	2	2	5	2	3	5	3	4	2	2	2
Mean	3	3	3	5	2	2	3	3	3	3	3	4	2	3	3
CV(%)	24.8			23.9			25.1			30.5			22.8		
LSD $_{0.05}$:Line	0.7			0.7			0.8			1.0			0.5		
LSD $_{0.05}$:Site	0.3			0.2			0.3			0.3			0.2		
LSD $_{0.05}$:L xS	1.2			1.2			1.3			1.7			0.9		

Table 3.17 Reaction of red kidney lines to five major diseases at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-158	2	3	3	4	2	2	3	4	2	3	4	2	2	2	2
BCB11-159	4	2	3	7	2	2	3	3	2	3	3	3	2	2	2
BCB11-162	2	2	3	3	3	3	4	3	4	3	3	5	2	2	2
BCB11-163	2	2	2	2	2	2	3	4	2	4	3	5	2	2	2
BCB11-166	5	3	3	4	3	2	2	3	3	2	4	4	2	2	2
BCB11-168	4	2	2	4	3	2	5	5	3	4	4	4	2	4	2
BCB11-171	2	3	3	3	4	2	4	3	3	4	4	6	2	2	2
BCB11-173	2	3	2	6	2	2	2	3	2	3	4	3	2	2	2
BCB11-174	4	3	2	6	2	2	4	3	3	3	3	5	2	2	2
BCB11-175	3	3	2	6	2	2	3	2	2	3	4	5	2	2	2
BCB11-176	2	3	3	3	2	2	4	3	2	2	2	3	2	2	2
BCB11-196	3	3	3	5	2	2	4	4	2	3	3	6	2	2	2
BCB11-285	5	3	3	3	2	2	3	3	3	5	3	5	2	2	2
BCB11-325	3	2	3	4	2	3	5	6	4	5	3	5	2	2	2
BCB11-327	3	3	2	3	2	2	3	3	2	4	5	3	2	2	2
BCB11-337	2	3	3	2	2	2	3	4	2	3	5	4	2	2	2
BCB11-342	3	2	2	2	3	2	4	3	2	6	4	5	2	2	2
BCB11-468	4	3	2	6	2	2	3	3	3	2	2	5	2	3	2
BCB11-492	2	3	3	3	2	2	3	3	2	5	2	4	2	2	2
BCB11-500	2	3	3	8	2	5	5	5	2	4	5	5	2	3	2
BCB11-503	4	3	2	3	3	2	3	5	2	5	5	4	2	2	2
BCB11-509	2	3	2	3	2	2	4	5	2	3	3	4	2	2	3
BCB11-522	2	2	3	2	2	2	3	4	2	3	4	5	2	2	2
GLP24	3	3	5	4	2	2	3	4	3	4	3	3	2	3	2
KAT56	4	4	4	6	2	2	3	4	3	5	4	5	2	2	2
Mean	3	3	3	4	2	2	3	4	2	4	3	4	2	2	2
CV(%)	24.0			18.5			24.0			19.9			14.4		
LSD $_{0.05}$ **:**Line	0.6			0.5			0.7			0.7			0.3		
LSD $_{0.05}$ **:**Site	0.2			0.2			0.2			0.2			0.1		
LSD $_{0.05}$**:**L xS	1.1			0.9			1.2			1.2			0.5		

Table 3.18: Reaction of speckled sugar lines to five major diseases at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-204	2	2	4	3	2	2	4	4	2	3	3	4	2	3	2
BCB11-209	2	3	6	7	2	2	3	3	2	5	4	5	2	4	2
BCB11-217	2	2	3	8	2	2	6	6	6	4	3	6	2	2	2
BCB11-267	2	4	6	3	4	2	7	7	6	7	5	7	2	3	2
BCB11-269	3	3	3	4	2	2	6	5	4	4	3	4	2	5	2
BCB11-282	3	3	3	2	2	2	2	4	2	4	4	5	6	4	3
BCB11-303	3	2	3	2	2	3	3	3	2	3	3	3	2	2	2
BCB11-336	3	3	6	7	2	2	6	5	2	4	4	3	2	2	2
BCB11-377	2	3	4	2	2	2	2	4	4	3	4	3	2	3	2
BCB11-380	4	3	4	2	2	2	3	2	2	4	3	4	2	2	3
BCB11-382	3	3	6	2	2	2	4	2	2	4	5	7	2	2	2
BCB11-386	2	2	4	2	2	2	3	2	2	5	4	5	2	2	4
BCB11-390	4	3	5	3	2	2	5	2	2	4	4	7	2	2	2
BCB11-393	2	3	3	6	2	2	3	2	2	5	3	5	2	2	2
BCB11-414	3	4	3	3	2	2	4	3	2	6	3	5	2	2	2
BCB11-421	4	3	5	7	2	2	5	4	2	4	4	6	2	2	4
BCB11-443	4	2	4	3	2	2	4	4	2	3	5	6	4	3	2
BCB11-467	4	2	2	2	2	2	3	3	3	3	3	2	2	2	2
BCB11-495	2	3	3	2	2	2	4	4	2	5	4	6	2	4	4
BCB11-498	4	5	6	2	2	2	5	3	2	4	4	6	2	2	2
BCB11-501	3	3	4	2	2	2	4	2	4	4	4	6	2	2	2
BCB11-507	4	2	3	2	2	2	2	3	2	3	2	2	2	2	2
BCB11-516	2	3	7	5	2	2	6	4	2	5	5	7	2	2	2
BCB11-530	2	2	6	2	2	2	4	3	2	6	3	5	2	2	2
Miezi Mbili	5	4	4	7	4	2	5	5	2	4	3	5	2	2	2
Mean	3	3	4	4	2	2	4	3	3	4	4	5	2	3	2
CV(%)	22.8			19.1			20.4			21.2			22.4		
LSD $_{0.05}$: Line	0.7			0.5			0.6			0.4			0.5		
LSD $_{0.05}$: Site	0.1			0.2			0.2			0.2			0.2		
LSD $_{0.05}$:L x S	0.6			0.8			1.1			0.7			0.9		

Table 3.19 Reaction of navy lines to five major diseases grown at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-10	2	2	3	2	2	2	6	5	6	5	3	5	2	2	2
BCB11-108	2	3	3	2	2	2	2	2	2	2	2	3	2	2	3
BCB11-14	2	2	2	2	2	2	5	2	5	5	2	3	2	2	2
BCB11-30	2	3	3	2	2	2	4	2	2	3	3	4	2	2	3
BCB11-33	2	3	3	2	2	2	5	5	3	4	4	4	2	2	2
BCB11-34	2	3	3	2	2	2	3	3	4	3	4	6	2	2	2
BCB11-35	3	4	3	2	2	2	5	2	4	5	3	7	2	2	2
BCB11-355	2	2	3	2	2	2	5	3	2	4	5	5	2	2	2
BCB11-40	2	2	3	2	2	2	6	4	4	4	2	5	2	2	2
BCB11-47	2	4	2	2	2	2	4	2	2	4	3	4	4	2	2
BCB11-476	2	4	5	2	4	2	6	5	5	5	6	6	2	2	2
BCB11-48	2	4	3	2	2	2	5	3	4	3	3	5	2	3	2
BCB11-49	2	2	3	2	2	2	4	3	6	4	4	3	2	2	2
BCB11-52	2	2	2	2	2	2	3	2	2	2	3	3	4	4	2
BCB11-55	2	4	4	2	2	3	3	4	4	3	3	4	2	2	2
BCB11-58	2	4	3	2	2	2	4	2	2	4	3	5	2	3	3
BCB11-62	2	3	3	2	2	2	5	3	3	3	2	3	2	2	2
BCB11-69	2	2	3	2	2	2	5	5	4	4	4	5	2	3	2
BCB11-75	2	3	3	2	2	2	3	3	2	3	4	2	2	2	2
BCB11-80	2	4	5	2	2	2	3	2	3	3	4	2	2	2	2
BCB11-87	2	4	2	2	2	2	4	3	4	3	4	3	2	2	2
BCB11-9	2	2	2	2	2	2	3	3	4	3	3	4	4	5	2
BCB11-94	2	2	3	2	2	2	5	4	2	3	4	5	2	2	2
BCB11-98	2	4	2	2	2	2	3	2	3	3	3	3	2	2	2
Mexican142	2	2	3	2	2	2	5	4	2	4	3	5	2	2	2
Mean	2	3	3	2	2	2	4	3	3	4	3	4	2	2	2
CV(%)	30.3			13.1			21.4			19.0			18.6		
LSD $_{0.05}$: Line	0.7			0.3			0.7			0.7			0.4		
LSD $_{0.05}$: Site	0.3			0.1			0.3			0.2			0.1		
LSD $_{0.05}$:L x S	1.3			0.4			1.2			1.1			0.7		

Table 3.20 Reaction to five major diseases of small red lines grown at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-182	2	3	3	2	2	2	2	2	2	2	3	3	2	2	2
BCB11-184	2	2	4	2	2	3	2	3	4	4	3	2	2	2	5
BCB11-191	4	2	2	6	4	5	6	4	4	3	4	2	2	2	5
BCB11-192	2	2	2	2	2	2	3	2	2	3	4	3	2	2	3
BCB11-193	2	2	3	4	2	2	3	4	2	4	5	5	2	2	4
BCB11-194	2	3	4	6	4	3	5	5	3	6	5	2	2	2	2
BCB11-195	3	3	3	4	4	2	6	4	5	4	6	4	2	2	2
BCB11-197	2	3	2	2	3	3	4	3	2	4	4	3	2	2	4
BCB11-199	2	2	2	3	3	3	4	3	4	4	3	5	2	2	5
BCB11-202	2	2	2	2	2	2	3	3	2	4	3	4	3	2	3
BCB11-245	2	2	2	2	2	2	2	2	3	2	3	3	2	2	5
BCB11-280	2	2	2	7	5	4	5	6	5	4	5	4	2	3	4
BCB11-323	2	2	2	3	5	3	6	5	4	3	4	4	2	2	2
BCB11-331	2	2	3	2	2	2	5	6	6	4	3	5	2	2	2
BCB11-344	2	2	2	2	2	2	2	2	5	3	3	6	2	2	2
BCB11-362	2	2	2	2	2	4	7	6	5	5	4	6	2	2	2
BCB11-366	2	2	2	7	6	7	7	6	2	5	4	4	2	2	2
BCB11-399	3	3	2	5	3	2	4	2	5	4	4	5	2	2	3
BCB11-401	2	3	3	6	6	7	6	6	4	5	4	3	2	2	2
BCB11-437	2	2	3	4	3	5	6	3	7	4	4	4	3	2	4
BCB11-443	2	2	3	6	6	7	7	7	6	4	4	4	2	2	2
BCB11-517	2	3	5	4	3	5	7	4	5	4	4	2	2	2	2
GLP585	3	2	5	7	6	2	6	3	6	4	5	4	4	2	6
KATB9	3	2	3	6	3	2	5	4	4	6	5	6	2	2	6
Tio canella	3	2	2	5	3	4	3	3	2	5	5	4	2	3	5
Mean	2	2	3	4	3	3	5	4	4	4	4	4	2	2	3
CV(%)	28.8			23.1			20.4			25.9			23.0		
LSD $_{0.05}$:Line	0.7			0.8			0.8			1.0			0.6		
LSD $_{0.05}$:Site	0.2			0.3			0.3			0.3			0.2		
LSD $_{0.05}$:L x S	1.1			1.4			1.4			1.7			1.0		

Table 3.21: Reaction of pinto and carioca lines to five major diseases at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-231	3	2	2	2	2	3	2	2	4	5	3	6	2	2	2
BCB11-232	2	2	3	2	2	2	5	4	2	5	2	5	2	2	2
BCB11-233	2	3	3	2	2	2	3	3	3	3	4	5	2	2	2
BCB11-234	2	3	3	4	2	2	5	2	2	5	4	5	2	2	4
BCB11-235	2	2	4	2	2	2	4	2	3	4	4	6	2	2	2
BCB11-236	2	3	6	2	2	2	5	2	3	3	2	4	2	2	2
BCB11-254	2	5	4	2	2	2	3	3	2	4	4	7	2	2	2
BCB11-271	2	2	3	2	2	2	4	3	2	5	4	3	2	2	2
BCB11-274	2	2	2	2	2	2	3	3	4	5	4	5	2	3	2
BCB11-293	2	3	3	5	2	3	3	2	4	3	3	3	2	2	2
BCB11-297	2	2	2	2	2	2	4	3	2	3	2	3	2	2	2
BCB11-338	2	2	4	2	2	2	5	2	6	5	5	5	2	2	2
BCB11-372	3	4	4	4	2	2	3	5	2	5	5	6	2	2	2
BCB11-383	2	2	4	2	2	2	6	5	3	6	3	5	2	3	2
BCB11-392	2	3	3	4	2	2	4	4	2	4	5	7	2	3	4
BCB11-425	2	2	3	2	2	2	3	3	3	3	3	5	2	2	2
BCB11-426	2	2	3	2	4	4	3	2	3	6	4	6	2	3	2
BCB11-428	2	2	2	2	2	2	4	2	2	3	3	3	2	2	2
BCB11-448	3	4	5	2	2	2	4	3	2	5	4	4	2	3	2
BCB11-508	2	2	3	2	4	2	4	3	2	5	2	6	2	2	2
BCB11-512	2	2	2	2	2	2	3	2	2	5	5	3	2	2	2
BCB11-515	2	2	5	2	2	2	3	2	2	4	3	3	2	2	2
BCB11-524	2	2	3	2	2	2	2	4	3	4	3	4	2	2	2
GLP1004	3	4	5	6	2	2	5	3	4	5	5	5	2	2	2
GLPX92	3	5	5	6	4	2	4	2	6	4	6	6	2	2	4
Mean	2	3	3	3	2	2	4	3	3	4	4	5	2	2	2
CV(%)	26.6			17.6			22			18.7			18.5		
LSD $_{0.05}$:Line	0.7			0.4			0.6			0.8			0.4		
LSD $_{0.05}$:Site	0.2			0.1			0.2			0.3			0.1		
LSD $_{0.05}$:L x S	1.2			0.7			1.1			1.3			0.7		

Table 3.22: Reaction of mixed colour lines to five major diseases at Kabete, Tigoni and Thika during 2012/2013 short-rain season.

	ALS			ANTH			BCMV			CBB			RUST		
Line	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**	**Kabete**	**Tigoni**	**Thika**
BCB11-219	2	2	2	4	2	2	5	4	2	4	3	2	2	2	3
BCB11-229	2	2	3	2	2	2	4	2	4	4	3	4	2	4	2
BCB11-230	2	2	2	2	2	2	2	3	2	4	3	4	4	3	3
BCB11-248	2	3	2	2	3	2	2	4	4	4	2	2	2	2	4
BCB11-253	2	2	5	6	7	6	3	3	2	3	4	6	2	4	2
BCB11-263	2	2	2	3	2	2	3	3	2	3	2	3	2	2	2
BCB11-273	2	2	6	3	2	4	3	3	2	4	5	6	2	2	3
BCB11-301	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2
BCB11-310	2	2	2	2	2	2	4	5	5	5	4	5	3	2	2
BCB11-313	2	2	2	2	2	3	3	3	2	3	3	2	2	2	2
BCB11-318	2	2	2	2	2	2	4	3	2	3	2	2	2	2	2
BCB11-326	2	2	2	4	2	4	6	5	5	4	4	4	2	2	2
BCB11-348	2	2	3	2	2	2	5	5	2	4	5	6	2	2	2
BCB11-359	2	2	3	4	2	4	2	2	2	5	3	4	2	3	5
BCB11-459	2	2	2	3	2	2	5	2	2	3	2	3	2	2	2
BCB11-469	2	2	2	2	2	2	3	3	2	3	3	2	2	3	2
BCB11-488	2	2	2	3	2	2	4	3	2	5	2	3	2	2	2
BCB11-493	2	4	3	2	2	2	4	3	4	5	5	5	3	2	2
BCB11-502	2	2	2	4	2	2	4	6	6	5	5	6	2	2	2
GLP585	2	2	5	4	2	4	5	3	3	4	5	6	2	2	4
GLPx92	2	2	5	7	5	6	6	6	4	5	4	5	2	2	3
KATB1	2	2	3	7	2	4	3	3	4	6	4	6	2	2	2
SEA15	2	2	3	3	2	4	2	3	2	4	3	3	2	4	4
SER16	2	3	2	5	2	2	2	3	2	3	3	3	2	5	4
SER76	3	2	3	5	2	2	2	3	2	4	2	2	2	2	5
Mean	2	2	3	3	2	3	4	3	3	4	3	4	2	3	3
CV(%)	15.8			24			20			20			23.5		
LSD $_{0.05}$ **:**Line	0.4			0.6			0.6			0.7			0.5		
LSD $_{0.05}$ **:**Site	0.1			0.2			0.2			0.2			0.2		
LSD $_{0.05}$ **:**L x S	0.6			1.1			1			1.2			0.9		

3.3.5. Grain yield

Advanced lines from seven market classes and local checks grown during the first season showed significant differences in yield potential due to treatments (water regime) ($p \leq 0.05$) and genotypes ($p<0.001$). On average Thika had higher yield (1259 kg ha^{-1}) compared to Kabete (1173 kg ha^{-1}). In general, drought stress had higher effect on yield at Thika with 30% lower yields observed in drought stressed rainfed plots compared to Kabete (12%). Yield performance of selected lines grown in the second season at four locations showed significant differences due to genotypes and location ($p<0.001$). Advanced bean lines performed best at Nakuru (2400 kg ha^{-1} on average) while at Kabete genotypes had the lowest yield (2071 kg ha^{-1}). Among the seven market classes, navy bean lines were consistently high yielding in both seasons. Genotypes from small red market class had the highest yield in the first season (Table 3.23).Advanced lines in each market class significantly differed in yield potential under water stress conditions and across agro-ecological zones (Table 3.24 to 3.37).

Among red mottled market class grown in the first season, more than 15 lines had average yield of more than 1500 kg ha^{-1} compared to the best check, Kenya Umoja, (1185 kg ha^{-1}). The best lines in the first season included BCB1-130 (2072kg ha^{-1}), BCB11-142 (2048kg ha^{-1})and BCB11-144 (1868kg ha^{-1}). The poorest performing lines included BCB11-418(418.8kg ha^{-1}), BCB11-367(511.5kg ha^{-1}) and BCB11-151 (596.8kg ha^{-1}) (Table 3.22).In the second season, best performing lines across locations included BCB11-142 (2862kg ha^{-1}),BCB11-324 (2804kg ha^{-1}) and BCB11-144 (2698kg ha^{-1}). The best check variety, Kenya Umoja, yielded 2878 kg ha^{-1} which is comparable to the best yieldingline (Table 3.25).

Among red kidney lines, 9 lines out-yielded (> 1500 kg ha^{-1}) the best performing check KAT56 (1394 kg ha^{-1}) in the first season. The highest yield was recorded on BCB11-342 (2189kg ha$^-$

^{1}),BCB11-492 (1678kg ha^{-1}),BCB11-176 (1674kg ha^{-1})and BCB11-162 (1672kg ha^{-1}).The lowest yield was obtained from BCB11-276(456kg ha^{-1}) and BCB11-299 (480kg ha^{-1}) (Table 3.26). Red kidney lines that had high yield across agro-ecological zones during the second season included BCB11-159 (2771kg ha^{-1}),BCB11-492 (2644kg ha^{-1}), BCB11-158 (2617kg ha^{-1}) and BCB11-168 (2461kg ha^{-1}) (Table 3.27).

Lines that were high yielding under both water treatments and locations in the speckled sugar market class were BCB11-303 (2235kg ha^{-1}),BCB11-507(1871kg ha^{-1}), BCB11-382 (1566kg ha^{-1}), and BCB11-386 (1564kg ha^{-1}).The lowest yielding lines BCB11-370 (376 kg ha^{-1}) and BCB11-461 (414kg ha^{-1}). The check variety Miezi Mbili was among low yielding genotypes (910 kg ha^{-}1) (Table 3.28). The best performing lines in this market class in the second season were BCB11-507 (3214kg ha^{-1}),BCB11-303 (2914kg ha^{-1}), BCB11-282 (2732kg ha^{-1}) and BCB11-386 (2416kg ha^{-1}).Miezi Mbili had mean yield of 1748 kg ha^{-1} (Table 3.29).

Among navy market class, BCB11-10 and BCB11-108 were the most outstanding lines across locations and seasonswith average yield of 2972 kg ha^{-1} and 2688 kg ha^{-1} respectively (Table 3.30, 3.31). Mexican142 (check) was among the top genotypes across sites and seasons with average yield of 2740 kg ha^{-1}. Other lines in this group with relatively high yield include BCB11-80,BCB11-98,BCB11-94BCB11-33 and BCB11-40.

Among small red genotypes evaluated in the first season, 20 lines had significantly higher yield (>1500 kg ha^{-1}) compared to local varieties KATB9 (1113 kg ha^{-1}) and GLP585 (1056 kg ha^{-1}) (Table 3.32). Genotypes from this group that also out-yielded the checks across agro-ecological zones during the second season included BCB11-344 (3002 kg ha^{-1}),BCB11-245 (2870 kg ha^{-1}) and BCB11-184 (2525 kg ha^{-1}) (Table 3.33).

Among pinto and carioca market class, 18 lines had significantly higher yield (> 1500 kg ha^{-1}) than the best check, GLP1004, (1106 kg ha^{-1}). Lines from this market class that were selected during the first season for high yield include BCB11-515, BCB11-448, BCB11-271,BCB11-508,BCB11-274 and BCB11-524. The lowest yielding lines were BCB11-486 and BCB11-329 with less than500 kg ha^{-1} (Table 3.34). The best performing genotypes from this group across locations in season two included BCB11-448 (3052kg ha^{-1}),BCB11-274 (2806kg ha^{-1}), BCB11-524 (2784kg ha^{-1}), BCB11-235 (2615kg ha^{-1}) and BCB11-515 (2521kg ha^{-1}) (Table 3.35).

Among mixed colour market class, BCB11-230 and BCB11-229 were the best performing lines across locations and seasons with average yields of 2480kg ha^{-1} and 2387kg ha^{-1}. Also, lines from this market class that were selected in the first season and were among the high yielding genotypes across locations include BCB11-248, BCB11-310 andBCB11-313 (Table 3.36, 3.37).

Fig 3.4: High yielding new red mottled line BCB11-142 and the popular local variety GLP2 at Kabete during 2012/2013 short rain season.

Fig 3.5: New yigh yielding navy lines BCB11-10, BCB11-108 and the popular commercial variety Mexican142. Note that BCB11-10 and Mexican142 have type III growth habit which farmers find difficult to manage.

Table 3.23: Performance of advanced lines from seven market classes across different environments

	Season 1						Season 2				
	Kabete			Thika			Kabete	Nakuru	Tigoni	Thika	Mean
Market class	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean					
Red mottled	1164.5	898.3	1031.4	1355.8	979.1	1167.4	2203.6	2611.7	2184.8	2067.4	2266.9
Red kidney	1211.6	966.4	1089.0	1215.9	866.0	1040.0	2259.0	1987.0	1981.0	2450.0	2169.0
Speckled sugar	871.0	901.0	886.0	1529.0	1011.0	1270.0	1713.0	2036.0	2402.0	2322.0	2118.0
Navy	1372.6	1376.6	1374.6	1657.6	1225.0	1441.3	2523.2	3070.8	2314.3	2475.7	2596.0
Small red	1720.0	1279.0	1499.0	1692.0	1201.0	1446.0	1975.7	2720.2	2160.4	2016.5	2218.2
Pinto and carioca	1306.0	1314.0	1310.0	1728.0	842.0	1285.0	1895.0	2241.0	2024.0	2504.0	2166.0
Mixed colour	1106.0	942.0	1024.0	1403.0	931.0	1167.0	1934.0	2137.6	1843.4	1584.6	1874.9
Mean	1250.2	1096.8	1173.4	15511.6	1007.9	1259.5	2071.9	2400.6	2129.8	2202.9	2201.2

Table 3.24: Yield (kg ha-1) of red mottled lines grown at Kabete and Thika under irrigated and rainfed treatments during the long-rain 2012

	Kabete			Thika			
Line	Irrigated	Rainfed	Site mean	Irrigated	Rainfed	Site mean	Line mean
BCB11-130	2597.1	2250.5	2423.8	1854.2	1585.8	1720.0	2071.9
BCB11-142	1959.4	1661.6	1810.5	2775.4	1794.9	2285.1	2047.8
BCB11-144	1914.9	1849.4	1882.2	2108.7	1598.1	1853.4	1867.8
BCB11-143	2006.4	1699.5	1852.9	2187.7	1490.9	1839.3	1846.1
BCB11-345	2562.4	2324.7	2443.6	1206.9	1006.2	1106.5	1775.0
BCB11-413	2099.4	1275.9	1687.7	1942.4	1771.3	1856.8	1772.2
BCB11-464	2114.8	1727.4	1921.1	1761.5	1226.8	1494.1	1707.6
BCB11-445	2406.1	1583.4	1994.7	1754.2	1063.9	1409.1	1701.9
BCB11-145	1890.4	1793.0	1841.7	1760.0	1275.3	1517.6	1679.6
BCB11-133	1270.0	1172.9	1221.4	2476.6	1765.5	2121.1	1671.2
BCB11-135	1807.4	1743.6	1775.5	1691.1	1264.4	1477.7	1626.6
BCB11-155	2791.1	1359.7	2075.4	1165.9	903.8	1034.9	1555.1
BCB11-400	1707.3	1554.9	1631.1	1759.3	1162.5	1460.9	1546.0
BCB11-305	1403.6	1262.2	1332.9	1885.2	1524.3	1704.8	1518.8
BCB11-314	1309.3	1273.1	1291.2	1910.6	1570.0	1740.3	1515.7
BCB11-324	1411.4	1640.2	1525.8	1637.7	1287.9	1462.8	1494.3
BCB11-148	1328.3	893.8	1111.0	2317.7	1192.7	1755.2	1433.1
BCB11-523	1482.0	949.0	1215.5	1997.9	1225.0	1611.5	1413.5
BCB11-334	1144.4	405.4	774.9	2109.4	1672.7	1891.1	1333.0
BCB11-347	1668.1	966.6	1317.3	1697.6	898.2	1297.9	1307.6
BCB11-349	1054.7	803.1	928.9	1637.1	1571.9	1604.5	1266.7
BCB11-290	920.5	915.8	918.1	1535.4	1340.3	1437.8	1178.0
BCB11-308	847.0	896.7	871.8	1749.9	1160.0	1454.9	1163.4
BCB11-470	755.3	879.1	817.2	1674.2	1293.0	1483.6	1150.4
BCB11-449	1323.3	1011.4	1167.3	1397.8	839.0	1118.4	1142.8
BCB11-511	1651.2	935.0	1293.1	1033.5	927.1	980.3	1136.7
BCB11-333	1654.7	1045.0	1349.8	1247.7	577.8	912.7	1131.3
BCB11-420	1484.2	1156.4	1320.3	819.7	1060.0	939.9	1130.1
BCB11-409	708.5	558.3	633.4	1868.7	1187.5	1528.1	1080.7
BCB11-141	1297.6	292.2	794.9	1582.0	1112.8	1347.4	1071.1
BCB11-354	1171.0	788.2	979.6	1409.5	870.6	1140.0	1059.8
BCB11-453	2058.4	924.4	1491.4	449.0	730.3	589.6	1040.5
BCB11-351	1864.3	1372.1	1618.2	453.6	418.9	436.2	1027.2
BCB11-379	1385.1	715.8	1050.4	1216.2	763.3	989.7	1020.1
BCB11-321	1138.0	693.5	915.8	1487.7	749.4	1118.5	1017.1
BCB11-131	1076.4	887.6	982.0	952.0	1070.7	1011.3	996.7
BCB11-433	993.4	470.7	732.1	1360.3	1160.3	1260.3	996.2
BCB11-139	198.3	880.7	539.5	1530.2	1308.4	1419.3	979.4
BCB11-330	786.2	969.7	877.9	1087.6	970.4	1029.0	953.5
BCB11-134	476.3	709.1	592.7	1347.4	1212.2	1279.8	936.2
BCB11-430	1275.3	1073.7	1174.5	973.9	327.8	650.8	912.7
BCB11-137	918.6	381.4	650.0	1213.6	1116.4	1165.0	907.5
BCB11-307	883.2	264.9	574.0	1262.3	1211.7	1237.0	905.5
BCB11-132	341.2	246.4	293.8	1838.4	1188.6	1513.5	903.6
BCB11-395	1629.5	656.2	1142.9	813.0	449.4	631.2	887.0

BCB11-356	685.2	529.3	607.3	1534.1	786.1	1160.1	883.7
BCB11-463	814.2	445.8	630.0	1232.4	1017.8	1125.1	877.6
BCB11-363	796.3	720.2	758.2	1293.1	579.9	936.5	847.3
BCB11-378	1162.0	811.2	986.6	803.8	553.7	678.7	832.7
BCB11-506	612.4	548.9	580.7	1491.9	673.8	1082.8	831.7
BCB11-136	559.7	459.1	509.4	1212.3	964.3	1088.3	798.8
BCB11-259	1372.9	1113.8	1243.3	369.7	324.1	346.9	795.1
BCB11-335	1046.4	513.2	779.8	1171.5	435.0	803.2	791.5
BCB11-312	604.3	533.9	569.1	1193.7	808.0	1000.8	785.0
BCB11-432	1353.5	1245.9	1299.7	146.4	369.6	258.0	778.8
BCB11-513	1025.2	774.8	900.0	782.4	417.5	599.9	749.9
BCB11-147	590.4	425.1	507.8	922.1	1013.7	967.9	737.8
BCB11-446	573.0	870.1	721.5	1096.7	284.0	690.3	705.9
BCB11-140	349.0	200.0	274.5	1321.3	933.4	1127.4	700.9
BCB11-265	669.1	295.8	482.5	781.3	914.4	847.9	665.2
BCB11-283	306.4	465.1	385.7	1064.2	762.1	913.1	649.4
BCB11-300	629.1	531.7	580.4	905.8	518.0	711.9	646.1
BCB11-441	652.2	411.0	531.6	965.1	538.4	751.7	641.6
BCB11-281	424.7	289.0	356.9	1069.8	772.8	921.3	639.1
BCB11-328	488.0	438.7	463.3	1214.0	413.1	813.6	638.4
BCB11-302	792.0	300.1	546.1	873.0	498.4	685.7	615.9
BCB11-151	392.6	253.2	322.9	835.9	905.3	870.6	596.8
BCB11-367	361.4	335.0	348.2	663.0	686.6	674.8	511.5
BCB11-418	563.6	231.5	397.5	457.5	422.6	440.0	418.8
Kenya Umoja	1108.8	702.0	905.4	1945.7	982.6	1464.1	1184.8
GLP2	853.5	1634.8	1244.1	759.9	751.3	755.6	999.9
KAT69	295.1	682.4	488.7	1572.6	1269.0	1420.8	954.8
Mean	1164.5	898.3	1031.4	1355.8	979.1	1167.4	1099.4
CV (%)	20.2						
LSD 0.05 : Lines =219, Treatments: 87.3, Locations= n/s							

Table 3.25: Yields (kg ha-1) of red mottled lines grown at Kabete, Nakuru, Tigoni and Thika during the 2012-2013 short-rain season.

Lines	Kabete	Nakuru	Tigoni	Thika	Line mean
BCB11-142	3901.8	3462.0	2180.1	1907.3	2862.8
BCB11-324	2433.7	3059.5	2916.8	2806.5	2804.1
BCB11-144	2922.9	3102.9	2407.9	2360.7	2698.6
BCB11-345	2487.3	3762.7	1625.6	2793.4	2667.2
BCB11-145	2621.3	2557.8	2184.3	3069.5	2608.2
BCB11-132	2495.5	3247.8	2464.8	1908.8	2529.2
BCB11-334	2475.9	2568.9	1641.8	3351.9	2509.6
BCB11-445	2246.3	2380.7	3653.4	1542.1	2455.6
BCB11-133	1899.2	2824.4	2627.1	2123.8	2368.6
BCB11-135	2735.5	2577.8	2458.0	1582.2	2338.4
BCB11-130	2888.6	2917.6	1843.1	1693.6	2335.7
BCB11-143	2313.3	2499.7	1561.3	2540.0	2228.6
BCB11-413	2009.8	2445.0	2326.2	1923.2	2176.1
BCB11-470	2093.8	2004.7	2244.3	2060.6	2100.9
BCB11-464	2012.3	1979.0	2461.2	1824.2	2069.2
BCB11-347	1994.0	2753.1	1975.1	1527.1	2062.3
BCB11-523	1805.0	2084.1	2270.7	1886.9	2011.7
BCB11-290	1756.2	2273.1	2049.4	1729.0	1951.9
BCB11-314	1301.7	2072.3	1615.9	2225.5	1803.9
BCB11-400	1838.1	1830.4	1526.8	1870.8	1766.5
BCB11-433	1274.1	2291.0	1695.2	1568.6	1707.2
BCB11-305	1319.9	2101.2	1486.9	1010.7	1479.7
Kenya Umoja	2914.4	3176.9	2966.6	2454.6	2878.1
GLP2	2001.5	2216.3	2442.9	2169.9	2207.6
KAT69	1348.6	3103.3	1995.5	1755.6	2050.7
Mean	2203.6	2611.7	2184.8	2067.4	2266.9
CV(%)	16.2				

LSD 0.05 : Lines =296.4, Locations= 118.6, Lines x Locations=592.7

Table 3.26: Yield (kg ha-1) of red kidney lines grown at Kabete and Thika under irrigated and rainfed treatments during the long-rain 2012.

	Kabete			Thika			
Line	Irrigated	Rainfed	Site mean	Irrigated	Rainfed	Site mean	Line mean
BCB11-342	2640.5	1949.3	2294.9	2388.7	1779.1	2083.9	2189.4
BCB11-492	1688.7	1250.0	1469.3	2090.2	1685.6	1887.9	1678.6
BCB11-176	1988.8	1899.1	1943.9	1660.4	1149.5	1405.0	1674.5
BCB11-162	2689.9	1185.1	1937.5	1509.3	1304.2	1406.8	1672.1
BCB11-522	2061.4	1591.7	1826.5	1730.3	1223.8	1477.0	1651.8
BCB11-285	1870.5	1470.8	1670.6	1689.0	1307.0	1498.0	1584.3
BCB11-327	1417.7	1443.7	1430.7	2044.3	1288.0	1666.2	1548.5
BCB11-304	1832.5	1980.8	1906.6	1440.5	887.9	1164.2	1535.4
BCB11-159	2067.6	1261.9	1664.8	1699.2	1077.0	1388.1	1526.4
BCB11-325	2336.9	635.8	1486.4	1718.5	1217.0	1467.8	1477.1
BCB11-158	1955.6	1231.8	1593.7	1503.3	1140.9	1322.1	1457.9
BCB11-168	1527.6	783.7	1155.7	2279.2	1185.4	1732.3	1444.0
BCB11-174	788.0	1889.8	1338.9	1623.5	1243.5	1433.5	1386.2
BCB11-509	1454.0	1317.9	1386.0	1567.1	1122.0	1344.5	1365.3
BCB11-434	1180.5	749.6	965.0	1665.5	1793.5	1729.5	1347.3
BCB11-500	1938.5	1150.5	1544.5	1472.2	680.7	1076.4	1310.5
BCB11-358	1401.7	1024.1	1212.9	1536.2	1099.4	1317.8	1265.4
BCB11-166	1505.1	1013.5	1259.3	1417.7	1093.3	1255.5	1257.4
BCB11-503	1690.9	1199.2	1445.1	1465.0	578.7	1021.8	1233.5
BCB11-337	1437.8	1239.2	1338.5	1221.7	976.8	1099.3	1218.9
BCB11-163	1548.0	996.4	1272.2	1337.4	887.7	1112.6	1192.4
BCB11-468	1467.5	1371.4	1419.5	1281.7	541.2	911.4	1165.5
BCB11-406	937.6	1247.8	1092.7	1396.2	1069.9	1233.1	1162.9
BCB11-264	1035.7	829.6	932.7	1531.1	986.0	1258.6	1095.6
BCB11-173	1410.6	905.8	1158.2	1471.7	574.8	1023.3	1090.8
BCB11-402	961.7	906.1	933.9	1484.0	952.8	1218.4	1076.1
BCB11-164	1278.8	1001.9	1140.3	1119.5	824.7	972.1	1056.2
BCB11-175	918.2	517.0	717.6	1585.6	1139.3	1362.4	1040.0
BCB11-196	1218.1	1137.7	1177.9	1034.0	685.7	859.9	1018.9
BCB11-374	1226.6	976.1	1101.4	1231.0	598.7	914.9	1008.1
BCB11-477	786.6	509.7	648.1	1271.0	1451.5	1361.2	1004.7
BCB11-440	681.1	691.7	686.4	1406.1	1000.5	1203.3	944.9
BCB11-257	1364.0	1349.5	1356.7	452.8	414.6	433.7	895.2
BCB11-496	195.5	699.5	447.5	1635.4	936.2	1285.8	866.7
BCB11-384	543.3	590.5	566.9	1200.3	1123.7	1162.0	864.5
BCB11-171	792.5	639.0	715.8	824.8	1058.0	941.4	828.6
BCB11-157	1242.3	1104.9	1173.6	588.2	307.4	447.8	810.7
BCB11-490	1305.7	885.9	1095.8	439.2	571.1	505.2	800.5
BCB11-272	425.3	1060.3	742.8	1469.9	174.7	822.3	782.6
BCB11-394	388.2	437.5	412.9	1246.8	1020.4	1133.6	773.2
BCB11-169	916.7	740.1	828.4	466.8	608.1	537.5	682.9
BCB11-353	1193.8	799.1	996.4	461.2	235.0	348.1	672.3
BCB11-484	245.2	546.6	395.9	1002.6	884.0	943.3	669.6
BCB11-451	474.7	752.1	613.4	1160.8	252.7	706.7	660.1
BCB11-266	687.2	431.4	559.3	659.4	766.5	713.0	636.2

BCB11-373	568.0	533.2	550.6	911.2	511.2	711.2	630.9
BCB11-489	752.4	550.8	651.6	704.8	315.0	509.9	580.7
BCB11-397	913.9	763.5	838.7	498.8	130.6	314.7	576.7
BCB11-167	665.0	510.9	588.0	663.8	436.8	550.3	569.2
BCB11-473	757.1	650.7	703.9	556.2	252.6	404.4	554.2
BCB11-170	832.7	608.5	720.6	262.3	327.3	294.8	507.7
BCB11-460	271.8	390.5	331.2	601.8	710.8	656.3	493.7
BCB11-299	622.6	630.5	626.5	453.6	214.0	333.8	480.2
BCB11-276	870.4	296.0	583.2	411.7	245.6	328.6	455.9
KAT56	1944.3	1175.6	1560.0	813.8	1644.0	1228.9	1394.4
GLP-24	930.3	613.9	772.1	730.4	807.5	768.9	770.5
Mean	1211.6	966.4	1089.0	1215.9	866.0	1040.9	1065.0
CV (%)	32.4						

LSD $_{0.05}$: Lines=336.4, Treatment= 272.9, Site= n/s

Table 3.27: Yield (kg ha-1) of red kidney lines grown at Kabete, Nakuru, Tigoni and Thika during 2012-2013 short-rain season.

