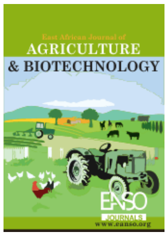

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Original Article

Productivity Screening of Common Bean (Phaseolus vulgaris L.) Varieties and Agronomic Trait Eco-Seasonal Morphological and Physiological Characterization

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ABSTRACT

The productivity of beans (*Phaseolus vulgaris* L**)** has been found to be influenced by biophysical stresses like ecological variations, genotype, climate, pests, and soil fertility. This has reduced bean productivity by 25% in some cases. Hence, research to improve bean varieties and the consequential assessment of their field performance is necessitated by global climate change scenarios. The eco-matching of genotypes in the midst of emerging issues like climate change and global warming has serious economic and food security implications. This research evaluated genotype, seasonal, ecological, and productivity variations of four bean varieties in three diverse ecological zones at the Mua Hills in Machakos County in Kenya. All the experiments were arranged in a Complete Randomized Block Design (RCBD). The research obtained data on growth (leaf numbers, plant heights, plant maturity times), seed parameters (seed water imbibition, shape, colour) and yield parameters (number of pods, pod weight, 100 seed weight) until harvesting time. Data collected were subjected to Multivariate analysis of variance (ANOVA) at $P \leq 0.05$ and means separated using the LSD significant difference test at $P \leq 0.05$. The study found that there were significant bean genotype and seasonal and eco-sensitive variation differences at $P \leq 0.05$. The economically valuable trait of 100 seed weight correlated positively with other traits in all zones. Therefore, bean varieties are season and eco-sensitive due to genotype, water stress, and current climate change scenarios. Hence, breeding experiments should endeavour to release varieties that have undergone seasonal ecological screening as exacerbated by the need for high productivity.

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INTRODUCTION

The common bean (*Phaseolus vulgaris* L**)** has been referred to as the meat of the poor because it is the main source of affordable protein in developing countries (Celmeli et al., 2018, Maphosa & Jideani, 2017). Beans also supply micronutrients such as iron and zinc, especially for children and the elderly, because it is easy to inter-grow in most agro-ecological lands (Larochelle et al., 2013). However, increasing soil acidity, land fragmentation, increased population, urbanization and climate change are threatening the productivity and food security in poor countries (FAO, 2015). Hence, there was a need to increase on-farm research efforts to select, breed, and disseminate new bean varieties. These bean varieties should be adaptable to climate variability, climate change, and ecological differences that will result in the reduction of food insecurity. Therefore, there is a growing need to assess bean performance in different scenarios (Shiferaw et al., 2014).

Surprisingly, in the Sub-Saharan region, especially in Kenya, bean production has been decreasing while the demand has been going up. For example, FAOSTAT; (2010) showed that the 2007 production was about 417 000 metric tons, but the demand was about 500,000 metric tons.

This research aimed at precipitating some of the key factors that can be used to increase the quality and quantity of bean productivity, especially in matching bean variety to ecological zones based on the highest returns. The productivity of beans has been found to be influenced by biophysical stresses such as climate, pests, and soil fertility with some decreasing it by 25% (Odendo et al., 2002). Even at the molecular level, the variability of the protein level and types in common beans (*Phaseolus vulgaris L*); was found to be influenced by geographic distribution (Koening & Gepts, 1989, Gouveia et al., 2014). For example, bean varieties with the dominating S type of phaseolin protein were found to be better adapted to areas with high temperature and erratic rainfall patterns compared to others (Genchev et al., 2002). Studies have shown that the common bean crop is generally a warm-season plant that does not require an excessive amount of moisture in the soil (Onwueme and Sinha, 1991). It can do well within 300- 600mm rainfall depending on the type, drainage, texture, and 6.0-7.5 pH of the soil and other climatic factors (Wortman, 2012). However, there should be

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sustained rain during flowering and pod setting stages in beans (Katungi et al., 2009).

