Journal of Agricultural Science; Vol. 10, No. 12; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Genotypic Performance of Short-Day Runner Bean (*Phaseolus coccineus* L.) Lines Combining High Grain Yield and Disease Resistance

Mable M. Mulanya[1], Paul M. Kimani[1] & Rama D. Narla[1]

[1] Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, Kenya

Correspondence: Mable M. Mulanya, Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, Kenya. Tel: 254-721-114-490. E-mail: mulasco@gmail.com

Received: August 14, 2018 Accepted: September 30, 2018 Online Published: November 15, 2018

doi:10.5539/jas.v10n12p54 URL: https://doi.org/10.5539/jas.v10n12p54

Abstract

Runner bean (*Phaseolus coccineus* L.) offers a great potential as a grain legume in Africa. However, its productivity is low because no improved short-day varieties are available. The aim of this study was to evaluate advanced short-day runner bean lines for high grain yield, resistance to diseases and suitable for cultivation under tropical conditions. $F_{6.8}$ recombinant inbred lines developed from crosses between local landraces and high yielding imported variety (White Emergo) were evaluated in 2013 and 2014 in a randomized complete block design with three replicates at Kabete (1860 m.a.s.l.) and Ol Joro-Orok (2300 m.a.s.l.) in Kenya. Four local runner bean landraces were used as checks. Analysis of variance showed that there were significant differences for days to flowering, response to diseases and grain yield among the evaluated lines. Improved lines flowered within 49 to 52 days in 2013 and 34 to 58 days in 2014.The improved lines flowered earlier at Kabete than Ol Joro-Orok and showed a higher degree of resistance (scores 1-3) to the major diseases rust, bean common mosaic virus (BCMV) and powdery mildew. The mean grain yield at Kabete was 4,426 kg ha^{-1} compared to 6,523 kg ha^{-1} at Ol Joro-Orok giving an average yield advantage of up to 67% compared with local short-day landraces. The results indicated that new high yielding short-day runner bean varieties with resistance to major diseases and tropical adaptation can be obtained from these lines.

Keywords: runner bean, disease resistance, high yield, tropical adaptation

1. Introduction

Grain legumes are rich in dietary protein hence compliment nutritional value of cereals. In the tropics, there has been a need to intensify productivity of other legumes to enhance food security (Wanjekeche et al., 1997). Runner bean is one of the cultivated *Phaseolus* species which offers a great opportunity as a grain legume in Africa. Runner bean (*Phaseolus coccineus* L.) has been cultivated since 9000-7000 BC (Smart, 1976), in the region surrounded by Mexican mountains—Puebla, Oaxaca and Chiapas states. In Kenya, the grain runner bean is traditionally grown at elevations between 2000 and 2500 meters above sea level (m.a.s.l.) in Nakuru and Nyandarua Counties. Based on (Kahuro, 1990; Suttie, 1969), the commonly grown variety in these counties is white seeded commonly referred to as 'butter bean. This is despite the fact that runner bean has other different grain colours ranging from black, white, cream, brown or pink to purple speckled or mottled in the country. The white seeded variety is also grown in South Africa (Brink, 2006). Runner bean is mainly grown both for dry grain and immature green pods as vegetable and can be of bush type or climbing. As a vegetable, the green pods can be harvested in 80 to 90 days from planting, and 100-120 days for dry grain depending on the climatic adaptations (Purseglove, 1987). Despite its importance, grain yield of runner bean in Kenya is as low as 900 to1100 kg ha^{-1}, estimated 27 years ago (Kahuro, 1990). Current production statistics in the country or region on the grain yield of runner bean are scanty mainly due to underutilization of this type of bean as a commercial crop. The white seeded Kenyan variety flowers and sets pods easily but has poor yields (Kahuro, 1990; Kay, 1981). Due to the out-crossing nature of runner beans in addition to lack of certified seed, most farmers have not been able to maintain a pure stock of seeds, resulting in mixed seeds. Therefore, there is a need of developing improved, pure stands and certified seed for commercial production of runner beans. Most breeding work in Kenya for the last three decades has been focused on common beans and other legumes (Kimani et al., 2009). Until recently, runner bean has received research attention in Kenya and other African countries. As result, runner bean is among the underutilized grain legumes, with low per capita consumption in Africa at large even though, this crop is of great potential as a grain legume, vegetable, fodder crop and as useful source of diversity for improvement of common beans (Singh, 2001). Runner bean has been known to possess useful agronomic and disease resistance traits such as lodging resistance, cold tolerance, long epicotyls and racemes, presence of a tuberous root system allowing a perennial cycle (Santalla et al., 2004), a high number of pods per inflorescence (Vanderborght, 1983), and resistance to *Sclerotinia sclerotiorum* (Gilmore et al., 2002), Ascochyta blight (Schmit & Baudoin, 1992), root rot caused by Pythium or Fusarium (Dickson & Boettger, 1977), among others. Runner bean has also been found to be highly adapted to cooler temperatures at higher altitude compared to common bean (Santalla et al., 2004). There has been a successful introgression of moderate levels of resistance to *Fusarium* root rot (Wallace & Wilkinson, 1965), *Xanthomonas* and white mold (Miklas et al., 1998) from *P. coccineus* to *P. vulgaris.* Other studies have also shown *P. coccineus* being included in breeding programs with common beans as a source of resistance to anthracnose (*Colletotrichum lindemuthianum*) (Schmit & Baudoin, 1992) or against the bean yellow mosaic virus (BYMV) (González, 2000; Osorno et al., 2007). Therefore, developing improved runner beans will enrich the available genetic resource of runner bean and conserve the nearly extinct local landraces. However, the major limitation to the genetic advancement of runner bean in Kenya has been photoperiod sensitivity since the available varieties are vegetable type and are mainly imported from temperate countries hence do not flower under the tropical conditions. Farmers are forced to install artificial light *e.g.* bulbs in field to provide extended lighting to enhance flowering of the long day vegetable varieties. This venture is however very expensive and excludes small holder farmers. In an attempt to improve productivity of grain runner bean, populations of short-day runner beans were developed in 2004 by University of Nairobi bean program. The populations were generated initially from crosses between the Kenyan runner bean landraces collected locally from Kinangop, Nyeri, Nyandarua (Cooler conditions) and Kabete (warm conditions) and high yielding imported vegetable variety (White Emergo). These populations were advanced through a series of bulk selections up to $F_{6.8}$ generations (Kimani et al., 2009). In the bulk population method, the F_2 populations and subsequent generations were harvested in mass or as bulks to raise the next generation. During the bulking period, natural selection plays an important role as opposed to artificial selection (Acquaah, 2007). In this study, the subsequent bulking was done up to F_6, after which single plant selections were done and planted out as progeny rows for the next generation. The single plant selection was continuous for 8 generations creating $F_{6.8}$ populations. However, these advanced runner bean lines had not been evaluated at different locations and seasons for special adaptability in combining high grain yield and disease resistant. The crop has been known to thrive in cooler temperature at higher altitudes but evaluation in warmer areas was not performed, which will be an important aspect to expand production areas of the crop. The objective of this study therefore was to evaluate and select locally adapted short day runner bean lines that combine high grain yield and resistance to diseases for smallholder farmers.