Line	Kabete	Nakuru	Tigoni	Thika	Line mean
BCB11-159	2993.0	2403.0	2742.0	2945.0	2771.0
BCB11-492	2734.0	3063.0	1856.0	2924.0	2644.0
BCB11-158	2879.0	1614.0	3445.0	2530.0	2617.0
BCB11-168	1988.0	2047.0	2379.0	3430.0	2461.0
BCB11-196	2402.0	2180.0	2357.0	2860.0	2450.0
BCB11-173	2804.0	1491.0	2619.0	2604.0	2379.0
BCB11-171	2556.0	2749.0	1524.0	2571.0	2350.0
BCB11-176	2047.0	2424.0	2478.0	2165.0	2279.0
BCB11-166	2169.0	2415.0	1719.0	2633.0	2234.0
BCB11-285	2574.0	2023.0	1601.0	2567.0	2191.0
BCB11-522	2326.0	1661.0	1685.0	3086.0	2189.0
BCB11-163	2496.0	1907.0	1822.0	2477.0	2175.0
BCB11-327	2628.0	2346.0	1132.0	2500.0	2151.0
BCB11-468	1738.0	2390.0	1908.0	2562.0	2149.0
BCB11-337	2323.0	2318.0	1444.0	2508.0	2148.0
BCB11-174	1872.0	1550.0	2945.0	2204.0	2143.0
BCB11-162	2500.0	1799.0	2738.0	1515.0	2138.0
BCB11-509	1924.0	2079.0	1376.0	2455.0	1959.0
BCB11-342	2119.0	1478.0	1961.0	2085.0	1911.0
BCB11-175	1995.0	1435.0	1355.0	2632.0	1854.0
BCB11-503	1414.0	1025.0	2402.0	2265.0	1776.0
BCB11-325	2557.0	1544.0	1262.0	1736.0	1775.0
BCB11-500	1179.0	1235.0	1355.0	2018.0	1447.0
GLP-24	2005.0	2111.0	1937.0	2199.0	2063.0
KAT56	2252.0	2391.0	1481.0	1766.0	1973.0
Mean	2259.0	1987.0	1981.0	2450.0	2169.0
CV (%)	14.2				

LSD $_{0.05}$: Lines=248.5, Site=99.4, Lines x Site= 497.0

Table 3.28: Yield (kg ha-1) of speckled sugar bean lines grown at Kabete and Thika under irrigated and rainfed treatments during the 2012 long-rain season.

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Site mean**	**Irrigated**	**Rainfed**	**Site mean**	**Line mean**
BCB11-303	2591.0	2442.0	2517.0	2120.0	1787.0	1953.0	2235.0
BCB11-507	1978.0	1963.0	1971.0	1961.0	1583.0	1772.0	1871.0
BCB11-377	1515.0	1517.0	1516.0	2139.0	1341.0	1740.0	1628.0
BCB11-382	1197.0	1321.0	1259.0	2935.0	811.0	1873.0	1566.0
BCB11-386	1762.0	1524.0	1643.0	1664.0	1307.0	1486.0	1564.0
BCB11-267	1602.0	1183.0	1392.0	1918.0	1356.0	1637.0	1515.0
BCB11-414	1293.0	823.0	1058.0	2568.0	1341.0	1954.0	1506.0
BCB11-204	1157.0	1320.0	1238.0	1774.0	1758.0	1766.0	1502.0
BCB11-390	1523.0	1681.0	1602.0	1557.0	984.0	1271.0	1436.0
BCB11-530	1304.0	1412.0	1358.0	1676.0	1200.0	1438.0	1398.0
BCB11-336	1203.0	1367.0	1285.0	1770.0	1176.0	1473.0	1379.0
BCB11-269	1235.0	1231.0	1233.0	1789.0	1129.0	1459.0	1346.0
BCB11-501	1563.0	1299.0	1431.0	1329.0	1067.0	1198.0	1314.0
BCB11-282	993.0	1466.0	1230.0	1481.0	1246.0	1364.0	1297.0
BCB11-380	865.0	1044.0	955.0	1779.0	1478.0	1628.0	1291.0
BCB11-443	1260.0	1039.0	1149.0	1354.0	1414.0	1384.0	1267.0
BCB11-209	462.0	808.0	635.0	2243.0	1085.0	1664.0	1150.0
BCB11-495	721.0	986.0	853.0	1647.0	1184.0	1416.0	1135.0
BCB11-516	1041.0	897.0	969.0	1691.0	880.0	1286.0	1127.0
BCB11-371	1091.0	1313.0	1202.0	1242.0	645.0	944.0	1073.0
BCB11-466	1092.0	1100.0	1096.0	1629.0	468.0	1049.0	1072.0
BCB11-456	631.0	986.0	809.0	1358.0	1231.0	1294.0	1052.0
BCB11-482	639.0	537.0	588.0	2026.0	899.0	1463.0	1025.0
BCB11-393	845.0	943.0	894.0	1289.0	923.0	1106.0	1000.0
BCB11-467	886.0	1021.0	954.0	1141.0	844.0	992.0	973.0
BCB11-421	606.0	1132.0	869.0	958.0	1068.0	1013.0	941.0
BCB11-217	484.0	820.0	652.0	1434.0	1021.0	1228.0	940.0
BCB11-498	592.0	863.0	727.0	1546.0	713.0	1130.0	928.0
BCB11-438	203.0	177.0	190.0	2041.0	1203.0	1622.0	906.0
BCB11-376	525.0	352.0	438.0	1434.0	1057.0	1246.0	842.0
BCB11-388	494.0	607.0	550.0	1276.0	977.0	1127.0	839.0
BCB11-514	337.0	203.0	270.0	2075.0	623.0	1349.0	809.0
BCB11-340	321.0	349.0	335.0	1315.0	1208.0	1262.0	798.0
BCB11-457	408.0	307.0	357.0	1366.0	994.0	1180.0	769.0
BCB11-472	230.0	319.0	274.0	1571.0	934.0	1253.0	763.0
BCB11-519	783.0	881.0	832.0	506.0	734.0	620.0	726.0
BCB11-289	565.0	583.0	574.0	925.0	821.0	873.0	723.0
BCB11-474	513.0	298.0	405.0	1314.0	704.0	1009.0	707.0
BCB11-458	377.0	166.0	272.0	1122.0	1024.0	1073.0	672.0
BCB11-391	381.0	517.0	449.0	933.0	777.0	855.0	652.0
BCB11-424	670.0	435.0	553.0	830.0	388.0	609.0	581.0
BCB11-415	190.0	250.0	220.0	1028.0	497.0	762.0	491.0
BCB11-461	178.0	149.0	164.0	880.0	450.0	665.0	414.0
BCB11-370	328.0	244.0	286.0	624.0	308.0	466.0	376.0
Miezi Mbili	549.0	665.0	607.0	1549.0	876.0	1213.0	910.0
Mean	871.0	901.0	886.0	1529.0	1011.0	1270.0	1078.0

CV (%)	26.0
LSD $_{0.05}$: Lines=276.5, Treatment= 260.6, Site= n/s	

Table 3.29: Yield (kg ha-1) of speckled sugar bean lines grown at Kabete, Nakuru, Tigoni and Thika during 2012-2013 short-rain season.

Lines	Kabete	Nakuru	Tigoni	Thika	Line mean
BCB11-507	3313.0	3032.0	3012.0	3496.0	3214.0
BCB11-303	2762.0	2842.0	2915.0	3214.0	2934.0
BCB11-282	2476.0	3538.0	2415.0	2500.0	2732.0
BCB11-386	2258.0	2324.0	2174.0	2908.0	2416.0
BCB11-380	2451.0	2073.0	2224.0	2558.0	2327.0
BCB11-414	1734.0	2337.0	2160.0	2955.0	2296.0
BCB11-204	2495.0	2018.0	2078.0	2440.0	2258.0
BCB11-382	1276.0	2161.0	2678.0	2884.0	2250.0
BCB11-421	1482.0	2871.0	2546.0	2066.0	2241.0
BCB11-269	2175.0	1875.0	2271.0	2329.0	2163.0
BCB11-443	1506.0	1767.0	2606.0	2675.0	2138.0
BCB11-467	2069.0	1295.0	3035.0	2096.0	2124.0
BCB11-209	1198.0	2158.0	2518.0	2320.0	2048.0
BCB11-377	1711.0	1338.0	2450.0	2523.0	2006.0
BCB11-501	1148.0	1529.0	2443.0	2896.0	2004.0
BCB11-495	1883.0	2056.0	1950.0	1978.0	1967.0
BCB11-393	924.0	2390.0	1824.0	2549.0	1922.0
BCB11-516	1434.0	1869.0	2508.0	1643.0	1864.0
BCB11-336	1411.0	1492.0	2569.0	1952.0	1856.0
BCB11-267	962.0	1563.0	2617.0	2176.0	1829.0
BCB11-498	1476.0	1743.0	2411.0	1319.0	1737.0
BCB11-530	1423.0	1853.0	2385.0	1076.0	1684.0
BCB11-390	931.0	1478.0	2382.0	1818.0	1652.0
BCB11-217	1312.0	1391.0	2230.0	1262.0	1549.0
Miezi Mbili	1022.0	1912.0	1636.0	2423.0	1748.0
Mean	1713.0	2036.0	2402.0	2322.0	2118.0
CV(%)	14.6				
LSD $_{0.05}$: Lines=249.7, Site= 99.6, Lines x Site= 497.9					

Table 3.30: Yield (kg ha-1) of navy bean lines grown at Kabete and Thika under irrigated and rainfed treatments during 2012 long-rain season.

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Site mean**	**Irrigated**	**Rainfed**	**Site mean**	**Line mean**
BCB11-10	2821.5	2829.2	2825.3	2917.6	2253.5	2585.6	2705.4
BCB11-55	1940.1	2131.5	2035.8	3310.7	2195.4	2753.0	2394.4
BCB11-108	2354.8	2000.6	2177.7	2697.1	2441.7	2569.4	2373.5

BCB11-80	2658.9	2592.5	2625.7	2030.9	1818.1	1924.5	2275.1
BCB11-98	2245.5	2856.0	2550.7	2145.3	1823.3	1984.3	2267.5
BCB11-94	2693.7	2565.5	2629.6	1908.8	1781.1	1844.9	2237.3
BCB11-33	1879.4	2448.6	2164.0	2382.3	2005.9	2194.1	2179.0
BCB11-52	1948.9	2047.5	1998.2	2455.5	2114.9	2285.2	2141.7
BCB11-40	2303.1	2083.2	2193.1	2206.3	1836.8	2021.5	2107.3
BCB11-69	1752.9	1587.2	1670.0	2701.8	2274.0	2487.9	2079.0
BCB11-75	1527.0	2933.0	2230.0	1839.5	1716.8	1778.1	2004.1
BCB11-49	2228.3	2168.2	2198.2	1909.4	1650.3	1779.9	1989.0
BCB11-476	2573.6	2624.2	2598.9	1452.4	1223.2	1337.8	1968.3
BCB11-48	1592.2	1740.1	1666.1	2369.0	2103.2	2236.1	1951.1
BCB11-62	1562.8	1536.1	1549.4	2624.6	2061.2	2342.9	1946.1
BCB11-34	2410.1	2275.1	2342.6	1418.1	1661.5	1539.8	1941.2
BCB11-14	1979.5	2286.1	2132.8	1964.8	1523.6	1744.2	1938.5
BCB11-30	2381.7	1939.9	2160.8	1671.2	1629.8	1650.5	1905.6
BCB11-57	2293.7	2271.3	2282.5	1617.7	1418.4	1518.0	1900.2
BCB11-9	1540.4	1495.0	1517.7	2409.8	2140.3	2275.1	1896.4
BCB11-87	1881.8	1947.7	1914.8	1976.9	1774.2	1875.6	1895.2
BCB11-96	1797.3	2120.0	1958.6	1720.0	1717.3	1718.6	1838.6
BCB11-287	2472.4	1985.6	2229.0	1704.0	1176.7	1440.3	1834.7
BCB11-355	1790.1	2141.2	1965.6	1792.6	1474.4	1633.5	1799.5
BCB11-66	1707.2	1722.2	1714.7	1843.7	1761.9	1802.8	1758.7
BCB11-95	2027.1	1513.5	1770.3	2114.4	1280.5	1697.5	1733.9
BCB11-47	1777.9	2105.2	1941.5	1827.2	1207.4	1517.3	1729.4
BCB11-11	1732.6	1909.1	1820.8	1841.1	1302.2	1571.7	1696.2
BCB11-1	1130.8	2451.9	1791.4	1964.7	1225.3	1595.0	1693.2
BCB11-455	1515.8	1440.6	1478.2	2089.4	1638.4	1863.9	1671.0
BCB11-102	1290.0	1015.3	1152.6	2310.2	1937.4	2123.8	1638.2
BCB11-67	1059.8	1641.4	1350.6	2078.1	1737.3	1907.7	1629.1
BCB11-419	1793.8	1421.7	1607.8	1791.1	1419.5	1605.3	1606.5
BCB11-20	1492.6	1669.3	1580.9	1787.3	1436.4	1611.9	1596.4
BCB11-104	1542.1	811.6	1176.9	2095.2	1906.7	2000.9	1588.9
BCB11-64	1674.9	1043.4	1359.2	1517.3	2081.7	1799.5	1579.3
BCB11-38	1753.2	1731.5	1742.4	1595.6	1199.1	1397.3	1569.8
BCB11-483	2178.3	2094.3	2136.3	1285.4	650.0	967.7	1552.0
BCB11-35	817.6	1007.2	912.4	2720.1	1656.7	2188.4	1550.4
BCB11-106	1700.2	1872.2	1786.2	1862.5	742.3	1302.4	1544.3
BCB11-70	1554.7	1159.5	1357.1	2239.9	1222.6	1731.2	1544.2
BCB11-518	2105.1	1696.8	1900.9	1669.9	693.3	1181.6	1541.3
BCB11-45	1528.6	1413.1	1470.8	2154.3	1022.8	1588.6	1529.7
BCB11-88	1453.3	1534.5	1493.9	1724.9	1399.0	1561.9	1527.9
BCB11-107	1207.9	1577.7	1392.8	2141.2	1137.5	1639.4	1516.1
BCB11-89	2188.3	1960.2	2074.2	1122.5	672.5	897.5	1485.9
BCB11-56	1883.9	1853.9	1868.9	1138.5	956.5	1047.5	1458.2
BCB11-36	1516.5	1292.6	1404.5	1615.7	1386.0	1500.8	1452.7
BCB11-42	1576.7	1578.6	1577.6	1498.7	1118.5	1308.6	1443.1
BCB11-29	1367.3	1330.3	1348.8	1937.8	1095.6	1516.7	1432.7
BCB11-84	1295.3	1684.5	1489.9	1408.1	1300.8	1354.4	1422.2
BCB11-51	1676.5	799.6	1238.0	1603.3	1557.5	1580.4	1409.2

BCB11-63	1454.1	1583.3	1518.7	1114.0	1390.9	1252.4	1385.5
BCB11-72	1061.6	1287.2	1174.4	1401.3	1768.3	1584.8	1379.6
BCB11-439	1115.9	1010.1	1063.0	2024.4	1361.4	1692.9	1377.9
BCB11-103	889.6	1012.5	951.1	1924.4	1637.5	1780.9	1366.0
BCB11-81	812.4	1811.2	1311.8	2132.6	685.2	1408.9	1360.3
BCB11-13	1116.9	1034.5	1075.7	1488.5	1784.2	1636.3	1356.0
BCB11-444	1754.0	1715.8	1734.9	1703.6	231.5	967.5	1351.2
BCB11-92	923.8	860.8	892.3	2121.8	1468.5	1795.2	1343.7
BCB11-105	778.3	552.5	665.4	2001.8	1983.0	1992.4	1328.9
BCB11-369	964.1	1655.5	1309.8	1493.8	1196.6	1345.2	1327.5
BCB11-58	1415.2	1452.5	1433.8	920.2	1515.3	1217.8	1325.8
BCB11-73	1511.4	1244.7	1378.0	1317.9	1193.2	1255.6	1316.8
BCB11-25	980.0	1232.6	1106.3	1627.1	1385.0	1506.0	1306.2
BCB11-32	1573.6	1791.5	1682.5	1268.1	568.9	918.5	1300.5
BCB11-16	1276.3	1060.6	1168.4	1544.8	1296.8	1420.8	1294.6
BCB11-405	1901.2	1579.8	1740.5	1073.5	608.5	841.0	1290.7
BCB11-46	1551.7	1157.9	1354.8	1010.2	1409.9	1210.0	1282.4
BCB11-54	1625.7	1547.8	1586.7	1104.4	850.9	977.6	1282.2
BCB11-83	1628.3	1145.7	1387.0	860.4	1458.6	1159.5	1273.2
BCB11-71	1581.1	1284.1	1432.6	1003.3	1206.3	1104.8	1268.7
BCB11-78	1651.2	1202.7	1427.0	1488.4	726.3	1107.3	1267.1
BCB11-31	1837.3	1483.4	1660.3	1017.9	635.4	826.7	1243.5
BCB11-396	1239.5	956.3	1097.9	1573.5	1199.7	1386.6	1242.3
BCB11-82	1210.8	1144.2	1177.5	1619.2	987.2	1303.2	1240.3
BCB11-8	1157.9	1561.8	1359.8	1138.1	1060.4	1099.2	1229.5
BCB11-410	1544.5	1665.2	1604.8	1077.3	627.5	852.4	1228.6
BCB11-44	980.2	1335.6	1157.9	1372.8	1198.5	1285.6	1221.7
BCB11-37	884.0	1027.4	955.7	1849.3	1082.2	1465.7	1210.7
BCB11-86	1259.9	1329.9	1294.9	1325.6	885.2	1105.4	1200.1
BCB11-41	635.6	699.2	667.4	2040.2	1402.9	1721.6	1194.5
BCB11-4	833.4	743.7	788.5	1740.6	1425.3	1582.9	1185.7
BCB11-275	1464.2	1302.7	1383.4	1426.8	547.5	987.1	1185.3
BCB11-24	1152.6	672.8	912.7	1639.6	1256.1	1447.8	1180.2
BCB11-429	950.7	1625.9	1288.3	1272.8	835.8	1054.3	1171.3
BCB11-74	982.5	1180.1	1081.3	1271.3	1218.4	1244.8	1163.0
BCB11-5	887.0	1041.8	964.4	1733.7	870.8	1302.2	1133.3
BCB11-475	736.5	1656.1	1196.3	1219.5	921.3	1070.4	1133.3
BCB11-53	913.4	461.8	687.6	1649.6	1406.9	1528.3	1107.9
BCB11-100	590.0	543.1	566.5	2515.6	764.8	1640.2	1103.4
BCB11-12	1127.3	681.7	904.5	1489.1	1012.9	1251.0	1077.7
BCB11-61	685.8	790.7	738.2	1732.7	1048.8	1390.8	1064.5
BCB11-65	1350.8	1294.2	1322.5	680.8	883.9	782.3	1052.4
BCB11-79	686.4	611.1	648.8	1924.7	976.7	1450.7	1049.7
BCB11-19	255.6	528.6	392.1	2301.2	1096.2	1698.7	1045.4
BCB11-18	487.5	425.5	456.5	1882.5	1351.5	1617.0	1036.7
BCB11-76	1198.5	951.6	1075.0	1183.0	591.0	887.0	981.0
BCB11-50	489.9	1002.2	746.0	1561.2	838.9	1200.0	973.0
BCB11-97	1283.8	1358.8	1321.3	986.9	222.8	604.8	963.1
BCB11-450	1120.1	1150.2	1135.1	1132.7	436.5	784.6	959.9

BCB11-427	1242.1	1202.2	1222.1	696.1	629.4	662.7	942.4
BCB11-59	1267.2	1148.0	1207.6	770.5	550.0	660.2	933.9
BCB11-109	788.5	631.0	709.7	1235.7	908.1	1071.9	890.8
BCB11-411	664.1	760.0	712.1	1321.2	757.4	1039.3	875.7
BCB11-68	930.0	467.3	698.7	925.7	1049.8	987.8	843.2
BCB11-77	499.5	621.3	560.4	1648.8	557.6	1103.2	831.8
BCB11-39	813.1	677.9	745.5	1095.8	730.6	913.2	829.3
BCB11-85	381.5	339.4	360.4	1523.6	958.0	1240.8	800.6
BCB11-15	950.4	532.2	741.3	1384.9	312.1	848.5	794.9
BCB11-101	381.8	674.9	528.3	1306.6	811.4	1059.0	793.7
BCB11-381	470.7	808.8	639.8	1137.7	595.9	866.8	753.3
BCB11-17	373.1	623.0	498.0	1485.5	447.7	966.6	732.3
BCB11-292	627.6	705.8	666.7	1164.0	117.0	640.5	653.6
BCB11-23	246.7	227.5	237.1	657.1	1405.9	1031.5	634.3
BCB11-481	291.5	226.3	258.9	1336.4	673.2	1004.8	631.8
BCB11-27	590.5	467.6	529.0	889.0	574.2	731.6	630.3
BCB11-43	300.5	212.0	256.3	1455.3	335.3	895.3	575.8
BCB11-286	298.3	411.9	355.1	1131.7	179.6	655.6	505.3
Mexican142	2911.1	2075.1	2493.1	2557.7	2347.2	2452.4	2472.7
Mean	1372.6	1376.6	1374.6	1657.6	1225.1	1441.3	1408.0
CV(%)	25.2						
LSD $_{0.05}$: Lines=348.7, Treatment= 220.5, Site= n/s							

Table 3.31: Yield (kg ha-1) of navy bean lines grown at Kabete, Nakuru, Tigoni and Thika during 2012-2013 short-rain season.

Line	Kabete	Nakuru	Tigoni	Thika	Line mean
BCB11-10	3331.0	3821.6	2222.9	3581.3	3239.2
BCB11-87	2877.5	3823.5	1963.2	3828.8	3123.2
BCB11-48	3201.7	3245.3	2618.7	3222.0	3071.9
BCB11-108	3054.2	3481.5	3443.9	2034.8	3003.6
BCB11-355	3293.0	3415.9	2170.3	2937.3	2954.1
BCB11-40	2921.2	4116.4	1686.1	2886.5	2902.5
BCB11-34	3691.5	3239.9	2143.5	2208.1	2820.7
BCB11-62	2378.0	3180.0	3165.8	2526.0	2812.5
BCB11-476	2838.7	3348.7	2843.5	2174.2	2801.3
BCB11-14	1972.5	3406.9	3043.4	2743.7	2791.6
BCB11-33	2695.3	3643.6	3144.7	1526.7	2752.6
BCB11-80	2212.1	3029.2	3249.0	2164.4	2663.7
BCB11-98	1999.5	3376.6	2179.8	2797.7	2588.4
BCB11-94	2523.5	3218.1	2013.3	2396.0	2537.7
BCB11-30	2130.2	3340.5	2483.2	1810.2	2441.0
BCB11-75	1604.9	2651.8	2596.7	2843.4	2424.2
BCB11-58	2087.9	2873.6	1962.6	2496.8	2355.2
BCB11-47	2280.5	2516.3	1846.6	2676.9	2330.1
BCB11-52	2735.9	2370.3	1264.9	2384.4	2188.9

BCB11-55	2092.2	2572.9	1810.3	2278.1	2188.4
BCB11-49	2709.6	2117.9	1736.3	1783.3	2086.8
BCB11-69	2314.8	2374.9	1421.4	2179.9	2072.7
BCB11-9	1930.3	2275.3	2183.6	1677.7	2016.7
BCB11-35	1491.7	1951.1	1885.4	1566.7	1723.7
Mexican142	2711.9	3377.1	2778.5	3168.1	3008.9
Mean	2523.2	3070.8	2314.3	2475.7	2596.0
CV(%)	13.9				
LSD $_{0.05}$: Lines=291.0, Site= 116.4, Lines x Site= 582.0					

Table 3.32: Yield (kg ha-1) of small red bean lines grown at Kabete and Thika under irrigated and rainfed treatments during the long-rain 2012.

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Site mean**	**Irrigated**	**Rainfed**	**Site mean**	**Line mean**
BCB11-195	2042.0	1357.0	1699.0	3015.0	2325.0	2670.0	2185.0
BCB11-280	2306.0	1286.0	1796.0	2714.0	2034.0	2374.0	2085.0
BCB11-366	2242.0	2226.0	2234.0	1990.0	1570.0	1780.0	2007.0
BCB11-443	2217.0	2005.0	2111.0	1824.0	1585.0	1704.0	1908.0
BCB11-193	2167.0	1585.0	1876.0	2076.0	1752.0	1914.0	1895.0
BCB11-182	1825.0	1320.0	1572.0	2581.0	1811.0	2196.0	1884.0
BCB11-191	2514.0	1806.0	2160.0	1641.0	1518.0	1579.0	1870.0
BCB11-202	1799.0	1606.0	1703.0	2528.0	1532.0	2030.0	1866.0
BCB11-192	2047.0	1616.0	1832.0	1990.0	1584.0	1787.0	1809.0
BCB11-245	2386.0	1398.0	1892.0	2023.0	1421.0	1722.0	1807.0
BCB11-197	1860.0	1185.0	1523.0	2416.0	1756.0	2086.0	1804.0
BCB11-517	2374.0	1547.0	1961.0	1963.0	1316.0	1640.0	1800.0
BCB11-279	2625.0	855.0	1740.0	2184.0	1443.0	1813.0	1776.0
BCB11-437	1703.0	2108.0	1906.0	1559.0	1513.0	1536.0	1721.0
BCB11-362	2449.0	1879.0	2164.0	1284.0	1040.0	1162.0	1663.0
BCB11-401	1793.0	1360.0	1576.0	2042.0	1432.0	1737.0	1656.0
BCB11-199	1472.0	1319.0	1395.0	2330.0	1487.0	1909.0	1652.0
BCB11-344	2215.0	2271.0	2243.0	1144.0	814.0	979.0	1611.0
BCB11-184	1686.0	875.0	1280.0	2286.0	1580.0	1933.0	1607.0
BCB11-399	1288.0	880.0	1084.0	2256.0	1616.0	1936.0	1510.0
BCB11-185	1736.0	1932.0	1834.0	1550.0	633.0	1092.0	1463.0
BCB11-331	1223.0	1345.0	1284.0	2133.0	1092.0	1613.0	1448.0
BCB11-510	1544.0	1123.0	1333.0	2028.0	961.0	1495.0	1414.0
BCB11-194	1503.0	1060.0	1282.0	1928.0	1118.0	1523.0	1402.0
BCB11-323	1459.0	609.0	1034.0	1950.0	1572.0	1761.0	1398.0
BCB11-251	1736.0	1448.0	1592.0	1376.0	910.0	1143.0	1367.0
BCB11-363	1940.0	357.0	1149.0	1716.0	1358.0	1537.0	1343.0
BCB11-317	1533.0	1260.0	1396.0	1523.0	969.0	1246.0	1321.0
BCB11-528	1797.0	1210.0	1503.0	1194.0	1032.0	1113.0	1308.0
BCB11-478	1413.0	958.0	1185.0	1815.0	1033.0	1424.0	1305.0
BCB11-200	1755.0	1411.0	1583.0	746.0	1298.0	1022.0	1303.0

BCB11-203	1465.0	1099.0	1282.0	1366.0	1099.0	1232.0	1257.0
BCB11-189	1769.0	1420.0	1594.0	947.0	845.0	896.0	1245.0
BCB11-190	1867.0	723.0	1295.0	1200.0	869.0	1035.0	1165.0
BCB11-196	1814.0	1478.0	1646.0	995.0	361.0	678.0	1162.0
BCB11-296	1388.0	1134.0	1261.0	1352.0	580.0	966.0	1114.0
BCB11-505	1864.0	1058.0	1461.0	849.0	648.0	748.0	1105.0
BCB11-422	1121.0	1616.0	1369.0	879.0	774.0	827.0	1098.0
BCB11-258	1351.0	851.0	1101.0	1036.0	631.0	834.0	967.0
BCB11-529	1053.0	449.0	751.0	1223.0	1039.0	1131.0	941.0
BCB11-332	798.0	451.0	624.0	1306.0	841.0	1074.0	849.0
BCB11-412	494.0	1092.0	793.0	1008.0	777.0	893.0	843.0
BCB11-436	1130.0	653.0	892.0	645.0	511.0	578.0	735.0
Tio Canella	1811.0	1933.0	1872.0	2197.0	1698.0	1947.0	1910.0
KATB9	1110.0	650.0	880.0	2032.0	661.0	1347.0	1113.0
GLP585	1441.0	1012.0	1226.0	980.0	790.0	885.0	1056.0
Mean	1720.0	1279.0	1499.0	1692.0	1201.0	1446.0	1473.0
CV(%)	23.8						

LSD $_{0.05}$: Lines=345.1, Treatment=173.6, Site= n/s

Table 3.33: Yield (kg ha-1) of small red bean lines grown at Kabete, Nakuru, Tigoni and Thika during 2012-2013 short-rain season.

Line	Kabete	Nakuru	Tigoni	Thika	Mean
BCB11-344	2959.3	3122.0	2998.4	2926.4	3001.5
BCB11-245	2616.8	3100.4	3236.4	2528.8	2870.6
BCB11-184	2524.8	2882.9	1614.0	3077.2	2524.8
BCB11-199	1545.8	3045.6	2693.1	2413.7	2424.6
BCB11-437	2357.4	2876.8	2315.9	2138.1	2422.0
BCB11-193	1875.6	3464.1	2299.4	2032.3	2417.9
BCB11-202	2461.3	3067.1	2294.4	1830.5	2413.3
BCB11-191	1841.2	2825.6	2640.9	2262.3	2392.5
BCB11-401	2218.8	2861.0	2942.1	1413.6	2358.9
BCB11-197	2179.7	2995.5	1863.6	2220.1	2314.7
BCB11-182	1644.2	2585.9	1672.0	3269.1	2292.8
BCB11-195	1632.6	2609.9	2947.9	1922.2	2278.2
BCB11-194	2007.6	2528.0	2739.7	1804.6	2270.0
BCB11-517	2259.2	2824.8	1962.4	1979.2	2256.4
BCB11-192	1839.4	2613.6	1954.1	2615.7	2255.7
BCB11-366	1160.0	2813.2	2764.2	1689.5	2106.7
BCB11-399	1835.5	2741.5	814.5	2973.0	2091.1
BCB11-362	1770.1	1967.2	2889.8	1399.5	2006.7
BCB11-443	2387.0	2469.3	1399.6	1654.0	1977.5
BCB11-323	1914.9	2514.0	2183.3	1259.9	1968.1
BCB11-280	1610.4	3085.1	1476.3	1323.2	1873.7
BCB11-331	1987.0	1896.8	891.3	1030.1	1451.3
Tio Canella	2299.5	2158.1	1605.7	2026.6	2022.5
GLP585	1475.5	2693.2	1899.3	1522.2	1897.6
KATB9	987.9	2262.0	1911.4	1100.0	1565.3

Mean	1975.7	2720.2	2160.4	2016.5	2218.2
CV (%)	17.8				

LSD $_{0.05}$: Lines=318.3, Site= 127.3, Lines x Site= 636.6

Table 3.34: Yield (kg ha-1) of pinto and carioca lines grown at Kabete and Thika under irrigated and rainfed treatments during the long-rain 2012.

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Site mean**	**Irrigated**	**Rainfed**	**Site mean**	**Line mean**
BCB11-515	2530.0	2438.0	2484.0	2018.0	1577.0	1797.0	2140.0
BCB11-448	2012.0	1729.0	1870.0	2479.0	1951.0	2215.0	2043.0
BCB11-271	1925.0	2922.0	2423.0	2084.0	1176.0	1630.0	2027.0
BCB11-508	2466.0	2346.0	2406.0	1778.0	1301.0	1540.0	1973.0
BCB11-274	2105.0	2461.0	2283.0	1901.0	1208.0	1554.0	1919.0
BCB11-524	1761.0	1390.0	1576.0	2234.0	1854.0	2044.0	1810.0
BCB11-231	2171.0	1848.0	2009.0	1922.0	1232.0	1577.0	1793.0
BCB11-512	1764.0	1714.0	1739.0	2038.0	1414.0	1726.0	1733.0
BCB11-392	1692.0	1287.0	1489.0	2074.0	1874.0	1974.0	1732.0
BCB11-425	1731.0	1713.0	1722.0	1983.0	1492.0	1738.0	1730.0
BCB11-383	1850.0	2022.0	1936.0	1919.0	951.0	1435.0	1686.0
BCB11-428	2043.0	2099.0	2071.0	1838.0	701.0	1270.0	1670.0
BCB11-338	1908.0	2051.0	1980.0	1935.0	651.0	1293.0	1636.0
BCB11-372	1518.0	1547.0	1533.0	1926.0	1427.0	1676.0	1604.0
BCB11-233	1778.0	2087.0	1933.0	1665.0	787.0	1226.0	1579.0
BCB11-236	2340.0	1851.0	2096.0	1221.0	856.0	1039.0	1567.0
BCB11-521	1340.0	999.0	1169.0	2543.0	1274.0	1908.0	1539.0
BCB11-297	1520.0	1468.0	1494.0	2149.0	1014.0	1582.0	1538.0
BCB11-293	1600.0	1669.0	1634.0	1742.0	990.0	1366.0	1500.0
BCB11-485	1545.0	1328.0	1437.0	2461.0	438.0	1449.0	1443.0
BCB11-232	1656.0	2025.0	1841.0	1224.0	799.0	1012.0	1426.0
BCB11-235	2101.0	1658.0	1880.0	1014.0	794.0	904.0	1392.0
BCB11-426	1160.0	1245.0	1203.0	2108.0	1014.0	1561.0	1382.0
BCB11-254	834.0	1412.0	1123.0	2128.0	1123.0	1625.0	1374.0
BCB11-234	1567.0	1511.0	1539.0	1573.0	617.0	1095.0	1317.0
BCB11-491	732.0	1029.0	881.0	2618.0	498.0	1558.0	1219.0
BCB11-339	1162.0	973.0	1068.0	2120.0	177.0	1149.0	1108.0
BCB11-291	915.0	1637.0	1276.0	889.0	968.0	928.0	1102.0
BCB11-350	773.0	1097.0	935.0	2149.0	342.0	1245.0	1090.0
BCB11-494	1330.0	1242.0	1286.0	1446.0	216.0	831.0	1059.0
BCB11-284	1120.0	1049.0	1085.0	1288.0	736.0	1012.0	1048.0
BCB11-480	921.0	944.0	932.0	1602.0	270.0	936.0	934.0
BCB11-341	521.0	849.0	685.0	1530.0	593.0	1062.0	874.0
BCB11-237	727.0	980.0	854.0	1251.0	493.0	872.0	863.0
BCB11-479	511.0	576.0	543.0	1953.0	361.0	1157.0	850.0
BCB11-499	698.0	573.0	636.0	1520.0	524.0	1022.0	829.0
BCB11-239	375.0	268.0	322.0	1270.0	858.0	1064.0	693.0
BCB11-408	307.0	328.0	318.0	1740.0	145.0	942.0	630.0
BCB11-320	430.0	221.0	326.0	1488.0	307.0	897.0	612.0

BCB11-289	523.0	303.0	413.0	1093.0	360.0	727.0	570.0
BCB11-357	382.0	363.0	372.0	1159.0	328.0	743.0	558.0
BCB11-486	235.0	271.0	253.0	1162.0	185.0	674.0	463.0
BCB11-329	348.0	187.0	268.0	226.0	456.0	341.0	304.0
GLP1004	606.0	393.0	499.0	2271.0	1154.0	1713.0	1106.0
GLPx92	1240.0	1031.0	1136.0	1006.0	420.0	713.0	924.0
Mean	1306.0	1314.0	1310.0	1728.0	842.0	1285.0	1298.0
CV(%)	22.6						
LSD $_{0.05}$: Lines=289.4, Treatment= 92.2, Site= n/s							

Table 3.35: Yield (kg ha-1) of pinto and carioca bean lines grown at Kabete, Nakuru, Tigoni and Thika during 2012-2013 short-rain season.