There have been efforts for continuous research to develop bean germplasm that is well adapted to various ecological zones in Kenya, where beans and maize make up the most common food in Kenya schools. This is because it is easy to cook maize and beans as a cheap carbohydrate and protein combination. The combination is called *Githeri* and has a high nutritional quality of bean protein which complements the starchy maize component (Maphosa & Jideani, 2017). Furthermore, vegetables and fat are also added to the high zinc and iron mineral content of beans. This staple food is advantageous in the sub-Saharan area where there are micronutrient deficiencies such as iron (Broughton et al., 2003). However, most of the recently produced germplasm has not been ecologically and comparatively evaluated and characterized to determine their productivity potential. On-farm trials can be vital tools for speeding up breeding programs and can enhance cultivar adoption rates in farming communities. (Assefa et al., 2005; Romney et al. 2003). Local farmers and bean marketers were found to be employing trial and error methods to determine which bean variety was suitable for their particular ecological conditions (Katuuramu et al., 2020). Hence, this research serves as a major contributor to the scientific screening of morphological and physiological agronomic traits of bean varieties aimed at food security in that area for generations depended on bean protein as a supplement in their staple foods (De Jager et al., 2019).

MATERIALS AND METHODS

Study Sites

The project was carried out in Machakos County, Kenya at three different sites in Mua hills in three different agro-ecological zones (AEZ). The sites were at the highest of the hills, hereby referred to as Mua radar, Kimua primary and Makyau.

The Mua radar site was in a farmer's field, found at an altitude of 2127m above sea level at a longitude -1.47401 and latitude 37.19249 and at an agro-ecological zone 2. The site has black sandy and volcanic soils, which are friable. The soils are deep with very few stones here and there. It has relatively low temperatures of (11-25^{0}C) even in dry periods.

The Makyau site was located at an altitude 1800m above sea level at a longitude of -1.47052 and latitude of 37.214093 within the agro-ecological zone of 3. The soil in this site was deep red soil and highly weathered. Temperatures in this zone were relatively hotter than the Mua radar site during the dry period.

The Kimua primary site was located at an altitude of 1752m above sea level at the latitude of 1.498 and longitude of 37.20471 within the agro-ecological zone 4. It had a mixture of red soils and a low percentage of sandy soils. The soils seemed to be poor in nutrients and could easily form a hard pan. During the dry period, the temperatures in this zone are as high as 30^{o}C and more (Jaetzold, 2007).

Planting Materials

Three of the bean varieties (Nyota, Angaza and Faida) used in this study were obtained from Kenya Agricultural and Livestock Research Organization, Katumani, Machakos County, Kenya, located at latitude 11^{0}35'S: longitude 37^{0}14'E, and 1560masl. The Centre experiences a semi-tropical climate described as AEZ IV with a bi-modal pattern of rainfall of an average of 200-400 mm of rain. The temperatures range from 13.7^{0}C to 24.7^{0}C (GoK, 2013). The fourth bean variety (Kakunzu) was obtained from the local farmer's field in the Mavoko sub-county, Kinanie location, which is located at a latitude of – 1.47401 longitude 37.19249 and 2127m above sea level. That area is described as AEZ 2 with a bi-modal pattern of rainfall. The Nyota and Angaza bean varieties were released to farmers in 2017, while the Faida and Kakunzu dates

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of release were debatable, although they were not earlier than 2015 and not later than 2017.

Plate 1: The physical appearance of the experimental bean varieties used in the research

Plate 1 shows the physical appearance of the experimental bean varieties used in the research, namely, Nyota, Angaza, Faida and Kakunzu. The origin of the varieties is the Kenya Agricultural Research Organization (KALRO), Katumani Station at Machakos county in Kenya

Experimental Design and Data collection

The experimental design was in a Randomized Complete Block Design in the three sites and four replicates in each site for each bean variety. Each plot size was 5m by 5m, and a bean plant spacing of 45 cm by 15 cm. Hence, the plant population was about 100 plants per the plot size of 5m x 5m. The following parameters were evaluated: Imbibition rate, germination rate, growth rates in the first week, biomass, yield, geometrical mean, seed weight, and moisture content. Most of the parameters were evaluated before and after the experiment except for the growth rate and biomass. At bean maturity, three plants per site were randomly selected to record data on seed yield and twenty morphological characters such as plant height (cm), internode diameter (mm), node number of the main stem, node number of lateral branches, the number of pods per plant, pod weight (g), seed number per pod, pod tail length (mm), pod length without a tail (cm), seed length (mm), seed diameter (mm), seed width (mm), straw (biomass) weight (g), biologic yield (g), internode length (cm), 100 seed weight (g), 50% flowering, 50% pod, days to maturity and seed number per plant were determined. The mean values were used for statistical analysis. The measurements were done according to the IPGRI descriptor list for *P. vulgaris* L.