2. Materials and Methods

2.1 Plant Materials

The study materials were $F_{6.8}$ lines which were initially developed since 2004 in Kenya from crosses between five short day local landraces collected from Kinangop, Nyeri, Nyahururu and Kabete as male parents, and one female imported variety (White Emergo). White Emergo was considered as female parent because it's a high yielding vegetable variety mainly produced in large scale farms in Kenya for export. The local landraces were designated based on the locations they were collected from as Kin 1, Kin 2, Kin 3 and Kin 4 from Kinangop, Nyeri from Nyeri, Ol Joro-Orok Dwarfs from Nyahururu and Kabete local from Kabete. Progenies from the crosses were advanced through bulk population method up to F_6 generation from which single plant selections were made. Continuous single plant selections were done up to $F_{6.8}$. For this study 43 $F_{6.8}$ lines were evaluated in 2013 and 2014 at Kabete Field Station and Ol Joro-Orok.

2.2 Trial Sites

Field experiments were conducted at University of Nairobi Kabete Field Station (1840 m a.s.l) and Kenya Agricultural and Livestock Research Organization (KALRO)-Ol Joro-Orok (2300m a.s.l) for the two seasons in Kenya. Kabete Field Station mainly experienced two crop season with a mean annual rainfall of about 1000 mm received during long rains (March to July), and short rains (October to December). The temperature in this area ranged from 13.7 °C to 24.3 °C. The soils were very deep, well drained, dark reddish, deep friable clay type resistant to erosion. On the other hand, Ol Joro-Orok had a mean annual rainfall of 1000 mm which permitted a continuous cropping between March and December with temperature ranging from 10 °C to 22 °C. Dominating soils were planosols which are deep, imperfectly drained, firm and very dark greyish brown in colour (Jaetzold et al., 2006).

2.3 Experimental Design

The experiments were conducted in 2013 and 2014. Each year, experiments were laid out in a randomized complete block design with three replications. A plot comprised of 10 plants laid in a single row of 3m length with spacing of 30cm and 50cm between rows. The test lines were planted using pod to progeny row method. Progeny selection method is commonly used in cross-pollinated and because of the outcrossing nature of runner bean (Labuda, 2010) this method was employed in runner bean improvement to attain homozygosity early enough among lines. Pod to progeny is a modification of ear to row method developed by Hopkins in 1908 (Cumo, 2007) where each ear from a heterogenous family is selected and planted in a row referred to progeny rows. In same way, in beans, each pod from a family was selected and planted in a row making a progeny row. The crop was weeded when necessary. A string or stakes were used to support the plant whereby each individual plant was stalked with wooden stakes or tied with a string (at the base of the plant) to a top placed heavy weight wire suspended horizontally across the row. The wire was supported by sturdy wooden Eucalyptus poles on each side of the row. Insect pests were controlled by alternate application of Cyclone® (10% cypermethrin + 35% chlorpryphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1} after every two months. The climatic conditions based on the weather data collected at the two sites varied for the two years from the past common trend. Therefore, grain yield was determined based on the year that showed the ideal climatic condition for each site. For this reason, grain yield was evaluated at Ol Joro-Orok (predominantly cool conditions) in 2013 and at Kabete (warm conditions) in 2014.Unlike other beans, the duration of growth to maturity of runner bean was two seasons (one year) at Ol Joro-Orok at Kabete it matured earlier in 7 months. Therefore, the two seasons (long and short rains) were not differentiated during the experiment and only site effects were considered significant. The four local landraces were incorporated in both years however due to poor germination percentage of local checks, Kin 2 and Kin 3 which established reasonable stand count were used as checks in 2013, while Dwarf 1 and Dwarf 2 used as checks in in 2014.