Line	Kabete	Nakuru	Tigoni	Thika	Line mean
BCB11-448	2919.0	3428.0	2208.0	3654.0	3052.0
BCB11-274	2846.0	3089.0	1875.0	3414.0	2806.0
BCB11-524	2364.0	3587.0	2508.0	2677.0	2784.0
BCB11-235	1738.0	3029.0	2583.0	3108.0	2615.0
BCB11-515	2015.0	2621.0	2243.0	3206.0	2521.0
BCB11-425	2301.0	3146.0	2270.0	2221.0	2485.0
BCB11-297	1617.0	2888.0	1770.0	3480.0	2439.0
BCB11-508	2031.0	1871.0	2284.0	3379.0	2391.0
BCB11-271	2033.0	2992.0	2391.0	1993.0	2352.0
BCB11-512	2125.0	1338.0	2554.0	3156.0	2293.0
BCB11-233	1964.0	2433.0	1799.0	2150.0	2087.0
BCB11-232	2384.0	1373.0	1741.0	2818.0	2079.0
BCB11-426	1877.0	2331.0	2035.0	2055.0	2074.0
BCB11-428	1655.0	1607.0	2486.0	2518.0	2067.0
BCB11-293	1786.0	1673.0	2022.0	2733.0	2053.0
BCB11-236	1013.0	2979.0	1916.0	1904.0	1953.0
BCB11-254	1196.0	1773.0	1848.0	2770.0	1897.0
BCB11-231	1955.0	1779.0	1587.0	2211.0	1883.0
BCB11-234	1509.0	1928.0	1603.0	2359.0	1850.0
BCB11-392	1410.0	1910.0	1805.0	2228.0	1838.0
BCB11-372	1822.0	1760.0	1716.0	1533.0	1708.0
BCB11-383	2114.0	1191.0	1677.0	1657.0	1660.0
BCB11-338	1605.0	1208.0	1377.0	2117.0	1577.0
GLP1004	1736.0	1527.0	2094.0	1926.0	1821.0
GLPx92	1364.0	2559.0	2211.0	1338.0	1868.0
Mean	1895.0	2241.0	2024.0	2504.0	2166.0
CV(%)	14.1				
LSD $_{0.05}$: Lines=245.3, Site= 98.1, Lines x Site= 490.6					

Table 3.36: Yield (kg ha-1) of mixed colour lines grown at Kabete and Thika under irrigated and rainfed treatments during the long-rain 2012.

	Kabete			Thika			
Line	Irrigated	Rainfed	Site mean	Irrigated	Rainfed	Site mean	Line mean
BCB11-230	3150.0	2740.0	2945.0	1957.0	1597.0	1777.0	2361.0
BCB11-229	3041.0	2730.0	2886.0	1700.0	1683.0	1691.0	2289.0
BCB11-310	2581.0	2005.0	2293.0	1919.0	1706.0	1812.0	2053.0
BCB11-253	2278.0	1881.0	2080.0	2105.0	1313.0	1709.0	1895.0
BCB11-248	1952.0	1725.0	1838.0	2040.0	1520.0	1780.0	1809.0
BCB11-313	2015.0	1414.0	1714.0	2074.0	1505.0	1789.0	1752.0
BCB11-318	2102.0	1609.0	1855.0	1644.0	1612.0	1628.0	1742.0
BCB11-348	1678.0	1690.0	1684.0	2116.0	1304.0	1710.0	1697.0
BCB11-273	1464.0	1438.0	1451.0	1891.0	1262.0	1576.0	1514.0
BCB11-493	1566.0	1336.0	1451.0	1526.0	1599.0	1563.0	1507.0
BCB11-459	2057.0	1422.0	1740.0	1191.0	1207.0	1199.0	1470.0
BCB11-263	1108.0	524.0	816.0	2334.0	1863.0	2098.0	1457.0
BCB11-326	1448.0	412.0	930.0	2290.0	1621.0	1956.0	1443.0
BCB11-246	1012.0	984.0	998.0	2117.0	1619.0	1868.0	1433.0
BCB11-301	1202.0	1123.0	1162.0	1634.0	1534.0	1584.0	1373.0
BCB11-219	1614.0	1456.0	1535.0	1686.0	619.0	1153.0	1344.0
BCB11-469	1447.0	1034.0	1240.0	1152.0	1710.0	1431.0	1336.0
BCB11-502	1333.0	1130.0	1231.0	1421.0	1174.0	1297.0	1264.0
BCB11-488	747.0	881.0	814.0	2055.0	1260.0	1657.0	1236.0
BCB11-277	2199.0	811.0	1505.0	1577.0	284.0	930.0	1218.0
BCB11-316	1280.0	778.0	1029.0	1811.0	864.0	1337.0	1183.0
BCB11-497	735.0	577.0	656.0	1670.0	1230.0	1450.0	1053.0
BCB11-359	593.0	932.0	763.0	1414.0	1262.0	1338.0	1050.0
BCB11-221	816.0	967.0	892.0	1450.0	934.0	1192.0	1042.0
BCB11-520	1221.0	1221.0	1221.0	1166.0	531.0	848.0	1035.0
BCB11-403	1269.0	632.0	951.0	1270.0	674.0	972.0	961.0
BCB11-226	1296.0	732.0	1014.0	823.0	984.0	904.0	959.0
BCB11-531	411.0	319.0	365.0	2072.0	899.0	1485.0	925.0
BCB11-417	805.0	482.0	644.0	1411.0	856.0	1134.0	889.0
BCB11-295	253.0	350.0	302.0	1722.0	1200.0	1461.0	881.0
BCB11-504	650.0	738.0	694.0	1382.0	747.0	1064.0	879.0
BCB11-224	1086.0	692.0	889.0	904.0	792.0	848.0	869.0
BCB11-252	1141.0	901.0	1021.0	1165.0	231.0	698.0	860.0
BCB11-365	1137.0	1197.0	1167.0	641.0	447.0	544.0	856.0
BCB11-404	1166.0	940.0	1053.0	1089.0	219.0	654.0	854.0
BCB11-447	950.0	1083.0	1017.0	897.0	456.0	677.0	847.0
BCB11-346	923.0	972.0	948.0	531.0	952.0	742.0	845.0
BCB11-322	674.0	862.0	768.0	1367.0	460.0	913.0	841.0
BCB11-225	1290.0	797.0	1044.0	641.0	629.0	635.0	839.0
BCB11-227	371.0	331.0	351.0	1426.0	1213.0	1320.0	835.0
BCB11-368	309.0	381.0	345.0	1693.0	859.0	1276.0	811.0
BCB11-407	986.0	930.0	958.0	879.0	449.0	664.0	811.0
BCB11-222	932.0	315.0	624.0	1493.0	468.0	981.0	802.0
BCB11-250	166.0	291.0	228.0	1335.0	1168.0	1251.0	740.0
BCB11-387	734.0	712.0	723.0	918.0	466.0	692.0	707.0
BCB11-288	332.0	484.0	408.0	1048.0	840.0	944.0	676.0

BCB11-352	343.0	573.0	458.0	1001.0	662.0	832.0	645.0
BCB11-416	712.0	186.0	449.0	1036.0	628.0	832.0	640.0
BCB11-223	300.0	266.0	283.0	1485.0	486.0	986.0	634.0
BCB11-315	269.0	279.0	274.0	1344.0	277.0	810.0	542.0
BCB11-375	318.0	279.0	299.0	1291.0	245.0	768.0	533.0
BCB11-220	604.0	260.0	432.0	849.0	393.0	621.0	527.0
BCB11-260	317.0	262.0	290.0	772.0	752.0	762.0	526.0
BCB11-435	241.0	208.0	225.0	864.0	698.0	781.0	503.0
BCB11-442	610.0	435.0	522.0	570.0	150.0	360.0	441.0
BCB11-449	244.0	226.0	235.0	623.0	419.0	521.0	378.0
SER76	1560.0	2141.0	1851.0	1801.0	1287.0	1544.0	1697.0
SER16	1544.0	2843.0	2193.0	1942.0	1522.0	1732.0	1963.0
GLP585	1141.0	812.0	976.0	1130.0	740.0	935.0	956.0
GLP92	1240.0	1031.0	1136.0	1006.0	420.0	713.0	924.0
KATB1	478.0	709.0	593.0	1204.0	294.0	749.0	671.0
Mean	1106	942	1024	1403	931	1167	1095.0
CV(%)	27.5						
LSD $_{0.05}$: Line=296.8, Treatment= 303.3, Site= n/s							

Table 3.37: Yield (kg ha-1) of mixed colour lines grown at Kabete, Nakuru, Tigoni and Thika during 2012-2013 short-rain season.

Line	Kabete	Nakuru	Tigoni	Thika	Mean
BCB11-230	3119.3	3141.7	1731.2	2415.6	2601.9
BCB11-229	2661.5	3316.4	2093.6	1866.7	2484.5
BCB11-248	3036.3	2937.9	1689.5	2181.3	2461.3
BCB11-310	2555.1	2741.6	1882.4	2091.2	2317.6
BCB11-469	2071.8	1948.4	2515.4	2250.9	2196.6
BCB11-313	2476.4	2850.5	1831.6	1384.1	2135.7
BCB11-273	1940.6	3031.7	2273.4	1049.2	2073.7
BCB11-348	1906.3	2380.7	2723.5	850.1	1965.2
BCB11-263	1420.0	2204.7	2001.0	2174.2	1949.9
BCB11-318	1485.7	2903.6	1770.3	1626.4	1946.5
BCB11-459	976.2	2061.2	2134.3	2087.6	1814.8
BCB11-219	1830.0	1996.7	1811.8	1560.7	1799.8
BCB11-301	2000.0	1783.4	1620.9	1751.6	1789
BCB11-493	2230.2	1732.2	1816.9	1294.5	1768.5
BCB11-253	2588.8	1876.2	1723.5	864.8	1763.3
BCB11-488	2235.6	1330.8	1592.4	1811.4	1742.5
BCB11-502	2128.7	1262.8	1660.8	1731.4	1695.9
BCB11-359	1552.8	1631.5	1564.4	1859.0	1651.9
BCB11-326	1805.2	1428.9	1881.5	1357.8	1618.3
GLP585	1174.9	2738.5	1168.5	1535.7	1654.4
SEA15	1824.2	2361.5	1648.6	761.5	1648.9
GLPx92	1488.9	2102.8	2049.5	883.3	1631.1
SER76	1429.2	1184.4	1563.0	2039.3	1554
SER16	1425.1	1262.4	1883.0	1351.8	1480.6
KATB1	986.1	1229.4	1454.1	835.1	1126.2

Mean	1934.0	2137.6	1843.4	1584.6	1874.9
CV(%)	15.1				
LSD $_{0.05}$: Line=227.2, Site=90.9, Line x Site= 454.5					

3.4. Discussion

The significant differences for days to flowering in the advanced lines within and among market classes can be attributed to genetic differences among genotype. In Thika, where higher temperatures were recorded, genotypes flowered earlier while the longest days to flowering were observed in Tigoni which had cooler conditions. According to Wallace et al. (1991) days to flowering of common beans is influenced by the temperature which alters the rate of vegetative development and cause faster flower development under higher temperatures. George (1988) found that under higher elevations with lower temperatures, common bean and soybean crop duration was prolonged. Days to flowering is also influenced by growth habit with indeterminate bean genotypes take longer than determinate types (Wallace et al. 1991; Singh 1991).This could explain the longer days to flowering observed in navy beanmarket class which is known to predominantly have indeterminate growth habit compared to other market classes.

Days to maturity consist of days to flowering and duration of the flowering period (Singh, 1991). Reduction in time to maturity in genotypes under drought stress could be a mechanism to escape terminal drought (Terán and Sigh, 2002). This may explain the early maturity of Katumani bean varieties (KATB9 and KATB1) and GLP lines (GLPx92 and GLP1004) which were initially developed for drought tolerance in Kenya. However, higher yields were associated with long maturing lines. In this study, nearly all high yielding varieties across market classes were among the latest maturing genotypes. Most of these lines performed well under drought stress and no stress conditions. Results of the second season show that high yielding lines such as BCB11-145 and BCB11-345 (red mottled), BCB11-492 and BCB11-159 (red kidney), BCB11-507 and BCB11-303 (speckled sugar),BCB11-10 and BCB11-87 (navy bean), BCB11-245 (small red),and BCB11-230 and BCB11-229 (mixed colour) all were amongst late maturing lines. Similar results were reported by Munyasa (2013). Beebe et al. (1998) found that mean days to maturity in bean lines varied from 74to 90 days and from 73 to 79 days in the non-stress and stress environments, respectively. They also found that lines with longer days to flowering and days to maturity tended to have higher yield in the non-stress environments. According to White and Singh (1991) selection for early maturity resulted in lower yields – yield potential was decreased by 72 kg ha^{-1} for each day less in maturity. Therefore, selection for other mechanisms other than accelerated maturity would probably aid in identifying drought tolerant genotypes in dry beans.

Anthracnose was found to be the most prevalent disease and cause severe damage to dry beans. The high severity of anthracnose in Kabete was probably due to high inoculums and presence of the favorable conditions for disease development. Under favorable conditions, the disease can cause 90% yield loss (Schwartz et al., 1981). Nkalubo *et al.* (2007) found that yield reduction among anthracnose susceptible cultivars was about 30-45%. Consistent lower yield observed in Kabete could be due to the higher disease pressure recorded in this site as evidenced by nearly total destruction of susceptible varieties. In addition, in the first season of this study, results show that some lines that were very susceptible to disease in Kabete performed well in Thika under drought stress conditions. These lines would have been selected for drought tolerance if data on diseases were not considered. According to Farhm *et al.* (2004) pathogens that attack susceptible genotypes can mask the expression of the desired performance-based traits. They concluded that breeding for drought tolerance should incorporate selection for resistance to diseases to meet the needs of the production area.The local checks like KAT69, KATB1, KATB9, GLP2, GLP585, GLP1004, GLPx92and Miezi mbili were highly susceptible to diseases compared to the new lines. This could be due to appearance of new races of the pathogens compared to 1980s and 1990s when they were being developed.

Yield potential across environments was significantly different among advanced lines. Yield of genotypes were reduced by drought in Thika during the first season trial. Effect of drought on yield is due to adverse effects on yield components such as number of pods per plant, number of seeds per pod and seed weight (Emmam *et al.,* 2010; Gebeyehu, 2006). Under rainfed environments, the level of drought effect on the crop is determined by amount, duration, frequency and time of rainfall in relation to growth stage of the plant (Terán and Singh, 2002).According to Terán and Sigh (2002) drought stress reduced yield of beans genotypes by 60%. Reduction in yield under rainfed plots observed in this study (30%) in Thika is comparable to 40% reported previously in Thika (CIAT, 2007) and 20% reported in Mwea (Munyasa, 2013).

3.5. Conclusions

In conclusion, from the available germplasm, several lines of different market classes which showed better yields than the local commercial varieties were identified. These lines included: BCB11-159, BCB11-492, BCB11-158 (red kidney), BCB11-507, BCB11-303 (speckled sugar), BCB11-344, BCB11-245 (small red), BCB11-448, BCB11-274 (pinto and carioca), and BCB11-230 and BCB11-229 from mixed color market class. However, in red mottled market class, the yield of local variety, Kenya Umoja, was comparable with the best line BCB11-142(2863 kg ha^{-1}). Similarly, in navy market class, Mexican142 had yield potential (3010 kg ha^{-1}) comparable with the best new lines BCB11-10, BCB11-87 and BCB11-48.

The performance of the selected lines under different environments indicate that selection of dry bean lines under drought conditions and disease pressures have aided in the identification of agronomically superior lines from the available germplasm. Considering the observed substantial genetic variation in agronomic performance of these lines, evaluation of these lines for traits related to grain quality such as cooking time, water absorption, hard-shell defect and canning and sensory attributes, to identify bean lines that meet requirements of the producers and the consumers, would contribute in increasing the utilization and commercialization of the crop.

Chapter 4

Cooking time, water absorption and hard-shell defect indry bean lines

Abstract

Culinary quality of dry beans (*Phaseolus vulgaris*) determines its utilization both at household and food processing levels. Fast cooking and low incidence of hard-shell defect are desired for household consumption and processing. More than 90% water absorption capacity after soaking for 16 hours in required for beans destined for canning industry. The objective of this study was to characterize 150 advanced dry bean lines from different market classes for cooking time, water absorption and percentage of hard-shell seeds (non-soakers). Genotypes were grown in Kabete during 2012 long rain season. Cooking time was determined on seeds soaked for 16 hours in water using the Mattson bean cooker. Water absorption and hard-shell defect was determined on seeds soaked for 16 hours in tap water. The results revealed significant differences ($p<0.05$ and 0.01) among the cultivars for cooking time, water absorption and percentage of hard-shell seeds. Cooking time among cultivars varied from 24.4 minutes to 76.4 minutes. More than 70 advanced lines cooked significantly faster cooking than the control variety, Mexican142. Water absorption of the advanced lines showed distinct water absorption behaviours. Lines in speckled sugars and navy market classes had the most uniform and fastest water absorption patterns when soaked for 16 hours. In contrast, red kidney and mixed colours genotypes showed slow water absorption patterns. Water-holding capacity of the lines after 16 hours of soaking varied from 25.5% to 118.9%. The highest percentages of hard-shell seeds were recorded in small red and mixed colours market classes, while the lowest was found in red mottled and speckled sugar lines. Except for red mottled and speckled sugar genotypes, highly significant correlation ($r= 0.661^{**}$ to 0.924^{**}) was found between water absorption and hard-shell percent. No significant correlation was found between cooking time and water absorption. About thirty lines from different market classes with fast-cooking (<35 minutes), high water-holding capacity (>90%) and zero percent hard-shell seeds were identified. These lines included: BCB11-158, BCB11-196 (red kidney), BCB11-386, BCB11-414 (speckled sugar), BCB11-108 (navy), BCB11-184 (small red) and BCB11-274 (pinto). These lines with combined superior traits will contribute to increased bean production and utilization both at household and industry processing levels.

Key Words: Cooking time, water absorption, pattern, hard-shell seeds

4.1. Introduction

Legumes play an important role in human nutrition, especially among low-income human groups in developing countries. In dry beans (*Phaseolus vulgaris*), culinary factors such as cooking time, water absorption and low incidence of hard-shell seeds which are related to grain quality determine its utilization. Long cooking time is a well known problem in common beanthat leads to under utilization of the crop (Elia et al., 1997; Hosfield and Beaver 2001; Garcia et al., 2012). According to Miles and Sonde (2004) cooking time of dry beans can vary from 1½ hour to 8 hours depending on variety. Therefore, cooking time is one of the quality variables of beans in the market worldwide because the cooking process consumes fuel and time (Maryanna Maryange et al., 2010). Among bean consumers in the developing countries, this trait is very important in both urban and rural areas due to high costs of electricity, natural gas, kerosene, charcoal and high cost of getting firewood in urban and rural areas. This may result in shift to other foods with faster cooking time but less nutritious which in turn threaten the well-being of these populations.

Seed hydration is important to optimize the cooking process parameters and to obtain a product that presents desired moisture content, texture, and taste (Abu-Ghannam, 1998; Zhang and McCarthy, 2013). Several studies have indicated that bean cultivars with high water absorption capacity have fast cooking time (Elia, 2003; Boros and Wawer, 2003; Castellanos and Guzntán-Maldonado, 1994). Seed hydration is the first step required in legume processing to facilitateoperations such as cooking or canning. Food processors are interested in how fast the absorption of water can be accomplished (Masken, 2002). In the food processing industry, beans are soaked for 12-16 hours (Abu-Ghannam, 1998).

Dry bean seeds, like other legumes, are susceptible to hard-shell defect (Corrêa *et al.,* 2010; Asensio-S.-Manzanera *et al.,* 2005) under poor storage conditions which predominate in tropical climates (Stanley, 1992). This defect has negative effect on water uptake (Asensio-S.-Manzanera *et al.,* 2005) and cooking time (Balamaze *et al.,* 2010). Thus, cooking time, water absorption and percentage of hard-shell seeds are major quality factors in dry beans destined for household consumption and bean canning industry. However, a few fast cooking bean varieties have been reported in eastern African region (Kimani *et al.,* 2005). Water absorption and incidence of non-soakers were the first selection criteria used to improve canning quality of dry beans in the region (Macartney, 1966). Unfortunately, new bean varieties are often released based on their agronomic performance and little focus is given to their culinary quality attributes. The objective of this study was to characterize advanced bean lines from different market classes for their cooking time, water absorption and hard-shell seeds defect to identify genotypes that combine good agronomic performance and good grain quality.

4.2. Materials and Methods

4.2.1. Plant materials

One hundred-fifty advanced bean lines from seven market classes were selected for this study based on their agronomic performance during long rain season 2012 trials in Thika and Kabete. Each market class is represented by a number of lines and based on the seed size they were classified as large-seeded and medium/small seeded (Table 4.1). The canning industry reference variety, Mexican142, was used as a control in this study.

Table 4.1: Market classes, number of entries, seed size and center of origin of the advanced lines

Market class	Number of entry	Seed size*	Center of origin
Red mottled	23	large	Andean
Red kidney	23	large	Andean
Speckled sugar	18	large	Andean
Navy	24	small	Mesoamerican
Small red	22	small	Mesoamerican
Pinto and carioca	21	small	Mesoamerican
Mixed colours	19	Medium/small	Mesoamerican

*Small size < 25g/100 seeds; medium size 25-39g/ 100 seeds; large size >40 g/100 seeds (Singh et al., 1991)

The test lines were grown in seeds increase plots at Kabete Field Station of the University of Nairobi during the 2012 long rain season. For each genotype, around 300 g portion of seeds, which were sun dried, manually harvested, threshed and cleaned, were packed in paper bags for the study. Each sample was divided into two portions. One portion was used for cooking time evaluation. The other portion was stored at room temperature 19 °C and relative humidity (RH) of 70.7 % for evaluation of water absorption and hard-shell defect.

4.2.2. Cooking time

The apparatus used for determining the cooking time was Mattson bean cooking device (Mattson, 1946) and modified by Jackson and Varriano-Marston (1981). The apparatus has a cooking rack with 25 hollow plungers, and 25 cylindrical holes. The piercing tip of 90 g rod was in contact with surface of the bean. In the study, 24 holes were used.

From each bean sample, 30 seeds were soaked in distilled water for 16 hours at room temperature before cooking. Only seeds that imbibed water were evaluated for cooking time, because seeds that fail to imbibe water would mask the overall genetic potential of the trait in the genotype (Shellie and Hosfield, 1991). Six soaked seeds from bean samples were selected for cooking (Balamaze et al., 2008), with 24 holes of the cooker holding bean seeds from three lines of the same market class and the control variety. Then the cooker was placed into a stainless steel pan containing ≈1.4 liters of boiling distilled water (94°C). Electric hot plate (Ramtons, China) was used to heat the water. Samples were considered cooked when the tip of the plunger passed through the bean. Time to cook was recorded on a digital stop clock (Joerex, Mesuca creations, China). Temperature of the cooking water was monitored by using a thermometer. Boiling water was added to keep beans well covered as needed. The trial was repeated three times.

4.2.3. Water absorption studies

Water absorption was conducted on seed samples stored for five months. Data on temperatures and relative humidity (RH %) during storage period were recorded. Seeds were cleaned manually for any damage and foreign material. Water absorption was determined by soaking duplicate bean samples with fresh weight of 10.00 ± 0.01 g in 100 ml tap water at ambient conditions for up to 16 h. To determine water absorption patterns, the soaked beans were blotted with a paper towels and cotton clothing to remove excess water, weighed and placed back into the soaking water at time intervals of 3, 6, 9, 12, and 16 hours. Water absorption rate at each sampling time was expressed as a percentage of weight increase of the initial weight by the following formula (Bereios *et al.,* 1999): Percentage water absorption = ((Weight of soaked beans-Weight of dry beans)/ (Weight of dry beans)) X 100. Water absorption capacity was expressed as the final percent weight increase recorded after 16 hours of soaking (Corrêa *et al.*, 2010).

4.2.4. Hard-shell seeds percentage

The study was conducted on seed samples stored for five months to stimulate seed hardening defect. Seeds were cleaned manually for any damage and foreign material. Duplicate 100 seed samples were counted and soaked for 16 hours in tap water and the seeds were visually verified for water absorption.Seeds that did not absorb water were counted. The hard-shell seed percentage was expressed as ratio of grains that did not absorb water after soaking in relation to the total number (Corrêa et al., 2010).

4.2.5. Data analysis

All data were subjected to analysis of variance using GenStat software (v.13, VSN, UK, 2010). Level of significant differences was determined at $p<0.05$ and 0.01 l. Fishers LSD (0.05) was used for mean separation where significant differences were detected.

4.3. Results

4.3.1. Cooking time

Analysis of variance showed that there were highly significant differences ($p<0.01$) among genotypes for cooking time within seven market classes. Cooking time values of seven market classes are presented in Figures 4.1 to 4.7.

Cooking time of advanced lines in red mottled market class varied from 30.6 minutes in BCB11-430 to 46.3 minutes for BCB11-130, with grand mean of 37.5 minutes (Fig 4.1). Fourteen lines cooked significantly ($p<0.05$) faster than Mexican142, the control, which cooked in 41.6 minutes. The fastest cooking lines in this market class were BCB11-430, BCB11-400 BCB11-290 and BCB11-464 with cooking time of 30.6,31.4, 31.8 and 32.2 minutes, respectively.

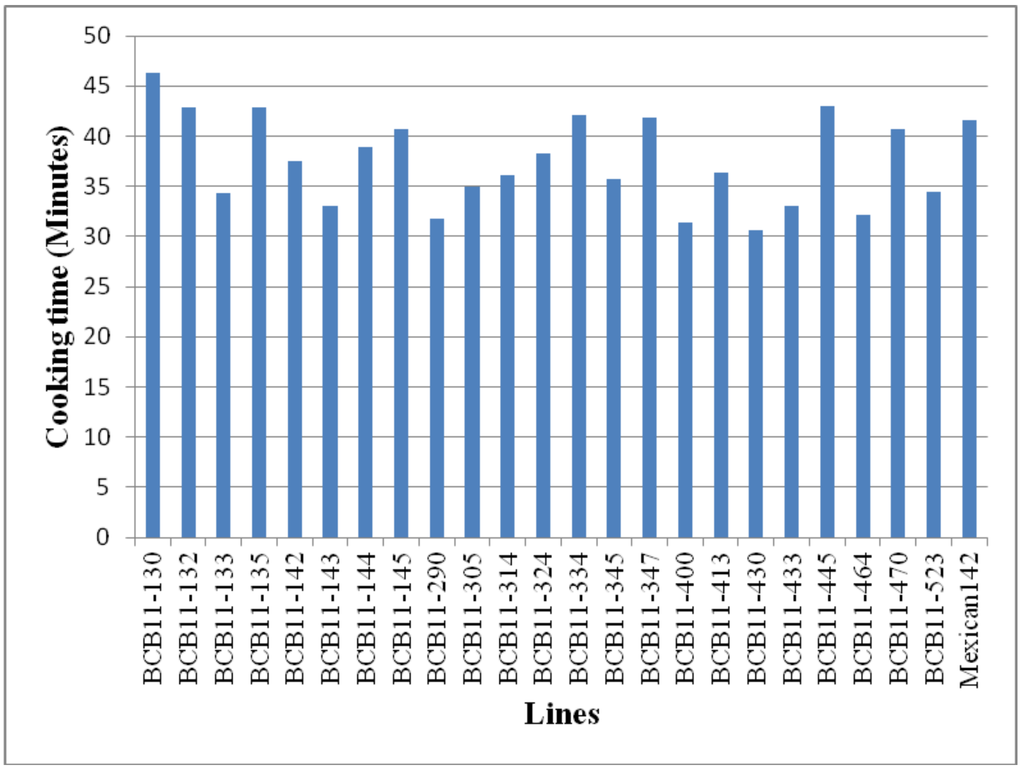

Figure 4.1: Cooking time of advanced red mottled lines.

Advanced lines of red kidney market class had cooking time which varied from 27 minutes in BCB11-327 to 48.8 minutes for BCB11-162 with a mean of 36.8 minutes (Fig 4.2). About 70% of red kidney lines cooked significantly faster than Mexican142. The fastest cooking lines were BCB11-327, BCB11-522, BCB11-509 and BCB11-337with cooking time of 27.1, 27.8, 29.6 and 31.1 minutes, respectively.

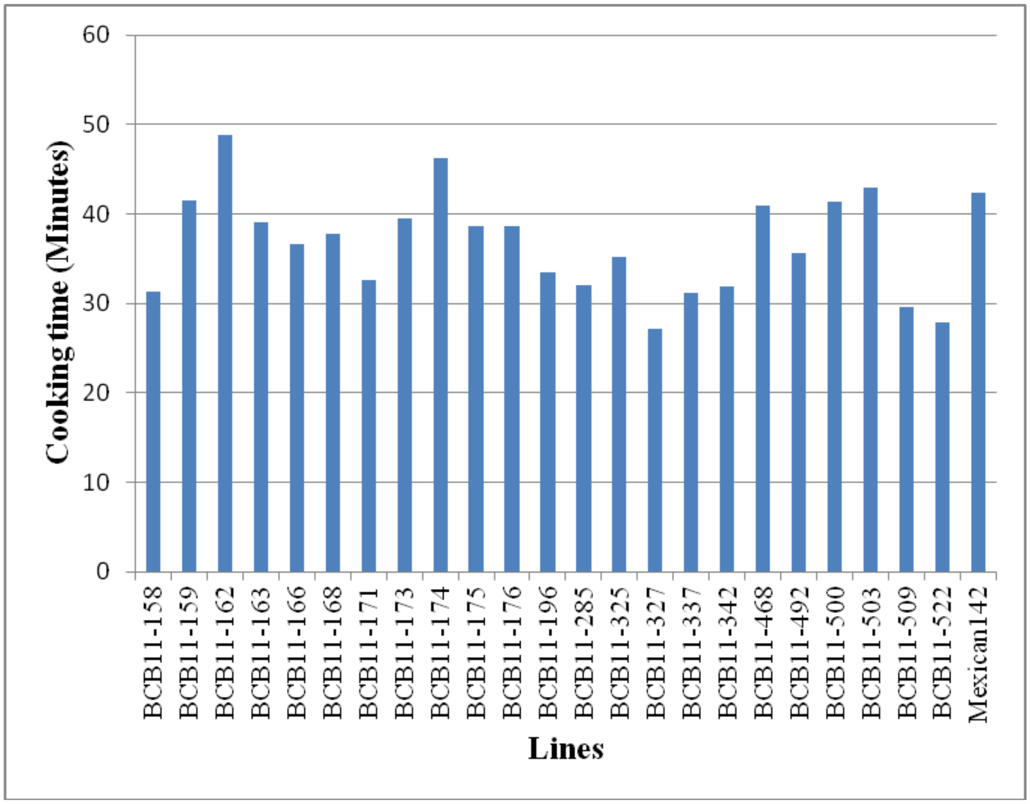

Figure 4.2: Cooking time of advanced red kidney lines

Among speckled sugar lines, cooking time ranged from 29.7 minutes in BCB11-336 to 51.5 minutes for BCB11-217 with a general mean of 36.96 minutes (Fig 4.3). Eleven lines cooked significantly ($p<0.05$) faster than Mexican142. BCB11- 336 (29.7 minutes) BCB11- 282 (30.1 minutes) and BCB11-414 (30.4 minutes) cooked fastest.

Among white navy market class, cooking time varied from 24.2 minutes in BCB11-55 to 50 minutes in BCB11-14 with general mean of 37.3 minutes (Fig 4.4). Thirteen lines cooked significantly ($p<0.05$) faster than Mexican142. The fastest cooking lines were BCB11-55, BCB11-62, BCB11-476 and BCB11-48 with cooking time 24.4, 30.4, 30.5 and 31.8 minutes, respectively.

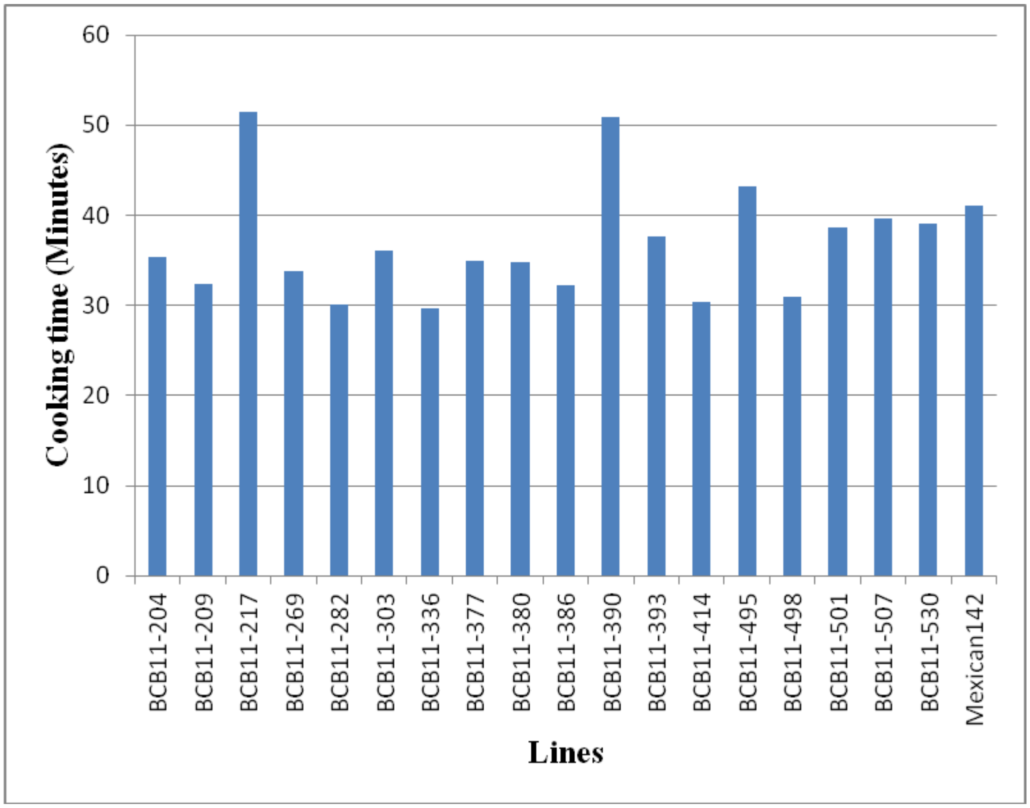

Figure 4.3: Cooking time of advanced speckled sugar lines

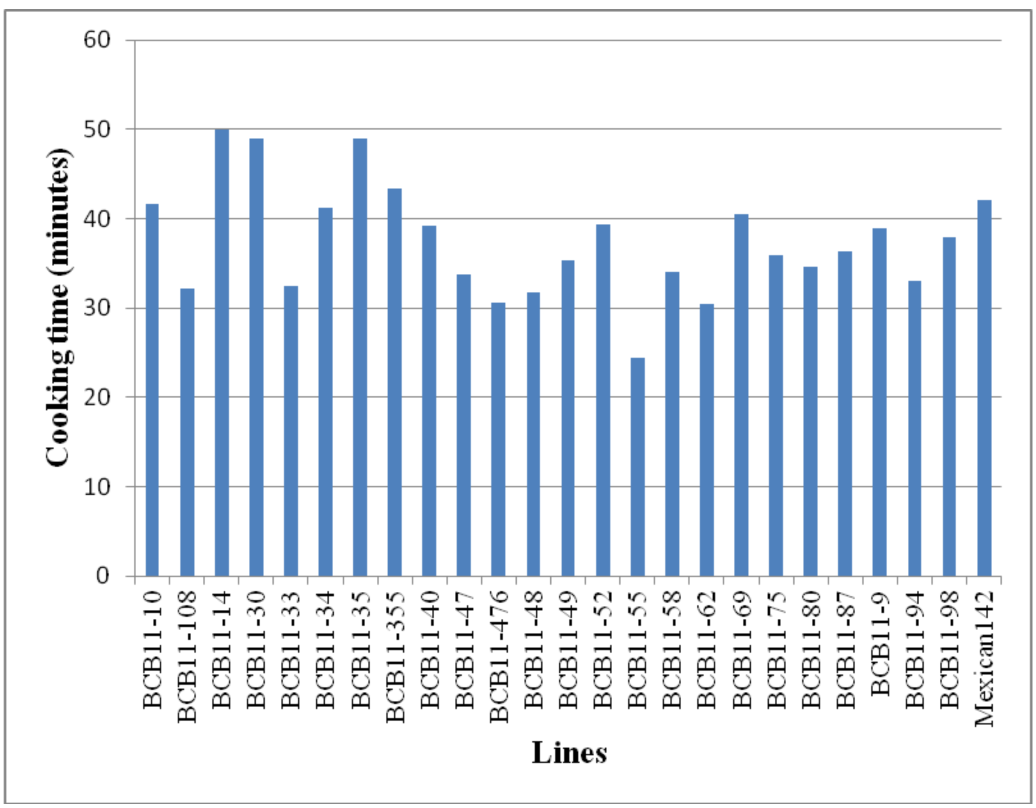

Figure 4.4: Cooking time of advanced navy bean lines

Among the small red market class lines, cooking time varied from 27.1 minutes in BCB11-191 to 52.4 in BCB11-401 with general mean of 35.74 minutes (Fig 4.5). Fifteen lines cooked significantly ($p<0.05$) faster than the control. The best four lines were BCB11-191, BCB11-197, BCB11-184 and BCB-344 with cooking time of 27.2, 28.7, 29.6 and 29.8 minutes, respectively.

