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Effect of plant population density on seed yield attributes of African yam bean (*Sphenostylis stenocarpa,* Hochst. ex. a. Rich.)

Alegiledoye AO
Department of Plant Breeding and Seed Technology, Federal University of Agriculture, P.M.B.2240, Abeokuta, Ogun State, Nigeria

E-mail: oladimejialegiledoye@yahoo.com

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Abstract

An experiment was conducted to determine the effect of plant population density on seed yield attributes of African Yam Bean (*Sphenostylis stenocarpa*) at the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria in 2013 and 2014 cropping seasons. In this experiment the effect of three plant populations (55,555, 24,975 and 10,000 plants ha^{-1}) were evaluated in a factorial arrangement laid out in 3 x 18 using Randomized Complete Block Design in three replicates with 18 genotypes and plant population as factors in 2013 and 2014 cropping years. Data were collected on (seed weight/plant (g), number of pods/plant (g), seed weight/pod(g), pod weight/plant(g), SPE%, number of seed/plant). Data collected from the experiment were subjected to analysis of variance, mean separation. In the experiment, plant population and genotype significantly influenced all seed yield characters in both cropping years. Significantly ($p \leq 0.05$) higher seed weight/plant (70.31 g), number of pods/plant (18.70), seed weight/pod (5.01 g) and pod weight/plant (98.66 g) was obtained under 10,000 plants ha^{-1}. Genotypes TSs86 (91.37 g) and TSs50 (85.87 g) had highest seed weight/plant across plant population and cropping year. Seed weight/plant positively correlated with other seed yield characters across plant population and years. In conclusion, Genotypes TSs86, TSs50, TSs331, TSs83 and TSs311 were the top yielding with over 65.87 g/plant across year and plant population. Plant population of 10,000 plants ha^{-1} (100 x 100 cm) is recommended for superior seed yield components in African yam bean crop.

Keywords: Cropping year, genotypes, SPE, hectare, African yam bean

Introduction

African yam bean (*Sphenostylis stenocarpa*) Hochst ex. A Rich family leguminosae, sub-family papilionacaea, belongs to the class: Magnoliospseda, order: Fabales and is one of the most valuable legumes in the family Fabaceae. Porter, (1992) reported that the domestication, cultivation and distribution of African yam bean are very evident in the tropics. It is one of the neglected pulses of tropical origin. African yam bean is classified as minor grain legume because it is under-exploited (Saka *et al*., 2004). It is an indigenous legume usually cultivated in association with yam, cassava, sorghum and maize and barely grown sole in Ghana and Nigeria. (Okigbo, 1973: Klu *et al*., 2001).

The seeds and tubers serve as food for human and livestock. Nevertheless, there is cultural and regional preference for each in the meals of the Africans. West African prefers the seeds to the tubers while the tubers are important as food in East and Central Africa, particularly among the Bandudus, the Shabas and a tribe in Kinshasha in Zaire (Adewale, 2011; Porter, 1992; Nwokolo, 1996). The seeds vary in size, colour and colour pattern (Adewale, 2011, Milne- Redheed and Polhill, 1971).

In order to obtain maximum yields, the time of sowing, planting depth and crop geometry are features identified to be borne in mind (Adeyemo *et al*., 1992, Petal *et al*., 1998). Testing for the development of high performing genotypes from different environments is a continuous exercise in order to increase local production and thereby boost importation. Therefore, such high-performing genotypes must have good agro-morphological characters which are normally variable among several variations. The establishment of such characters and genotypes is a major step to crop improvement programme particularly selection for high yielding crop. The agronomy on field studies of African yam beans (AYB) had not been well attended to in research compared to the quantity of work on the crop's food value (Adewale, 2011). Majority of the few studies had concentrated on farming systems in mixture with other crops for yield performance (Obiagwu, 1997; Saka *et al*., 2004; Adeniyan *et al*., 2007).

Available genetic resources of AYB for research materials are the few accessions/landraces in the hands of market women and rural farmers. However, such genetic materials lack sufficient information on influence of plant population density on seed yield attributes in tropically grown AYB genotypes in Nigeria. Nyandacti (1999), Adebisi (2004) and Abdul-Rafiu (2015) reported that differently spaced crops of the same variety would produce different yields and physiological quality of seeds obtained will also differ. The objective of this study, therefore, was to evaluate the effect of seed production environment (plant population density) on seed yield characters in 18 AYB genotypes over two cropping years.