Determining Percentage Moisture Content

Ten bean grains from each variety were picked at random to obtain averages of the per cent grain moisture contents using a GMK-303RS moisture meter calibrated to measure bean grain moisture content 12.5 - 19.7% with an accuracy of ±0.5% to obtain an average data in nine repetitions (Kimatu et al., 2014). Ten grains from each variety were picked randomly after thorough mixing. The grains were crushed inside the grain moisture meter and reading was recorded. The process was repeated three times for different bean grains from each variety and the averages of percentage Moisture content were recorded for analysis.

Bean Water Imbibition Ability

The water imbibition ability of the beans was determined according to (Lu & Chang (1996). In which 100 g of beans were soaked into a beaker of distilled water for 16 hours at room temperature. They were at a ratio of 1:5 (p v-1) beans: water. After this period, the difference in weight of the bean was measured, and the level of hydration was expressed as grams of water absorbed by 100g of

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the bean variety. The test was carried out in triplicate and averages were taken and recorded.

Measurement of Seed Weight

The average weight of 500 seeds was determined using a digital weighing balance of 0.01 g accuracy in order to make comparisons of the beans and relate them with the moisture contents. The measurements were repeated to achieve an average for each variety. The average size of the raw beans of each variety was established according to the weight in grams of 100 units according to Zirmmermann et al. (1988) as very small beans <20g; small, 20 to 30 g; average, 30 to 40 g; normal, 40 to 50 g and big >60 g.

Measurement of Agro-Morphological Characters

The morphological inspection of the bean was done in order to estimate the possible aesthetic market value of each bean variety together with the phenotype variations. These included physical properties like shape, length, width and thickness (Kimatu et al., 2014). Then, the geometric mean diameter of the seeds will be evaluated using the relationship given as Dg = (LWT) 1/3. Where; Dg = geometric mean diameter; L = length; W = width; T = thickness.

The degree of sphericity of the various varieties of beans was determined using the equation; φ = Dg /L= (LWT) 1/3L. Where; φ = degree of sphericity; Dg= geometric mean diameter; L = length; W = width; T = thickness as described by Adejumo and Abayomi, (2012).

Data Analysis

The yield data was analyzed using MS X-Cel and GenStat Discovery edition (Buysse et al., 2004). Analysis of variance (ANOVA) was done to evaluate significant ($p \leq 0.01$) differences among genotypes with respect to the parameters of the study. Correlation analysis was used to determine seed yield correlations to seed number per plant, per season and seed number per pod, as these traits had been suggested as being useful in common bean breeding programs (Dewey & Lu, 1959). Stepwise regression analysis was used to determine whether pod weight, seed number per pod and 100 seed weight contributed to the seed yield prediction. The Pearson's correlation coefficients were computed among the phenotypic traits in order to determine the relationships between traits and seed yield per plant. The Factor analysis with varimax rotation was used in order to make each factor uniquely defined as a distinct cluster of inter-correlated variables (Rao, 1952). The correlation coefficients, stepwise multiple regression analysis and factor analysis were carried out using SAS statistical program (SAS, 2004).

RESULTS

Pod Plus Seed Weight Analysis

The pod size gave an approximate of the seeds in the pod, while the weight of the seeds gives the economic value to the farmer after selling the beans. This was done because some of the families consumed green pods of beans like French beans as vegetables.

Table 1 shows the ANOVA table of the interaction between seed weight and pod size showing a significant interaction of $p<0.05$ due to genotype differences, seasonal conditions, and ecological variations of beans at Machakos County sites in Kenya.

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Table 1: The ANOVA table of the interaction between seed weight and pod size

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	118770.3	2	59385.14	3.546072	0.096255	5.143253
Seed weight	6117.599	1	6117.599	0.365301	0.567713	5.987378
Pod/seed weight Interactions	319016.5	2	159508.3	9.524738	0.013742	5.143253
Within	100480.4	6	16746.74			
Total	544384.8	11				

The experimental regions received two seasons of rain in a year. There were short rains in the months of October, November and December (OND) and long rains in the months of March, April and May (MAM). The relationship between the rainfall seasons and the pod plus seed weight is shown in *Figure 1* below.