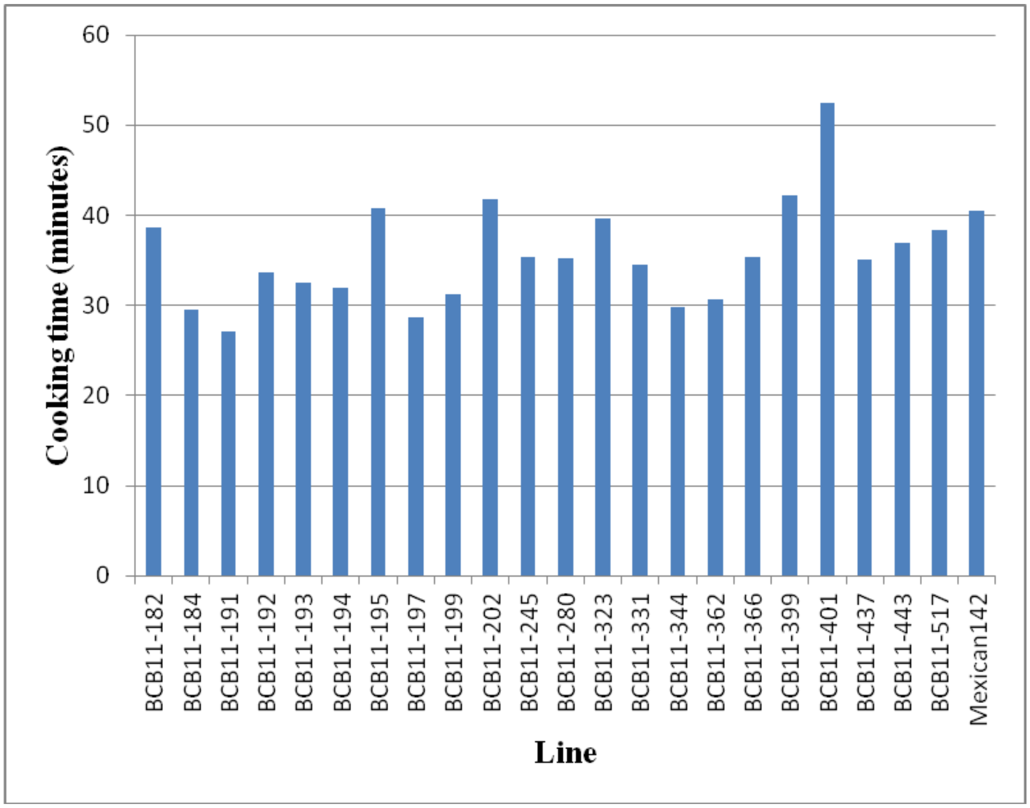

Figure 4.5: Cooking time of advanced small red line

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Among pintos and carioca market class, cooking time varied from 29.8 minutes in BCB11-448 to 53.6 minutes in BCB11-234 with mean of 37.9 minutes. Nine lines from this market class had faster cooking time than the control. The best lines were BCB11-448 (29.8 minutes), BCB11-508 (30.4 minutes) and BCB-383 (30.7 minutes) (Fig 4.6).

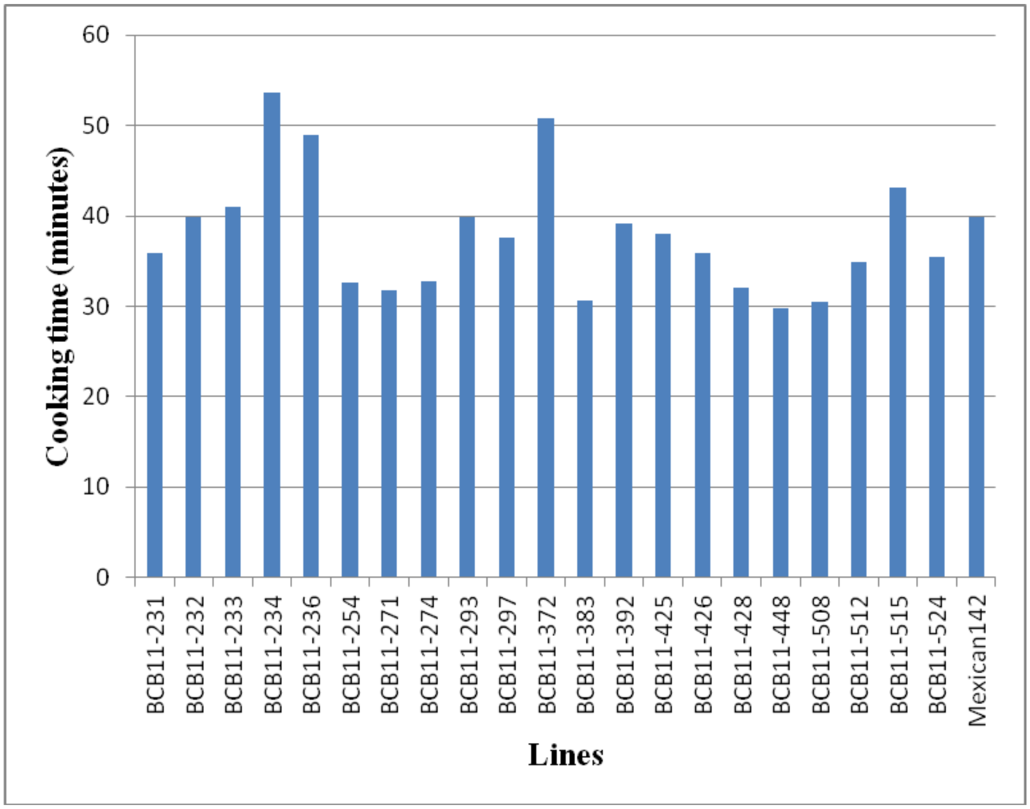

Figure 4.6: Cooking time of advanced pinto and carioca lines

Mixed coloured marked class showed the widest variation for cooking time which ranged from 25.9 minutes in BCB11-263 to 76.4 minutes for BCB11-313 with a mean of 45.5 minutes. Only two lines, BCB11-263(25.9 minutes) and BCB11-459(27.3), had significantly ($p<0.05$) faster cooking time than Mexican142 (Fig 4.7).

Between market classes, small red market class showed least cooking time of 35.7 minutes, while the longest cooking time was recorded in mixed color market class. All other market classes showed nearly similar means for cooking time.

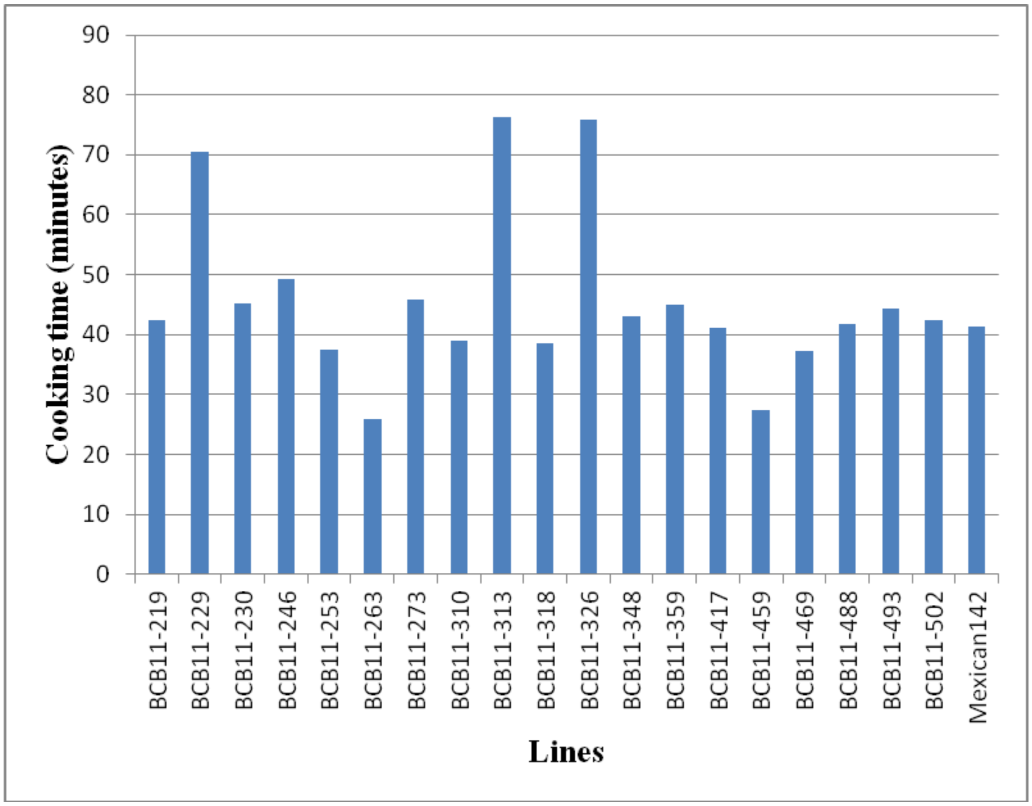

Figure 4.7: Cooking time of advanced mixed colour lines

4.3.2. Water absorption

Analysis of variance showed that there were highly significant ($p<0.01$) differences inrate of water absorption and water absorption capacity among advanced lines in all market classes except for speckled sugar market class. Within each market class, water absorption of the bean lines increased with the soaking time, but the lines presented distinct patterns of water uptake. The values for water absorption capacity and water uptake patterns of the advanced lines in seven market classes are presented in Tables 4.2 to 4.8.

Among red mottled market class, advanced lines showed various water uptake patterns during soaking period, but most lines did not differ statistically in their final water absorption capacity. Lines in this market class can be classified as medium water absorbers where 50% of the lines achieved 70% weight increase in nine hours (Table 4.2). Water absorption capacity ranged from 93.7% for BCB11-145 to 115.5% for BCB11-132. Twelve lines achieved more than 100% weight increase while Mexican142, the industry reference variety, showed water absorption capacity of 90%.

In red kidney market class, lines showed slow water absorption where 50% of the lines reached 70% weight increase in 12 hours. In comparison, Mexican142 had the third highest water uptake value (70%) in the first 6 hours, but it had the 4th lowest water uptake value after 16 hours (Table 4.3). This indicates existence of different water uptake mechanisms in dry beans during soaking period. Water absorption capacity ranged from 52.1% in BCB11-500 to 115.3% for BCB11-159.

Advanced lines in speckled sugar market class showed rapid and uniform water absorption behavior. Nearly 50% of lines achieved 70% weight increase in six hours. In nine hours, water absorption was stabilized and no significant differences ($p<0.01$) were observed among the lines in water uptake rates (Table 4.4). Water absorption capacity of speckled sugar lines ranged from 91.6% in BCB11-336 to 110.6% in BCB11-507.

Table 4.2: Water absorption (%) of red mottled bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-132	56.4	89.1	104.4	110.1	115.5
BCB11-347	7.6	22.7	47.6	76.4	107.8
BCB11-470	9.7	49.5	77.1	94.5	107.0
BCB11-464	15.0	46.8	83.3	98.9	104.9
BCB11-130	63.2	85.1	96.5	99.6	104.0
BCB11-142	16.4	52.9	84.5	95.2	103.8
BCB11-135	25.9	55.7	79.8	91.4	103.7
BCB11-290	15.8	41.6	76.9	92.3	103.5
BCB11-334	44.5	78.2	93.0	97.6	102.9
BCB11-445	10.4	28.8	64.9	89.5	101.9
BCB11-133	56.1	82.3	94.1	98.3	101.8
BCB11-314	14.7	34.3	61.0	86.2	101.4
BCB11-143	6.3	27.1	74.4	93.1	100.2
BCB11-324	22.5	66.6	89.3	95.0	100.0
BCB11-433	39.2	76.1	89.5	93.8	99.5
BCB11-413	2.1	6.9	33.9	67.5	99.2
BCB11-400	2.1	14.9	48.2	75.5	99.1
BCB11-430	38.3	72.8	88.5	92.5	98.8
BCB11-345	1.0	9.7	43.0	77.5	97.9
BCB11-305	13.9	32.5	63.5	80.5	95.5
BCB11-144	45.1	74.1	84.5	90.9	95.3
BCB11-523	8.5	23.4	44.6	60.4	95.0
BCB11-145	1.9	13.2	50.5	80.4	93.7
Mex142	39.7	72.7	82.7	86.1	89.7
Mean	22.9	47.8	72.9	88.6	101.3
CV (%)	15.5	11.3	9.1	5.4	4.4
SED	3.5	5.4	6.6	4.8	4.5
LSD(0.05)	7.4	11.2	13.7	9.9	9.3

Table 4.3: Water absorption (%) of red kidney bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-159	84.2	96.9	104.7	111.4	115.35
BCB11-166	13.9	41.1	79.1	99.6	105.43
BCB11-492	21.0	54.3	79.1	93.7	105.33
BCB11-327	9.5	25.2	59.2	96.2	104.29
BCB11-162	30.3	63.4	87.7	99.9	103.94
BCB11-285	17.2	51.8	81.3	92.8	100.90
BCB11-158	25.5	59.4	87.0	96.6	100.60
BCB11-325	9.6	32.0	67.0	95.2	100.50
BCB11-503	16.6	37.2	74.0	94.9	100.50
BCB11-173	13.9	32.9	60.8	92.5	100.30
BCB11-171	63.8	80.9	86.6	97.2	99.50
BCB11-174	33.3	64.6	87.4	95.8	99.40
BCB11-176	14.3	47.1	80.2	96.8	99.25
BCB11-468	15.6	36.6	65.5	91.1	98.40
BCB11-337	6.5	19.5	49.7	88.7	97.46
BCB11-175	17.4	32.5	52.6	79.6	96.81
BCB11-163	5.4	16.0	46.0	86.2	96.76
BCB11-196	7.9	28.0	56.0	86.0	94.50
BCB11-168	13.3	32.1	55.8	75.0	92.62
BCB11-342	1.9	4.7	16.5	56.9	91.09
BCB11-509	5.9	7.8	20.5	52.7	78.79
BCB11-522	1.5	4.0	11.0	38.3	69.59
BCB11-500	14.3	24.9	30.2	39.3	52.07
Mex 142	51.6	73.3	84.0	88.4	91.05
Mean	20.6	40.2	63.4	85.2	95.60
CV (%)	22.7	16.4	9.2	4.9	2.70
SED	4.7	6.6	5.9	4.1	2.60
LSD(0.05)	9.7	13.6	12.1	8.5	5.40

Navy lines showed rapid water uptake patterns in which more than 50% of the lines obtained more than 70% weight increase in six hours (Table 4.5). In this market class, water absorption capacity ranged from 78.3% in BCB11-48 to 118.9% in BCB11-35. Eight navy lines achieved water absorption capacity of more than 100% after 16 hours

Table 4.4: Water absorption (%) of speckled sugar bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-507	75.4	97.5	101.3	107.8	110.6
BCB11-217	66.2	91.8	96.4	98.9	102.1
BCB11-282	60.7	91.1	96.2	99.8	101.8
BCB11-414	57.1	94.8	99.1	98.9	101.4
BCB11-377	20.6	71.1	87.8	95.9	100.9
BCB11-380	78.2	95.6	94.9	95.2	99.0
BCB11-530	22.2	79.2	90.1	94.9	98.8
BCB11-495	82.0	92.4	94.2	94.9	97.9
BCB11-204	18.1	63.3	82.1	92.3	97.3
BCB11-209	48.0	85.2	89.3	92.9	96.1
BCB11-386	81.3	96.4	98.3	93.0	95.4
BCB11-269	9.9	59.0	80.5	90.2	95.1
BCB11-393	30.9	74.7	84.7	90.6	95.0
BCB11-303	79.2	88.5	90.1	92.2	94.4
BCB11-498	69.4	85.5	89.0	91.6	93.7
BCB11-390	73.0	86.1	88.8	91.6	93.4
BCB11-501	71.5	85.7	89.0	91.0	93.4
BCB11-336	59.2	80.6	85.6	89.2	91.6
Mex142	46.6	82.7	87.5	90.0	91.9
Mean	55.2	84.3	90.8	94.2	97.4
CV (%)	11.9	6.1	6.1	5.9	5.6
SED	6.6	5.2	5.5	5.6	5.4
LSD(0.05)	13.7	10.8	11.6	11.7	11.4

In general, genotypes in small red market class can be classified as rapid water absorbers with nearly 50% of lines achieved 70% weight increase in six hours. However, they also showed the biggest variation for water uptake patterns. In the first 3 hours, only four lines had achieved more 80% weight increase while 50% of the lines absorbed less than 20% water. In six hours, 50% of the lines had achieved more than 90% weight increase (Table 4.6). Among small red lines, water absorption capacity ranged from 25.5% in BCB11-197 to 108.8% in BCB11-184.

Table 4.5: Water absorption (%) of navy bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-35	71.8	102.5	107.2	110.8	118.9
BCB11-30	77.9	90.6	96.3	95.7	110.0
BCB11-355	83.2	93.2	96.1	98.1	109.6
BCB11-75	56.6	81.6	92.1	95.3	106.8
BCB11-40	75.3	88.0	92.2	93.7	102.4
BCB11-34	17.2	59.0	86.2	94.3	101.2
BCB11-62	61.5	83.0	89.6	92.4	101.1
BCB11-14	77.1	87.5	91.9	93.8	100.9
BCB11-94	16.4	69.2	85.1	90.9	99.3
BCB11-80	77.8	88.7	93.9	96.9	99.2
BCB11-33	27.3	76.7	87.8	93.3	98.7
BCB11-87	21.8	67.3	91.3	92.8	98.3
BCB11-476	24.1	73.4	86.4	90.7	97.4
BCB11-98	73.4	88.2	90.8	92.9	97.2
BCB11-10	67.8	84.2	88.4	89.9	96.6
BCB11-52	32.8	68.5	78.9	88.4	95.8
BCB11-108	75.4	88.2	89.5	91.1	95.1
BCB11-47	28.3	74.8	85.7	92.2	95.1
BCB11-49	21.8	57.0	70.8	79.2	88.1
BCB11-9	42.3	63.3	73.5	77.6	85.2
BCB11-55	16.2	52.0	65.8	75.7	85.1
BCB11-69	8.9	46.2	62.9	69.9	80.9
BCB11-58	31.1	52.5	63.0	73.6	80.4
BCB11-48	12.0	42.2	59.0	68.2	78.3
Mex142	44.1	79.0	87.5	89.9	94.87
Mean	45.7	74.3	84.5	89.1	96.65
CV (%)	12.9	5.7	5.4	4.1	5.20
SED	5.9	4.3	4.6	3.6	5.10
LSD(0.05)	12.2	8.8	9.4	7.5	10.40

Pinto and carioca lines showed slow water uptake patterns with 50% of the lines achieving 70% weight increase in nine hours (Table 4.7). The water absorption capacity in this market class varied from 71.3% in BCB11-383 to 107.0% in BCB11-524.

Table 4.6: Water absorption (%) of small red bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-184	85.6	101.3	104.4	107.8	108.8
BCB11-194	76.4	99.8	103.1	106.0	108.8
BCB11-401	83.3	98.1	101.7	106.4	107.5
BCB11-443	83.1	98.4	103.3	105.9	106.6
BCB11-437	79.1	96.9	100.9	104.2	105.5
BCB11-399	49.3	90.9	98.0	102.8	105.2
BCB11-280	70.7	95.2	101.0	103.6	105.2
BCB11-323	80.5	95.6	101.1	102.8	104.7
BCB11-517	74.1	91.6	97.5	101.1	102.2
BCB11-366	73.0	91.7	96.7	99.0	101.3
BCB11-362	15.7	67.0	89.5	97.1	99.7
BCB11-193	23.7	45.2	54.7	79.1	96.8
BCB11-182	15.4	45.9	69.8	87.3	93.8
BCB11-344	3.2	20.3	56.9	81.9	88.9
BCB11-192	1.9	28.4	57.0	78.2	86.1
BCB11-331	2.8	15.5	35.1	65.1	80.7
BCB11-191	44.0	55.3	60.8	69.0	75.0
BCB11-195	6.8	13.4	25.3	50.4	65.0
BCB11-199	1.2	11.6	28.5	48.2	56.6
BCB11-202	13.6	25.7	34.5	45.6	50.0
BCB11-245	1.4	3.4	10.3	32.1	46.0
BCB11-197	3.5	6.3	12.2	21.8	25.5
Mex142	46.1	80.2	87.9	90.4	91.6
Mean	40.6	59.9	70.9	82.0	87.5
CV (%)	10.4	7.2	7.0	5.7	6.5
SED	4.2	4.3	5.0	4.6	5.7
LSD(0.05)	8.8	9.0	10.3	9.6	11.7

Mixed colour market class showed the slowest pattern of water uptake with 50% of the lines reached 70% water absorption after 12 hours. Further, in contrast to all other market classes, even after 16 hours of soaking, 50% of the lines showed less 90% weight increase (Table 4.8). In this class, water absorption capacity ranged from 55.2% in BCB11-273 to 105.6% in BCB11-253. Only four lines achieved more than 100% water absorption capacity after 16 hours.

Table 4.7: Water absorption (%) of pinto and carioca bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-231	11.0	39.9	72.1	97.4	107.0
BCB11-232	93.7	100.0	102.7	104.1	106.0
BCB11-233	54.2	81.7	94.1	99.1	102.6
BCB11-234	67.6	85.6	93.0	96.2	98.9
BCB11-236	15.3	56.8	83.0	93.4	98.7
BCB11-254	16.5	55.0	82.4	90.9	97.4
BCB11-271	5.3	28.2	62.4	83.6	96.4
BCB11-274	42.9	76.1	86.3	90.6	95.2
BCB11-293	29.0	54.5	71.7	85.2	94.6
BCB11-297	6.0	26.4	59.9	84.6	94.2
BCB11-372	4.7	32.8	67.9	86.0	94.1
BCB11-383	45.7	78.7	86.3	89.7	93.4
BCB11-392	7.9	35.0	68.9	85.9	92.5
BCB11-425	6.1	41.6	70.1	82.3	88.5
BCB11-426	4.3	25.8	57.3	80.0	88.3
BCB11-428	2.8	26.9	59.4	80.2	88.2
BCB11-448	42.8	53.1	67.3	81.8	88.1
BCB11-508	30.0	67.9	80.1	84.4	88.1
BCB11-512	10.0	23.9	51.2	76.3	87.1
BCB11-515	2.0	17.4	52.1	73.9	83.7
BCB11-524	2.5	9.2	21.5	44.8	71.3
Mex142	48.0	74.8	84.0	86.8	89.7
Mean	24.9	49.6	71.5	85.3	92.9
CV (%)	23.3	10.0	6.4	4.6	3.5
SED	5.8	5.0	4.6	4.0	3.3
LSD(0.05)	12.0	10.3	9.5	8.2	6.8

Table 4.8: Water absorption (%) of pinto and carioca bean lines over 16 hours

Genotype	3 hrs	6 hrs	9 hrs	12 hrs	16 hrs
BCB11-253	78.2	101.3	103.2	104.9	105.6
BCB11-246	48.1	97.7	100.9	103.4	104.3
BCB11-488	3.6	55.5	79.3	99.3	103.0
BCB11-417	17.5	76.2	89.9	97.0	100.2
BCB11-229	4.8	53.8	80.3	92.6	98.0
BCB11-469	26.4	62.8	73.7	85.9	96.1
BCB11-230	3.5	45.2	70.9	87.9	95.2
BCB11-219	8.2	67.0	82.3	90.0	95.0
BCB11-318	1.9	29.3	58.5	79.8	94.3
BCB11-313	9.1	35.1	72.4	81.8	89.3
BCB11-263	3.3	19.4	47.9	75.5	87.6
BCB11-310	7.6	36.7	60.5	77.5	87.3
BCB11-326	1.2	13.3	43.9	63.8	79.8
BCB11-459	1.1	11.9	33.6	61.9	79.4
BCB11-348	12.9	35.4	48.5	62.9	76.9
BCB11-502	3.2	22.6	38.2	54.0	65.7
BCB11-493	3.1	22.9	33.1	46.5	59.4
BCB11-273	5.6	23.7	33.6	44.9	55.2
BCB11-359	2.1	13.7	23.9	36.2	47.3
Mex142	29.3	79.6	86.0	90.0	91.4
Mean	13.5	45.2	63.0	76.8	85.5
CV(%)	18.3	9.2	12.0	8.4	6.5
SED	2.5	4.1	7.5	4.6	5.5
LSD(0.05)	5.2	8.6	15.7	13.5	11.5

4.3.3. Hard-shell seeds

Analysis of variance showed that there were highly significant ($p<0.01$) differences inpercentage of hard-shell seeds among advanced lines in all market classes. The values for percentage of hard-shell seeds in the advanced lines of large seeded and small seed market classes are shown in Tables 4.9 and 4.10, respectively.

Among red mottled lines, only three lines showed significantly ($p<0.05$) high percentage of hard-shell seeds. BCB11-145 had the highest percentage of 16%. Mexican142, the check, had 1.5%. Among red kidney lines, five lines had significantly ($p<0.05$) high percentage of hard-shell seeds. BCB11-500 (57.5%) had highest percentage of hard-shell seeds, followed by BCB11-171 (18.6%), BCB11-522 (12.5%) and BCB11-509 (11.5%). Among speckled sugar lines, only two lines, BCB11-377 (7.5%) and BCB11-269 (2%) had high percentage of hard-shell seeds. Mexican142 had hard-shell percentage 2.5%.

Among navy bean lines, 12 lines showed high percentagehard-shell seeds. BCB11-48 had the highest (8.5%) followed by BCB11-69, BCB11-9 and Mexican142 each with 6.5%.

Small red market class presented the highest percentages of hard-shell defect compared to other market classes. Nearly half the lines had high percentages of hard-shell seeds. The highest percentages were recorded in BCB11-197, BCB11-245 and BCB11-195 with means of 68%, 58.5%, and 51.5% respectively.

Among pinto and carioca lines, only four lines had significant percentages of hard-shell seeds. The highest percentage was recorded on BCB11-271 (20.5%) followed by BCB11-383 (16.9%) and BCB11-515(14.5%). Among mixed colours lines, nine lines showed significant percentages of hard-shell seeds in which the highest was recorded in BCB11-326 (16%) followed by BCB11-493 (14.5), BCB11-359(13.5) and BCB11-273(12.5).water absorption and hard-shell percentage were highly correlate while none of the two correlated with cooking time.

Table 4.9: Hard-shell percentages among large seeded advanced lines after storage for five months at 19°C and 70.7% RH

Market classes					
Red mottled		Red kidney		Speckled sugar	
Line	hard-shell seeds %	Line	Hard-shell seeds (%)	Line	Hard-shell seeds (%)
BCB11-145	16.0	BCB11-500	57.5	BCB11-377	7.5
BCB11-314	2.5	BCB11-171	18.6	Mexican142	2.5
BCB11-523	2.5	BCB11-522	12.5	BCB11-269	2.0
Mexican142	1.5	BCB11-509	11.5	BCB11-204	0.0
BCB11-133	0.5	BCB11-492	4.0	BCB11-209	0.0
BCB11-135	0.5	BCB11-503	2.6	BCB11-217	0.0
BCB11-347	0.5	BCB11-168	2.5	BCB11-282	0.0
BCB11-470	0.5	Mexican142	2.5	BCB11-303	0.0
BCB11-130	0.0	BCB11-174	1.0	BCB11-336	0.0
BCB11-132	0.0	BCB11-342	0.6	BCB11-380	0.0
BCB11-142	0.0	BCB11-175	0.5	BCB11-386	0.0
BCB11-143	0.0	BCB11-285	0.5	BCB11-390	0.0
BCB11-144	0.0	BCB11-158	0.0	BCB11-393	0.0
BCB11-290	0.0	BCB11-159	0.0	BCB11-414	0.0
BCB11-305	0.0	BCB11-162	0.0	BCB11-495	0.0
BCB11-324	0.0	BCB11-163	0.0	BCB11-498	0.0
BCB11-334	0.0	BCB11-166	0.0	BCB11-501	0.0
BCB11-345	0.0	BCB11-173	0.0	BCB11-507	0.0
BCB11-400	0.0	BCB11-176	0.0	BCB11-530	0.0
BCB11-413	0.0	BCB11-196	0.0	—	—
BCB11-430	0.0	BCB11-325	0.0	—	—
BCB11-433	0.0	BCB11-327	0.0	—	—
BCB11-445	0.0	BCB11-337	0.0	—	—
BCB11-464	0.0	BCB11-468	0.0	—	—
Mean	1	Mean	4.8	Mean	0.63
CV (%)	37.4	CV (%)	33.45	CV (%)	36.32
LSD (0.05)	0.8	LSD (0.05)	3.29	LSD (0.05)	0.48

Table 4.10. Hard-shell percentages among small seeded advanced lines after storage for five months at 19°C and 70.7% RH

Market classes							
Navy		**Small red**		**Pinto and carioca**		**Mixed colours**	
Line	**Hard-shell seeds (%)**	**Line**	**Hard-shell seeds (%)**	**Line**	**Hard-shell seeds (%)**	**Line**	**Hard-shell seeds (%)**
BCB11-48	8.5	BCB11-197	68.0	BCB11-271	20.5	BCB11-326	16.0
BCB11-69	6.5	BCB11-245	58.5	BCB11-383	16.9	BCB11-493	14.5
BCB11-9	6.5	BCB11-195	51.5	BCB11-515	14.5	BCB11-359	13.5
Mexican142	6.5	BCB11-202	48.5	BCB11-512	5.5	BCB11-273	12.5
BCB11-49	6.0	BCB11-191	38.5	BCB11-428	3.5	BCB11-502	6.5
BCB11-47	5.0	BCB11-193	27.5	BCB11-293	3.0	BCB11-348	5.0
BCB11-58	4.0	BCB11-199	26.0	Mexican142	3.0	BCB11-313	2.0
BCB11-52	3.5	BCB11-192	14.5	BCB11-425	2.0	BCB11-469	2.0
BCB11-34	3.0	BCB11-331	9.0	BCB11-508	1.0	BCB11-459	1.5
BCB11-80	2.5	BCB11-182	7.5	BCB11-231	0.0	BCB11-263	1.0
BCB11-33	2.0	BCB11-344	5.0	BCB11-232	0.0	Mexican142	1.0
BCB11-55	2.0	BCB11-517	5.0	BCB11-233	0.0	BCB11-219	0.0
BCB11-62	2.0	BCB11-323	2.5	BCB11-234	0.0	BCB11-229	0.0
BCB11-87	1.0	BCB11-366	2.5	BCB11-236	0.0	BCB11-230	0.0
BCB11-10	0.0	Mexican142	2.5	BCB11-254	0.0	BCB11-246	0.0
BCB11-108	0.0	BCB11-362	0.5	BCB11-274	0.0	BCB11-253	0.0
BCB11-14	0.0	BCB11-399	0.5	BCB11-297	0.0	BCB11-310	0.0
BCB11-30	0.0	BCB11-184	0.0	BCB11-372	0.0	BCB11-318	0.0
BCB11-35	0.0	BCB11-194	0.0	BCB11-392	0.0	BCB11-417	0.0
BCB11-355	0.0	BCB11-280	0.0	BCB11-426	0.0	BCB11-488	0.0
BCB11-40	0.0	BCB11-401	0.0	BCB11-448	0.0	—	—
BCB11-476	0.0	BCB11-437	0.0	BCB11-524	0.0	—	—
BCB11-75	0.0	BCB11-443	0.0	—	—	—	—
BCB11-94	0.0	—	—	—	—	—	—
BCB11-98	0.0	—	—	—	—	—	—
Mean	2.4	Mean	16	Mean	3.2	Mean	3.8
CV (%)	32.82	CV (%)	16.89	CV (%)	17.2	CV (%)	15.1
LSD (0.05)	1.6	LSD (0.05)	5.59	LSD (0.05)	1.1	LSD (0.05)	1.2

Table 4.11. Correlation matrix between culinary quality properties of advanced lines in seven market classes

Market class		1	2	3
Red mottled	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	-0.46	1	
	3- Cooking time (min)	0.144	0.260	1
		1	2	3
Red kidney	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	-0.805**	1	
	3- Cooking time (min)	0.017	0.156	1
		1	2	3
Speckled sugar	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	0.060	1	
	3- Cooking time (min)	-0.057	0.085	1
		1	2	3
Navy	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	-0.728**	1	
	3- Cooking time (min)	-0.186	0.157	1
		1	2	3
Small red	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	-0.924**	1	
	3- Cooking time (min)	-0.182	0.218	1
		1	2	3
Pinto carioca	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	-0.661**	1	
	3- Cooking time (min)	-0.248	0.281	1
		1	2	3
Mixed colours	1- Non-soakers (%)	1		
	2- Water-holding capacity (%)	-0.836**	1	
	3- Cooking time (min)	0.294	0.003	1

* Correlation is significant at p<0.05
** Correlation is significant at p<0.01

4.4. Discussion

The observed variation in cooking time of the advanced lines in the different market classes may be caused by several factors such as energy source, type of cooking water, environment, age of beans and genetics of the lines among others (Shivachi*et al.*, 2012). Since most of these factors were considered constant during the experiment, the observed variation in cooking time could be attributed to factors which are genetically inherent in bean seeds.

Although the advanced bean lines can be categorized in market classes based on seed size, results showed that seed size had no effect on cooking time because some large and small seeded market classes showed almost the same cooking time means. In addition, in both groups, lines that either took long time to cook or cooked fast were found, suggesting differences in other seed-based factors are responsible for differences in cooking time in dry beans. It was expected that small seeded types, which have larger surface area per unit mass, to cook faster than large seeded types. Results of this study are in agreement with findings reported by Mkanda (2007), Boros and Wawer (2000) who found no relationship between seed size and cooking time among dry bean varieties.

The range of variation in cooking time found in this study is comparable to findings of other researchers. Elia (2003) found that cooking time ranged from 30.5 to 46.5 minutes among F_4 progenies of dry beans. Similar results were reported by Shellie and Hosfield (1991) who found a range of 34 to 46 minutes among ten dry bean genotypes. A range of 19.5 to 41.7 minutes was reported by Shimelis and Rakshit (2005). A relatively wider range of 29 to 83 minutes was reported among 32 dry bean genotypes by Maryanna-Maryange et al., (2010).

The variation in cooking time is most frequently related to presence of hard-to-cook defect (Stanley, 1992; Balameze et al., 2008). This defect is related to inability of cotyledons to be hydrated during cooking (Nasar-Abbas et al. 2008). Since only hydrated seeds were used in the study, other factors that have not been measured in the present study may have contributed to the variation in cooking time within each market class. Chemical composition of legume seeds has been reported to influence cooking time. Elia et al. (1997) found that cooking time of dry beans correlated negatively with protein content while correlated positively with tannin content. Balamaze et al. (2008) found significant positive correlation between lignin content and cooking time in dry bean cultivars (r= 0.72).Casaňas et al.(2002) found that higher percentage loses of some seed coat components (dietary fiber, soluble dietary fiber, celluloseand pectin) during cooking in dry bean variety led to more break down of the seed coat, which probably lead to shortened time to soften other components of the seed.

The large variation in cooking time recorded among mixed colour market class compared to other market classes may be due to variation in physical and chemical properties of seeds. This group of lines contains different seed sizes (medium/small) and colours such as black, brown, yellow, grayish-green, beige and tan red/brown. Differences in cooking time due to seed colour have been reported. Shivachi*et al.* (2012) found that among Dolichos genotypes, the longest cooking time was recorded on black genotypes. Similar findings were reported by Fasoyiro et al. (2005) in pigeon peas.