2.4 Data Collection and Statistical Analysis

Data was collected on duration to 50% flowering, disease resistance and grain yield. Duration to 50% flowering was recorded as the number of days from sowing to the date when 50% of plants had one or more open flowers in the racemes. Since runner been has two flowering stages, days to 50% flowering were based on the first flush which is the significant flowering stage. The numbers of racemes were counted on a single plant basis at 1st and 2nd flush of flowering. Disease scale used by (Centro International de Agricultura Tropical (CIAT) for different diseases was utilized to score for the reaction of lines to infection by powdery mildew, rust and bean common mosaic virus diseases (Schoonhoven & Pastor-Corrales, 1987). On this scale, a mean score of 1-3 = resistant, 4-6 = intermediate, and 7-9 susceptible (Table 1). The disease scores were taken on a sample of 20 plants in a plot at flowering stage in each location. However, disease evaluation in this study was done at locations considered as hotspots for that specific disease since the two locations are hosts of different diseases. For this reason, resistance to BCMV was evaluated at Ol Joro-Orok as it has been identified as one of the areas with high incidence of BCMV Omunyin et al., 1995) and powdery mildew at Kabete. Rust scores were however taken at both locations. Pods were then harvested at maturity stage (for both flowering flushes) and threshed to obtain seeds which were dried then weighed in grams and grain yield per hectare computed. Quantitative data was subjected to analysis of variance (ANOVA) using Genstat statistical package, 14th edition (VSN international, 2011). The analysis was done separately for each site and year. The means were separated by Fisher's Protected Least Significant Difference method at 5% probability level. Data is presented for the performance of the 43 lines in 2013 and 2014.

3. Results

3.1 Evaluation of Lines to Number of Days to Flowering

Significant differences were observed among the lines for duration to flowering at both sites in the second year only (Table 2). Flowering in the second year varied and thus lines took 47 to 52 days to flower at Kabete and 49 to 52 days at Ol Joro-Orok. In this second year, lines flowered earlier at Kabete (on average 43 days) and took longer to flower at Ol Joro-Orok (average of 55 days). This represents a considerable site difference in time to flowering among lines in the second year (Table 3). Among the checks, the dwarf lines flowered earlier with 30 days, while the climbing types such as Kin 2 & Kin 3 flowered in more than 50 days. Lines were grouped as early or late flowering based on the large variation of flowering in the year 2014. At Kabete, 10 lines were found to flower early within 33-40 days while 32 lines flowered late within 40-49 days. At Ol Joro-Orok, 15 lines were found to flower early in 50-55 days and 27 flowered late in 56-59 days. In regard to the distinction, lines KAB-RB13-326-207, KAB-RB13-37-16, KAB-RB13-379-148 and SUB-OL-RB13-269-129 were identified to flower early at both sites and years.

Table 1. CIAT Scale used to evaluate the reaction of bean germplasm to rust, powdery mildew and bean common mosaic virus

Rating	Category	Description	Comments
1-3	Resistant	No visible symptom or light symptoms (2% of the leaf)	Germplasm useful as a parent or commercial variety.
4-6	Intermediate	Visible and conspicuous symptoms (2-5% of the leaf) resulting only in limited economic damage.	Germplasm can be used as commercial variety or source of resistance to disease.
7-9	Susceptible	Severe to very severe symptoms (10-25% of the leaf) causing yield losses or plant death.	Germplasm in most cases not useful as parent or commercial variety

3.2 Reaction of Improved Grain Runner Bean Lines to Prevalent Diseases

Runner bean lines in this study were exposed to the disease pressure in both sites. The prevalent diseases observed were rust, Bean common mosaic virus and powdery mildew. The lines reaction to rust infection had a significant effect in the first year at Ol Joro-orok and in second year at Kabete (Table 3). The evaluated lines showed resistance to rust infection with a mean of 1 to 3 at both sites and years. In all lines, susceptibility to rust was observed in line KAB-RB13-379-148 only at Kabete in the second year while the local landraces showed resistance to rust in both years and sites except in the second year where Dwarf 1 had intermediate resistance at Kabete (Table 3). No susceptible line was observed at Ol Joro-Orok in both years.

Powdery mildew symptoms were prevalent at Kabete and therefore disease evaluation was done at this site only. There were significant differences among lines in reaction to powdery mildew infection in both years at Kabete (Table 3). More than 90% of the lines were rated resistant to powdery mildew. About 10% of lines showed intermediate resistance with a score of 6. The local landraces were also resistant (scores of 1 to 3) at both sites and years. However, among the landraces; Dwarf 1 was highly infected by powdery mildews (score of 5 to 6) at Kabete in the second year (Table 3).

Bean common mosaic virus (BCMV) was observed at Ol Joro-Orok in both years and not Kabete. There were no significant effects among lines reaction to the disease in both years (Table 3). Disease scores varied from two to four in 2013, and from two to five in 2014. 79% and 70% of lines were highly tolerant based on CIAT scale used with scores of 1 to 3 in first and second year accordingly. About 15% of lines showed susceptibility (scores of 4-6) in the first year (Table 3). This susceptibility effect increased to 30% during the second year. Among the local checks, Kin 2 and Kin 3 showed susceptibility with (scores of 4) in the first year. However, the two dwarf checks showed resistance scores of 1 to 3 in both years (Table 3).