Figure 1: Relationship between the rainfall seasons and the pod plus seed weight

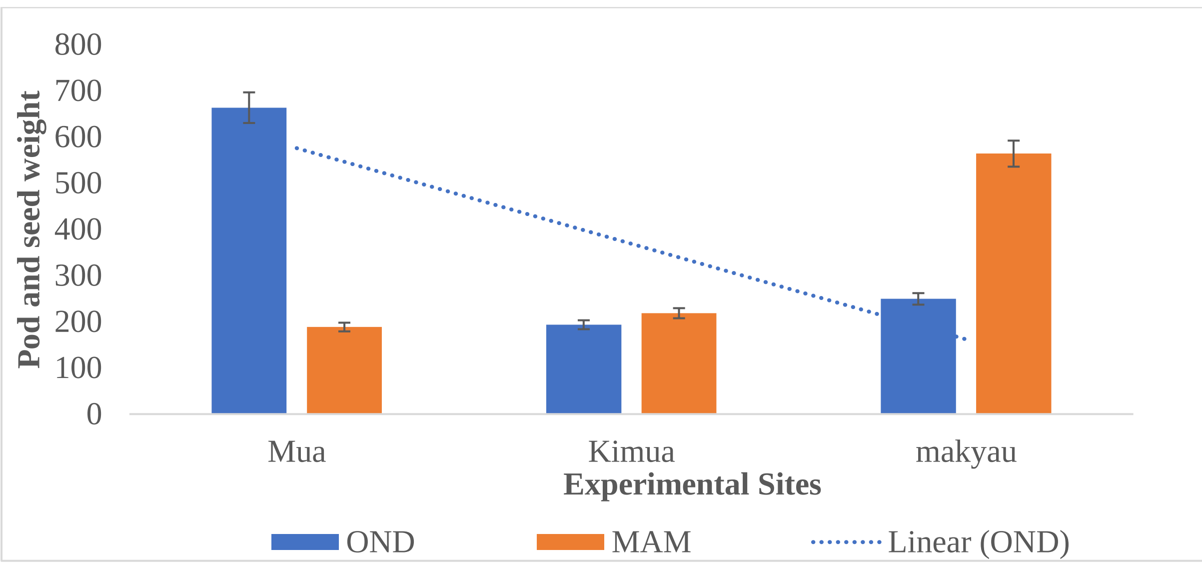

Figure 1 shows that the short cold rain season OND yielded more in Mua than the rest of the sites but had the lowest in the long warm seasons MAM. The Makyau yielded more in the long warm seasons compared to other sites. While Kimua primary had relatively lower yield in both the short cold rain and the long warm rainfall season or OND and MAM, respectively

Analysis of Seasonal Variations of 100 Bean Seed Weights

One of the most valuable economic traits was grain weight. This was because the drop was mainly sold and consumed in grain form and is measured in weight. This can be influenced by the water imbibed by the seed, the amount of water in the soil and the genotype's ability to physiologically absorb it.

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Table 2: Seasonal variations of 100 bean seed weights for the Genotypes in different ecological zones

Source of Variation	SS	Df	MS	F	P-value	F crit
Sample	412.56	3.00	137.52	0.65	0.59	2.84
OND/MAM Seasons	2010.95	1.00	2010.95	9.48	0.00	4.08
Interactions	1027.26	3.00	342.42	1.61	0.20	2.84
Within	8481.42	40.00	212.04			
Total	11932.19	47				

Table 2 shows *the* ANOVA table showing seasonal variations of 100 bean seed weight within four genotypes in three different ecological zones. The results show a significant difference (P<0.005) in seasonal differences in seed weights amongst bean varieties.

Analysis of Seasonal Variations of 100 Bean Seed Weights of each Genotype

The careful examination of specific bean genotype performances in particular seasons showed that even at the genomic level, there were significant differences. The Nyota variety performed much better in the long rains of MAM compared to other varieties (*Figure 2*). The Faida variety performed better than the others in the short rains of OND.