On the other hand, the control variety Mexican142 was found to be slow cooking variety (≥ 40 minutes) when compared to most of advanced lines from the different market classes. In a study by Lunjalu (2007) on cooking time of 37 dry bean varieties, more than 10 were significantly faster-cooking than Mexican142. The explanation of popularity of this long-cooking variety in the region, especially in food processing industry, could be that this variety is the only bean variety with known canning quality developed since 1960s (Leakey 1970). Moreover, the standard thermal processing under high temperature (115.6°C) for 45 minutes used in the canning industry are enough to eliminate the long-cooking trait (Stanley, 1992).

Advanced bean lines from seven market classes showed genetic variation for water uptake patterns and water absorption capacity after 16 hours of soaking at room temperature. Across market classes, three types of water absorption behaviors were observed: rapid (70% water absorption in 6 hours), intermediate (70% water absorption in 9 hours) and slow water absorption (70% water absorption in 12 hours or more). Similar behavior was found in legume seeds by other studies (Lunjalu, 2007; Piergiovanni, 2011). Water uptake curves of the advanced lines showed exponentially increasing rate of water uptakebut slowed in the later stages. These results are in agreement with other reports on water absorption of dry bean and other legumes (Abu-Ghannam, 1998; Wang *et al.*, 2003; Berrios*et al.,* 1999; Sayar*et al.,* 2001). Across genotypes, range for water absorption capacity was 25.5% to 118.9%. Corrêa *et al.*, (2010) found that water absorption of seven common bean cultivars after 16 hours ranged from 100.33% to 120.33 %. A range from 98 to 117 among six white bean cultivars was reported by Santalla *et al.*(1999). Jacinto-Hernández *et al.* (2012) found that among 16 dry bean RILs, water absorption capacity ranged from 20 to 88% after 18 hours of soaking.

The observed variation in waster absorption may be due to various factors which influence water absorption of beans. Stanley, (1992) suggested that seed coat components such as cellulose, hemicellulose, and lignin has influence on water imbibitions. Studies on seed coat colour of dry beans and other legumes showed that seeds with light or white colour had faster and higher water absorption compared to dark or coloured seeds (Boros and Wawer, 2003;Jacinto-Hernández *et* *al.*, 2012; Piergiovanni, 2011).Seed coat thickness was negatively correlated withwater absorption in cowpeas (Peksen, *et al.*, 2004) and field peas (Wang *et al.*, 2003).

Hard-shell seeds were found to occur in all market classes but the small seeded ones showed the highest percentages of non-soakers. The largest numbers of lines with hard-shell defect were found in small seeded market classes. Asensio-S.-Manzanera *et al.*(2005) found significant negative correlation ($p<0.001$) between seed size and percentage of hard-shell seeds. According to Stanley et al. (1990), this correlation is due to tendency of small seeded bean to lose moisture faster than bigger ones resulting in concentration of bean hardening enzymes (phytases and poly-methyl esterases) which accelerates liginification of the beans. Overall, the percentage of hard-shell seeds found in this study is comparable to findings of other researchers. Corrêa et al., (2010) found that among seven common beans cultivars, percentage hard-shell seeds ranged from zero to 42%. In another study by Shimelis and Rakshit (2005) found that among eight bean varieties from different market classes, that were soaked for 24hrs, percentages of hard-shell seeds varied from 1.5% to 40.3% in which Mexican142 had 4.7%.

Correlation analysis showed no significant relationship between water absorption and cooking time. However, correlation between water absorption and percent hard-shell in five market classes was between $r= 0.661^{**}$ and 0.924^{**}. Red mottled and speckled sugar lines showed no significant correlation for these traits. In contrast to what was previously reported in the literature, lack of significant negative correlation between cooking time and water absorption is probably due to use of only soaked seeds in the cooking experiment in all market classes. Shellie and Hosfield (1991) did not find significant correlation between water absorption and cooking time when only soaked seeds were used for cooking time determination. Thus, it can be suggested that percentage of hard-shell seeds contribute greatly in long cooking time in dry beans. This is supported by Castellanos and Guzntán-Maldonado (1994) who suggested that selecting bean genotypes against hard-shell problem (non-soakers) is an effective way to reduce the long cooking time.

4.5. Conclusions

One hundred fifty advanced bean lines from seven market classes evaluated for cooking time, water absorption and hard-shell defect seeds showed significant differences for all traits studied. Across the advanced lines, cooking time ranged from 24.4 minutes to 76.4 minutes. Among the seven market classes studied, small reds were the fastest cooking (35.7 minutes), while mixed colours market class had the longest (45.5 minutes). More than 70 advanced lines cooked significantly faster than the control variety, Mexi142.

Water absorption of the advanced lines in seven market classes showed distinct water absorption behaviors. Lines in speckled sugars and navy market classes had the most uniform and fastest water absorption patterns while genotypes in red kidney and mixed colours market classes show slow water absorption patterns. Water absorption capacity of the lines after 16 hours of soaking ranged from 25.5% to 118.9%. Lines with the poorest water-holding capacity were found in small red and mixed colours market classes. Hard-shell defect was found to occur in all bean market classes. However, the highest percentages were recorded in small red and mixed colours market classes while the lowest was found in red mottled and speckled sugar lines. The range of hard-shell seeds varied from zero percent to 68%. A significant correlation was found only between hard-shell percentage and water-holding capacity.

This study revealed the significance of this trait in bean improvement. For instance, the line BCB11-229 was ranked the second highest yielding genotype among mixed colour market class.

If only agronomic data was used for variety selection, this lines which had the third longest cooking time (70 minutes) among all lines would have been promoted. Similarly, hard-shell evaluation showed that the small red line BCB11-245 which had the second highest yield, had also the second highest hard-shell seed percentage (59%).

Overall, more than 30 lines from different market classes with fast-cooking (<35 minutes), high water-holding capacity (>90%) and low percent hard-shell seeds (< 2%) were found. From these lines, it can be selected genotypes which combine desired agronomic traits and culinary quality. Also they can be used as parents in the future as donors of these traits. Bean varieties with superior agronomic traits and good culinary quality will contribute to increased production and utilization of beans.

Chapter 5

Canning quality of new dry bean lines

Abstract

Grain quality traits related to end-user preferences are of utmost importance for success of new bean varieties. In Kenya and other countries in eastern Africa, the bean processing industry depends on asingle variety, Mex142, a white navy bean variety. Several bean lines from different market classes with superior agronomic traits have been identified. However, their potential for use by the processing industry is not known. The objective of this study was to evaluate canning quality of dry bean lines and to identify lines that combine good agronomic and canning quality. Twenty nine advanced lines from seven market classes and the industry standard check variety Mex142 were evaluated. Beans were soaked, blanched, canned in brine and stored for three weeks, and subsequently evaluated for canning quality attributes including: hydration coefficient (HC), washed drained weight (WDWT), percentage washed drained weight (PWDWT) and texture (firmness). Physical properties (size, shape, uniformity) and visual appearance properties (splits, clumping and brine clarity) were determined subjectively using a seven point hedonic scale. Results showed significant ($p<0.05$, 0.01) differences in nearly all traits evaluated. Results showed that linessuch asBCB11-108, BCB11-80, BCB11-98(navy) BCB11-182, BCB11-344 (small reds**)**, BCB11-162, BCB11-327 (red kidneys), BCB11-324 (red mottled) had canning quality attributes which meet industry standards**.** Lines that showed poor canning quality traits such as very low HC included BCB11-245, BCB11-145 and BCB11-204. Lines with high splits included BCB11-10, BCB11-48, BCB11-184, BCB11-202, BCB11-62 and the check variety, Mexican142. Results show that lines BCB11-182 (small red), BCB11-108 (navy) BCB11-98 (navy), BCB11-162 (red kidney) and BCB11-324 (red mottled) combine good agronomic and canning quality traits. These new lines of different grain types will provide the bean processing industry with adequate raw materials and to meet the consumer preferences.

Key words: market classes, canning quality, sensory quality, hydration coefficient

5.1. Introduction

Canned beans are becoming a major form of dry bean (*Phaseolus vulgaris* L.) consumption especially in urban areas for its convenience and distinctive flavor while providing excellent consumer value (Uebersax, 2006). Bean processors have established a definite set of standards that are rigorously adhered to. They require beans to be easy to cook, processed efficiently and deliver high processor yields (Walters *et al.,* 1997). Processors are constrained by consumer preferences that have certain sensory and palatability requirements that must be met in order to be acceptable. As a result, production of beans with poor canning quality will increase the risk of producers not being able to sell their product, due to the 'bad name' that poor-quality products might develop in the market (Van der Merwe *et al.,* 2006; Van Loggerenberg, 2004). Thus, laboratory testing of canning quality is necessary for bean varieties destined for canning industry before the commercial releases of the new varieties, since producers might reject a cultivar with poor canning quality regardless of its high yields.

In Kenya, bean processors depend on a single variety, Mex142, which was selected for canning industry based on seed soakability, resistance to rust and high yield 50 years ago (Leaky, 1970). However, the variety is susceptible to rust, angular leaf spot, anthracnose and common bacterial blight, and also susceptible drought and relatively low yielding (Kimani *et al.,* 2005). This has resulted in inadequate bean supply to processors forcing them to operate below installed capacity. Supplied materials often do not meet processing standards. Little work has been done to develop improved canning bean varieties in Kenya and eastern Africa in general.Due to changing consumer preferences, urbanization and changing eating habits, demand for canned beans of other grain types such as red mottled, red kidney, speckled sugar, pinto and small red is expected to grow. In addition, bean breeding programs in the region mainly focused on agronomic characteristics and most often little consideration is given to consumer acceptability. Therefore, the objective of this study was to evaluate advanced dry bean lines of diverse market classes for canning and sensory quality.

5.2. Materials and Methods

5.2.1. Plant materials

Based on field evaluation results from the 2012 long-rain season trials at Kabete Field Station and KARI-Thika, and visual selections done across sites during 2012/2013 short-rain season, 29 advanced lines and the industry reference variety, Mexican142, were selected for this study. The advanced lines were grouped, based on seed size, into two distinct gene pools; Andean gene pool which comprises of large seeded lines (>40 g per 100-seeds), and the Mesoamerican gene pool which is characterized by medium and small seeded grain types (<40 g per 100-seed) (Singh *et al.*, 1991). Each gene pool was represented by several market classes (Table 5.1).Considering the relatively large number of genotypes selected for the study and the fact that canning quality traits are affected by the location (Van Loggerenberg, 2004; Van der Merwe *et al.* 2006; De Lange and Labuschagne, 2000),beans harvested from one location, Kabete, were used in this study.

5.2.2. Sample preparation

Sample preparation for the canning process was done at the Department of Food Science, Technology and Nutrition, College of Agriculture and Veterinary Sciences, University of Nairobi.Beans were manually cleaned for any foreign materials and damaged seeds. Initial moisture content (MC) was determined by taking 10 g samples with two replicates from each line and oven-dried at 100°C for 48 hours. Then, MC% was calculated as in AOAC (1999):

MC % = ((mass of fresh beans (g) – mass of dried beans (g)) / mass of fresh beans (g)) x 100.

Table 5.1: Gene pools and market classes of the advanced bean lines used in the study

Andean Lines	Market Classes	100-seed mass (g)	Mesoamerican Lines	Market Classes	100-seed mass (g)
BCB11-130	Red mottled	52.0	BCB11-10	White navy	25.3
BCB11-142	Red mottled	51.8	BCB11-108	White navy	22.0
BCB11-144	Red mottled	47.2	BCB11-182	Small red	23.9
BCB11-145	Red mottled	50.2	BCB11-184	Small red	20.6
BCB11-158	Red kidney	52.4	BCB11-202	Small red	23.9
BCB11-159	Red kidney	52.3	BCB11-245	Small red	24.1
BCB11-162	Red kidney	51.2	BCB11-344	Small red	21.3
BCB11-176	Red kidney	41.6	BCB11-48	White navy	25.1
BCB11-204	Speckled sugar	50.4	BCB11-512	Carioca	22.6
BCB11-303	Speckled sugar	46.7	BCB11-515	Pinto	21.9
BCB11-324	Red mottled	52.2	BCB11-62	White navy	25.0
BCB11-327	Red kidney	52.1	BCB11-80	White navy	21.1
BCB11-386	Speckled sugar	54.0	BCB11-98	White navy	23.0
BCB11-467	Speckled sugar	54.7	…………	…………	…………
BCB11-488	Yellow	54.0	…………	…………	…………
BCB11-507	Speckled sugar	51.7	…………	…………	…………

Triplicate samples of one hundred grams of bean solids were taken from each line and transferred into nylon mesh bags for canning process. To determine 100 g of bean solids, the following equation was used (Uebersax and Hosfield, 1996):

Fresh weight to yield required solids = solids required / solids at given moisture.

5.2.3. Canning process

The canning process was conducted at Njoro Canning Factory, Njoro district, Nakuru. The process of canning dry beans included the following steps: cleaning, soaking, blanching, filling and sealing, and retort cooking (Van Loggerenberg, 2004; Mekonnen, 2012; Uebersax and Hosfield, 1996) (Fig 3.1). Bean samples in coded nylon mesh bags were soaked in water containing 100 ppm of calcium ion for optimum quality evaluation (Uebersax and Hosfield, 1996). Before the soaking, samples were separated into colour groups to avoid color distortion during soaking process. Then, samples were soaked for 30 minutes in cold water (25°C) followed by blanching for 30 minutes in hot water (87° C). The temperature was monitored with hand-held electronic digital thermometer (Checktemp, model HI 98501, Hanna instruments, USA).The blanched samples were drained, weighted and transferred into M1 cans (73x110 mm). Then seeds were covered with hot brine (88°C) with a concentrations of 100 ppm Ca^{++} , 1.3 % NaCl and 1.56% sugar (Uebersax and Hosfield, 1996) and sealed with automatic can seamer (Angelus Sanitary Can Machine Co., Loss Angles, CA, USA). The sealed cans were heat sterilized in an automatic retort (Barriquand Steriflow, Roanne, France) at 115.6° C for 45 minutes followed by instant cooling. Canned beans were stored for 20 days before reopening the cans for evaluation to facilitate equilibration of bean brine (Uebersax and Hosfield, 1996).

5.2.4. Post-canning evaluation

After the storage period, all cans were weighted to record total weight, and then opened using hand-held can opener and contents poured on U.S. Standard No. 8 screen. Can products were drained at an angle and the brine was collected and the drained weight was recorded.Data was collected on hydration coefficient (HC), washed drained weight (WDWT), percentage washed drained weight (PWDWT), texture (firmness), physical properties (seed size, shape and uniformity) and visual appearance (splits, degree of clumping and brine clarity).

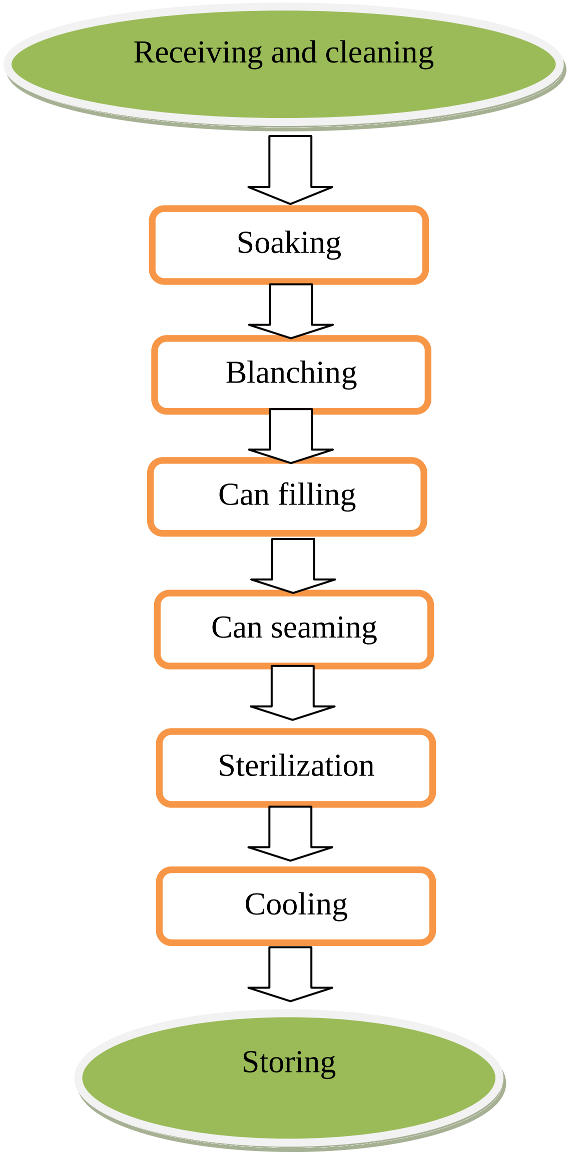

Figure 3.1: Flow chart of bean canning process

Hydration coefficient (HC): The amount of water imbibed by the seeds during soaking and blanching is quantified by the HC (Balasubramanian et al., 2000). HC is important in bean canning, as a larger quantity of beans is necessary to fill a certain can volume, when the HC ratio is low. A higher HC would therefore improve canning yield (Ghaderi et al., 1984). The following formula was used to determine hydration coefficient (Van der Merwe et al., 2006):

HC= mass of soaked beans / mass of dry beans.

Washed drained weight (WDWT) and percentage washed drained weight (PWDWT): The WDWT refers to the mass of rinsed beans drained for 2 min on a 0.239 cm screen positioned at a 15 ° angle (Hosfield et al., 1984). Drained weight of dry beans relates to "processors yield", as it would require fewer beans with a high WDWT to fill a can than in the case of beans with low WDWT. A high WDWT indicate large swelling capacity. According to (Balasubramanian et al., 2000) the PWDWT of dry beans should be at least 60 %. Percentage washed drained weight is calculated as follows (Van Loggerenberg, 2004): PWDWT = (WDWT(g) / weight of can contents (g)) x 100.

Texture: Texture is used as an indication of the degree of consumer acceptance of canned beans as it affects the perceived stimulus of chewing. Consumers usually rate texture of beans from "too soft" or "mushy" to "too firm / tough" or "hard" (Loggerenberg, 2004). Texture of canned beans is usually measured by shear press as kg force required to shear 100 g of beans. However, due to unavailability of shear press, firmness of the canned beans wasdetermined using a texture analyzer (Model TA-XT Plus, Stable Micro Systems, Surrey, UK) at Kenya Industrial Research and Development Institute (KIRDI).

Size and shape: The size of beans selected for canning purposes is an important consideration in terms of quality (Van Loggerenberg, 2004). Bean size and shape was determined subjectively using 1-7 scale (Uebersax and Hosfield, 1996). For the size, the value 1 represented very small bean and a value 7 represented very large beans. For the shape, the value 1 represented very elongated bean and value 7 represented very round beans. Size and shape of canned beans are important for the canning industry due to consumer preferences.

Uniformity: Uniformity in size, shape and color is considered among important canning quality atributes (Van Loggerenberg, 2004). This was determined subjectively using 1-7 scale (Uebersax and Hosfield, 1996). On this scale, value of 1 represents very uniform beans and value 7 represents very varied beans.

Splits: Splitting of cooked beans is one of the factors that determine the intactness of cooked beans, and is determined subjectively. Beans with splits were evaluated on scale from 1-7 (Uebersax and Hosfield, 1996). Where the value 1 represents very broken bean and value 7 represents very intact beans.

Degree of clumping: The degree of packing indicates the degree of clumping that would occur after processing, which might lead to cultivar rejection by the processor. The degree of clumping was determined subjectively using 1-7 scale (Uebersax and Hosfield, 1996). A value 1 represents a very high degree of clumping and value 7 represents very few clumps.

Brine clarity: The canned beans undergo loss of colour and solids to the canning medium. This was determined subjectively using 1-7 scale (Uebersax and Hosfield, 1996). On this scale, value of 1 represents 'very much cloudy' and value 7 represents 'very clear brine'. Very cloudy brine colour may indicate loss of colour or starch. According to Allavena (1989) canners dislike darkening of the brine due to excessive loss of pigmentation of seeds.

5.2.6. Data analysis

Canning and sensory quality data were subjected to analysis of variance using GenStat software (v.13, VSN, UK, 2010). Fisher's LSD (0.05) was used for mean separation if significant differences were detected. Pearson's correlation was calculated using SPSS software (IBM, New York, USA, version 18).

5.3. Results

The canning quality values of the advanced bean lines are presented in Tables 5.2 and 5.3. Although all genotypes were treated equally, results of canning quality of beans are reported separately based on gene pools as medium/small-seeded and large-seeded for better comparison and interpretation of the results.

Among small seeded genotypes, analysis of variance showed significant differences ($P<0.05$) for all canning quality traits studied (Table 5.2). The hydration coefficient (HC) varied from 1.4 to 2.1. BCB11-184 had the maximum hydration coefficient and BCB11-245 had the lowest hydration coefficient. Four new advanced lines achieved significantly higher HC compared to Mexican142, the standard variety. BCB11-184 (small red) and white navy lines BCB11-108, BCB11-98 and BCB11-80 had HC of 2.1, 2.0, 2.0 and 1.9, respectively

BCB11- 10 showed the highest washed drained weight (WDWT) and percentage washed drained weight (PWDWT) which was 294.4g and 71.1%, respectively among the small seeded genotypes, followed by Mexican142. The lowest PWDWT was observed in BCB11-512 which was 61.2%. Firmness (N) of beans ranged from 14.6 to 6.7. BCB11-344 had the highest score for firmness, and BCB11-184 had the lowest, with mean of 9.9 N. The control variety, Mexican142, had firmness of 6.6 Newton.

Size, shape and uniformity are physical characteristics of seeds related to canning quality. Evaluation of these parameters was conducted subjectively on a scale from 1 to 7. The size ranged from 1.7 to 3.7. BCB11-62 had the highest score and BCB11-182 the lowest. The highest value of uniformity was recorded on BCB11-515 and BCB11-245 (6.7). Mexican142 had the lowest uniformity value (3.7).

Visual appearance parameters such as splitting, clumping and brine clarity were evaluated subjectively on scale from 1 to 7. The range for the splits, clumping and brine clarity was 2.3 to 6.3, 2.7 to 6.3, and 1.7 to 7.0, respectively. The most intact canned product was showed by BCB11-245 (small red) which had highest score for splits (6.3). The white navy genotypes BCB11-80, BCB11-108 and BCB11-98 also showed high values for all visual appearance parameters.

Among large seeded genotypes, differences were significant for hydration coefficient (HC) (Table 5.3). BCB11-507 had the maximum hydration coefficient of 1.6 and BCB11-145 had the minimum value of HC (1.4). Mexican142, the white navy check variety, showed the highest HC value (1.7) compared to all large seeded genotypes (Table 5.3). Differences were significant among large-seeded genotypes for WDWT but not for PWDWT ($P< 0.05$) (Table 5.3). BCB11-176 and BCB11-327 (red kidney) and BCB11-324 (red mottled) showed high washed drained weight (WDWT) and percentage washed drained weight (PWDWT) compared to Mexican142, the check variety, achieving WDWT of 294.1g, 291.9g and 290.5, and PWDWT of 70.9%, 70.5% and 70.0% respectively. The check variety, Mexican142, had WDWT and PWDWT of 282.8 and 69.7% respectively. In general, all large seeded genotypes meet minimum standards for WDWT and PWDWT required for processing industry.

The firmness (N) of bean among large-seeded lines ranged from 11.4 in BCB11-130 to 5.6 in BCB11-386, with general mean of 8.4 N. Physical characteristics like size, shape and uniformity were evaluated subjectively on a scale from1 to 7. Among large seeded genotypes, BCB11-159 has the highest size value of 6.3 (7 indicates very large seeds), shape score of 2 (1 indicates very elongated) and lowest uniformity value of 2.7 (1 indicates very variable).

Visual appearance parameters like splitting, clumping and brine clarity were also evaluated on a scale from 1 to 7. BCB11-467 (speckled sugar) and BCB11-176 (red kidney) showed the lowest score of splitting with 2.0 and 2.7 respectively (1 indicates very broken beans). All large seeded genotypes showed brine clarity value range from 2.0 to 3.7 (1 indicates very cloudy brine). This is probably due to color loss during canning process.

Correlation analysis between canning quality attributes of the advanced lines showed a significant ($p< 0.05$ and 0.01) correlations among some traits (Table 5.3). Hydration coefficient correlated negatively with PWDWT ($r= -0.38^{*}$) and size ($r= -0.50^{**}$). This indicates that small seeded lines absorbed more water during soaking and blanching compared to large seeded ones. WDWT and PWDWT have a high positive correlation ($r= 0.8^{**}$), as expected.Both WDWT and PWDWT have significant negative correlation with firmness $r= -0.39^{*}$ and -0.48^{**} respectively. Size of the beans was found to correlate negatively to shape and uniformity ($r= -0.74^{**}$ and $r= -0.47^{*}$) respectively suggesting that small seeded genotypes had higher uniformity and rounded shape.

Table 5.2: Canning quality characteristics of small-seeded bean genotypes

Line	Market class	HC	WDWT	PWDWT	Firmness (N)	Size	Shape	Uniformity	Splits	clumping	Brine clarity
BCB11-10	Navy	1.7	294.4	71.1	8.2	2.7	2.7	4.7	2.3	5.7	6.0
BCB11-108	Navy	2.0	277.2	63.4	10.8	3.0	3.0	6.0	5.7	6.0	6.7
BCB11-182	Small red	1.8	265.6	63.3	10.2	1.7	6.0	6.0	4.0	5.0	2.7
BCB11-184	Small red	2.1	269.1	65.1	6.7	1.7	5.3	6.3	3.0	4.3	3.0
BCB11-202	Small red	1.6	276.6	67.1	10.6	2.7	5.7	5.3	2.7	3.7	3.0
BCB11-245	Small red	1.4	270.5	63.9	13.8	1.7	6.3	6.7	6.3	5.3	1.7
BCB11-344	Small red	1.6	269.0	64.8	14.6	1.7	6.0	6.0	5.3	4.3	2.3
BCB11-48	Navy	1.6	267.1	64.8	8.0	2.7	5.0	4.7	2.3	5.7	6.0
BCB11-512	Carioca	1.7	265.3	61.2	9.6	3.3	5.3	6.3	5.3	6.0	3.0
BCB11-515	Pinto	1.6	272.7	65.4	12.4	2.0	6.3	6.7	5.7	2.7	3.0
BCB11-62	Navy	1.8	273.6	67.8	8.0	3.7	5.3	5.0	3.3	6.0	6.7
BCB11-80	Navy	1.9	272.4	66.0	8.3	2.3	4.7	6.3	5.7	6.3	7.0
BCB11-98	Navy	2.0	282.2	66.2	9.5	3.0	3.0	5.7	5.7	6.3	6.7
Mex142	Navy	1.7	282.8	69.7	6.6	2.7	5.0	3.7	3.3	5.3	6.0
Mean		1.8	274.2	65.7	9.9	2.5	5.0	5.7	4.3	5.2	4.6
CV%		1.5	1.7	3.6	18.0	23.3	8.8	11.9	13.8	14.9	11.8
LSD		0.04	7.6	3.9	2.2	1.3	0.7	1.1	1.0	1.3	0.9

HC- Hydration Coefficient WDWT- washed drained weight, PWDWT- percentage washed drained weight, N- Newton

Table 5.3: Canning quality characteristics of large-seeded bean genotypes

Line	Market class	HC	WDWT	PWDWT%	Firmness (N)	Size	Shape	Uniformity	Splits	Clumping	Brine clarity
BCB11-130	Red mottled	1.5	284.0	69.0	11.4	5.3	4.0	6.0	5.7	5.7	3.0
BCB11-142	Red mottled	1.5	284.3	69.4	9.4	4.7	5.3	5.0	5.0	6.0	3.0
BCB11-144	Red mottled	1.6	279.6	65.6	10.2	5.0	3.3	5.3	4.3	6.0	2.7
BCB11-145	Red mottled	1.4	285.6	68.8	6.8	5.0	3.0	4.0	4.0	5.3	3.0
BCB11-158	Red kidney	1.5	279.9	67.6	9.9	5.3	5.0	4.0	4.0	5.7	3.7
BCB11-159	Red kidney	1.5	279.1	67.5	8.9	6.3	2.0	2.7	3.0	5.7	3.0
BCB11-162	Red kidney	1.6	284.2	68.2	8.4	6.0	2.7	5.0	5.0	5.0	2.0
BCB11-176	Red kidney	1.6	294.1	70.9	6.1	5.0	2.3	5.0	2.7	5.3	2.7
BCB11-204	Speckled sugar	1.4	278.7	71.6	8.4	5.3	3.0	5.0	4.0	4.3	2.7
BCB11-303	Speckled sugar	1.6	274.3	67.0	9.8	5.3	3.0	5.7	3.0	6.0	2.3
BCB11-324	Red mottled	1.6	290.5	70.0	9.2	5.3	3.0	5.3	5.3	5.7	3.0
BCB11-327	Red kidney	1.6	291.9	70.5	6.8	5.0	4.7	6.0	5.7	6.3	2.7
BCB11-386	Speckled sugar	1.6	281.1	67.2	5.6	5.0	2.7	5.7	5.0	6.0	3.7
BCB11-467	Speckled sugar	1.6	282.5	65.1	11.1	6.0	2.0	4.7	2.0	5.0	3.0
BCB11-488	Yellow	1.6	277.0	67.6	6.8	6.0	2.0	6.0	5.0	5.7	2.3
BCB11-507	Speckled sugar	1.6	274.4	67.8	9.7	5.3	3.0	5.0	4.0	6.0	2.7
Mex142		1.7	282.8	69.7	6.6	2.7	5.0	3.7	3.0	5.3	6.0
Mean		1.6	282.6	68.4	8.4	5.2	3.3	4.9	4.2	5.6	3.02
CV%		1.9	1.0	4.6	22.0	11.4	18.3	15	19.9	15.2	13.9
LSD		0.05	4.8	5.2	2.3	1.0	1.0	1.2	1.4	1.4	0.7

Table 5.3: Correlation matrix between canning quality parameters

	HC	WDWT	PWDWT	Firmness	size	shape	uniformity	splits	clumps	Brine Clarity
HC	1									
WDWT	-0.24	1								
PWDWT	-0.38*	0.80**	1							
Firmness	-0.15	-0.39*	-0.48**	1						
size	-0.50**	0.52**	0.49**	-0.32	1					
shape	0.10	-0.56**	-0.40*	0.41*	-0.74**	1				
uniformity	0.34	-0.38*	-0.45*	0.34	-0.47**	0.40*	1			
splits	0.02	-0.08	-0.20	0.32	-0.12	0.23	0.60*	1		
clumps	0.13	0.23	0.08	-0.33	0.34	-0.37*	-0.15	0.14	1	
Brine Clarity	0.59**	0.01	-0.03	-0.23	-0.36	0.02	-0.13	-0.09	0.35	1

* Correlation is significant at 0.05 level

** Correlation is significant at 0.01 level

5.4. Discussion

Among canning quality traits, hydration coefficient (HC) is considered one of the most important traits in bean canning industry as it indicates the amount of seeds needed to fill the can after soaking and blanching (Van Loggerenberg, 2004). HC of 1.8 to 2.0 is considered optimum by the industry and gives an indication of well-soaked beans (Balasubramanian et al., 2000). Almost all small seeded lines had HC that ranged from 1.6 to 2.0 which is somewhat comparable with results found by other researchers. Mekonnen (2012) reported that HC of five white beans ranged from 1.67 to 1.84.Hosfield & Uebersax (1980) reported that the HC of seven types of white dry beans to range from 1.82 to 1.94. The three lines with lowest HC are from small red market class. This can be due to presence of hard-shell defect which restricts water uptake. Except white navy beans, Bourne (1967) found that hard-shell defect increases as seed size decreases.

The Canadian Agricultural Products Standards Act (1978) stated that PWDWT of canned beans should be no less than 60%. In South Africa, a standard of washed drained weight (WDWT) of 272 g was reported by Van Loggerenberg (2004). All small seeded genotypes evaluated in this study meet the above standards for both WDWT and PWDWT.

The small red line BCB11-245 with the lowest HC (1.35) achieved PWDWT comparable with BCB11-80 which has HC of 1.92. This suggests that beans undergo more weight increase due to equilibration of beans and brine in the can. According to Van Loggerenberg (2004) WDWT is a function of the equilibrium of beans and brine in the can, and it is highly dependent on the moisture content of beans after soaking, the fill weight and the brine fill.

The lower HC observed among large-seeded genotypes compared to small seeded genotypes, may be attributed to differences in factors inherent in seeds.Deshpande *et al.*, (1984) reported that among ten dry bean types evaluated for water imbibitions, smaller beans, such as small white had the fastest rate of imbibitions. Del Valle *et al.*, (1992) found that seed coats of white bean are preferentially permeable to water when compared to those of black and red beans, while large red beans displayed the slowest water uptake rate. In this study, measurement of weight after soaking and blanching showed that small seeded types achieved average weight increase of 75.2% compared 54.6% recorded in large-seeded genotypes. These results are also confirmed by the observed significant negative correlation between seed size and HC. Although HC was lower among large-seeded genotypes, WDWT and PWDWT were higher than that of small seeded genotypes. This indicates that low HC leads undesired extensive water uptake and subsequent further expansion of beans in the can. According to Bolles *et al.* (1982) water uptake takes place inside the can during the first seven days after canning, due to increased water migration within the can. The undesired expansion of beans in the can be avoided by increasing soaking and blanching period for large seeded beans to achieve the desired 80% weight increase before can-filling as reported by Van Loggerenberg (2004).

Specific canning quality standards for large-seeded beans was not been found in the literature, however by comparing with the existing canning bean standards, large-seeded bean types evaluated in this study meet the 60% PWDWT (Balasubramanian et al.2000) and the WDWT of 272 g (van Loggerenberg 2004). Texture (firmness) results showed that lines that had high WDWT and PWDWT had soft textures. Similar negative relationship was reported by van Loggerenberg (2004) and De Lange and Labuschagne (2000).

Seed size and shape of common bean are determined on uncooked dry beans based on breadth thickness (B/T) ratio and the length / breadth (L/B) ratio of uncooked dry beans to indicate shape and size (Deshpande et al., 1984). Size and shape of canned beans are evaluated subjectively and they are important for the canning industry due to consumer preferences. Beans destined for canning purposes should be uniform in size with regular shape. Considering the diversity of dry beans consumed in eastern and central Africa for seed size and colour (Wortmann et al., 1998; Buruchara et al., 2011), genotypes from different bean types suitable for canning industry will contribute to commercialization of dry beans in the region.

The observed less uniformity in Mexican142 may indicate variety purity deterioration since the variety has been grown since 1960s (Leakey, 1970). Furthermore, these results explain the frequent complaints by the processing industry on the purity of existing canning beans and subsequent costs of the cleaning operations (TruFoods, personal communication).

Visual appearance of canned beans is an evaluation of the general suitability of beans for commercial processing (Hosfield & Uebersax, 1980). Canned beans are evaluated for splits, free seed coats and brine consistency (Hosfield & Uebersax, 1980). Bean genotypes that have high

PWDWT tend to split (Van Loggerenberg 2004; Balasubramanian et al.2000; Mekonnen, 2012). Results of this study confirmed these findings and the lowest scores for splits was recorded on BCB11-10 (small navy) and BCB11-176 (large red kidney) which had the highest and second highest PWDWT among small and large seeded types respectively. Overall fewer splits and clumps found in this study may be due to high concentration of Ca++ ion used in soaking and blanching water. Wang et al., (1988) found that the addition of $CaCl_2$ to the brine reduced splitting and clumping of canned navy and pinto beans.

5.5. Conclusions

The 30 bean genotypes evaluated showed significant differences for both canning quality traits which are probably due to genetic factors inherent in the genotypes. Results showed that small seeded genotypes of BCB11-108, BCB11-80, BCB11-98(white navy) and BCB11-182 (small reds) had superior canning quality attributes.Lines that showed poor canning quality traits such as very low HC included BCB11-245, BCB11-145 and BCB11-204. Also lines with high splits included BCB11-10, BCB11-48, BCB11-184, BCB11-202, BCB11-62 and the check variety, Mexican142.

Results show that lines BCB11-182 (small red), BCB11-108 (navy) BCB11-98 (navy), BCB11-162 (red kidney) and BCB11-324 (red mottled) had better canning quality compared to existing canning bean variety, Mexican142. These lines were also superior for agronomic traits compared to local varieties. These new lines will contribute to increased production and utilization of dry beans in eastern Africa region.

Chapter 6

Sensory quality evaluation of dry bean lines

Abstract

Sensory quality profile, besides agronomic traits, is of great importance for the adoption, production and consumption of the new dry bean varieties. The objective of this study was to evaluate new advanced beans, for the canning industry, for their sensory quality attributes. Twenty nine advanced lines from two distinct bean types: small seeded types (Mesoamerican gene pool) large seeded types (Andean gene pool) with each gene pool having different market classes, and the industry reference variety Mex142 were studied. Beans that were soaked, blanched, canned in brine and stored for three weeks were evaluated for sensory quality attributes.Sensory quality evaluation was done by professional panels in two food processing companies in Kenya using a 7-point hedonic scale. Sensory quality traits evaluated included: size, colour, appearance, taste, mouth-feel, flavor, wholesomeness and overall acceptability (OA). Results of the sensory evaluation revealed significant difference among genotypes in all sensory attributes at ($P<0.01$, 0.05). Among small seeded genotypes, BCB11-182, BCB11-108 and BCB11-98 were the most preferred genotypes by the panelists (like moderately to like very much) while BCB11-10 and BCB11-48 were rated low for nearly all sensory attributes. Among large seeded genotypes, BCB11-162, BCB11-176 BCB11-324 were consistently highly ranked for all sensory attributes. Out of five speckled sugar lines evaluated among large seeded genotypes, four were discriminated against by the panelists and were consistently ranked lowest for nearly all sensory quality traits. The results also suggest that speckled sugar market class is less preferred by Kenyan consumers, suggesting the importance of market oriented strategy in dry bean research programs.