Table 2. Number of days to 50% flowering and grain yield of runner bean lines at two locations

Runner bean lines	Days to 50% flowering				Grain Yield (Kg ha^{-1})	
	2013		2014		2013	2014
	Kabete	Ol Joro-Orok	Kabete	Ol Joro-Orok	Ol Joro-orok	Kabete
KAB-RB13-440-232	49.0	50.0	47.0	56.0	6404.0	4035.0
KAB-RB13-155-122	49.0	50.7	43.0	53.0	7213.0	4394.0
KAB-RB13-308-222	51.7	50.0	45.0	58.0	6721.0	6473.0
KAB-RB13-310-161	50.7	50.7	46.0	56.0	5201.0	3557.0
KAB-RB13-310-162	49.0	50.7	44.0	57.0	9575.0	7033.0
KAB-RB13-312-160	47.0	50.0	46.0	58.0	8936.0	4496.0
KAB-RB13-314-191	51.3	51.0	44.0	56.0	7651.0	5611.0
KAB-RB13-315-197	49.7	50.7	45.0	52.0	6024.0	3236.0
KAB-RB13-319-182	50.3	50.7	48.0	58.0	7292.0	4385.0
KAB-RB13-319-193	51.3	50.0	48.0	56.0	4772.0	4425.0
KAB-RB13-319-194	50.0	51.0	47.0	58.0	5483.0	5166.0
KAB-RB13-321-185	52.0	50.7	41.0	55.0	8150.0	6248.0
KAB-RB13-325-200	49.7	50.0	48.0	57.0	10422.0	3038.0
KAB-RB13-326-207	50.7	51.0	35.0	52.0	7450.0	5130.0
KAB-RB13-327-48	51.7	49.0	46.0	58.0	9449.0	5257.0
KAB-RB13-327-92	49.7	48.7	49.0	57.0	12934.0	3857.0
KAB-RB13-329-165	49.7	50.0	44.0	55.0	6063.0	5487.0
KAB-RB13-331-113	50.7	48.3	47.0	54.0	9188.0	3441.0
KAB-RB13-334-29	50.3	50.0	49.0	59.0	13128.0	4337.0
KAB-RB13-336-63	49.3	49.3	44.0	55.0	11231.0	4648.0
KAB-RB13-338-41	50.0	50.3	34.0	56.0	13285.0	3773.0
KAB-RB13-341-143	50.0	50.7	38.0	54.0	7625.0	5463.0
KAB-RB13-343-184	49.3	50.3	47.0	57.0	8696.0	3642.0
KAB-RB13-343-189	49.3	50.0	45.0	57.0	5828.0	6352.0
KAB-RB13-364-212	50.3	50.7	37.0	54.0	10311.0	3845.0
KAB-RB13-37-16	49.0	49.0	35.0	52.0	14999.0	4260.0
KAB-RB13-379-148	49.7	51.7	34.0	51.0	6162.0	3622.0
KAB-RB13-396-210	50.0	50.7	48.0	58.0	7778.0	2958.0
KAB-RB13-399-219	50.7	50.3	41.0	57.0	6393.0	4969.0
KAB-RB13-426-84	50.0	48.0	45.0	58.0	11576.0	4718.0
KAB-RB13-46-124	49.7	51.0	42.0	56.0	10270.0	4736.0
KAB-RB13-471-117	49.0	49.3	47.0	57.0	11563.0	6078.0
KAB-RB13-522-73	50.7	49.7	44.0	56.0	7440.0	4689.0
KAB-RB13-62-9	52.0	50.0	48.0	56.0	6859.0	6227.0
KAB-RB13-85-18	50.0	50.0	42.0	56.0	7995.0	2717.0
SUB-RB13-177-3	49.0	50.0	42.0	59.0	9254.0	3457.0
SUB-RB13-226-251	50.0	50.7	39.0	56.0	10052.0	5161.0
SUB-RB13-275-248	50.3	51.3	34.0	55.0	7394.0	3406.0
SUB-RB13-275-249	50.0	51.0	33.0	55.0	6846.0	3036.0
SUB-RB13-221-128	49.0	49.3	48.0	55.0	5825.0	4268.0
SUB-RB13-269-129	49.0	49.7	39.0	52.0	11452.0	5221.0
SUB-RB13-308-75	49.7	49.0	48.0	58.0	8309.0	4204.0
SUB-RB13-325-134	50.7	48.7	45.0	54.0	10260.0	3165.0
Checks						
Dwarf 1	50.3	50.7	30.0	52.0	0.0	0.0
Dwarf 3	51.3	51.0	31.0	54.0	0.0	0.0
Kin 2	49.7	51.0	52.0	50.0	2343.0	2612.0
Kin 3	48.7	52.3	51.0	54.0	3820.0	2524.0
Mean	50.9	50.2	43.0	55.0	6753.0	4426.0
CV (%)	41.9	6.5	13.0	5.0	55.6	38.9
$LSD_{0.05}$	34.3	5.2	9.0	4.0	6034.0	2782.4