Figure 2: 100 seed weight performance for the different varieties

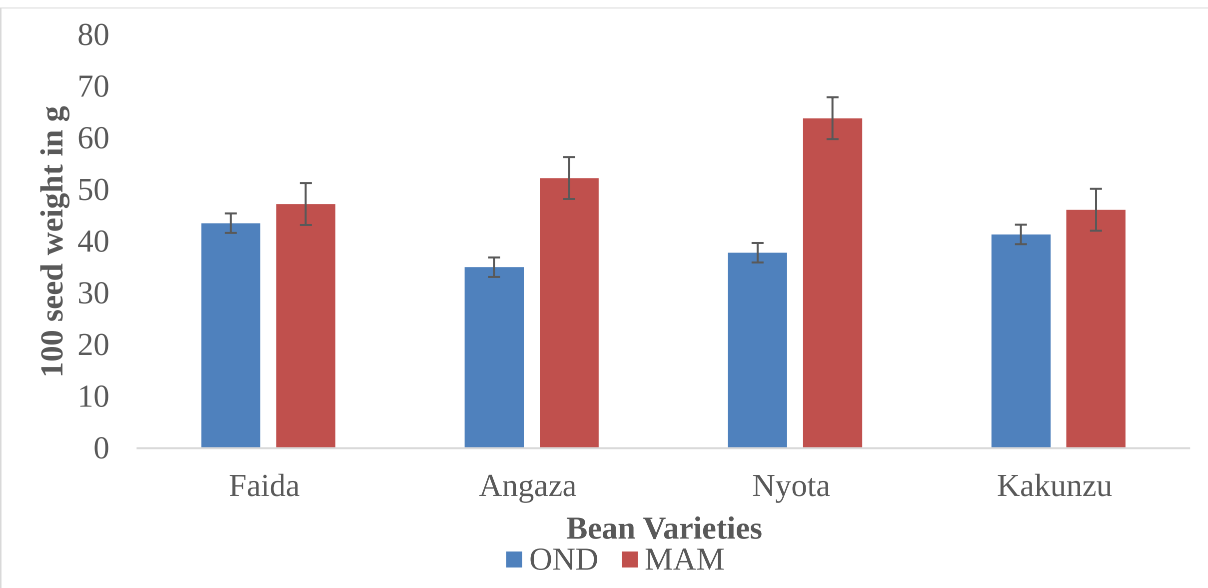

Figure 2 shows the 100 seed weight performance for the different varieties in both the short OND rains and the long MAM rains

Analysis of 100 Seed Weight Variation in Specific Bean Varieties in Different Agro-ecological zones

The experiment also determined the specific genotype seasonal and ecological sensitivity in influencing the seed weight parameter, as shown in

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Table 3. The Faida variety showed significant a difference ($p < 0.05$).

Table 3: Faida seed variety analysis in different season and ecological zones

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	639.8220792	2	319.9110396	7.818158	0.021326	5.143253
Columns	41.12551875	1	41.12551875	1.005048	0.354794	5.987378
Interaction	365.0644125	2	182.5322063	4.46082	0.065014	5.143253
Within	245.5138625	6	40.91897708			
Total	1291.525873	11				

Table 3 shows the Faida seed variety analysis of its 100 seeds alone in different seasons and ecological zones, showing significant differences at $p<0.05$. The Faida seed variety showed an above-average performance at the Makyau site during the long rains (MAM).

Table 4 shows Angaza seed variety analysis of its 100 seeds alone in different seasons and ecological zones, showing significance at $p<0.05$

Table 4: Angaza seed variety analysis in different seasons and ecological zones

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	532.8087	2	266.4043	0.5777	0.5895	5.1432
Columns	893.5502	1	893.5502	1.9377	0.2133	5.9873
Interaction	741.0254	2	370.5127	0.8035	0.4906	5.1432
Within	2766.7020	6	461.1170			
Total	4934.0864	11				

Angaza showed better performance at the Mua radar station in the Long MAM rains. And performed similarly in both Mua radar and Makyau station in the colder, shorter rain OND

Table 5 shows ANOVA of the Nyota bean variety, showing how it was eco-influenced in the short rains at the Mua Radar site and Makyau sites with a p-value of less than 0.05.