Key words: Dry beans; sensory quality; gene pool; market class

6.1. Introduction

Dry bean consumers are conscious of characteristics relating to color, size, wholesomeness, texture, appearance, flavor, taste, and cooking time of bean product (Rivera *et al.*, 2013; Mkanda, 2007; Hosfield *et al.*, 1984; Mekonnen, 2012; Van Loggerenberg, 2004). Since bean growers and processors are constrained by end-user preferences, the success of any new bean variety will depend on its ability to satisfy these consumer demands. However, bean breeding programs in the region mainly focused on agronomic characteristics and most often a little consideration is given to consumer acceptability. Sensory evaluation is used to evaluate dry bean quality and its acceptability by consumers (De Castillo et al. 2012; Calvo et al. 1999; Mkanda, 2007; Mekonnen, 2012) and genetics and diversity in sensory quality attributes in dry bean has been studied (Ferreira *et al.*, 2012; Rivera *et al.*, 2013).

In Kenya, processing industry depends on single variety, Mex142, which is susceptible to major production constraints (Kimani *et al.*, 2005) resulting in inadequate bean supply for the industry or the supplied materials does not meet processing standards. In an attempt to contribute tackling with this problem, new bean lines from different market classes have been selected for drought tolerance, disease resistance and other agronomic traits. However, consumer acceptability of the canned product of these was not known. Thus, the objective of this study was to evaluate sensory quality of these new advanced lines.

6.2. Materials and methods

6.2.1. Plant materials

As described in 5.2.1

6.2.2. Sample preparation

Sensory evaluation was conducted on canned beans (5.3.3) by two groups of trained and experienced panelists from two food processing companies in Kenya, namely TruFoods Ltd (Nairobi) and Njoro Canning Factory (K) Ltd (Njoro, Nakuru). Each panel consisted of seven judges. Gender and the age of the panelist were not considered important because they were trained and the two companies serve the same market, and therefore assumed to have similar abilities to identify sensory characteristics of the product. Discussion sessions were held with the panelists and were instructed about the purpose and objective of the study. The drained canned bean product was served in coded red plastic plates (14 x 3 cm). Panelists were asked to examine the bean product subjectively and rank it on the basis of eight sensory characteristics using a seven point hedonic scale depending on intensity of sensation perceived (Appendix 23). They were asked to rinse their mouths with purified drinking water before the next sample. The two gene pools were evaluated over two days; the small seeded group was evaluated in the first day and the large-seeded group in the second day. The evaluation site was calm and lit by standard fluorescent fixtures.

6.2.3. Data analysis

Sensory quality data were subjected to analysis of variance using GenStat software (v.13, VSN, UK, 2010). Fisher's LSD (0.05) was used for mean separation if significant differences were detected. Pearson's correlation was calculated using SPSS software (IBM, New York, USA, version 18).

6.3. Results

Except for size in small seeded genotypes, analysis of variance (ANOVA) revealed highly significant differences ($p<0.01$) in sensory quality attributes among bean genotypes across gene pools, with average rating from 'dislike slightly' to 'like very much' on a 7-point hedonic scale (1=dislike very much; 7= like very much).

Among small-seeded types, BCB11-182(small red) and BCB11-108 (white navy) showed consistently higher scores for all sensory quality attributes while Mexican142 scored 'like slightly' for half of the quality attributes (Table 5.5). Genotypes BCB11-80 and BCB11-98 obtained high scores for most of sensory quality traits. In contrast, BCB11-10 (white navy) was consistently ranked low for most of sensory quality attributes, followed by BCB11-48 (white navy). BCB11-515 (pinto) received 'like very much' score only for the size. The most acceptable small seeded genotypes were BCB11-108, BCB11-182 and BCB11-98 while BCB11-10, BCB11-48 and BCB11-512 received the least scores for overall acceptability (Table 5.5). Although this group of small seeded bean consisted of different market classes, there is no indication that panelists discriminated particular market class.

Table 5.5: Means of hedonic scores for sensory quality parameters of small-seeded bean genotypes

Line	Market class	Color	Size	Appearance	Taste	Mouth-feel	Flavor	Whole-someness	Overall acceptability
BCB11-108	Navy	5.9	6.1	5.6	5.7	6	5.5	5.7	5.8
BCB11-182	Small red	6.2	6.4	6.2	6.1	5.8	5.5	5.5	5.8
BCB11-80	Navy	6.5	6.5	6.1	5.2	4.9	5.1	5.6	5.7
BCB11-98	Navy	6.4	6	5.7	5.4	5.3	5.5	5.7	5.6
BCB11-344	Small red	5.6	5.9	5.4	5.2	5.2	5.6	5.4	5.4
BCB11-62	Navy	6.2	5.7	6.1	5.3	5.6	5.7	5.4	5.4
BCB11-184	Small red	4.7	5.6	4.5	5.4	5.7	5.3	4.9	5.3
BCB11-245	Small red	5.4	6.1	5.9	5.3	5.3	5.1	5.5	5.3
BCB11-202	Small red	5.1	5.4	4.9	6	5.1	4.6	5.1	5.2
BCB11-515	Pinto	5.4	6.3	5.4	5.3	5.6	5	5.1	5.1
BCB11-48	Navy	5.2	5.2	5.1	4.6	4.6	5	4.4	4.8
BCB11-512	Carioca	4.9	5.8	5.1	5.6	5.2	4.9	5.1	4.8
BCB11-10	Navy	5.2	5.5	3.3	3.6	3.9	3.6	4.1	3.6
Mex142	Navy	5.8	5.9	5.6	4.8	4.9	4.9	5.2	4.9

Mean	5.6	5.9	5.3	5.3	5.2	5.1	5.2	5.2
CV%	15.7	14.4	18.8	19.4	17.4	16.8	16.6	15.9
LSD	0.7	0.6	0.8	0.8	0.7	0.6	0.6	0.6

Among large-seeded types, BCB11-162 and BCB11-176 (red kidney) recorded the highest for all sensory qualities (Table 5.6). BCB11-324 (red mottled) was also ranked high in nearly all traits. BCB11-159 (red kidney) was ranked low for appearance, flavor, wholesomeness, and overall acceptability. Out of five speckled sugar genotypes, four (BCB11-467, BCB11-204, BCB11-507 and BCB11-303) were ranked lowest in nearly all other sensory quality attributes. In general, BCB11-467, BCB11-159 and BCB11-204 showed the least overall acceptability scores in this group.

Table 5.6: Means of hedonic scores for sensory quality parameters of large-seeded genotypes

Line	Market class	Color	Size	Appearance	Taste	Mouth-feel	Flavor	Whole-someness	Overall acceptability
BCB11-162	Red kidney	6.3	5.9	5.8	6.4	6.0	6.1	5.7	5.9
BCB11-176	Red kidney	6.2	5.6	5.9	6.0	5.8	5.8	5.7	5.7
BCB11-324	Red mottled	6.2	5.9	5.9	5.8	5.5	5.6	5.6	5.6
BCB11-386	Speckled sugar	5.4	5.7	5.5	5.6	5.4	5.6	5.0	5.6
BCB11-158	Red kidney	5.6	5.8	5.6	5.6	5.4	5.7	5.1	5.4
BCB11-142	Red mottled	5.4	5.1	5.2	5.4	5.0	5.1	5.3	5.3
BCB11-144	Red mottled	6.1	5.2	5.9	4.8	5.3	5.2	5.3	5.3
BCB11-130	Red mottled	5.6	5.5	5.4	5.6	5.4	5.3	5.2	5.2
BCB11-488	Yellow	5.6	4.9	4.1	5.0	5.3	5.4	5.6	5.1
BCB11-145	Red mottled	5.2	5.4	3.9	5.0	4.5	4.8	4.4	4.9
BCB11-327	Red kidney	4.4	4.9	4.2	4.6	4.4	5.1	4.7	4.8
BCB11-204	Speckled sugar	2.4	4.6	3.4	4.8	4.7	4.4	4.2	3.9
BCB11-303	Speckled sugar	3.1	4.9	3.8	4.8	4.4	5.2	5.1	3.9
BCB11-507	Speckled sugar	2.9	4.7	2.9	4.5	4.9	4.2	4.9	3.9
BCB11-159	Red kidney	5.4	5.1	4.6	5.7	5.4	4.8	3.9	3.8
BCB11-467	Speckled sugar	2.9	4.6	3.6	4.3	4.1	4.4	3.9	3.3
Mex142	Navy	5.8	5.9	5.6	4.8	4.9	4.9	5.2	4.9
Mean		5.0	5.3	4.8	5.2	5.1	5.1	5	4.9
CV%		20	19.7	23.4	20.3	21	20	21.8	21.8
LSD(0.05)		0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8

6.4. Discussion

Sensory evaluationresults showed that the panelists had clear preferences for certain bean genotypes from both gene pools based on their color, size, appearance, taste, mouth-feel, flavor, wholesomeness and overall acceptability. According to Calvo *et al.*, (1999), Casanas et al. (2002), Mkanda (2007), Mekonnen (2012) trained panels of judges detected differences in sensory quality attributes among different cooked dry bean varieties.

With regard to colour, despite that coloured beans lost their original colours after processing, panelists showed significantly different preferences for colour within market classes in both gene pools. For instance, preference for colour was significantly different ($p<0.05$) between the two white navy genotypes BCB11-80 and BCB11-10, and between large red kidney genotypes BCB11-162 and BCB11-327. This may be due to differences in other traits which may contribute to the eye appeal. Van Loggerenberg, (2004) reported that intact navy beans gave brighter colour compared to broken beans. Wszelaki et al. (2005) reported texture of soybean product influenced sensory scores for taste.

In general, results do not indicate preference for particular bean size because genotypes from both small and large types were rated high. However, it is clear that speckled sugar genotypes were discriminated in nearly all traits including size. This may be due to unpopularity of this market class in Kenya. In contrast to these findings, in South Africa, Makanda (2007) found that consumers rated low a cooked bean variety for its small seed size compared to large seeded speckled sugar varieties. Speckled sugar beans are very popular in SA and account for 65-75% of the local production of dry beans (DAFF, 2010). Therefore, if this study was conducted in South

Africa, these genotypes may have scored high sensory quality. In Ethiopia, where small-seeded beans are traditionally grown and canned, a study byMekonnen (2012) showed that among five canned dry bean varieties, larger seeded variety was rated low for sensory quality by assessors. Results of this study could be an indication that seed size preference is market specific trait but Kenyan consumers are neutral for bean size preferences.

Appearance scores were significantly different ($p<0.05$) within gene pools and market classes. Lower appearance scores may be due to undesirable colour or splits or both because they are the major components of appearance **(**Van Loggerenberg, 2004). BCB11-10 (small white navy) and BCB11-467 (large speckled sugar) which score lowest appearance values had also the lowest scores for wholesomeness, and colour and wholesomeness respectively. Mekonnen (2012) showed that among five haricot beans, the variety with highest splits had the lowest sensory scores.

Taste is the most important sensory quality from the consumers' point of view and product purchase criterion (Kihlberg, 2004). High scores for taste for certain genotypes may be due to sweet taste. In cooked beans sweet taste is due to break down of complex sugars into simple sugars such as glucose and fructose. On the other hand, phenolic compounds have been reported to be possible reason for bitter taste in beans (Makanda, 2007) and may have caused the observed lower scores for taste of some genotypes. Soft texture and flavor of cooked beans has been found to be the major reason for rating a cooked bean variety high by consumers while bitter taste, soapy and metallic mouth-feel and hard texture contributed to consumers' dislike of certain bean varieties (Makanda, 2007). Casnas et al. (2002) reported that poor sensory quality of dry bean variety was due to high contents of pectins and break down of the seed coat.

Small seeded genotypes BCB11-108, BCB11-182 BCB11-80 and BCB11-98, and large seeded genotypes BCB11-162, BCB11-176 and BCB 11-324 received the highest overall acceptance scores in that order. This observation could be accredited to their good sensory qualities including colour, size, appearance, taste, mouth-feel, flavor and wholesomeness. Shivachi et al., (2012) found that among 13 Dolichos genotypes, the highest overall acceptability was recorded on the genotypes with the highest values for appearance, texture and taste.

In contrast what was expected, Mex142 variety which is 'the ruling variety' in canning industry in the region, and has been cultivated for canning purposes for its good canning and probably good sensory qualities, sensory results of this study do not reveal that superiority. This may suggest the need for comparing the most outstanding lines identified in this study and Mex142 under different locations, seasons and including tomato sauce as canning media.

6.5. Conclusion

The 30 bean genotypes evaluated showed significant differences for both canning quality traits which are probably due to genetic factors inherent in the genotypes.Lines of different market classes that had good sensory qualities has been identified. Among small seeded genotypes, BCB11-182, BCB11-108 and BCB11-98 were the most preferred genotypes by the panelists (like moderately to like very much). Among large seeded genotypes, BCB11-162, BCB11-176 BCB11-324 were consistently highly ranked for all sensory attributes. These new bean lines that combine superior agronomic performance, good canning and sensory qualities will contribute to the commercialization of dry beans in region.

Chapter 7

Iron and zinc concentrations in advanced bean lines

Abstract

Iron and zinc deficiencies pose serious health consequences such as anemia, poor growth and low productivity in adults among poor populations in the developing world. Development of micronutrient-rich staple foods such as beans, are considered the most cost effective and sustainable approach to tackle this problem. Therefore, screening for these minerals during variety development would be of a great importance. The aim of this study was to evaluate variability of iron and zinc concentrations among germplasm consisting of agronomically superior advanced lines and biofortified lines. Forty nine lines and six check varieties that were grown in Kabete during short-rain 2012/2013 were used in the study. Seeds were cleaned, dried, ground and digested with perchloric-nitric acid mixture. Iron and zinc concentration was determined using atomic absorption spectrophotometer. Significant ($p<0.001$) variation in iron and zinc contents was observed among the genotypes. The highest iron content was found in BCB11-145 (136 ppm) and the highest zinc content was found in BF08-7-74 and BF08-36-127 each with 41.2 ppm. The line BF08-13-181had the highest combination iron and zinc with 105.5 ppm and 39.5 ppm respectively. Results showed a positive and significant correlation (r=0.439***) between iron and zinc concentrations in bean genotypes. Theses genotypes have a considerable potential for improving the micronutrient nutrition by promoting consumption of cultivars rich in these nutrients. The agronomically superior lines low in these nutrients can be improved by crossing with these lines of the same market class. Rather than starting a new breeding effort, focus should be on utilization of lines identified in this study to solve the problems of malnutrition.

Key words: micronutrient malnutrition, iron, zinc, dry beans

7.1. Introduction

Iron and/or zinc deficiency is widespread in the world. About 3.7 billion people are deficient in iron (Welch, 2002), and 49% of the human population is at risk for inadequate zinc in their diet (Brown *et al.*, 2001). The problem is most severe in developing regions of the world because of consumption of energy rich diets, which are poor in minerals and proteins(Qaim *et al.*, 2007; White and Broadley, 2009; Aizat *et al.*, 2011).

The problem is further aggravated by low crop productivity, which results in inadequate food intake in rural farming communities. Traditional interventions in reducing micronutrients malnutrition in developing world have had weaknesses either in terms of sustainability, cost or coverage (Ruel and Bouis, 1998; Kimani, 2005; Qaim *et al.*,2007; White and Broadley, 2009). Biofortification is the development of micronutrient-dense staple crops using the best traditional breeding practices and modern biotechnology (Nestel *et al.*, 2006). Mineral-rich bean varieties can contribute to the alleviation of the micronutrient deficiency in Africa because bean is widely cultivated, consumed, relatively cheap compared to other sources, and complements cereal and root crop based diets (Kimani *et al.*, 2013). Bean also fits into many cropping systems. Therefore, development of bean cultivars combining high minerals with good agronomic potential and consumer preferred grain characteristics would be the best strategy to curb micronutrient malnutrition among poor populations in the region. The objective of this study was to evaluate iron and zinc concentrations in advanced dry bean lines of different grain types which have been selected for good agronomic performance.

Key words: dry beans, iron, zinc

7.2. Materials and Methods

7.2.1. Plant materials

The study materials consisted of two sets. The first set consisted of 31 advanced lines from different market classes selected for agronomic performance during short-rain 2012/2013. Due to expected narrow genetic base of the first set due to selection for other traits, a second set of 18 lines were selected from Biofort nursery which was deliberatel

y bred for higher iron and zinc (Kimani et al, 2013). Several cultivars with higher iron and/or zinc were used as checks. Only seeds that were harvested from Kabete site were used in the study (3.3.2.1.).

7.2.2. Sample preparation

Bean samples were cleaned manually for any foreign materials and washed with distilled water and were dried overnight at 85°C. Then, bean samples were ground to pass 1mm stainless steel sieve using ceramic mortar and pestle followed by further fining using iron free mill (MM 200, Retsch, Haan, Germany). The powder was stored in screw-top polycarbonate vials until digestion. All equipments were cleaned with distilled water and cotton cloth before every use.

7.2.3. Sample digestion

Digestion of the bean samples was done using the perchloric-nitric acid mixture digestion method of Zarcinas *et al* (1987). Ten milliliters of nitric acid and 1 ml of perchloric acid were added to duplicate 1.0 g bean sample in digestion tubes and the mixture was allowed to stand overnight at room temperature. Then, tubes were transferred to Gerhardt Kjeldatherm block digestion system (Gerhardt, Bonn, Germany) and heated for 1 hour at 120°C and then increased the temperature to 175°C. Towards the end of the digestion, temperature was increased to 225°C until digest cleared and complete digestion was achieved. Then digest was cooled and diluted to

50 ml with 1% V/V nitric acid and transferred into screw-top polycarbonate vials. Mineral concentration was determined with atomic absorption spectrophotometer (Spectr AA-10, Varian Techtron Pty Ltd, Mulgrave,Australia). The concentration of the standards was 2, 8 and 20 ppm for Fe and 0.5, 1 and 3 ppm for Zn. The wave length used was 248 nm and the flame was acetylene and air. Data was subjected to analysis of variance using GenStat statistical software (VSN International Ltd., UK, Version 13). pearson's correlation was calculated using SPSS software (IBM, New York, USA, version 18).

7.3. Results and Discussion

Results showed that there were significant differences ($p<0.001$) among bean genotypes for the concentrations of iron and zinc in the grains. In general, iron concentration varied from 54.5 ppm to 136ppm while zinc ranged from 19 ppm to 41.2 ppm (Table 7.1). Biofort lines had the higher means for iron and zinc compared to the advanced lines. The highest iron concentration was recorded on BCB11-145 (136 ppm), BF08-13-181(105.5 ppm), Nain de Kyondo (105.2 ppm) and BF08-1-18 (98.5 ppm). The lowest iron concentrations was found in BCB11-182 (54.5 ppm),BCB11-386 (55.8) and BCB11-184 (59.8).The highest zinc concentration was recorded in BF08-7-74 (41.2),BF08-36-127 (41.2 ppm) and BF08-13-181 (39.5 ppm).The lowest zinc concentration was recorded on BCB11-162 (19.0ppm), BCB11-515 (19.5ppm) and BCB11-386 (19.6 ppm). Bean genotypes that combined high iron and zinc included BF08-13-181, BF08-7-74, BF08-16-36 and BF08-36-18.Overall, lines from BF-08 nursery had the higher frequency of higher iron and zinc concentrations. Pearson's correlation analysis showed highly significant positive correlation ($r=0.439^{***}$) between iron and zinc concentrations in bean grains.

Results from this study compare well with the findings of other researchers. Among core collection of over 1000 bean genotypes, Beebe *et al.* (2000) found that iron and zinc concentrations in grains varied from 34 to 89 ppm and 21 to 54 ppm respectively. Kimani et al. (2006) reported a range between 59 and 131 ppm of iron and 12 and 62 ppm of zinc among bean cultivars collected from eastern Africa. A wider range of iron between 54.2 and 161.5 ppm was found by Silva *et al.* (2010) among 100 bean genotypes. The significant correlation between the two elements found in this study was also reported by previous studies. Tryphone and Nchimbi-Msolla(2010) found a correlation of $r = 0.416^{***}$. In another study, Zacharias *et al.* (2012) reported a correlation between iron and zinc of $r = 0.87^{*}$. This correlation suggests that genetic factors that increase Fe concentration co-segregate with genetic factors that increase Zn concentration. Blair *et al.* (2009) found that the two minerals were represented by a similar total number of QTL which co-localized together. They also found that inheritance of the two minerals was mainly controlled by additive genes. This may explain observed higher iron and zinc concentrations among Biofort lines which resulted from cross between parents with higher iron and zinc.

7.4. Conclusion

The findings of the study have a major implication on reducing micronutrient malnutrition problem among poor in the region.In regard to iron, the red mottled line BCB11-145 which had been selected under different stress conditions, would give a unique opportunity in reduction in iron deficiency anemia (IDA) among poor people in the region. Although high percentage of hard-shell seeds (18%) observed in this genotype may limit its utilization. In addition, mineral concentration of advanced lines with superior agronomic performance and preferred grain type can be further improved by crossing with other lines of the same market class that have higher mineral content.

Table 7.1: Grain iron and zinc concentration of advanced bean lines grown at Kabete Field Station during the 2012/2013 short rain season.

Genotype	Nursery	Market class	Iron (ppm)	Zinc (ppm)
BCB11-145	BCB11	Red mottled	136.0	22.5
BF-08-13-181	BF-08	Yellow	105.5	39.5
BF-08-1-18	BF-08	Yellow	98.5	34.8
BF-08-7-74	BF-08	Yellow	96.5	41.2
BF-08-1-47	BF-08	Yellow	96.5	31.5
BF-08-16-36	BF-08	Yellow	92.5	39.2
BF-08-36-18	BF-08	Red mottled	92.0	35.2
BF-08-7-84	BF-08	Yellow	91.0	36.5
BCB11-80	BCB11	Navy	89.5	23.2
BF-08-36-100	BF-08	Red mottled	88.8	39.2
BF-08-1-80	BF-08	Yellow	88.0	38.8
BCB11-344	BCB11	Small red	87.2	24.2
BF-08-36-205	BF-08	Red mottled	84.5	35.5
BCB11-428	BCB11	Black	84.5	21.8
BF-08-36-49	BF-08	Red mottled	82.2	38.8
BCB11-130	BCB11	Red mottled	81.5	23.8
BCB11-62	BCB11	Navy	81.2	23.8
BCB11-142	BCB11	Red mottled	81.2	22.0
BCB11-144	BCB11	Red mottled	81.2	21.2
BCB11-507	BCB11	Speckled sugar	80.8	28.9
BF-08-36-127	BF-08	Red mottled	78.2	41.2
BF-08-13-102	BF-08	Yellow	78.0	38.5
BF-08-13-121	BF-08	Yellow	77.0	36.8
BF-08-3-1	BF-08	Yellow	76.8	38.8
BCB11-108	BCB11	Navy	76.0	24.5
BCB11-204	BCB11	Speckled sugar	75.2	25.5
BF-08-26-162	BF-08	Small red	74.2	35.2
BCB11-324	BCB11	Red mottled	73.0	21.0
BF-08-1-90	BF-08	Yellow	72.5	34.0
BCB11-158	BCB11	Red kidney	70.2	22.0
BCB11-303	BCB11	Speckled sugar	69.8	27.2
BCB11-467	BCB11	Speckled sugar	69.8	22.5
BCB11-488	BCB11	Yellow	68.5	20.8
BCB11-159	BCB11	Red kidney	68.2	23.0
BCB11-48	BCB11	Navy	68.2	21.5
BCB11-202	BCB11	Small red	67.7	21.9
BCB11-98	BCB11	Navy	67.0	21.0
BF-08-36-162	BF-08	Red mottled	66.8	31.5
BCB11-176	BCB11	Red kidney	66.5	22.5
BCB11-245	BCB11	Black	66.2	24.5

BCB11-327	BCB11	Red kidney	65.0	23.8
BCB11-515	BCB11	Carioca	64.5	19.5
BCB11-512	BCB11	Pinto	62.2	20.5
BCB11-162	BCB11	Red kidney	61.8	19.0
BCB11-219	BCB11	Yellow	60.8	22.0
BCB11-301	BCB11	Black	60.3	21.4
BCB11-184	BCB11	Small red	59.8	22.8
BCB11-386	BCB11	Speckled sugar	55.8	19.6
BCB11-182	BCB11	Small red	54.5	21.5
Checks				
Nain de kyondo	-	Navy	105.2	25.8
MLB89/49	-	Black	83.5	24.2
Maharagi soja	-	Brown	83.2	25.2
MV19	-	Yellow	78.8	23.8
Mex142	-	Navy	78.5	24.5
NUA1	-	Red mottled	69.0	22.2
Mean			78.0	27.5
CV (%)			10.9	6.3
LSD(0.05)			17.1	3.5

Chapter 8

General discussion and conclusions

Agronomic performance of the bean genotypes revealed that local varieties, except Mexican142 and Kenya Umoja, are low yielding and very susceptible to droughts and diseases. On the other hand, bean lines from different market classes with tolerance to major stresses have been identified. Results of the multi-location trial in the second season identified lines from different market classes that consistently performed better than local check varieties. The best lines among red kidney market class were BCB11-159 (2771kg ha^{-1}), BCB11-492(2644kg ha^{-1}) and BCB11-158(2617kg ha^{-1}) compared to best check GLP-24 (2063kg ha^{-1}).The speckled sugar lines BCB11-507 and BCB11-303 had more than 1000 kg ha^{-1} yield advantage over the local check Miezi mbili. Among small red market class, BCB11-344 and BCB11-245 had the highest yield (>2870 kg ha^{-1}) compared to the best check GLP585 (1898 kg ha^{-1}). Among pinto and carioca genotypes, BCB11-448 and BCB11-274 recorded yield advantage of more than 900 kg ha^{-1} over the best performing check variety GLPx92. Among mixed color market class, the highest yield was recorded on BCB11-230 (2600kg ha^{-1}) and BCB11-229 (2484kg ha^{-1}) compared to checks GLP585 (1654kg ha^{-1}) and KATB1 (1126kg ha^{-1}). However, in red mottled market class, the yield of local variety Kenya Umoja (2878 kg ha^{-1}) was comparable with best line BCB11-142(2863 kg ha^{-1}). Similarly, in navy market class, the Mexican142 had yield potential (3010 kg ha^{-1}) comparable with the best lines BCB11-10 (3239kg ha^{-1}), BCB11-87 (3123kg ha^{-1}) and BCB11-48 (3072kg ha^{-1}).

Evaluation of the advanced lines identified about30 lines from different market classes with fast-cooking (<35 minutes), high water-holding capacity (>90%) and zero percent hard-shell seeds were identified. These lines included: BCB11-158, BCB11-196 (red kidney), BCB11-386, BCB11-414 (speckled sugar), BCB11-108 (navy), BCB11-184 (small red) and BCB11-274 (pinto).

Canning quality and sensory evaluation revealed that the existing canning bean variety Mexican142 had inferior qualities compared to the new lines. BCB11-182 (small red), BCB11-108 (navy) BCB11-98 (navy), BCB11-162 (red kidney) and BCB11-324 (red mottled) combined good canning and sensory qualities .Nutritional quality analysis showed considerable genetic variation for high iron and zinc. In general, test lines showed lower iron and zinc concentrations compared to biofortified lines.

Finally, to identify the genotypes that combine the most important traits, selected lines were ranked using critical weighting factors which included yield, cooking time, hard-shell defect, hydration coefficient and overall acceptability (sensory) (Table 7.1). Lines BCB11-108 (navy), BCB11-62 (navy)BCB11-344 (small red),BCB11-324 (red mottled),BCB11-80 (navy) and BCB11-303 (speckled sugar) were the best 6 lines in that order.Mexican142 was ranked 15th out of 30 genotypes. Therefore, the methodology used in this study showed that significant improvement in beans can be made by selection from the available genetic variation.

Table 8.1: Ranking of bean genotypes using critical weighting factors

Genotype	Yield	Cooking time	Had-shell	HC	Overall acceptability (OAA)	Total points*	Ranking
BCB11-108	80	40	20	40	20	200	1
BCB11-62	80	40	20	40	10	190	2
BCB11-344	80	40	20	20	10	170	3
BCB11-324	80	20	20	20	20	160	4
BCB11-80	40	40	20	40	20	160	5
BCB11-303	80	36	20	20	0	156	6
BCB11-184	40	40	20	40	10	150	7
BCB11-48	80	40	10	20	0	150	8
BCB11-144	76	20	20	20	10	146	9
BCB11-98	40	24	20	40	20	144	10
BCB11-158	60	40	20	0	20	140	11
BCB11-386	40	40	20	20	20	140	12
BCB11-142	80	20	20	0	10	130	13
BCB11-245	80	40	0	0	10	130	14
Mexican142	**80**	**14**	**15**	**20**	**0**	**129**	**15**
BCB11-507	80	6	20	20	0	126	16
BCB11-10	80	0	20	20	0	120	17
BCB11-176	24	20	20	20	20	104	18
BCB11-327	16	40	20	20	0	96	19
BCB11-204	32	40	20	0	0	92	20
BCB11-182	0	20	10	40	20	90	21
BCB11-159	68	0	20	0	0	88	22
BCB11-162	24	0	20	20	20	84	23
BCB11-512	0	40	16	20	0	76	24
BCB11-515	40	0	0	20	10	70	25
BCB11-130	28	0	20	0	10	58	26
BCB11-488	0	0	20	20	10	50	27
BCB11-145	40	0	0	0	0	40	28
BCB11-202	0	0	0	20	10	30	29
BCB11-467	0	0	0	20	0	20	30

Weights: yield=40, cooking time=20, hard-shell=10, HC=20, OAA= 10.
Targets:yield= ≥ 2800 kg ha^{-1}, cooking time= ≤35 min, Hard-shell= ≤ 5%, HC= ≥1.8, OAA= ≥5.5 score.
Scores:2= fully satisfies, 1= partially satisfies, 0= does not satisfy.
***Total points=** ∑weight x score

Recommendations

1- Further investigations on drought tolerance mechanisms and disease resistance of the elite lines identified in this study should be done under greenhouse conditions to confirm the superiority of these lines.

2- Traits such as cooking time and hard-shell defect should be considered as major selection criteria during bean variety development.

3- Future research is needed to compare these new lines with Mexican142 using tomato sauce as canning medium.

4- Factors responsible for poor canning and sensory qualities of speckled sugar lines need to be further investigated.

5- When evaluating canning quality of new lines, market class and canning process components should be taken into consideration.

6- This study provided phenotypic characterization of the germplasm for important traits. Therefore, genotypes with contrasting traits should be used in further studies on genetic behavior of these traits.

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APPENDICES

Appendix1: Days to flowering of red mottled lines grown at Kabete and Thika during 2012 long rain season

Line	Kabete	Thika	Mean
BCB11-354	42.0	37.3	39.7
BCB11-378	42.0	37.3	39.7
BCB11-147	41.8	37.8	39.8
BCB11-151	42.0	38.0	40.0
BCB11-305	41.8	38.3	40.0
BCB11-321	42.0	38.0	40.0
BCB11-302	42.3	38.8	40.5
BCB11-356	43.0	38.3	40.7
BCB11-430	42.8	38.8	40.8
BCB11-433	42.8	38.8	40.8
BCB11-333	43.0	39.0	41.0
BCB11-511	43.3	39.3	41.3
BCB11-324	43.5	39.5	41.5
BCB11-144	43.8	39.8	41.8
BCB11-283	43.5	40.0	41.8
BCB11-453	44.5	39.5	42.0
BCB11-133	43.5	41.0	42.3
BCB11-290	44.0	40.5	42.3
BCB11-135	44.5	40.5	42.5
BCB11-265	44.3	40.8	42.5
BCB11-307	44.5	40.5	42.5
BCB11-446	45.0	40.0	42.5
BCB11-464	45.0	40.0	42.5
BCB11-445	45.3	40.3	42.8
BCB11-367	45.3	40.6	42.9
BCB11-137	45.0	41.0	43.0
BCB11-312	45.0	41.0	43.0
BCB11-314	45.0	41.0	43.0
BCB11-470	45.5	40.5	43.0
BCB11-259	45.0	41.1	43.1
BCB11-130	44.3	42.3	43.3
BCB11-418	45.3	41.3	43.3
BCB11-432	45.3	41.3	43.3
BCB11-441	45.8	40.8	43.3
BCB11-420	45.5	41.5	43.5
BCB11-463	46.0	41.0	43.5
BCB11-379	45.8	41.6	43.7
BCB11-349	46.0	41.5	43.7
BCB11-136	45.8	41.8	43.8
BCB11-145	45.8	41.8	43.8
BCB11-330	45.8	41.8	43.8
BCB11-409	45.8	41.8	43.8
BCB11-523	45.8	41.8	43.8

BCB11-140	45.0	43.0	44.0
BCB11-300	45.8	42.3	44.0
BCB11-400	46.0	42.0	44.0
BCB11-449	46.5	41.5	44.0
BCB11-142	45.3	43.3	44.3
BCB11-347	46.3	42.3	44.3
BCB11-413	46.3	42.3	44.3
BCB11-506	46.8	41.8	44.3
BCB11-131	47.0	41.8	44.4
BCB11-363	46.8	42.1	44.4
BCB11-143	45.5	43.5	44.5
BCB11-141	45.8	43.8	44.8
BCB11-328	46.8	42.8	44.8
BCB11-351	47.5	42.8	45.2
BCB11-334	47.3	43.3	45.3
BCB11-132	46.8	44.3	45.5
BCB11-281	47.3	43.8	45.5
BCB11-139	47.3	44.3	45.8
BCB11-335	47.8	43.8	45.8
BCB11-134	47.3	44.8	46.0
BCB11-148	48.0	44.0	46.0
BCB11-308	48.0	44.0	46.0
BCB11-395	48.0	44.0	46.0
BCB11-155	48.8	44.8	46.8
BCB11-345	49.0	45.0	47.0
BCB11-513	49.5	45.5	47.5
Kenya Umoja	45.3	41.3	43.3
GLP2	46.5	42.5	44.5
KAT69	47.8	43.8	45.8
Mean	45.3	41.4	43.4
CV (%)	2.2		

Appendix 2: Days to flowering of red kidney lines grown at Kabete and Thika during 2012 long rain season.