3.3 Grain Yield of Improved Grain Runner Beans

Analysis of variance showed that there were significant differences in grain yield among the test lines at both sites (Table 3). Mean grain yield varied from 2,300 to 13,300 kg ha^{-1} at Ol Joro-Orok and from 2500 to 7100 kg ha^{-1} at Kabete. The mean yield was higher (6753 kg ha^{-1}) at Ol Joro-Orok compared to 4426 kg ha^{-1} at Kabete. At Ol Joro-Orok, 15 lines yielded more than 9500 kg ha^{-1} in comparison to Kabete where higher yields of more than 5000 kg ha^{-1} were recorded by 14 lines. The results clearly demonstrated that grain yield was influenced by site effects due to differential climatic conditions especially temperature and the lines showed significance yield difference when grown at the two locations Yields of test lines were higher under cooler conditions at Ol Joro-Orok (Table 3). About 20 lines yielded more than 8000 kg ha^{-1} at Ol Joro-Orok. The local landraces; Kin 2 and Kin 3 grown at Ol Joro-Orok had the least yield of less than 3000kg/ha^{-1} while Nyeri grown at Ol Joro-Orok yielded up to 6000 kg ha^{-1} at Kabete. For instance, KAB-RB13-325-200, KAB-RB13-327-92, KAB-RB13-338-41 yielded more than 10,000 kg ha^{-1} at Ol Joro-Orok, yet the same lines yielded less than 4000 kg ha-1 when grown at Kabete (Table 2). Based on the yield performance and resistance to diseases, eleven lines; KAB-RB13-334-29, KAB-RB13-336-63, KAB-RB13-338-41, KAB-RB13-364-212, KAB-RB13-37-16, KAB-RB13-426-84, KAB-RB13-46-124, KAB-RB13-471-117, SUB-OL-RB13-226-251, SUB-RB13-269-129 and SUB-RB13-325-134 were selected to perform well at Ol Joro-Orok and KAB-RB13-308-222, KAB-RB13-314-191, KAB-RB13-321-185, KAB-RB13-326-207, KAB-RB13-327-48, KAB-RB13-329-165, KAB-RB13-341-143, KAB-RB13-343-189, KAB-RB13-62-9, SUB-RB13-226-251 and SUB-RB13-269-129 at Kabete. These selected lines had yield more than 10,000 kg ha^{-1} at Ol Joro-Orok and more than 5000 kg ha^{-1} at Kabete. Among the selected lines; KAB-RB13-364-212, SUB-RB13-226-251 and SUB-RB13-269-129 were found to be high yielding and resistant to rust, powdery mildew and bean Common mosaic virus at both locations.

Table 3. Reaction of runner bean lines to rust, powdery mildew infection and Bean common mosaic virus (BCMV) at Kabete and Ol Joro-Orok in two years

Runner bean lines	**Rust**				**Powdery Mildew**		**Bean Common Mosaic Virus (BCMV)**	
	2013		**2014**		**2013**	**2014**	**2013**	**2014**
	KAB	**OLJ**	**KAB**	**OLJ**	**KAB**		**OLJ**	
KAB-RB13-440-232	1.0	1.0	1.7	3.0	1.7	3.0	3.0	3.7
KAB-RB13-155-122	1.0	1.0	1.3	2.3	1.0	1.7	4.3	4.0
KAB-RB13-308-222	1.0	1.0	1.7	2.7	2.3	1.7	2.7	4.0
KAB-RB13-310-161	1.0	1.0	2.3	2.3	1.0	3.0	2.7	3.7
KAB-RB13-310-162	1.0	1.0	1.0	2.0	1.3	2.0	2.3	3.0
KAB-RB13-312-160	2.0	1.0	2.0	2.3	2.7	3.7	3.0	3.7
KAB-RB13-314-191	1.3	1.0	1.3	2.0	2.3	2.0	3.0	3.3
KAB-RB13-315-197	1.0	1.0	2.3	1.7	1.0	2.0	2.7	4.0
KAB-RB13-319-182	1.0	1.3	1.3	2.0	1.0	2.7	3.0	2.7
KAB-RB13-319-193	1.0	1.3	3.0	2.3	2.3	2.3	2.3	3.0
KAB-RB13-319-194	1.0	2.3	1.0	2.7	1.0	2.0	3.3	5.0
KAB-RB13-321-185	1.0	1.0	1.7	1.7	1.0	2.0	2.7	2.3
KAB-RB13-325-200	1.0	1.0	2.3	3.0	1.0	1.3	3.0	2.7
KAB-RB13-326-207	1.7	1.0	1.0	1.7	1.0	3.7	3.0	4.0
KAB-RB13-327-48	1.7	1.7	1.0	3.3	1.7	2.0	4.3	3.3
KAB-RB13-327-92	1.7	1.7	1.3	3.0	3.7	2.3	3.7	4.0
KAB-RB13-329-165	1.0	1.0	1.3	2.3	1.0	3.0	2.7	3.0
KAB-RB13-331-113	1.7	1.7	1.7	3.0	4.7	3.0	2.3	2.0
KAB-RB13-334-29	1.3	3.0	1.7	3.7	3.0	3.3	3.7	2.3
KAB-RB13-336-63	2.0	1.7	2.3	2.3	3.0	3.7	3.7	3.0
KAB-RB13-338-41	1.7	1.7	1.7	2.7	1.0	2.3	3.0	2.7
KAB-RB13-341-143	1.0	1.0	1.7	3.0	1.0	3.0	3.0	2.0
KAB-RB13-343-184	1.0	1.0	1.3	2.0	1.0	2.7	3.0	2.0
KAB-RB13-343-189	1.0	1.0	1.3	1.3	1.0	2.0	3.0	2.3
KAB-RB13-364-212	1.0	1.3	1.3	2.7	1.0	2.0	3.0	3.0
KAB-RB13-37-16	2.7	1.7	2.3	1.7	2.3	2.3	3.0	2.0
KAB-RB13-379-148	1.7	1.0	4.7	2.3	4.3	1.7	3.0	3.0
KAB-RB13-396-210	1.7	1.0	1.0	2.7	1.0	2.7	3.0	4.7
KAB-RB13-399-219	1.3	1.0	2.0	1.7	1.3	2.3	3.0	4.3
KAB-RB13-426-84	1.7	1.7	1.0	3.3	1.0	2.3	3.3	3.3
KAB-RB13-46-124	1.0	1.0	1.3	2.3	1.0	2.7	3.0	3.7
KAB-RB13-471-117	1.7	1.7	1.7	2.3	1.7	3.3	3.7	2.0
KAB-RB13-522-73	1.7	1.7	1.7	1.0	1.7	2.7	3.7	2.3
KAB-RB13-62-9	1.0	1.0	2.0	1.7	1.0	2.0	3.0	3.3
KAB-RB13-85-18	1.0	1.7	1.3	2.3	1.0	2.0	3.0	2.7
SUB-RB13-177-3	1.0	1.0	1.3	3.0	4.3	2.0	2.3	2.0
SUB-RB13-226-251	1.0	1.0	1.0	2.3	1.0	2.3	3.0	2.3
SUB-RB13-275-248	1.0	1.0	2.0	2.7	1.3	3.3	3.0	3.3
SUB-RB13-275-249	1.0	1.0	1.0	2.3	1.0	2.3	3.0	3.3
SUB-RB13-221-128	1.7	2.0	1.3	2.7	1.3	2.0	3.7	3.3
SUB-RB13-269-129	1.7	1.7	1.0	3.0	1.3	2.0	3.0	2.0
SUB-RB13-308-75	1.7	2.3	1.0	2.3	1.7	2.3	2.3	2.3
SUB-RB13-325-134	1.3	1.7	2.0	2.3	1.7	3.3	2.3	2.7
Checks								
Dwarf 1	1.3	1.7	5.0	3.3	2.7	5.7	3.0	3.3
Dwarf 3	1.0	1.0	3.0	3.3	1.0	3.3	3.0	3.0
Kin 2	1.0	1.7	3.5	4.0	2.3	4.5	3.7	3.3
Kin 3	1.0	1.0	3.0	3.5	1.3	5.0	3.7	4.0
Mean	1.2	1.4	1.4	2.4	1.6	2.3	3.0	3.0
CV (%)	14.9	52.5	42.9	58.7	83.4	32.4	34.0	51.8
$LSD_{0.05}$	0.7	1.2	0.9	2.3	2.2	1.2	1.0	2.5