Materials and Methods

The trials were conducted at the Directorate of University Farms (Dufarms) of the Federal University of Agriculture, Abeokuta (7^{o}15'N,3^{o}25'E), Ogun State, Nigeria in 2013 and 2014 cropping years under rain-fed field conditions. Seeds of 18 AYB genotypes (TSs9, TSs22, TSs23,TSs24, TSs42, TSs48, TSs50, TSs77, TSs81, TSs82, TSs83, TSs86, TSs94, TSs209, TSs311, TSs331, TSs349 and TSs370) were collected from International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria in early May, 2013. These genotypes were collected by IITA from different countries in Africa.

The field experiment was a 3x18 factorial arrangement in randomized complete block design with three replications. The experiment was conducted during the early season of 2013 and repeated in the same early cropping season of 2014. The eighteen genotypes of African yam beans were sown on the 29th May, 2013 for the first trial and June 12th 2014 for the second trial.

The plot size for the first plant density (60 cm×30 cm) was 3 m by 3 m with 50 plants for each replicate. The plot size for the second plant density (91 cm×44 cm) was 3 m by 3 m with 28 plants for each replicate. The plot size for the third plant density (100 cm×100 cm) was 3 m by 3 m with 9 plants for each replicate. Each replicate consisted of ten rows for plant density 1, seven rows for plant density 2 and three rows for plant density 3. A total land area of 2293.5 m (33 m × 69.5 m) was used. There were two factors in the experiment-:18 genotypes and three plant population densities,) with three replications. In all, the study consisted of 162 experimental units (18 genotypes x 3 plant densities in three replications in each cropping year.

Three seeds of each genotype were sown per stand and later thinned to one plant per stand after emergence and establishment. Staking was carried out at three weeks after sowing (WAS) in order to provide support for the young seedlings. Insect control was carried out using a synthetic pyrethroid insecticide at 40 mls in 16 litres of water during flowering stage for the control of insects. Manual weeding was carried out twice at third and eight weeks after sowing and combination of a contact-Photosynthesis inhibitor at 150mls in 16 litres of water on the second day after planting.

Data on seed yield/plant (g), number of pods/plant, seed weight/pod (g), pod weight/plant (g) and number of seeds/pod were collected from 10 randomly selected plants in the two inner rows. Seed production efficiency (%) was estimated from the ratio of seed weight to pod weight from five randomly selected plants (Ogunbodede and Ogunremi, 1986; Adebisi, 2004).

Data Analysis

Data collected in the experiment were subjected to analysis of variance (ANOVA) using SPSS version 17.0 for windows statistical software package and treatment means were separated using Tukey's HSD test at 5% level of probability.

Results and Discussion

Results

Result of mean square values for the seed yield characters evaluated in 18 African yam bean genotypes under three plant population densities in 2013 and 2014 cropping years and combined cropping years are presented in Table 1. In the 2013 cropping year, the genotype, plant density and genotype × plant density interaction effects were highly significant ($p \leq 0.01$) on seed yield/plant, number of pods/plant, seed weight/pod, pod weight/plant and number of seeds/pod. However, only genotype effect was highly significant ($p \leq 0.01$) on seed production efficiency. Replication effect was highly significant on number of pods/plant. For the 2014 cropping year, genotype effect was highly significant ($p \leq 0.01$) on all the seed yield characters except on number of seeds/pod. Also, the plant density effect was highly significant ($p \leq 0.01$) on number of pods/plant and seed production efficiency (SPE). The interaction effect of genotype x plant density was highly significant ($p \leq 0.01$) on all the seed yield characters except pod weight/plant. The replication effect was highly significant on seed weight/plant and number of pods/plant. For the combined cropping year, (Table 1) genotype effect was highly significant ($p \leq 0.01$) on seed weight/plant, number of pods/plant, seed weight/pod and SPE but had significant ($p \leq 0.05$) effect on pod weight per plant and number of seeds per pod. Similarly, plant density effect was highly significant ($p \leq 0.01$) on seed weight per plant, number of pods per plant and seed weight per pod but had significant ($p \leq 0.05$) effect on number of seeds per pod. However, the genotype x plant density effect was highly significant ($p \leq 0.01$) on number of pods per plant, seed weight per pod and SPE but showed significant ($p \leq 0.05$) effect on seed weight per plant and pod weight per plant.