Line	**Kabete**	**Thika**	**Mean**
BCB11-276	43.0	38.4	40.7
BCB11-397	43.1	38.6	40.9
BCB11-503	43.2	39.0	41.1
BCB11-325	43.5	38.9	41.2
BCB11-169	43.7	39.1	41.4
BCB11-175	43.7	39.1	41.4
BCB11-170	44.0	39.4	41.7
BCB11-402	44.1	39.6	41.9
BCB11-440	44.0	39.7	41.9
BCB11-257	44.5	39.9	42.2

BCB11-434	44.5	40.1	42.3
BCB11-176	44.7	40.1	42.4
BCB11-358	44.6	40.3	42.4
BCB11-162	44.9	40.1	42.5
BCB11-327	44.8	40.4	42.6
BCB11-173	45.0	40.4	42.7
BCB11-166	45.1	40.4	42.7
BCB11-384	45.1	40.6	42.9
BCB11-168	45.2	40.6	42.9
BCB11-473	45.2	40.7	42.9
BCB11-353	45.1	40.8	42.9
BCB11-451	45.3	41.0	43.1
BCB11-171	45.7	41.1	43.4
BCB11-174	45.7	41.1	43.4
BCB11-477	45.7	41.2	43.4
BCB11-158	45.4	43.6	43.5
BCB11-163	45.9	41.1	43.5
BCB11-266	46.0	41.4	43.7
BCB11-159	46.1	41.6	43.8
BCB11-285	46.3	41.6	43.9
BCB11-299	46.3	41.6	43.9
BCB11-157	46.0	42.3	44.2
BCB11-167	46.6	41.9	44.2
BCB11-196	46.7	42.1	44.4
BCB11-490	46.7	42.2	44.4
BCB11-406	46.9	42.3	44.6
BCB11-164	47.1	42.4	44.7
BCB11-272	47.0	42.6	44.8
BCB11-522	47.2	43.0	45.1
BCB11-394	47.4	42.8	45.1
BCB11-460	47.3	43.0	45.1
BCB11-304	47.5	42.9	45.2
BCB11-337	47.5	43.1	45.3
BCB11-509	47.4	43.2	45.3
BCB11-373	48.1	43.8	45.9
BCB11-342	48.9	44.5	46.7
BCB11-264	49.2	44.6	46.9
BCB11-500	49.2	45.0	47.1
BCB11-484	49.4	45.0	47.2
BCB11-374	49.4	45.0	47.2
BCB11-496	49.7	45.5	47.6
BCB11-468	49.8	45.5	47.6
BCB11-489	50.7	46.2	48.4
BCB11-492	51.7	47.2	49.4
GLP-24	46.7	42.5	44.6
KAT56	49.2	45.0	47.1

Mean	46.3	41.8	44.1
CV (%)	2.4		

Appendix 3: Days to flowering ofspeckled sugar lines grown at Kabete and Thikaduring 2012 long-rain season

Line	**Kabete**	**Thika**	**Mean**
BCB11-530	39.9	36.0	38.0
BCB11-382	40.0	36.1	38.1
BCB11-289	40.5	36.4	38.4
BCB11-414	40.6	36.5	38.5
BCB11-456	40.6	36.5	38.5
BCB11-498	40.9	36.5	38.7
BCB11-391	40.9	37.0	39.0
BCB11-457	41.1	37.0	39.0
BCB11-390	41.2	37.1	39.1
BCB11-371	41.3	37.1	39.2
BCB11-380	41.3	37.1	39.2
BCB11-438	41.3	37.3	39.3
BCB11-501	41.7	37.3	39.5
BCB11-516	41.4	37.5	39.5
BCB11-421	41.6	37.5	39.5
BCB11-519	41.7	37.8	39.7
BCB11-204	41.8	38.3	40.0
BCB11-424	42.3	38.3	40.3
BCB11-466	42.3	38.3	40.3
BCB11-386	42.3	38.4	40.3
BCB11-269	42.5	38.6	40.6
BCB11-474	42.8	38.5	40.7
BCB11-209	42.5	39.1	40.8
BCB11-388	43.0	38.9	40.9
BCB11-376	43.3	39.1	41.2
BCB11-495	43.4	39.0	41.2
BCB11-336	43.5	39.4	41.4
BCB11-458	44.3	40.3	42.3
BCB11-393	44.7	40.8	42.7
BCB11-217	44.5	41.1	42.8
BCB11-467	45.1	40.8	42.9
BCB11-303	45.5	41.4	43.4
BCB11-507	45.7	41.3	43.5
BCB11-267	46.0	42.6	44.3
BCB11-461	47.1	43.0	45.0
BCB11-282	47.3	43.0	45.1
BCB11-482	47.4	43.0	45.2
BCB11-514	47.7	43.3	45.5

BCB11-472	48.1	43.8	45.9
BCB11-377	48.0	43.9	45.9
BCB11-340	48.3	44.1	46.2
BCB11-370	48.3	44.1	46.2
BCB11-415	48.6	44.5	46.5
BCB11-443	49.6	45.5	47.5
Miezi Mbili	42.9	39.3	41.1
Mean	43.7	39.6	41.6
CV (%)	2.9		

Appendix 4: Days to flowering of navy lines grown at Kabete and Thika during 2012 long rain season.

Line	Kabete	Thika	Mean
BCB11-475	47.3	38.0	42.6
BCB11-70	46.0	39.5	42.8
BCB11-18	46.4	39.4	42.9
BCB11-56	45.5	40.3	42.9
BCB11-35	45.4	40.5	42.9
BCB11-71	45.8	40.5	43.1
BCB11-59	45.0	42.3	43.6
BCB11-64	46.8	40.5	43.6
BCB11-69	45.0	42.3	43.6
BCB11-74	46.5	40.8	43.6
BCB11-79	46.8	40.5	43.6
BCB11-19	46.9	40.6	43.7
BCB11-57	47.5	40.3	43.9
BCB11-75	46.5	41.3	43.9
BCB11-68	47.8	40.5	44.1
BCB11-49	46.8	42.0	44.4
BCB11-53	47.3	41.5	44.4
BCB11-427	47.9	41.3	44.6
BCB11-42	46.9	42.5	44.7
BCB11-101	47.6	41.9	44.8
BCB11-292	46.8	42.8	44.8
BCB11-47	46.5	43.3	44.9
BCB11-58	47.5	42.3	44.9
BCB11-381	48.9	41.0	44.9
BCB11-17	45.1	44.9	45.0
BCB11-61	50.3	39.8	45.0
BCB11-81	45.8	44.3	45.0
BCB11-97	45.3	44.8	45.0
BCB11-38	46.6	43.5	45.1
BCB11-410	48.6	41.5	45.1
BCB11-476	48.8	41.5	45.1
BCB11-48	47.3	43.0	45.1
BCB11-41	47.1	43.3	45.2

BCB11-55	46.5	44.0	45.3
BCB11-63	45.8	44.8	45.3
BCB11-82	50.3	44.3	45.3
BCB11-419	48.1	42.5	45.3
BCB11-14	48.6	42.3	45.4
BCB11-45	49.9	41.0	45.4
BCB11-8	49.8	41.3	45.5
BCB11-83	45.8	45.3	45.5
BCB11-29	48.4	42.7	45.5
BCB11-52	46.5	44.8	45.6
BCB11-102	49.9	41.4	45.6
BCB11-15	48.9	42.5	45.7
BCB11-411	48.4	43.0	45.7
BCB11-51	49.8	41.8	45.8
BCB11-98	51.3	40.3	45.8
BCB11-439	46.6	45.0	45.8
BCB11-275	47.6	44.1	45.9
BCB11-5	50.0	41.8	45.9
BCB11-50	46.8	45.0	45.9
BCB11-405	48.9	43.0	45.9
BCB11-286	49.9	42.1	46.0
BCB11-72	52.0	40.0	46.0
BCB11-84	51.3	45.0	46.0
BCB11-9	46.8	45.3	46.0
BCB11-444	46.4	45.8	46.1
BCB11-24	46.6	45.6	46.1
BCB11-78	45.9	46.5	46.2
BCB11-40	48.6	43.8	46.2
BCB11-44	51.1	41.3	46.2
BCB11-100	48.1	44.5	46.3
BCB11-33	48.4	44.3	46.4
BCB11-355	53.1	47.6	46.4
BCB11-287	48.4	44.4	46.4
BCB11-13	49.0	44.0	46.5
BCB11-76	51.1	42.0	46.6
BCB11-108	49.6	43.5	46.6
BCB11-46	48.9	44.3	46.6
BCB11-25	52.1	41.1	46.6
BCB11-65	52.0	41.3	46.6
BCB11-109	50.9	42.5	46.7
BCB11-16	50.6	42.8	46.7
BCB11-429	51.1	42.3	46.7
BCB11-31	50.4	43.1	46.7
BCB11-481	51.8	41.8	46.8
BCB11-34	51.1	42.6	46.9
BCB11-483	47.0	46.8	46.9

BCB11-94	48.0	45.8	46.9
BCB11-12	50.8	43.3	47.0
BCB11-80	49.8	44.3	47.0
BCB11-11	50.4	43.8	47.1
BCB11-73	48.3	46.0	47.1
BCB11-39	51.1	43.3	47.2
BCB11-20	53.4	41.1	47.2
BCB11-10	50.3	44.3	47.3
BCB11-518	49.8	44.8	47.3
BCB11-54	52.3	42.3	47.3
BCB11-103	51.4	43.2	47.3
BCB11-95	51.8	42.8	47.3
BCB11-32	49.9	44.8	47.4
BCB11-62	50.0	45.0	47.5
BCB11-87	49.3	45.8	47.5
BCB11-107	50.6	44.5	47.6
BCB11-369	52.6	42.5	47.6
BCB11-67	48.0	47.3	47.6
BCB11-92	53.5	41.8	47.6
BCB11-36	48.1	47.3	47.7
BCB11-450	51.4	44.3	47.8
BCB11-455	49.9	45.8	47.8
BCB11-30	48.6	47.1	47.9
BCB11-86	50.8	45.0	47.9
BCB11-4	49.4	46.5	47.9
BCB11-43	50.4	45.5	47.9
BCB11-37	49.1	47.0	48.1
BCB11-27	49.6	46.6	48.1
BCB11-1	50.0	46.3	48.1
BCB11-85	50.0	46.3	48.1
BCB11-104	52.1	44.3	48.2
BCB11-96	49.8	46.8	48.3
BCB11-106	51.6	45.3	48.4
BCB11-88	53.0	44.3	48.6
BCB11-105	52.4	45.0	48.7
BCB11-396	52.1	45.5	48.8
BCB11-77	51.9	46.3	49.1
BCB11-89	50.3	48.0	49.1
BCB11-23	51.1	47.9	49.5
BCB11-66	52.8	46.5	49.6
Mexican142	53.8	46.3	50.0
Mean	49.0	43.3	46.2
CV (%)	2.7		

Appendix 5: Days to flowering of small red lines grown at Kabete and Thika during 2012 long-rain season.

Line	Kabete	Thika	Mean
BCB11-399	43.5	37.8	40.6
BCB11-197	44.5	37.6	41.1
BCB11-363	44.8	39.3	42.0
BCB11-202	45.5	38.6	42.1
BCB11-528	45.0	39.1	42.1
BCB11-362	45.1	39.5	42.3
BCB11-203	45.7	38.9	42.3
BCB11-437	45.3	39.6	42.4
BCB11-401	45.5	39.8	42.6
BCB11-195	46.2	39.4	42.8
BCB11-517	45.8	40.1	42.9
BCB11-422	46.0	40.0	43.0
BCB11-194	46.5	39.6	43.1
BCB11-279	46.2	40.1	43.2
BCB11-200	47.0	40.1	43.6
BCB11-366	46.5	40.8	43.6
BCB11-182	46.6	40.8	43.7
BCB11-443	46.5	40.9	43.7
BCB11-510	46.5	40.9	43.7
BCB11-199	47.2	40.4	43.8
BCB11-245	47.2	40.4	43.8
BCB11-196	47.5	40.6	44.1
BCB11-344	47.1	41.5	44.3
BCB11-296	47.3	41.8	44.5
BCB11-478	47.5	41.9	44.7
BCB11-505	47.5	41.9	44.7
BCB11-280	47.6	42.0	44.8
BCB11-317	47.6	42.0	44.8
BCB11-251	48.3	41.6	45.0
BCB11-332	47.8	42.3	45.0
BCB11-192	48.5	41.6	45.1
BCB11-258	48.5	41.9	45.2
BCB11-184	49.1	42.5	45.8
BCB11-191	49.8	43.4	46.6
BCB11-323	49.8	44.3	47.0
BCB11-412	50.0	44.3	47.1
BCB11-193	50.7	43.9	47.3
BCB11-185	50.6	44.5	47.5
BCB11-331	50.3	44.8	47.5
BCB11-190	51.1	44.6	47.8
BCB11-529	51.0	45.1	48.1
BCB11-189	51.3	44.9	48.1
BCB11-436	51.3	45.5	48.4

KATB9	44.0	38.1	41.1
GLP585	45.8	39.9	42.8
Tio Canella	47.0	41.1	44.1
Mean	47.4	41.3	44.3
CV (%)	2.6		

Appendix 6: Days to flowering of pinto and carioca lines grown at Kabete and Thika during 2012 long rain season.

Line	**Kabete**	**Thika**	**Mean**
BCB11-372	44.1	38.5	41.3
BCB11-486	44.7	39.0	41.9
BCB11-254	45.0	38.8	41.9
BCB11-426	45.2	39.5	42.4
BCB11-480	45.7	40.0	42.9
BCB11-499	45.7	40.0	42.9
BCB11-339	45.8	40.0	42.9
BCB11-341	45.8	40.0	42.9
BCB11-392	45.8	40.3	43.0
BCB11-291	46.3	40.0	43.1
BCB11-512	46.2	40.5	43.4
BCB11-494	46.5	40.8	43.6
BCB11-237	47.0	40.3	43.6
BCB11-485	46.7	41.0	43.9
BCB11-231	47.3	40.5	43.9
BCB11-232	47.3	40.5	43.9
BCB11-233	47.3	40.5	43.9
BCB11-274	47.5	41.3	44.4
BCB11-428	47.5	41.8	44.6
BCB11-515	47.7	42.0	44.9
BCB11-320	47.8	42.0	44.9
BCB11-236	48.5	41.8	45.1
BCB11-338	48.0	42.3	45.1
BCB11-235	48.8	42.0	45.4
BCB11-408	48.3	42.8	45.5
BCB11-524	49.0	43.3	46.1
BCB11-448	49.5	43.8	46.6
BCB11-357	49.8	44.0	46.9
BCB11-521	50.0	44.3	47.1
BCB11-289	50.3	44.0	47.1
BCB11-293	50.3	44.0	47.1
BCB11-479	50.2	44.5	47.4
BCB11-491	50.2	44.5	47.4
BCB11-234	50.8	44.0	47.4
BCB11-383	50.3	44.8	47.5
BCB11-425	50.5	44.8	47.6

BCB11-297	51.3	45.5	48.4
BCB11-271	51.8	45.5	48.6
BCB11-329	51.8	46.0	48.9
BCB11-239	52.8	46.0	49.4
BCB11-350	52.3	46.5	49.4
BCB11-284	52.8	46.5	49.6
BCB11-508	54.2	48.5	51.4
GLP1004	44.7	39.0	41.9
GLP92	44.7	39.0	41.9
Mean	48.3	42.3	45.3
CV (%)	3.2		

Appendix 7: Days to flowering of mixed colour lines grown at Kabete and Thika during 2012 long rain season.

Line	Kabete	Thika	Mean
BCB11-493	44.1	36.9	40.5
BCB11-359	44.8	36.8	40.8
BCB11-365	45.0	37.0	41.0
BCB11-488	44.9	37.6	41.2
BCB11-288	45.8	37.8	41.8
BCB11-315	46.0	38.0	42.0
BCB11-417	45.9	38.4	42.1
BCB11-447	45.9	38.4	42.1
BCB11-225	45.9	38.6	42.2
BCB11-221	46.1	38.9	42.5
BCB11-277	46.5	38.8	42.6
BCB11-459	46.4	39.1	42.7
BCB11-310	46.8	38.8	42.8
BCB11-520	46.6	39.4	43.0
BCB11-318	47.0	39.0	43.0
BCB11-326	47.0	39.0	43.0
BCB11-352	47.0	39.0	43.0
BCB11-502	46.9	39.6	43.2
BCB11-469	47.1	39.9	43.5
BCB11-263	47.5	39.8	43.6
BCB11-313	47.8	39.8	43.8
BCB11-322	47.8	39.8	43.8
BCB11-403	47.8	39.9	43.8
BCB11-497	47.6	40.4	44.0
BCB11-250	48.4	41.0	44.7
BCB11-222	48.4	41.1	44.7
BCB11-348	48.8	40.8	44.8
BCB11-435	48.6	41.1	44.9
BCB11-260	48.8	41.0	44.9
BCB11-246	48.6	41.4	45.0

BCB11-368	49.0	41.1	45.1
BCB11-248	48.9	41.6	45.2
BCB11-301	49.8	41.8	45.8
BCB11-407	49.9	42.4	46.1
BCB11-252	49.9	42.5	46.2
BCB11-230	50.1	42.9	46.5
BCB11-227	50.4	43.1	46.7
BCB11-442	51.1	43.6	47.4
BCB11-220	51.1	43.9	47.5
BCB11-224	51.9	44.6	48.2
BCB11-416	52.1	44.6	48.4
BCB11-219	52.6	45.4	49.0
BCB11-226	52.6	45.4	49.0
BCB11-295	53.0	45.0	49.0
BCB11-375	53.3	45.4	49.3
BCB11-223	53.1	45.9	49.5
BCB11-346	53.5	45.5	49.5
BCB11-449	53.4	45.9	49.6
BCB11-504	53.4	46.1	49.7
BCB11-531	53.4	46.1	49.7
BCB11-316	53.8	45.8	49.8
BCB11-387	53.8	45.9	49.8
BCB11-253	53.8	46.0	49.9
BCB11-404	53.9	46.4	50.1
BCB11-273	54.8	47.0	50.9
BCB11-229	55.4	48.1	51.7
KATB1	42.4	35.1	38.7
GLPx92	45.4	38.1	41.7
GLP585	45.9	38.6	42.2
SER16	46.1	38.9	42.5
SER76	48.4	41.1	44.7
Mean	49.0	41.5	45.3
CV (%)	2.3		

Appendix 8: Days to physiological maturity of red mottled lines grown at Kabete and Thika under irrigated and rainfed treatments during 2012 long rain season

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	**Line mean**
BCB11-305	93.5	90.5	92.0	86.5	76.5	81.5	86.8
BCB11-147	93.5	91.5	92.5	86.5	77.5	82.0	87.3
BCB11-290	94.5	91.5	93.0	87.5	77.5	82.5	87.8
BCB11-312	94.5	91.5	93.0	87.5	77.5	82.5	87.8
BCB11-151	94.5	92.0	93.3	87.5	78.0	82.8	88.0
BCB11-137	87.5	92.5	90.0	91.0	81.5	86.3	88.1
BCB11-302	95.5	91.5	93.5	88.5	77.5	83.0	88.3
BCB11-321	94.5	92.5	93.5	87.5	78.5	83.0	88.3
BCB11-283	95.5	92.5	94.0	88.5	78.5	83.5	88.8
BCB11-354	95.5	92.5	94.0	88.5	78.5	83.5	88.8
BCB11-130	95.5	93.5	94.5	88.5	79.5	84.0	89.3
BCB11-324	95.5	93.5	94.5	88.5	79.5	84.0	89.3
BCB11-314	96.5	93.5	95.0	89.5	79.5	84.5	89.8
BCB11-511	96.5	93.5	95.0	89.5	79.5	84.5	89.8
BCB11-132	97.5	93.0	95.3	90.5	79.0	84.8	90.0
BCB11-328	97.0	93.5	95.3	90.0	79.5	84.8	90.0
BCB11-470	96.5	94.5	95.5	89.5	80.5	85.0	90.3
BCB11-143	97.0	94.5	95.8	90.0	80.5	85.3	90.5
BCB11-333	98.5	93.5	96.0	91.5	79.5	85.5	90.8
BCB11-347	97.5	94.5	96.0	90.5	80.5	85.5	90.8
BCB11-453	97.5	94.5	96.0	90.5	80.5	85.5	90.8
BCB11-356	98.0	94.5	96.3	91.0	80.5	85.8	91.0
BCB11-140	98.0	95.0	96.5	91.0	81.0	86.0	91.3
BCB11-259	98.5	94.5	96.5	91.5	80.5	86.0	91.3
BCB11-463	97.5	95.5	96.5	90.5	81.5	86.0	91.3
BCB11-131	98.5	95.0	96.8	91.5	81.0	86.3	91.5
BCB11-265	98.5	95.0	96.8	91.5	81.0	86.3	91.5
BCB11-308	99.0	94.5	96.8	92.0	80.5	86.3	91.5
BCB11-523	99.0	94.5	96.8	92.0	80.5	86.3	91.5
BCB11-144	99.0	95.0	97.0	92.0	81.0	86.5	91.8
BCB11-307	100.5	93.5	97.0	93.5	79.5	86.5	91.8
BCB11-330	99.5	94.5	97.0	92.5	80.5	86.5	91.8
BCB11-145	98.5	96.0	97.3	91.5	82.0	86.8	92.0
BCB11-378	99.5	95.0	97.3	92.5	81.0	86.8	92.0
BCB11-506	99.0	95.5	97.3	92.0	81.5	86.8	92.0
BCB11-139	99.5	95.5	97.5	92.5	81.5	87.0	92.3
BCB11-141	100.0	95.0	97.5	93.0	81.0	87.0	92.3
BCB11-334	99.5	95.5	97.5	92.5	81.5	87.0	92.3
BCB11-413	99.5	95.5	97.5	92.5	81.5	87.0	92.3
BCB11-433	99.5	95.5	97.5	92.5	81.5	87.0	92.3
BCB11-464	98.5	96.5	97.5	91.5	82.5	87.0	92.3
BCB11-281	100.5	95.0	97.8	93.5	81.0	87.3	92.5

BCB11-363	100.0	95.5	97.8	93.0	81.5	87.3	92.5
BCB11-418	99.0	96.5	97.8	92.0	82.5	87.3	92.5
BCB11-430	100.0	95.5	97.8	93.0	81.5	87.3	92.5
BCB11-300	101.0	95.0	98.0	94.0	81.0	87.5	92.8
BCB11-349	100.5	95.5	98.0	93.5	81.5	87.5	92.8
BCB11-351	100.5	95.5	98.0	93.5	81.5	87.5	92.8
BCB11-379	100.0	96.0	98.0	93.0	82.0	87.5	92.8
BCB11-400	99.5	96.5	98.0	92.5	82.5	87.5	92.8
BCB11-409	100.5	96.5	98.5	93.5	82.5	88.0	93.3
BCB11-445	100.5	96.5	98.5	93.5	82.5	88.0	93.3
BCB11-513	100.5	96.5	98.5	93.5	82.5	88.0	93.3
BCB11-142	100.5	97.0	98.8	93.5	83.0	88.3	93.5
BCB11-367	101.5	96.0	98.8	94.5	82.0	88.3	93.5
BCB11-446	100.5	97.0	98.8	93.5	83.0	88.3	93.5
BCB11-449	100.0	97.5	98.8	93.0	83.5	88.3	93.5
BCB11-133	102.5	95.5	99.0	95.5	81.5	88.5	93.8
BCB11-345	101.5	96.5	99.0	94.5	82.5	88.5	93.8
BCB11-420	101.5	96.5	99.0	94.5	82.5	88.5	93.8
BCB11-441	101.0	97.0	99.0	94.0	83.0	88.5	93.8
BCB11-135	100.5	98.0	99.3	93.5	84.0	88.8	94.0
BCB11-136	102.0	97.0	99.5	95.0	83.0	89.0	94.3
BCB11-148	104.5	94.5	99.5	97.5	80.5	89.0	94.3
BCB11-155	103.0	96.5	99.8	96.0	82.5	89.3	94.5
BCB11-335	102.0	97.5	99.8	95.0	83.5	89.3	94.5
BCB11-395	103.0	98.0	100.5	96.0	84.0	90.0	95.3
BCB11-432	103.0	98.0	100.5	96.0	84.0	90.0	95.3
BCB11-134	103.5	100.5	102.0	96.5	86.5	91.5	96.8
GLP2	98.5	96.5	97.5	91.5	82.5	87.0	92.3
KAT69	98.5	102.5	100.5	91.5	88.5	90.0	95.3
Kenya Umoja	95.0	93.5	94.3	88.0	79.5	83.8	89.0
Mean	98.736	95.111	96.924	91.882	81.153	86.517	91.7
CV (%)	13.0						

Appendix 9: Days to physiological maturity of red kidney lines grown at Kabete and Thika under irrigated and rainfed conditions during 2012 long rain season.

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	**Line mean**
BCB11-384	89.0	93.0	91.0	84.0	74.5	79.3	85.2
BCB11-325	92.5	89.5	91.0	87.5	75.5	81.5	86.3
BCB11-327	94.5	90.0	92.3	89.5	76.0	82.8	87.5
BCB11-257	97.5	81.0	89.3	92.5	79.5	86.0	87.6
BCB11-402	93.5	91.5	92.5	88.5	77.5	83.0	87.8
BCB11-397	94.5	91.0	92.8	89.5	77.0	83.3	88.0
BCB11-440	94.5	91.0	92.8	89.5	77.0	83.3	88.0
BCB11-276	95.5	91.5	93.5	90.5	77.5	84.0	88.8
BCB11-266	95.5	92.5	94.0	90.5	78.5	84.5	89.3
BCB11-451	95.5	92.5	94.0	90.5	78.5	84.5	89.3
BCB11-175	95.5	93.0	94.3	90.5	79.0	84.8	89.5
BCB11-503	96.0	93.5	94.8	91.0	79.5	85.3	90.0
BCB11-169	96.5	93.5	95.0	91.5	79.5	85.5	90.3
BCB11-353	96.5	93.5	95.0	91.5	79.5	85.5	90.3
BCB11-358	96.5	94.0	95.3	91.5	80.0	85.8	90.5
BCB11-162	97.5	93.5	95.5	92.5	79.5	86.0	90.8
BCB11-285	96.5	94.5	95.5	91.5	80.5	86.0	90.8
BCB11-166	97.5	94.0	95.8	92.5	80.0	86.3	91.0
BCB11-477	96.5	95.0	95.8	91.5	81.0	86.3	91.0
BCB11-304	98.0	94.0	96.0	93.0	80.0	86.5	91.3
BCB11-406	97.5	95.0	96.3	92.5	81.0	86.8	91.5
BCB11-473	97.0	95.5	96.3	92.0	81.5	86.8	91.5
BCB11-490	97.5	95.0	96.3	92.5	81.0	86.8	91.5
BCB11-394	97.5	95.5	96.5	92.5	81.5	87.0	91.8
BCB11-159	98.5	95.0	96.8	93.5	81.0	87.3	92.0
BCB11-174	98.5	95.0	96.8	93.5	81.0	87.3	92.0
BCB11-299	98.5	95.0	96.8	93.5	81.0	87.3	92.0
BCB11-157	98.5	95.5	97.0	93.5	81.5	87.5	92.3
BCB11-272	98.5	95.5	97.0	93.5	81.5	87.5	92.3
BCB11-337	98.5	96.0	97.3	93.5	82.0	87.8	92.5
BCB11-434	98.0	96.5	97.3	93.0	82.5	87.8	92.5
BCB11-460	98.5	96.5	97.5	93.5	82.5	88.0	92.8
BCB11-496	98.5	96.5	97.5	93.5	82.5	88.0	92.8
BCB11-522	98.5	96.5	97.5	93.5	82.5	88.0	92.8
BCB11-167	100.0	96.0	98.0	95.0	82.0	88.5	93.3
BCB11-373	99.5	96.5	98.0	94.5	82.5	88.5	93.3
BCB11-163	100.5	96.0	98.3	95.5	82.0	88.8	93.5
BCB11-342	99.5	97.0	98.3	94.5	83.0	88.8	93.5
BCB11-158	100.5	96.5	98.5	95.5	82.5	89.0	93.8
BCB11-168	100.5	96.5	98.5	95.5	82.5	89.0	93.8
BCB11-171	101.0	96.0	98.5	96.0	82.0	89.0	93.8
BCB11-173	100.5	96.5	98.5	95.5	82.5	89.0	93.8

BCB11-509	100.5	98.0	99.3	95.5	84.0	89.8	94.5
BCB11-170	101.5	97.5	99.5	96.5	83.5	90.0	94.8
BCB11-176	101.5	97.5	99.5	96.5	83.5	90.0	94.8
BCB11-196	102.5	97.5	100.0	97.5	82.0	89.8	94.9
BCB11-164	102.5	97.5	100.0	97.5	83.5	90.5	95.3
BCB11-374	102.5	97.5	100.0	97.5	83.5	90.5	95.3
BCB11-484	102.5	98.0	100.3	97.5	84.0	90.8	95.5
BCB11-264	103.5	97.5	100.5	98.5	83.5	91.0	95.8
BCB11-468	102.5	98.5	100.5	97.5	84.5	91.0	95.8
BCB11-500	102.5	98.5	100.5	97.5	84.5	91.0	95.8
BCB11-489	103.5	98.5	101.0	98.5	84.5	91.5	96.3
BCB11-492	103.5	99.5	101.5	98.5	85.5	92.0	96.8
GLP-24	97.0	95.5	96.3	92.0	81.5	86.8	91.5
KAT56	102.0	98.0	100.0	94.0	84.0	89.0	94.5
Mean	98.3	94.8	96.6	93.223	81.321	87.3	91.9
CV (%)	11.0						

Appendix 10: Days to physiological maturity of speckled sugar lines grown at Kabete and Thika under irrigated and rainfed conditions during 2012 long rain season.

	Kabete			**Thika**			
Line	**Irrigated**	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	**Line mean**
BCB11-456	95.0	92.5	93.8	81.0	74.5	77.8	85.8
BCB11-530	95.0	92.5	93.8	81.0	74.5	77.8	85.8
BCB11-421	95.5	92.5	94.0	81.5	74.5	78.0	86.0
BCB11-498	95.5	93.5	94.5	81.5	75.5	78.5	86.5
BCB11-516	95.5	93.5	94.5	81.5	75.5	78.5	86.5
BCB11-289	96.5	93.5	95.0	82.5	75.5	79.0	87.0
BCB11-390	96.5	93.5	95.0	82.5	75.5	79.0	87.0
BCB11-382	96.5	94.0	95.3	82.5	76.0	79.3	87.3
BCB11-438	97.0	93.5	95.3	83.0	75.5	79.3	87.3
BCB11-391	97.0	94.0	95.5	83.0	76.0	79.5	87.5
BCB11-519	96.5	94.5	95.5	82.5	76.5	79.5	87.5
BCB11-371	97.5	94.5	96.0	83.5	76.5	80.0	88.0
BCB11-474	97.0	95.0	96.0	83.0	77.0	80.0	88.0
BCB11-388	97.5	95.5	96.5	83.5	77.5	80.5	88.5
BCB11-495	97.5	95.5	96.5	83.5	77.5	80.5	88.5
BCB11-501	97.5	95.5	96.5	83.5	77.5	80.5	88.5
BCB11-380	98.5	95.5	97.0	84.5	77.5	81.0	89.0
BCB11-414	98.5	96.0	97.3	84.5	78.0	81.3	89.3
BCB11-209	98.5	96.5	97.5	84.5	78.5	81.5	89.5
BCB11-336	99.0	96.0	97.5	85.0	78.0	81.5	89.5
BCB11-457	98.5	96.5	97.5	84.5	78.5	81.5	89.5
BCB11-466	98.5	96.5	97.5	84.5	78.5	81.5	89.5
BCB11-267	100.0	96.5	98.3	86.0	78.5	82.3	90.3
BCB11-376	99.5	97.0	98.3	85.5	79.0	82.3	90.3

BCB11-393	99.5	97.0	98.3	85.5	79.0	82.3	90.3
BCB11-424	100.0	96.5	98.3	86.0	78.5	82.3	90.3
BCB11-458	100.5	97.5	99.0	86.5	79.5	83.0	91.0
BCB11-386	101.5	98.0	99.8	87.5	80.0	83.8	91.8
BCB11-467	103.0	99.5	101.3	89.0	81.5	85.3	93.3
BCB11-204	104.5	98.5	101.5	90.5	80.5	85.5	93.5
BCB11-269	103.5	100.0	101.8	89.5	82.0	85.8	93.8
BCB11-303	105.0	98.5	101.8	91.0	80.5	85.8	93.8
BCB11-370	103.5	100.0	101.8	89.5	82.0	85.8	93.8
BCB11-514	104.5	99.5	102.0	90.5	81.5	86.0	94.0
BCB11-217	104.5	101.0	102.8	90.5	83.0	86.8	94.8
BCB11-461	104.5	101.0	102.8	90.5	83.0	86.8	94.8
BCB11-507	104.0	101.5	102.8	90.0	83.5	86.8	94.8
BCB11-340	105.5	101.0	103.3	91.5	83.0	87.3	95.3
BCB11-377	105.0	101.5	103.3	91.0	83.5	87.3	95.3
BCB11-415	106.0	101.5	103.8	92.0	83.5	87.8	95.8
BCB11-472	105.5	103.5	104.5	91.5	85.5	88.5	96.5
BCB11-482	106.5	104.5	105.5	92.5	86.5	89.5	97.5
BCB11-282	107.0	104.5	105.8	93.0	86.5	89.8	97.8
BCB11-443	107.5	104.5	106.0	93.5	86.5	90.0	98.0
Miezi Mbili	98.5	95.5	97.0	84.5	77.5	81.0	89.0
Mean	100.3	97.3	98.8	86.3	79.3	82.8	90.8
CV (%)	11.0						

Appendix 11: Days to physiological maturity of navy lines grown at Kabete and Thika under irrigated and rainfed conditions during 2012 long rain season.

	Kabete			**Thika**			
Line	**Irrigated**	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	**Line mean**
BCB11-97	94.5	92.5	93.5	80.5	75.5	78.0	85.8
BCB11-79	94.0	93.5	93.8	80.0	76.5	78.3	86.0
BCB11-35	95.5	92.5	94.0	81.5	75.5	78.5	86.3
BCB11-38	95.0	93.5	94.3	81.0	76.5	78.8	86.5
BCB11-63	95.5	93.0	94.3	81.5	76.0	78.8	86.5
BCB11-71	96.0	93.0	94.5	82.0	76.0	79.0	86.8
BCB11-100	96.5	93.5	95.0	82.5	76.5	79.5	87.3
BCB11-47	96.0	94.0	95.0	82.0	77.0	79.5	87.3
BCB11-55	96.5	93.5	95.0	82.5	76.5	79.5	87.3
BCB11-59	96.5	93.5	95.0	82.5	76.5	79.5	87.3
BCB11-78	95.5	94.5	95.0	81.5	77.5	79.5	87.3
BCB11-17	96.0	94.5	95.3	82.0	77.5	79.8	87.5
BCB11-56	96.5	94.5	95.5	82.5	77.5	80.0	87.8
BCB11-41	97.0	94.5	95.8	83.0	77.5	80.3	88.0
BCB11-49	97.0	94.5	95.8	83.0	77.5	80.3	88.0
BCB11-53	97.0	94.5	95.8	83.0	77.5	80.3	88.0
BCB11-83	97.0	94.5	95.8	83.0	77.5	80.3	88.0

BCB11-73	98.5	93.5	96.0	84.0	76.5	80.3	88.1
BCB11-69	97.5	94.5	96.0	83.5	77.5	80.5	88.3
BCB11-101	98.0	94.5	96.3	84.0	77.5	80.8	88.5
BCB11-13	97.5	95.0	96.3	83.5	78.0	80.8	88.5
BCB11-18	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-381	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-419	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-42	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-57	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-58	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-74	97.5	96.0	96.8	83.5	79.0	81.3	89.0
BCB11-483	98.0	96.0	97.0	84.0	79.0	81.5	89.3
BCB11-81	98.5	96.0	97.3	84.5	79.0	81.8	89.5
BCB11-67	96.5	94.5	95.5	85.5	82.0	83.8	89.6
BCB11-439	98.5	96.5	97.5	84.5	79.5	82.0	89.8
BCB11-52	98.5	96.5	97.5	84.5	79.5	82.0	89.8
BCB11-75	97.0	94.5	95.8	90.5	77.5	84.0	89.9
BCB11-19	98.5	97.0	97.8	84.5	80.0	82.3	90.0
BCB11-427	98.5	97.0	97.8	84.5	80.0	82.3	90.0
BCB11-70	99.0	96.5	97.8	85.0	79.5	82.3	90.0
BCB11-48	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-50	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-64	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-9	99.0	97.5	98.3	85.0	80.5	82.8	90.5
BCB11-1	100.0	97.0	98.5	86.0	80.0	83.0	90.8
BCB11-36	100.0	97.0	98.5	86.0	80.0	83.0	90.8
BCB11-94	99.5	97.5	98.5	85.5	80.5	83.0	90.8
BCB11-24	100.0	97.5	98.8	86.0	80.5	83.3	91.0
BCB11-275	100.5	97.0	98.8	86.5	80.0	83.3	91.0
BCB11-14	101.0	98.0	99.5	87.0	81.0	84.0	91.8
BCB11-455	101.0	98.0	99.5	87.0	81.0	84.0	91.8
BCB11-5	100.5	98.5	99.5	86.5	81.5	84.0	91.8
BCB11-46	103.0	98.5	100.8	87.0	79.0	83.0	91.9
BCB11-109	101.0	98.5	99.8	87.0	81.5	84.3	92.0
BCB11-4	101.5	98.0	99.8	87.5	81.0	84.3	92.0
BCB11-475	101.0	98.5	99.8	87.0	81.5	84.3	92.0
BCB11-86	101.0	98.5	99.8	87.0	81.5	84.3	92.0
BCB11-27	102.5	97.5	100.0	88.5	80.5	84.5	92.3
BCB11-410	102.0	98.0	100.0	88.0	81.0	84.5	92.3
BCB11-108	102.0	98.5	100.3	88.0	81.5	84.8	92.5
BCB11-287	102.0	98.5	100.3	88.0	81.5	84.8	92.5
BCB11-61	102.5	98.0	100.3	88.5	81.0	84.8	92.5
BCB11-102	102.5	98.5	100.5	88.5	81.5	85.0	92.8
BCB11-405	102.5	98.5	100.5	88.5	81.5	85.0	92.8
BCB11-43	102.5	98.5	100.5	88.5	81.5	85.0	92.8
BCB11-444	102.5	98.5	100.5	88.5	81.5	85.0	92.8

BCB11-411	103.5	98.0	100.8	89.5	81.0	85.3	93.0
BCB11-54	103.0	98.5	100.8	89.0	81.5	85.3	93.0
BCB11-68	103.5	98.0	100.8	89.5	81.0	85.3	93.0
BCB11-98	102.5	99.0	100.8	88.5	82.0	85.3	93.0
BCB11-32	103.0	99.0	101.0	89.0	82.0	85.5	93.3
BCB11-286	103.0	99.5	101.3	89.0	82.5	85.8	93.5
BCB11-30	102.5	100.0	101.3	88.5	83.0	85.8	93.5
BCB11-31	102.5	100.0	101.3	88.5	83.0	85.8	93.5
BCB11-476	105.0	97.5	101.3	88.5	83.5	86.0	93.6
BCB11-11	102.5	100.5	101.5	88.5	83.5	86.0	93.8
BCB11-23	102.5	100.5	101.5	88.5	83.5	86.0	93.8
BCB11-29	103.5	99.5	101.5	89.5	82.5	86.0	93.8
BCB11-82	103.5	99.5	101.5	89.5	82.5	86.0	93.8
BCB11-84	103.5	99.5	101.5	89.5	82.5	86.0	93.8
BCB11-89	103.5	99.5	101.5	89.5	82.5	86.0	93.8
BCB11-33	103.0	100.5	101.8	89.0	83.5	86.3	94.0
BCB11-103	103.5	100.5	102.0	89.5	83.5	86.5	94.3
BCB11-105	103.5	100.5	102.0	89.5	83.5	86.5	94.3
BCB11-15	104.0	100.0	102.0	90.0	83.0	86.5	94.3
BCB11-429	103.5	100.5	102.0	89.5	83.5	86.5	94.3
BCB11-8	103.5	100.5	102.0	89.5	83.5	86.5	94.3
BCB11-80	104.5	99.5	102.0	90.5	82.5	86.5	94.3
BCB11-85	104.0	100.5	102.3	90.0	83.5	86.8	94.5
BCB11-10	103.5	101.5	102.5	89.5	84.5	87.0	94.8
BCB11-37	104.0	101.0	102.5	90.0	84.0	87.0	94.8
BCB11-44	103.5	101.5	102.5	89.5	84.5	87.0	94.8
BCB11-62	103.5	101.5	102.5	89.5	84.5	87.0	94.8
BCB11-39	104.0	101.5	102.8	90.0	84.5	87.3	95.0
BCB11-96	104.5	101.0	102.8	90.5	84.0	87.3	95.0
BCB11-106	104.5	101.5	103.0	90.5	84.5	87.5	95.3
BCB11-51	104.5	101.5	103.0	90.5	84.5	87.5	95.3
BCB11-76	105.0	101.0	103.0	91.0	84.0	87.5	95.3
BCB11-12	104.5	102.5	103.5	90.5	85.5	88.0	95.8
BCB11-34	104.5	102.5	103.5	90.5	85.5	88.0	95.8
BCB11-45	104.5	102.5	103.5	90.5	85.5	88.0	95.8
BCB11-104	105.5	102.0	103.8	91.5	85.0	88.3	96.0
BCB11-16	105.0	102.5	103.8	91.0	85.5	88.3	96.0
BCB11-66	105.0	102.5	103.8	91.0	85.5	88.3	96.0
BCB11-95	105.5	102.0	103.8	91.5	85.0	88.3	96.0
BCB11-369	105.0	103.0	104.0	91.0	86.0	88.5	96.3
BCB11-40	105.5	102.5	104.0	91.5	85.5	88.5	96.3
BCB11-87	105.5	102.5	104.0	91.5	85.5	88.5	96.3
BCB11-65	106.5	102.0	104.3	92.5	85.0	88.8	96.5
BCB11-77	106.0	103.5	104.8	90.5	86.5	88.5	96.6
BCB11-25	106.0	103.0	104.5	92.0	86.0	89.0	96.8
BCB11-355	105.5	103.5	104.5	91.5	86.5	89.0	96.8

BCB11-396	105.5	103.5	104.5	91.5	86.5	89.0	96.8
BCB11-481	105.5	103.5	104.5	91.5	86.5	89.0	96.8
BCB11-292	106.0	103.5	104.8	92.0	86.5	89.3	97.0
BCB11-450	106.0	103.5	104.8	92.0	86.5	89.3	97.0
BCB11-518	106.0	103.5	104.8	92.0	86.5	89.3	97.0
BCB11-72	106.5	103.0	104.8	92.5	86.0	89.3	97.0
BCB11-88	106.0	103.5	104.8	92.0	86.5	89.3	97.0
BCB11-107	106.5	104.5	105.5	92.5	87.5	90.0	97.8
BCB11-20	106.5	104.5	105.5	92.5	87.5	90.0	97.8
BCB11-92	107.0	104.5	105.8	93.0	87.5	90.3	98.0
Mixican142	106.5	103.5	105.0	92.5	86.5	89.5	97.3
Mean	101.5	98.6	100.0	87.5	81.6	84.6	92.3
CV (%)	10.0						

Appendix 12: Days to physiological maturity of small red lines grown at Kabete and Thika under irrigated and rainfed conditions during 2012 long-rain season.