Note. KAB = Kabete and OLJ = Ol Joro-Orok.

4. Discussion

4.1 Days to 50 % Flowering

The significant differences in days to flowering among lines in the second year could be due to environmental and genetic effects. In the second year, lines flowered earlier at Kabete than at Ol Joro-Orok due to the prevalent cooler conditions that delayed flowering at Ol Joro-Orok. The effect of temperature on plants has been studied by Galloway and Etterson (2009) who found that cooler temperatures tend to delay initiation of flowering and thus slows the reproductive phenology. Early experiments on temperature and photoperiod by Kornegay et al. (1993) revealed that sensitive common bean germplasm took shorter days to flower when planted at Palmira (warm area) and flowered late when grown at Popayan (cooler area). Most evaluated lines were found to flower within the range of 30 to 60 days as documented by Purseglove, 1987.The dwarf local landraces were found to flower earlier compared to the climbers; Kin 2 and Kin 3 therefore could be used for improvement of early flowering in runner beans. Among the evaluated lines, KAB-RB13-326-207/1, KAB-RB13-341-143/4, KAB-RB13-364-212/2, KAB-RB13-37-16/1, KAB-RB13-379-148/1, SUB-OL-RB13-248/3 and SUB-OL-RB13-275-248/5 were identified to flower early.

4.2 Reaction of Lines to Diseases

According to Brink, (2006) runner beans are mainly affected by anthracnose (*Colletotrichum lindemuthianum*), fusarium wilt (*Fusarium wilt* f.sp. phaseoli), rust (*Uromyces phaseoli*), and halo blight (*Pseudomonas savastanoi* pv. phaseolicola). In this study, the prevalent diseases were bean rust, powdery mildew and bean common mosaic virus. The lines showed a higher resistance to bean rust, bean common mosaic virus and powdery mildew indicating that runner beans are generally resistant to a wide array of bean pathogens (Singh, 2001). Runner bean has been considered as a potential source of resistance against diseases of common bean, including anthracnose, Ascochyta blight (*Phoma exigua*), angular leaf spot (*Phaeoisariopsis griseola*), powdery mildew (*Erysiphe polygoni*) and rust (*Uromyces appendiculatus*). These results therefore show that the studied lines can be a source of selection of resistant germplasm to be used in future breeding activities. Although, low levels of susceptibility were observed during the study indicating low disease pressure, the materials can be evaluated in high disease pressure areas or inoculated to ascertain the levels of resistance. The occurrence of one disease in one location and not the other could was due to presence of high innoculums and favorable conditions for the development of such disease. High humidity experienced at Kabete in June-August has always resulted in infection by powdery mildew unlike at Ol Joro orok. As stated by Hagedorn, (1986) high humidity provides favorable environment for infection and development of powdery mildew. Nyandarua county where Ol joro-Orok is located has been identified as a hot spot for Bean Common mosaic virus (Omunyin et al., 1995). Most local landraces exhibited intermediate resistance which affected the yields compared to the improved grain lines.

4.3 Grain Yield of Lines

The grain yield varied significantly among lines due to genetic factors and climatic conditions. Lines yielded twice more at Ol Joro-Orok (cooler conditions) than Kabete (warmer) because of the inherent adaptability of *P. coccineus* to thrive well under cooler conditions. Besides, Freytag and Debouck (2002) also reveal that runner beans are mainly adapted to cooler and moist environment and therefore their performance in warmer conditions is constrained. These results suggest that high yields can be achieved if cool temperatures prevail in the entire cropping season of runner beans. Nonetheless, some lines had satisfactory yields at Kabete indicating that they can be selected for utilization under such warmer climatic conditions. From assessment of number of racemes (data not presented), lines had many racemes at Ol Joro-Orok than Kabete in both years which consequently resulted into higher yields. The results therefore, show the association between number of racemes and grain yield such that the lines that had more racemes yielded more grain than those with fewer racemes.