Table 2 presents the effect of three plant densities on seed weight/plant in 18 AYB genotypes in 2013, 2014 and across cropping years. At 55,555 plants ha^{-1}, the genotypes performance in 2013 shows that TSs86 had the highest significant seed weight/plant (72.10 g) while the lowest value was recorded in TSs370 with 21.79 g. In the corresponding 2014 cropping year, at 55,555 plants ha^{-1}, TSs86 had the highest seed weight/plant of 88.67 g, closely followed by TSs23 and TSs311 with 85.89 and 82.32 g, respectively whereas TSs349 had the least seed weight/plant of 38.77 g. Also, the genotype performance under the combined cropping years show that TSs86 had the highest seed weight/plant (70.38 g), followed by TSs50 and TSs311 with 65.24 and 63.41 g, respectively while the lowest value was recorded in TSs370 with 33.80 g. With a decrease in the plant population to 24,975 plants ha^{-1}, the performance of the genotypes in 2013 reveals that TSs86 had significantly highest value of 91.84 g in terms of seed weight/plant while the lowest values were obtained in TSs94 and TSs81 with 33.72 and 34.33 g, respectively. Similarly, in the corresponding 2014 cropping year, the performance of the genotypes in seed weight/plant indicates that TSs50, TSs86, TSs331 and TSs83 had significantly highest values of 94.06, 93.89, 84.46 and 81.63 g, respectively whereas TSs9 gave the lowest value of 35.26 g. The genotype performance under the combined cropping years also reveals that TSs86 and TSs50 had the highest seed weight/plant of 92.87 and 88.66 g, respectively whereas the lowest values ranged between 38.01 g in TsSs94 and 46.49g in TSs349. When the plant density was further reduced to 10,000 plants per ha, the genotypes performance in 2013 reveals that TSs86 had significantly highest seed weight/plant (101.54 g) while TSs81 and TSs94 had the least values of 33.79 and 36.27 g, respectively. Still under the 10,000 plants ha^{-1} in 2014 cropping year, TSs83, TSs86, TSs50 recorded the highest significant values of 127.42, 120.19 and 114.87 g while TSs94 and TSs77 gave the lowest values of 46.68 and 55.57 g, respectively. In the combined cropping years, TSs86, TSs83 and TSs50 had the highest seed weight/plant with 110.87, 105.12 and 103.72 g, respectively whereas TSs94 recorded the least value of 41.48 g.

Data on effect of three plant densities on number of pods/plant in 18 AYB genotypes in 2013, 2014 and across cropping years are presented in Table 3. At 55,555 plants ha^{-1}, the genotypes performance in 2013 cropping year indicates that TSs94 gave highest number of pods/plant with 22.47, closely followed by TSs81 with 20.00 while TSs42 gave the least of 9.17. In the corresponding 2014 cropping year, TSs24 had the highest number of pods/plant with value of 26.00 though was not statistically different from values of 23.33, 21.67 and 21.37 observed in TSs22, TSs23 and TSs9, respectively whereas TSs77 had least value of 9.00. In the combined cropping years, TSs94 had the highest value of 20.40, followed by 18.93, 18.80, 18.34, 18.07, 18.03, 17.84 and 17.60 observed in TSs9, TSs24, TSs81, TSs82, TSs22, TSs23 and TSs370. The performance of the genotypes under 24,975 plants ha^{-1} in 2013 cropping year shows that TSs86 had highest value of 19.13, closely followed by TSs50, TSs23 and TSs82 with 17.43, 17.33 and 17.27 while TSs22 had least value of 10.40. In the 2014 cropping year, however, TSs86 gave the highest number of pods/plant with 19.67 followed by TSs349, TSs50, TSs24, TSs83 and TSs22 with

18.33, 18.00, 17.67 and 17.33, respectively whereas TSs94 had the lowest value of 10.67. In the combined cropping years, TSs86 gave the highest value of 19 40 followed by TSs50 with 17.88 while TSs209 recorded the least value of 11.27. Under the 10,000 plants ha^{-1} in 2013 cropping year, TSs86 had significantly highest value of 25.13 whereas TSs77 had least value of 13.00. However, in the corresponding 2014 cropping year, TSs86 had the highest pods of 26.00, followed by genotypes TSs50 and TSs83 with pod values of 21.33 and 20.67, respectively. In the combined cropping years, TSs86 had significantly highest pod value of 25.57 while TSs82 gave the lowest value of 12.93.