Table 5: Nyota seed variety analysis in different season and ecological zones

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	1272.891	2	636.4454	46.56968	0.000222	5.143253
Columns	2035.156	1	2035.156	148.9155	1.84E-05	5.987378
Interaction	18.15753	2	9.078765	0.664307	0.548767	5.143253
Within	81.99911	6	13.66652			
Total	3408.204	11				

The Nyota variety showed a significant performance $p< 0.05$. with the best 100 seed weight performance at Mua Radar station, especially during the hotter, longer season of MAM, followed by Makyau and Kimua stations, respectively. During the shorter, colder season of OND rains

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Nyota did relatively similar in both Makyau and Mua stations

Table 6 shows the ANOVA table showing the significant performance ($p<0.05$) of the Kakunzu bean variety.

Table 6: Kakunzu bean seed variety analysis in different seasons and ecological zones

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	527.1105527	2	263.5553	8.646951	0.017089	5.143253
Columns	68.38277633	1	68.38278	2.243562	0.184821	5.987378
Interaction	1107.444553	2	553.7223	18.167	0.002847	5.143253
Within	182.877362	6	30.47956			
Total	1885.815244	11				

The performance of the Kakunzu bean variety showed better performance in long hot rain conditions MAM compared to the other varieties. It performed highest at Mua rader and in the short colder season OND compared to other sites. Showing it is quite site-selective and season sensitive.

Moisture Content

The analysis of moisture content for the bean did not yield very significant differences. The $P>0.05$. This showed that the bean plant tended to regulate the amount of water to be as constant as possible. In the case of less water, the seeds became smaller and slender. But in the case of much continuous moisture, the seeds tended to be roundish and bigger, as shown in *Figure 3* and *Table 7 below.*

Figure 3: moisture content of various bean varieties

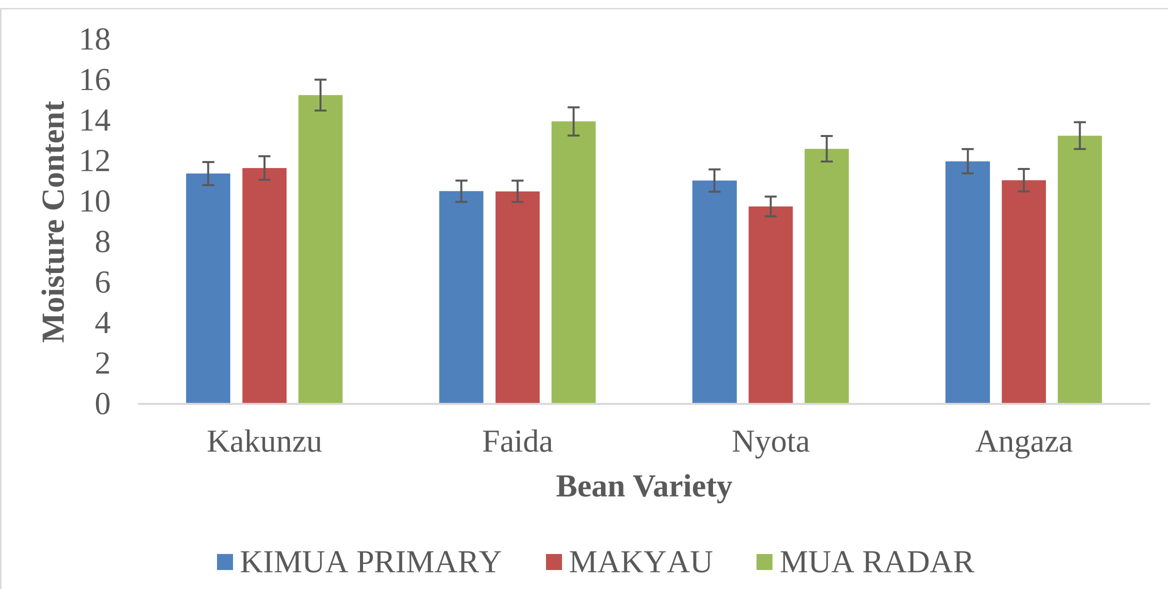

Figure 3 shows that the levels of moisture content of various bean varieties were not significantly different, but bean varieties grown in more moisture seem to imbibe more moisture to be bigger and roundish.