The developed lines showed the ability of combining better adaptability to short day conditions and disease resistance hence resulting in higher yields than the local landraces. Among the local landraces, the dwarf cultivars were the low yielders and this could be linked to the fact that most dwarfing genes have pleiotropic effect on other plant characters. For instance, in soybean the dwarfism gene *df* has been found to cause reduction in leaf size and internode length hence resulting subsequent low seed yield per plant (Huyghe, 1998). Nonetheless, the seed of the harvested local landraces was mixed (showing variant seed colours) indicating the high level of outcrossing that has been reported in runner bean before (Gonzalez et al., 2014). However, most of the improved lines had pure seed which shows that the materials had attained homozygosity.

Production statistics available on grain yield of current varieties or landraces of grain runner bean have shown low yields compared to the yields realized in this study. A study conducted in Chile showed grain yields of runner bean accessions ranging between 3542-3920 kg ha^{-1} (Tay et al., 2011). In Romania a country in Europe where runner bean is considered successful, yields ranging from 1735kgha^{-1} to 3745kgha^{-1} were realized when domesticated accessions were evaluated (Munteanu et al., 2013). Its therefore evident that the materials in this study performed well under the studied environments and eleven lines considered to have combined high yield and disease resistance were selected. These lines were; KAB-RB13-334-29, KAB-RB13-336-63, KAB-RB13-338-41, KAB-RB13-364-212, KAB-RB13-37-16, KAB-RB13-426-84, KAB-RB13-46-124, KAB-RB13-471-117, SUB-OL-RB13-226-251, SUB-RB13-269-129 and SUB-RB13-325-134 were selected to perform well at Ol Joro-Orok and KAB-RB13-308-222/1, KAB-RB13-314-191/3, KAB-RB13-321-185/1, KAB-RB13-326-207/1, KAB-RB13-327-48/1, KAB-RB13-329-165/1, KAB-RB13-341-143/4, KAB-RB13-343-189/5A, KAB-RB13-62-9/2, SUB-RB13-226-251/4 and SUB-RB13-269-129/3 at Kabete.

5. Conclusion

The findings of this study showed that the locally developed short-day runner bean lines differed significantly with local landraces in grain yield and disease resistance. Yields of promising lines were significantly higher compared to available yield statistics of local landraces or cultivated varieties. From the study eleven lines; KAB-RB13-334-29, KAB-RB13-336-63, KAB-RB13-338-41, KAB-RB13-364-212, KAB-RB13-37-16, KAB-RB13-426-84, KAB-RB13-46-124, KAB-RB13-471-117, SUB-OL-RB13-226-251, SUB-RB13-269-129 and SUB-RB13-325-134 selected to perform well at Ol Joro-Orok and KAB-RB13-308-222/1, KAB-RB13-314-191/3, KAB-RB13-321-185/1, KAB-RB13-326-207/1, KAB-RB13-327-48/1, KAB-RB13-329-165/1, KAB-RB13-341-143/4, KAB-RB13-343-189/5A, KAB-RB13-62-9/2, SUB-RB13-226-251/4 and SUB-RB13-269-129/3 at Kabete were found to combine high yield and were resistant to rust, BCMV and Powdery mildew. Two lines; KAB-RB13-364-212, SUB-RB13-226-251 and SUB-RB13-269-129 were found to be high yielding and resistant to rust, powdery mildew and bean Common mosaic virus at both locations.

The selected lines show a great potential of being selected for improved grain yield and disease resistance under studied conditions and can produce pure seed stock. We recommend that the materials be evaluated in different environments to determine yield stability and subjected to high disease pressure to ascertain levels of resistance to diseases.

Acknowledgements

This research was supported by funds from Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and the authors are very grateful for the support. The University of Nairobi and Kenya Agricultural Livestock and Research Organization (KALRO) are also acknowledged for providing experimental fields and support throughout the course of this research.

References

Acquaah, G. (2007). *Principles of plant genetics and breeding* (2nd ed., pp. 121-140). Wiley-Blackwell Publishing, Oxford.

Cumo, C. (2007). *Science and Technology in 20th Century American life* (pp. 7-8). Greenwood Publishing Group.

Dickson, M., & Boettger, M. (1977). Breeding for multiple root rot resistance in snap beans. *Journal of American Society for Horticultural Science, 102*, 373-377.

Freytag, G. F., & Debouck, D. G. (2002). *Taxonomy, Distribution and Ecology of the Genus Phaseolus (Leguminosae-Papilionideae) in North America, Mexico and Central America* (p. 23). Sida Botanical Miscellany.

Galloway, L. F., & Burgess, K. S. (2012). Artificial selection on flowering time: Influence on reproductive phenology across natural light environments. *Journal of Ecology, 100*(4), 852-861. https://doi.org/10.1111/j.1365-2745.2012.01967

Gilmore, B., Myers, J. R., & Kean, D. (2002). Completion of testing of *Phaseolus coccineus* plant introductions (PIs) for white mold, *Sclerotinia sclerotiorum*, resistance. *Annual Report Bean Improvement Cooperative, 45*, 64-65.