Table 4 shows the effect of three plant densities on seed weight/pod in 18 AYB genotypes in 2013, 2014 and across cropping years. At 55,555 plants ha^{-1}, the genotypes performance in 2013 cropping year shows that TSs50 exhibited significantly highest seed weight/pod with a value of 6.01 g while TSs94 gave the lowest of 2.90 g. In the corresponding 2014 cropping year, TSs50 and TSs23 had similar highest value of 7.13 and 6.37 g, respectively but TSs94 had the least value of 3.16 g. In the combined cropping years, TSs50 had the significantly highest seed weight/pod of 6.57 g while TSs94 recorded the lowest value of 3.03 g. In addition, seed weight/pod under the 24,975 plants ha^{-1} 2013 recorded significantly highest seed weight/pod of 6.55 g in TSs370 while TSs50 had the least seed weight/pod of 3.16 g. However, in the corresponding 2014 cropping year, TSs50 and TSs86 had significantly highest values of 6.25 and 6.11 g, respectively while TSs94 recorded the lowest value (3.01 g). In the combined cropping years, TSs81 and TSs370 showed the highest of 5.60 g which was not significantly different from seed weight values of 5.39, 5.29, 5.28 and 5.07 g, respectively observed in TSs83, TSs24 TSs48 and TSs349 while TSs94, TSs311, TSs77, TSs23 and TSs209 with lower seed weight values ranging from 3.49-3.94 g. Also, at 10,000 plants ha^{-1}, the data in 2013 reveals that TSs42 and TSs50 showed the highest values of 6.84 and 6.81 g seed weight, respectively, followed by TSs209, TSs370, TSs81 with 6.20, 6.02 and 5.94 g, respectively while TSs331 gave least seed weight value of 2.66 g. Similarly, in the corresponding 2014 cropping year, TSs50 gave highest seed weight/pod of 7.21g, though was not significantly different from values of 6.44 g in TSs86 while TSs311 recorded the lowest value of 2.88 g.

Table 5 shows the effect of three plant densities on pod weight/plant in 18 AYB genotypes in 2013, 2014 and across cropping years. The performance of the genotypes under the 55,555 plants ha^{-1} in 2013 shows that TSs48, TSs349, TSs50, TSs86, TSs83 and TSs370 were genotypes with significantly highest pod weight/plant of between 69.88 and 85.22 g while TSs94 and TSs82 had the lowest values of 37.98 and 41.90 g respectively. In the corresponding 2014 cropping year, TSs86 was distinctly highest in performance in pod weight/plant (154.96 g) while TSs7 and TSs23 had the least values of 53.95 and 55.07 g, respectively. In the combined cropping years, TSs86 gave the highest value of 115.89 g, though was not significantly different from 105.83 g observed in TSs50 while TSs82, TSs23, TSs94, TSs81, TSs22 and TSs9 recorded the lowest values of between 50.46 and 56.44 g. Under 24,975 plants ha^{-1}, the performance of the genotypes in 2013 indicates that pod weight/plant values obtained in Ts81, TSs48, TSs50 and TSs83 were highest with pod between 98.43 and 90.87 g, though were not statistically different from values of 85.87 and 84.75 g observed in TSs86 and TSs349 whereas TSs94 recorded the least value of 39.48 g. Also, in the corresponding 2014 cropping year, TSs86 recorded the significantly highest value of 146.68 g whereas TSs23 had the least value of 56.00 g pod weight. In the combined cropping years, TSs86 had the highest value of 116.28 g followed by TSs50, TSs83, TSs48, TSs81, TSs370 and TSs331 with values of between 107.14 and 93.21 g whereas TSs23, TSs94, TSs9, TSs22, TSs82, TSs4 and TSs209 gave the lowest values of between 53.38 and 62.75 g. At 10,000 plants ha^{-1}, the performance in 2013 shows that TSs349 had the highest pod weight/plant of 118.47 g which was not statistically different from values of 104.16 and 105.03 g observed in TSs81 and TSs83 while TSs94, TSs82 and TSs209 had the least values of 38.87, 42.26 and 45.13 g, respectively. In 2014 cropping year, the result reveals that TSs86 gave significantly highest pod weight/plant of 171.60 g while TSs94 had the lowest value of 93.06 g. In the combined cropping years, TSs86, TSs83, TSs50 gave the highest values of 133.31, 130.30 and 127.32 g, though were not statistically different from TSs349, TSs48, TSs331, TSs42, TSs81 and TSs370 with values of between 121.01 and 101.85 g while TSs94, TSs22, TSs82, TSs9, TSs23 and TSs77 had least pod weights of between 65.97 and 79.57 g.