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Table 7 shows the ANOVA for moisture content of various bean genotypes in various ecological zones showing not much significant difference, although the Kakunzu variety seemed to overshoot in the expected water content in wetter, warmer conditions

Table 7: Moisture content of various bean genotypes in various ecological zones

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.2125	3	1.7375	0.367482	0.781471	6.591382
Within Groups	18.9125	4	4.728125			
Total	24.125	7				

DISCUSSIONS

In the present *Phaseolus vulgaris* study, responses to ecological, seasonal, and genotype variations have been analyzed. This was occasioned by the studies that the average productivity per annum in many African countries is lower than that of the world. However, the lack of improved varieties associated with abiotic and biotic factors has been cited as a primary source of lower bean production (Graham & Ranalli, 1997; Caldas et al., 2016). This study reveals that there are other intra-genomic and eco-sensitive parameters which have significant economic and social impacts on bean production strategies. It is through the specific ecological, yield and growth parameter analysis that these results have been precipitated. This also agrees with Ulukan *et al. (*2003), who showed that path analysis could be used to determine the amount of direct and indirect effects of independent variables on the dependent variable. This interrelationship of characters between productivity and its components in bean have also been studied by Sadeghi *et al.* (2011); Golparvar (2012); Cokkizgin *et al*. (2013) and have shown that factor analysis is a multivariate statistical method that can reduce a large number of correlated variables into a small number of uncorrelated factors. We linked growth factors of agronomic traits like seed weight and pod sizes. Pod sizes were related to plant heights, internodes, and biomass. Therefore, these correlation studies, using factor analysis and path analysis as multivariate statistical methods, provided the possibility of recognizing the most important effective characteristics of bean grain yield, as was also seen by Johnson & Wichern (1982).

The morphological analysis revealed that *Phaseolus Vulgaris* L. has much diversity in colour, size, chemical composition, shape, hardness, and moisture content depending on the cultivars. These differences could be the effects of interactions of intrinsic factors like genotype, ecological, climate variations, agronomic practices and even technological factors (Amir et al., 2007; Gathu & Njage, 2012; Aghkhani et al., 2012). The focus on the economic qualities of beans includes customer acceptable morphological and physiological characteristics. These are highly considered by farmers, consumers and plant breeders (Arteaga et al., 2020; Bassinello et al., 2003; Gathu & Njage, 2012). Measurements of size and seed shape and their correlation and relationship are important in breeding for seed yield. The relationship between seed shape and agronomic characteristics can be useful in improving yield or quality (Adewale et al., 2010; Williams et al., 2013). This study proves that ecological matching should be a factor to be considered in the future. The climate change phenomenon is also influencing the length of rain seasons and this shall have a great impact on the productivity of beans and eventual food security strategies.

This research showed that a variety like Kakunzu and Nyota could differ in productivity due to temperature differences and moisture content within

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what we can refer to as microclimate-induced conditions. These differences have also been observed in other parameters like soil salinity tolerance and water stress, of which selections have been made (Zhumabayeva et al., 2019; Gama et al., 2007).

CONCLUSIONS

Although the common bean *Phaseolus vulgaris* is generally a warm-season crop that does not require an excessive amount of moisture in the soil (Onwueme & Sinha, 1991**),** current prolonged droughts and floods due to climate change shall impact bean productivity even within narrow ecological zones.

The *Phaseolus vulgaris* generally requires 300-600mm of rainfall and is also influenced by the type of soil, soil drainage, and soil texture, soil pH (Wortman, 2012**)**. This study observed that little or excess rains could affect productivity even between seasons. Hence, efforts should be made to screen genotypes that are able to sustain yield parameters like flowering and pod setting stages under these ecological constraints (Katungi et al., 2009).

The identification of landrace genotypes that can be more competitive in low-input agriculture can be used by breeders as a source of allelic richness that can enhance bean agronomic production in the light of unpredictable climate change scenarios. This was also observed by Fess et al. (2011).

This study observed that there should be genotypic studies for each bean variety on the length, moisture content and temperature for every planting season. Farmers should be advised to understand that what worked best in a particular season in a particular ecological zone should not be blinded copied into farms. Extension officers should come up with seasonal charts of bean varieties for every ecological zone and rainy season so as to maximize all the productivity parameters in bean farming.

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Conflicts of Interest

The authors declare no conflict of interest.

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