	Kabete			Thika			
Line	**Irrigated**	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	**Line mean**
BCB11-194	96.5	92.5	94.5	82.5	75.5	79.0	86.8
BCB11-399	96.5	92.5	94.5	82.5	75.5	79.0	86.8
BCB11-197	97.5	92.5	95.0	83.5	75.5	79.5	87.3
BCB11-195	97.5	93.5	95.5	83.5	76.5	80.0	87.8
BCB11-401	97.5	94.5	96.0	83.5	77.5	80.5	88.3
BCB11-362	98.5	94.5	96.5	84.5	77.5	81.0	88.8
BCB11-363	98.0	95.0	96.5	84.0	78.0	81.0	88.8
BCB11-203	98.5	95.0	96.8	84.5	78.0	81.3	89.0
BCB11-199	99.0	95.0	97.0	85.0	78.0	81.5	89.3
BCB11-279	98.5	95.5	97.0	84.5	78.5	81.5	89.3
BCB11-528	98.5	95.5	97.0	84.5	78.5	81.5	89.3
BCB11-200	99.0	95.5	97.3	85.0	78.5	81.8	89.5
BCB11-422	98.5	96.0	97.3	84.5	79.0	81.8	89.5
BCB11-510	99.0	95.5	97.3	85.0	78.5	81.8	89.5
BCB11-280	98.5	96.5	97.5	84.5	79.5	82.0	89.8
BCB11-192	99.5	96.0	97.8	85.5	79.0	82.3	90.0
BCB11-196	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-202	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-296	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-437	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-517	99.5	96.5	98.0	85.5	79.5	82.5	90.3
BCB11-332	100.0	96.5	98.3	86.0	79.5	82.8	90.5
BCB11-344	100.5	96.5	98.5	86.5	79.5	83.0	90.8
BCB11-443	100.5	96.5	98.5	86.5	79.5	83.0	90.8
BCB11-182	101.0	96.5	98.8	87.0	79.5	83.3	91.0
BCB11-366	100.5	97.0	98.8	86.5	80.0	83.3	91.0
BCB11-317	101.0	97.5	99.3	87.0	80.5	83.8	91.5

BCB11-191	101.5	97.5	99.5	87.5	80.5	84.0	91.8
BCB11-193	101.5	97.5	99.5	87.5	80.5	84.0	91.8
BCB11-245	101.5	97.5	99.5	87.5	80.5	84.0	91.8
BCB11-478	101.5	97.5	99.5	87.5	80.5	84.0	91.8
BCB11-185	102.5	97.5	100.0	88.5	80.5	84.5	92.3
BCB11-184	103.5	97.5	100.5	89.5	80.5	85.0	92.8
BCB11-258	102.5	98.5	100.5	88.5	81.5	85.0	92.8
BCB11-251	103.5	98.0	100.8	89.5	81.0	85.3	93.0
BCB11-505	103.5	98.0	100.8	89.5	81.0	85.3	93.0
BCB11-323	104.0	98.5	101.3	90.0	81.5	85.8	93.5
BCB11-412	104.0	98.5	101.3	90.0	81.5	85.8	93.5
BCB11-190	104.5	98.5	101.5	90.5	81.5	86.0	93.8
BCB11-189	105.5	98.5	102.0	91.5	81.5	86.5	94.3
BCB11-529	104.5	100.0	102.3	90.5	83.0	86.8	94.5
BCB11-331	104.5	100.5	102.5	90.5	83.5	87.0	94.8
BCB11-436	105.5	99.5	102.5	91.5	82.5	87.0	94.8
KATB9	95.5	91.5	93.5	81.5	74.5	78.0	85.8
Tio Canella	97.0	94.5	95.8	83.0	77.5	80.3	88.0
GLP585	97.5	94.5	96.0	83.5	77.5	80.5	88.3
Mean	100.3	96.4	98.4	86.3	79.4	82.9	90.6
CV (%)	8.0						

Appendix 13: Days to physiological maturity of pinto and carioca lines grown at Kabete and Thika under irrigated and rainfed conditions during 2012 long rain season.

	Kabete			**Thika**			
Line	**Irrigated**	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	**Line mean**
BCB11-254	94.5	92.5	93.5	80.5	75.5	78.0	85.8
BCB11-341	95.5	92.5	94.0	81.5	75.5	78.5	86.3
BCB11-372	95.5	93.0	94.3	81.5	76.0	78.8	86.5
BCB11-291	96.5	94.5	95.5	82.5	77.5	80.0	87.8
BCB11-480	97.5	94.5	96.0	83.5	77.5	80.5	88.3
BCB11-486	97.0	95.0	96.0	83.0	78.0	80.5	88.3
BCB11-426	97.0	95.5	96.3	83.0	78.5	80.8	88.5
BCB11-236	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-392	97.5	95.5	96.5	83.5	78.5	81.0	88.8
BCB11-232	98.0	95.5	96.8	84.0	78.5	81.3	89.0
BCB11-339	98.0	95.5	96.8	84.0	78.5	81.3	89.0
BCB11-494	98.0	96.0	97.0	84.0	79.0	81.5	89.3
BCB11-338	98.5	96.0	97.3	85.5	78.0	81.8	89.5
BCB11-512	98.0	96.5	97.3	84.0	79.5	81.8	89.5
BCB11-499	99.0	96.0	97.5	85.0	79.0	82.0	89.8
BCB11-485	100.0	96.5	98.3	86.0	79.5	82.8	90.5
BCB11-408	99.5	97.5	98.5	85.5	80.5	83.0	90.8
BCB11-428	100.0	97.0	98.5	86.0	80.0	83.0	90.8
BCB11-231	100.5	97.5	99.0	86.5	80.5	83.5	91.3

BCB11-237	100.5	97.5	99.0	86.5	80.5	83.5	91.3
BCB11-274	100.5	97.5	99.0	86.5	80.5	83.5	91.3
BCB11-320	101.0	98.0	99.5	87.0	81.0	84.0	91.8
BCB11-233	102.0	97.5	99.8	88.0	80.5	84.3	92.0
BCB11-515	102.0	97.5	99.8	88.0	80.5	84.3	92.0
BCB11-524	101.5	98.0	99.8	87.5	81.0	84.3	92.0
BCB11-235	102.5	97.5	100.0	88.5	80.5	84.5	92.3
BCB11-479	102.5	98.0	100.3	88.5	81.0	84.8	92.5
BCB11-293	103.0	99.0	101.0	89.0	82.0	85.5	93.3
BCB11-357	104.0	99.0	101.5	90.0	82.0	86.0	93.8
BCB11-234	103.5	99.0	101.3	90.0	83.0	86.5	93.9
BCB11-271	103.0	100.5	101.8	89.0	83.5	86.3	94.0
BCB11-383	103.5	100.0	101.8	89.5	83.0	86.3	94.0
BCB11-239	103.5	100.5	102.0	89.5	83.5	86.5	94.3
BCB11-284	103.5	100.5	102.0	89.5	83.5	86.5	94.3
BCB11-448	104.0	100.0	102.0	90.0	83.0	86.5	94.3
BCB11-521	104.0	100.5	102.3	90.0	83.5	86.8	94.5
BCB11-329	105.0	100.0	102.5	91.0	83.0	87.0	94.8
BCB11-491	103.5	101.5	102.5	89.5	84.5	87.0	94.8
BCB11-350	105.0	100.5	102.8	91.0	83.5	87.3	95.0
BCB11-297	105.5	101.0	103.3	91.5	84.0	87.8	95.5
BCB11-425	105.5	103.0	104.3	91.5	86.0	88.8	96.5
BCB11-289	106.5	104.5	105.5	92.5	87.5	90.0	97.8
BCB11-508	107.5	105.5	106.5	93.5	88.5	91.0	98.8
GLPx92	96.5	94.5	95.5	82.5	77.5	80.0	87.8
GLP1004	97.5	95.0	96.3	83.5	78.0	80.8	88.5
Mean	100.8	97.7	99.3	86.8	80.7	83.8	91.5
CV (%)	12.0						

Appendix 14: Days to physiological maturity of mixed colour lines grown at Kabete and Thika under irrigated and rainfed treatments during the long-rain 2012.

Line	Kabete			Thika			Line mean
	Irrigated	**Rainfed**	**Mean**	**Irrigated**	**Rainfed**	**Mean**	
BCB11-359	94.5	92.5	93.5	80.5	74.5	77.5	85.5
BCB11-493	94.5	92.5	93.5	80.5	74.5	77.5	85.5
BCB11-318	95.0	92.5	93.8	81.0	74.5	77.8	85.8
BCB11-263	95.5	93.5	94.5	81.5	75.5	78.5	86.5
BCB11-288	95.5	93.5	94.5	81.5	75.5	78.5	86.5
BCB11-315	95.5	93.5	94.5	81.5	75.5	78.5	86.5
BCB11-488	95.5	93.5	94.5	81.5	75.5	78.5	86.5
BCB11-277	96.0	93.5	94.8	82.0	75.5	78.8	86.8
BCB11-365	96.5	93.5	95.0	82.5	75.5	79.0	87.0

BCB11-447	96.5	93.5	95.0	82.5	75.5	79.0	87.0
BCB11-273	96.5	94.5	95.5	82.5	76.5	79.5	87.5
BCB11-310	96.5	94.5	95.5	82.5	76.5	79.5	87.5
BCB11-417	96.5	94.5	95.5	82.5	76.5	79.5	87.5
BCB11-435	96.5	94.5	95.5	82.5	76.5	79.5	87.5
BCB11-469	96.5	94.5	95.5	82.5	76.5	79.5	87.5
BCB11-348	97.5	94.5	96.0	83.5	76.5	80.0	88.0
BCB11-221	97.0	95.5	96.3	83.0	77.5	80.3	88.3
BCB11-313	97.5	95.0	96.3	83.5	77.0	80.3	88.3
BCB11-322	97.5	95.5	96.5	83.5	77.5	80.5	88.5
BCB11-222	98.0	95.5	96.8	84.0	77.5	80.8	88.8
BCB11-225	98.0	95.5	96.8	84.0	77.5	80.8	88.8
BCB11-403	97.5	96.0	96.8	83.5	78.0	80.8	88.8
BCB11-502	98.5	95.5	97.0	84.5	77.5	81.0	89.0
BCB11-497	98.5	96.0	97.3	84.5	78.0	81.3	89.3
BCB11-246	98.5	96.5	97.5	84.5	78.5	81.5	89.5
BCB11-352	98.5	96.5	97.5	84.5	78.5	81.5	89.5
BCB11-459	98.5	96.5	97.5	84.5	78.5	81.5	89.5
BCB11-520	99.0	96.0	97.5	85.0	78.0	81.5	89.5
BCB11-326	99.0	96.5	97.8	85.0	78.5	81.8	89.8
BCB11-407	99.5	96.5	98.0	85.5	78.5	82.0	90.0
BCB11-227	99.5	97.0	98.3	85.5	79.0	82.3	90.3
BCB11-260	99.5	97.5	98.5	85.5	79.5	82.5	90.5
BCB11-295	99.5	97.5	98.5	85.5	79.5	82.5	90.5
BCB11-368	99.5	97.5	98.5	85.5	79.5	82.5	90.5
BCB11-230	100.5	97.5	99.0	86.5	79.5	83.0	91.0
BCB11-301	100.5	97.5	99.0	86.5	79.5	83.0	91.0
BCB11-220	101.0	97.5	99.3	87.0	79.5	83.3	91.3
BCB11-250	101.0	97.5	99.3	87.0	79.5	83.3	91.3
BCB11-224	101.5	97.5	99.5	87.5	79.5	83.5	91.5
BCB11-252	100.5	98.5	99.5	86.5	80.5	83.5	91.5
BCB11-226	101.0	98.5	99.8	87.0	80.5	83.8	91.8
BCB11-316	102.0	98.0	100.0	88.0	80.0	84.0	92.0
BCB11-442	101.5	99.0	100.3	87.5	81.0	84.3	92.3
BCB11-248	103.0	98.5	100.8	89.0	80.5	84.8	92.8
BCB11-531	102.5	99.5	101.0	88.5	81.5	85.0	93.0
BCB11-346	104.0	99.5	101.8	90.0	81.5	85.8	93.8
BCB11-375	103.0	101.0	102.0	89.0	83.0	86.0	94.0
BCB11-416	103.5	100.5	102.0	89.5	82.5	86.0	94.0
BCB11-223	104.5	100.0	102.3	90.5	82.0	86.3	94.3
BCB11-387	103.5	101.0	102.3	89.5	83.0	86.3	94.3
BCB11-449	103.5	101.5	102.5	89.5	83.5	86.5	94.5
BCB11-404	104.0	101.5	102.8	90.0	83.5	86.8	94.8
BCB11-504	104.0	102.0	103.0	90.0	84.0	87.0	95.0
BCB11-219	105.0	102.5	103.8	91.0	84.5	87.8	95.8
BCB11-253	104.5	103.5	104.0	90.5	85.5	88.0	96.0

BCB11-229	106.5	104.0	105.3	92.5	86.0	89.3	97.3
KATB1	93.5	90.5	92.0	79.5	72.5	76.0	84.0
GLP585	96.5	94.5	95.5	82.0	76.5	79.3	87.4
GLPx92	96.5	94.5	95.5	82.5	76.5	79.5	87.5
SER16	94.5	96.5	95.5	80.5	78.5	79.5	87.5
SER76	99.5	97.5	98.5	85.5	79.5	82.5	90.5
Mean	99.2	96.7	98.0	85.2	78.7	82.0	90.0
CV(%)	10						

Appendix 14: Reaction of red mottled lines to four major diseases at Kabete during 2012 long-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-445	3	3	3	2
BCB11-351	3	3	2	3
BCB11-155	3	3	3	3
BCB11-345	3	3	3	2
BCB11-400	3	3	3	2
BCB11-453	3	3	3	2
BCB11-314	3	3	3	2
BCB11-464	3	3	3	2
BCB11-511	3	3	3	3
BCB11-144	4	3	3	3
BCB11-523	4	3	3	3
BCB11-420	4	3	4	3
BCB11-333	4	3	3	2
BCB11-142	3	3	3	3
BCB11-334	3	3	3	3
BCB11-324	4	3	3	3
BCB11-395	3	3	3	3
BCB11-379	3	3	3	4
BCB11-330	4	3	3	4
BCB11-130	3	4	3	2
BCB11-349	4	4	3	3
BCB11-347	3	4	3	2
BCB11-143	3	4	3	3
BCB11-145	3	4	3	2
BCB11-135	4	4	3	3
BCB11-432	3	4	3	3
BCB11-290	3	5	3	4
BCB11-305	5	5	3	5
BCB11-409	6	5	3	6
BCB11-363	5	6	3	3
BCB11-430	3	6	3	6
BCB11-302	4	6	3	6
BCB11-308	4	6	3	3

BCB11-312	6	6	3	3
BCB11-307	6	6	4	3
BCB11-413	5	6	3	3
BCB11-441	6	6	3	3
BCB11-131	4	7	4	3
BCB11-321	5	7	4	4
BCB11-513	4	7	3	6
BCB11-354	5	7	4	2
BCB11-148	4	7	3	3
BCB11-259	5	7	3	3
BCB11-449	5	7	4	5
BCB11-356	6	7	3	3
BCB11-265	5	7	5	3
BCB11-433	4	7	5	3
BCB11-367	5	7	5	6
BCB11-141	3	7	2	7
BCB11-133	4	7	3	3
BCB11-134	5	7	3	3
BCB11-147	5	7	4	3
BCB11-335	4	7	3	3
BCB11-281	6	7	4	3
BCB11-283	5	7	3	4
BCB11-470	5	7	3	4
BCB11-506	5	7	4	4
BCB11-300	4	7	3	4
BCB11-378	6	8	3	3
BCB11-139	4	8	3	4
BCB11-418	6	8	4	5
BCB11-463	6	8	3	5
BCB11-137	3	8	5	3
BCB11-136	5	8	7	4
BCB11-140	6	8	5	3
BCB11-151	7	8	3	3
BCB11-446	4	8	3	5
BCB11-328	4	8	3	5
BCB11-132	5	9	4	3
GLP2	5	6	3	3
KAT69	5	7	5	5
Kenya Umoja	4	5	3	3
Mean	4	6	3	3
CV (%)	21.7	15.2	21.9	25.5

Appendix 15: Reaction of red kidney lines to four major diseases at Kabete during 2012 short-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-337	3	3	2	4
BCB11-434	3	3	3	4
BCB11-162	3	3	3	3
BCB11-174	4	3	3	3
BCB11-304	3	3	3	3
BCB11-327	3	3	2	2
BCB11-468	3	3	2	3
BCB11-509	4	3	3	4
BCB11-163	4	3	2	3
BCB11-171	4	3	3	3
BCB11-176	2	3	3	2
BCB11-342	3	3	3	3
BCB11-522	3	3	2	2
BCB11-440	3	3	3	3
BCB11-500	3	3	3	3
BCB11-175	4	4	3	4
BCB11-492	4	4	2	3
BCB11-166	3	4	3	3
BCB11-285	3	4	3	2
BCB11-325	3	4	2	3
BCB11-397	4	4	4	4
BCB11-353	3	4	4	3
BCB11-264	4	4	3	5
BCB11-272	4	4	4	3
BCB11-173	5	5	3	3
BCB11-358	5	5	3	4
BCB11-503	3	5	3	2
BCB11-157	3	5	3	3
BCB11-158	4	5	3	3
BCB11-159	5	5	4	4
BCB11-164	4	5	3	3
BCB11-168	3	5	3	3
BCB11-196	3	5	3	3
BCB11-406	3	5	3	3
BCB11-490	4	5	4	3
BCB11-374	4	5	3	3
BCB11-170	5	5	5	6
BCB11-169	4	6	3	3
BCB11-276	4	6	3	5
BCB11-402	4	6	3	3
BCB11-167	5	6	3	5
BCB11-257	5	6	4	5
BCB11-477	5	6	3	5

BCB11-489	3	6	4	3
BCB11-299	6	7	3	5
BCB11-484	5	7	3	3
BCB11-266	4	7	3	4
BCB11-373	4	7	3	3
BCB11-496	6	7	4	4
BCB11-384	5	8	3	3
BCB11-460	3	8	5	3
BCB11-394	5	8	3	5
BCB11-473	7	8	3	5
BCB11-451	5	8	3	4
GLP24	5	6	3	3
KAT56	4	5	3	3
Mean	4	5	3	3
CV (%)	20.2	16.5	24.2	25.6

Appendix 16: Reaction of speckled sugar lines to four major diseases at Kabete during 2012 short-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-303	3	3	2	3
BCB11-386	3	3	2	3
BCB11-424	6	3	3	4
BCB11-474	5	3	3	6
BCB11-507	3	3	3	2
BCB11-282	4	3	3	2
BCB11-380	3	3	2	3
BCB11-414	3	3	3	3
BCB11-377	3	3	2	3
BCB11-390	4	3	3	3
BCB11-501	3	3	3	2
BCB11-530	3	3	2	2
BCB11-371	3	4	2	3
BCB11-443	5	4	4	4
BCB11-495	3	4	3	2
BCB11-519	3	4	2	3
BCB11-336	5	5	3	4
BCB11-382	3	5	3	3
BCB11-388	7	5	3	3
BCB11-421	5	6	3	5
BCB11-467	5	6	3	3
BCB11-204	3	6	3	4
BCB11-267	6	6	7	3
BCB11-498	6	6	3	4
BCB11-269	4	6	3	3
BCB11-466	4	6	3	3

BCB11-393	3	7	3	3
BCB11-456	3	7	3	3
BCB11-209	5	7	3	3
BCB11-217	6	7	5	4
BCB11-289	6	7	3	4
BCB11-482	6	7	3	4
BCB11-514	6	7	3	4
BCB11-516	3	7	3	5
BCB11-376	6	7	3	3
BCB11-391	6	7	3	4
BCB11-415	7	7	3	6
BCB11-458	5	7	3	5
BCB11-472	6	7	3	3
BCB11-457	7	8	4	5
BCB11-461	6	8	6	4
BCB11-438	4	8	4	4
BCB11-340	6	8	4	2
BCB11-370	7	8	3	5
Miezi Mbili	6	8	5	4
Mean	5	5	3	3
CV (%)	19.6	15.8	20.7	28

Appendix 17: Reaction of navy lines to four major diseases at Kabete during 2012 short-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-105	3	2	3	3
BCB11-108	2	2	2	3
BCB11-11	2	3	2	2
BCB11-30	3	3	3	2
BCB11-355	2	3	2	2
BCB11-410	2	3	2	2
BCB11-476	3	3	2	2
BCB11-63	2	3	2	2
BCB11-75	3	3	2	2
BCB11-82	5	3	3	3
BCB11-89	3	3	2	2
BCB11-96	2	3	2	3
BCB11-98	2	3	2	2
BCB11-104	3	3	3	3
BCB11-16	3	3	2	3
BCB11-29	3	3	3	3
BCB11-419	3	3	2	3
BCB11-46	5	3	3	4
BCB11-47	3	3	3	2
BCB11-483	5	3	3	3

BCB11-518	5	3	3	3
BCB11-52	3	3	3	2
BCB11-57	2	3	2	2
BCB11-59	3	3	3	3
BCB11-69	3	3	3	3
BCB11-87	3	3	3	2
BCB11-88	3	3	2	3
BCB11-287	4	3	3	3
BCB11-31	2	3	2	3
BCB11-34	2	3	2	2
BCB11-405	2	3	3	5
BCB11-48	3	3	2	3
BCB11-49	4	3	3	3
BCB11-5	5	3	3	3
BCB11-50	5	3	3	5
BCB11-51	3	3	2	3
BCB11-56	3	3	3	3
BCB11-62	2	3	2	3
BCB11-70	5	3	3	5
BCB11-73	3	3	2	3
BCB11-76	3	3	3	3
BCB11-80	3	3	3	3
BCB11-84	3	3	3	4
BCB11-94	3	3	3	3
BCB11-36	3	3	2	3
BCB11-369	3	3	3	3
BCB11-37	4	3	3	3
BCB11-38	3	3	3	3
BCB11-40	3	3	3	2
BCB11-455	3	3	2	3
BCB11-54	5	3	2	2
BCB11-58	3	3	3	3
BCB11-10	3	4	2	2
BCB11-24	4	4	3	3
BCB11-33	3	4	3	3
BCB11-45	3	4	3	3
BCB11-475	5	4	3	5
BCB11-86	4	4	3	3
BCB11-14	3	4	2	3
BCB11-35	5	4	3	3
BCB11-81	3	4	3	2
BCB11-9	3	4	2	3
BCB11-95	5	4	3	4
BCB11-97	4	4	3	3
BCB11-20	3	4	2	3
BCB11-444	3	4	3	3

BCB11-107	3	4	3	3
BCB11-429	4	4	2	3
BCB11-66	3	4	3	3
BCB11-85	6	5	3	5
BCB11-1	3	5	3	4
BCB11-13	5	5	3	3
BCB11-32	3	5	3	3
BCB11-44	4	5	3	3
BCB11-450	5	5	5	3
BCB11-64	5	5	3	3
BCB11-67	3	5	3	3
BCB11-72	2	5	2	3
BCB11-12	2	5	3	3
BCB11-4	5	5	3	3
BCB11-65	4	5	3	3
BCB11-83	3	5	3	3
BCB11-102	4	5	3	2
BCB11-103	3	5	4	3
BCB11-106	3	5	3	3
BCB11-396	4	5	3	3
BCB11-427	3	5	3	2
BCB11-55	3	5	3	2
BCB11-61	3	5	3	3
BCB11-77	5	5	3	6
BCB11-78	4	5	3	4
BCB11-8	5	5	3	3
BCB11-275	4	6	4	4
BCB11-42	5	6	2	3
BCB11-439	6	6	4	4
BCB11-71	5	6	3	3
BCB11-74	6	6	3	3
BCB11-100	5	6	3	3
BCB11-15	3	6	3	3
BCB11-39	4	6	4	4
BCB11-92	5	6	3	3
BCB11-109	5	6	3	3
BCB11-25	6	6	3	3
BCB11-292	5	6	3	3
BCB11-68	5	6	3	5
BCB11-381	5	7	3	3
BCB11-411	6	7	3	5
BCB11-53	4	7	3	3
BCB11-101	3	7	3	5
BCB11-17	6	7	3	4
BCB11-18	7	7	5	4
BCB11-79	3	7	4	3

BCB11-286	5	7	3	5
BCB11-41	3	7	3	4
BCB11-19	6	7	3	4
BCB11-27	3	7	2	3
BCB11-23	6	8	5	5
BCB11-43	6	8	3	4
BCB11-481	6	9	3	5
Mixican142	4	5	3	2
Mean	3.6	4.2	2.6	3.0
CV (%)	21.8	16.3	20.2	26.2

Appendix 18: Reaction of small red line to four major diseases at Kabete during 2012 short-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-245	2	3	2	2
BCB11-478	3	3	3	2
BCB11-185	3	3	2	2
BCB11-199	3	3	3	3
BCB11-202	2	3	3	2
BCB11-296	5	3	3	5
BCB11-344	3	3	2	2
BCB11-362	3	3	3	3
BCB11-366	2	3	5	2
BCB11-437	3	3	3	2
BCB11-528	3	3	2	3
BCB11-182	3	3	3	3
BCB11-189	3	3	2	3
BCB11-193	3	3	3	3
BCB11-196	3	3	2	3
BCB11-197	5	3	3	3
BCB11-203	5	3	3	3
BCB11-331	5	3	4	6
BCB11-192	4	3	2	3
BCB11-195	4	3	3	3
BCB11-251	5	3	3	3
BCB11-317	5	3	5	4
BCB11-401	3	3	3	3
BCB11-422	4	3	3	4
BCB11-443	4	3	3	3
BCB11-505	4	3	3	5
BCB11-517	3	3	3	3
BCB11-280	4	4	3	4
BCB11-363	4	4	3	5
BCB11-194	4	4	3	3
BCB11-200	5	4	3	4

BCB11-191	4	4	3	3
BCB11-184	4	5	2	3
BCB11-279	5	5	3	3
BCB11-323	4	5	3	4
BCB11-510	3	5	2	3
BCB11-399	3	5	3	3
BCB11-190	3	6	2	3
BCB11-258	3	7	3	5
BCB11-332	4	7	4	4
BCB11-529	4	7	3	5
BCB11-412	4	7	4	4
BCB11-436	5	7	4	4
GLP585	5	7	3	4
KATB9	4	7	3	4
Tiocanella	3	3	2	2
Mean	4	4	2.8	3
CV (%)	23.8	16.7	22.0	24.9

Appendix 19: Reaction of pinto and carioca lines to four major diseases at Kabete during 2012 short-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-515	3	2	2	2
BCB11-297	3	2	2	3
BCB11-233	3	3	2	2
BCB11-425	3	3	2	3
BCB11-428	2	3	2	2
BCB11-508	3	3	2	2
BCB11-512	3	3	2	2
BCB11-231	3	3	2	4
BCB11-271	3	3	3	3
BCB11-274	3	3	2	2
BCB11-293	2	3	2	2
BCB11-485	4	3	3	3
BCB11-521	3	3	3	3
BCB11-232	4	3	3	2
BCB11-235	3	3	3	3
BCB11-239	7	3	3	5
BCB11-291	3	3	3	4
BCB11-448	3	3	3	5
BCB11-234	4	3	3	2
BCB11-236	3	3	3	2
BCB11-289	7	3	3	6
BCB11-491	5	3	4	3
BCB11-524	5	3	3	3
BCB11-284	5	4	3	3
BCB11-338	5	4	3	3

BCB11-383	3	4	3	2
BCB11-392	4	4	3	6
BCB11-499	4	5	3	3
BCB11-494	4	5	2	3
BCB11-237	6	6	3	3
BCB11-254	3	6	3	3
BCB11-339	4	6	3	3
BCB11-426	4	6	3	4
BCB11-372	5	7	4	3
BCB11-341	4	7	3	3
BCB11-350	6	7	3	4
BCB11-480	5	7	4	4
BCB11-320	7	8	5	4
BCB11-357	4	8	3	3
BCB11-479	3	8	3	4
BCB11-329	5	8	4	4
BCB11-408	5	8	3	4
BCB11-486	4	9	3	3
GLP1004	6	8	5	5
GLPx92	6	6	3	6
Mean	4.0	4.5	2.9	3.2
CV (%)	20.5	15.3	24.0	23.9

Appendix 20: Reaction of mixed colour lines to four major diseases grown at Kabete during 2012 short-rain season.

Line	ALS	ANTH	CBB	RR
BCB11-263	3	3	2	3
BCB11-313	2	3	2	3
BCB11-301	3	3	2	4
BCB11-219	3	3	2	3
BCB11-222	3	3	3	5
BCB11-229	3	3	2	3
BCB11-253	4	3	3	4
BCB11-318	3	3	3	3
BCB11-326	4	3	3	5
BCB11-348	4	3	2	3
BCB11-403	3	3	2	6
BCB11-407	3	3	2	3
BCB11-469	3	3	3	3
BCB11-225	5	3	3	3
BCB11-248	3	3	3	5
BCB11-310	3	3	3	3
BCB11-346	3	3	3	4
BCB11-449	3	3	3	7
BCB11-493	3	3	3	3
BCB11-520	4	3	3	2

BCB11-230	2	4	3	3
BCB11-273	5	4	4	3
BCB11-277	5	4	3	5
BCB11-459	2	4	3	3
BCB11-504	3	4	3	3
BCB11-252	6	4	3	5
BCB11-221	5	4	4	4
BCB11-223	7	5	3	5
BCB11-435	5	5	3	7
BCB11-502	5	5	3	3
BCB11-531	3	5	2	6
BCB11-316	5	5	3	4
BCB11-387	5	5	3	6
BCB11-417	6	5	3	5
BCB11-224	5	6	3	5
BCB11-226	3	6	3	3
BCB11-295	7	6	3	5
BCB11-488	5	6	3	3
BCB11-322	5	6	3	5
BCB11-404	5	6	3	5
BCB11-246	3	6	5	3
BCB11-359	5	6	3	3
BCB11-365	3	6	3	3
BCB11-250	6	7	4	6
BCB11-447	5	7	3	3
BCB11-315	4	7	3	5
BCB11-352	5	7	3	3
BCB11-416	5	7	4	6
BCB11-497	4	7	3	3
BCB11-227	3	7	3	6
BCB11-260	3	7	5	6
BCB11-288	5	8	3	4
BCB11-442	5	8	3	4
BCB11-220	6	8	5	6
BCB11-368	4	8	4	4
BCB11-375	4	8	2	5
GLP585	6	7	3	4
GLP92	6	6	3	4
KATB1	4	8	3	5
SER16	3	3	2	2
SER76	3	3	3	2
Mean	4	5	3	4
CV (%)	19.5	14.7	21.2	21.3

Appendix 21: Monthly means of rainfall and temperature in Kabete and thika during the 2012 long-rain season

	Rainfall (mm)		Max temperature		Min temperature	
Month	**Kabete**	**Thika**	**Kabete**	**Thika**	**Kabete**	**Thika**
April	352.6	248.5	23.9	26.7	15	15.0
May	262	182.6	23.5	25.8	14.2	15.4
June	23	38.1	21.4	24.1	12	14.0
July	12	7.5	21.1	22.8	12	13.3
Mean	649.6	476.7	22.7	24.9	12.7	14.4

Appendix 22: Monthly means of rainfall and temperature across study sites during the 2012/2013 short-rain season

	Rainfall (mm)				Maximum temperature (°C)				Minmum temperature (°C)			
Month	**Kabete**	**Thika**	**Nakuru**	**Tigoni**	**Kabete**	**Thika**	**Nakuru**	**Tigoni**	**Kabete**	**Thika**	**Nakuru**	**Tigoni**
October	241.5	50.8	102.7	220.0	24.6	27.8	25.3	19.2	14.2	15.4	12	13
November	261.8	177.1	116.3	134.2	23.3	26.2	24.6	18.6	14.1	15.2	11.7	14.9
December	231.8	168.4	116.1	176.5	22.8	25.9	25.1	18.3	14.1	14.8	12.1	13.2
January	45.1	73.3	70.1	48.0	23.9	26.6	22.1	18.4	13.9	14.2	8	14.5
Mean	779.4	469.6	405.2	578.7	23.7	26.6	24.3	18.6	14.1	14.9	8.1	13.9

Appendix 23. Sensory evaluation form used by the panelists

Product characteristics	**7**= Like very much	**6**=Like moderately	**5**=Like slightly	**4**=Neither like Nor dislike	**3**=Dislike slightly	**2**=Dislike moderately	**1**=Dislike very much
Color							
Size							
Appearance							
Taste							
Mouth feel							
Flavor							
Wholesomeness							
Overall acceptability*							

*7= very much acceptable, 1= very much unacceptable