González, A. J. (2000). *Pathogenic microbiota in Asturian farm-type bean seed* (p. 132, Obtaining Healthy Seed, Doctoral Thesis, University of Oviedo).

Gonzalez, A. M., De Ron, A. M., Lores, M., & Santalla, M. (2014). Effect of the inbreeding depression in progeny fitness of runner bean (*Phaseolus coccineus* L.) and its implications for breeding. *Euphytica, 200*, 413-428. https://doi.org/10.1007/s10681-014-1177-2

Hagedorn, D. J., & Inglis, D. A. (1986). *Handbook of bean Diseases* (pp. 6-10). Madison, Wisconsin.

Huyghe, C. (1998). Genetics and genetic modifications of plant architecture in grain legumes: A review. *Agronomie, EDP Sciences, 1*(5-6), 383-411. https://doi.org/10.1051/agro:19980505

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, B. (2006). *Farm management hand book of Kenya* (Vol. II). Nairobi, Kenya Ministry of Agriculture, Natural Conditions and Farm Management Information of Central Kenya. Retrieved from https://www.uni-trier.de/index.php?id=58581

Kahuro, J. G. (1990). *The effect of plant population and phosphate fertilizer application on growth, yield, yield components and nutrient concentration of runner bean* (Unpublished Master's thesis, University of Nairobi, Kenya).

Kay, D. E. (1981). Food legumes. *Crops and Product Digest, 3*. https://doi.org/10.1016/0378-4290(81)90089-7

Kornegay, J., White, J. W., Dominguez, J. R. Tejada, G., & Cajiao, G. (1993). Inheritance of photoperiod response in Andean and Mesoamerican common bean. *Crop Science, 33*, 977-984. https://doi.org/10.2135/cropsci1993.0011183x003300050021x

Labuda, H. (2010). Runner bean (*Phaseolus coccineus* L.) biology and use. *Acta Scientarium Polonorum Hortorum Cultus, 9*, 117-132.

Miklas, P. N., Grafton, K. F., Kelly, J. D., Steadman, J. R., & Silbernagel, M. J. (1998). Registration of four white mold resistant dry bean germplasm lines: I9365-3, I9365-5, I9365-31, and 92BG-7. *Crop Science, 38*, 1728. https://doi.org/10.2135/cropsci1998.0011183X003800060073x

Munteanu, N., Hamburda, S. B., & Popa, L. (2013). Research on the main productivity features in an assortment of runner bean (*Phaseoulus coccineus* L.) in the environmental conditions from Ne Romania. *Scientific Papers, 56*, 159-162.

Omunyin, M. E., Gathuru, E. M., & Mukunga, D. M. (1995). Pathogenicity groups of bean common mosaic virus isolates in Kenya. *Plant Disease, 79*, 985-989. https://doi.org/10.1094/PD-79-0985

Osorno, M., Mu˜noz, C., Beaver, J., Fewerda, F., Basset, M., Miklas, P., Olezyk, T., & Bussey, B. (2007). Two Genes from *Phaseolus coccineus* L. Confer Resistance to Bean Golden Yellow Mosaic Virus in Common Bean. *Journal of American Society for Horticultural Science, 132*, 530-533.

Purseglove, J.W. (1987). *Tropical crops (Dicotyledons)*. Cambridge University Press. Wiley, New York.

Santalla, M., Monteagudo, A. B., Gonz´alez, A. M., & De Ron, A. M. (2004). Agronomical and quality traits of runner bean germplasm and implications for breeding. *Euphytica, 135*, 205-215. https://doi.org/10.1023/B:EUPH.0000014912.07993.e7

Schmit, V., & Baudoin, J. P. (1992). Screening for resistance to Ascochyta blight in populations of *Phaseolus coccineus* L. and P. polyanthus Greenman. *Field Crops Research, 30*, 155-165. https://doi.org/10.1016/0378-4290(92)90064-G

Singh, S. P. (2001). Broadening genetic base of common bean cultivars: A review. *Crop Science, 41*, 1659-1675. https://doi.org/10.2135/cropsci2001.1659

Suttie, J. M. (1969). The butter bean (*Phaseolus coccineus* L.) in Kenya. *East African Agricultural and Forestry Journal, 35*, 211-212. https://doi.org/10.1080/00128325.1969.11662395

Tay, J., Pedreros, A., & France. A. (2011). Runner Bean (*Phaseoulus coccineus* L.) Production in Chile. *Journal of Agricultural Science and Technology, B1*, 360-362.

Van Schoonhoven, A., & Pastor-Corrales M. A. (1987). *Standard system for the evaluation of bean germplasm*. CIAT, Cali, Colombia.

Vanderborght, T. (1983). Increasing seed of *Phaseolus coccineus* L. *Plant Genetic Resources Newsletter, 53*, 17-18.

VSN International. (2011). *Gen Stat for Windows 13th Edition*. VSN International, Hemel Hempstead, UK.

Wallace, D. H. (1985). Physiological aspects of plant maturity, adaptation and yield. *Plant Breeding Review, 3*, 21-67.

Wanjekeche, E., Mwangi, T. J., Kamidi, M., Powon, P., & Khaemba, J. (1997). Farmer Participation in the Evaluation of Grain Legumes in North Western Kenya. *KARI. Participatory technology development for soil management by small holders in Kenya* (pp. 273-279).

Wilkinson, R. E. (1983). Incorporation of *Phaseolus coccineus* germplasm may facilitate production of high yielding P. vulgaris lines. *Annual Report of Bean Improvement Cooperative, 26*, 28-29.

Copyrights