Data in Table 6 presents the effect of three plant densities on seed production efficiency (SPE) in 18 AYB genotypes in 2013, 2014 and across cropping years. The performance of the genotypes under the 55,555 plants ha^{-1} in 2013 shows that SPE ranged from 31.19 % in TSs370 to 92.43 % in TSs86 but the SPE values were statistically similar. In the corresponding 2014 cropping year, SPE ranged from 28.87 to 80.70 %. TSs311 had the highest SPE of 80.70 % followed by TSs83, TSs82, TSs50, TSs331 and TSs48 with values ranging from 72.57 to 75.63 %. In the combined cropping years, TSs86, TSs311 and TSs81 had the significantly highest SPE of 83.50, 82.10 and 81.35 %, respectively followed by TSs50, TSs82, TSs94, TSs209 and TSs331 with SPE values of between 77 94 % and 71.74 % while TSs370 and TSs24 gave the lowest SPE value of 39.31 and 46.28 %, respectively. Also, at 24.975 plants ha^{-1}, the performance of the genotypes in 2013 cropping year reveals that TSs82 and TSs22 had significantly highest SPE with values of 97.69 and 92.26 % but the values were statistically similar to those of TSs50, TSs86 and TSs311 with 90.85, 88.17 and 88.04 %, respectively while TSs81 recorded the lowest of 39.34 %.

For the corresponding 2014 cropping year, the performance of the genotypes indicates that SPE was significantly highest in TSs349 and TSs86 with 82.83 and 81.77 %, respectively followed by TSs83, TSs331, TSs50, TSs42 and TSs77 with values ranging between 80.47 and 73.30 % while TSs81, TSs82 and TSs9 with 31.70, 38.09 and 41.20 %, respectively. However, in the combined cropping years, TSs50 and TSs86 had significantly highest values of 85.26 and 84.67 %, respectively followed by TSs311, TSs42, TSs23, TSs94, TSs22, TSs24, TSs331 and TSs82 with values of between 72.85 and 80.09 % while TSs81 gave the lowest value of 35.52 %. At 10,000 plants ha^{-1}, the performance of the genotypes in 2013 shows that SPE values ranged from 40.34 % in TSs81 to 97.29 % in TSs50 but the values among the 18 AYB genotypes were statistically similar. Furthermore, in the corresponding 2014 cropping year, SPE values ranged from 50.03 % in TSs94 to 89.20 % in TSs349. Genotypes TSs349, TSs311, TSs331, TSs83, TSs42, TSs48 and TSs82 had significant highest values of 81.00 to 89.20 %, closely followed by TSs209, TSs50 and TSs77 with values of between 74.53 and 79.07 % while lowest value of 50.03 % was observed in TSs94. However, in the combined cropping years, TSs50, TSs311, TSs209 and TSs82 gave the highest values of between 84.34 and 88.08 %, though were not significantly different from values of 80.09, 81.61 and 82.47 % recorded in TSs83, TSs86 and TSs42, respectively whereas the least SPE value of 50.07 % was observed in TSs81.

Discussion

Analysis of variance results showed variability in the genotypes for seed yield/plant, number of pods/plant, seed weight/pod, pod weight/plant and number of seeds/pods. This implies that the 18 genotypes differed in all the above attributes, thereby providing opportunity for selecting AYB genotypes with superior seed yield qualities.

Generally, seed yield characters were highest in the second cropping year (2014) compared to the first year (2013). This was as a result of changes noticed in the weather conditions. In the first cropping year, rainfall pattern was not well distributed during the production year (682.2mm (97.46 mm per month). However, moisture was fairly and evenly distributed during the 2014 cropping year (798mm (114mm per month). Hence, environmental stress due to moisture shortage at crucial stage was reduced to a barest condition. Adebisi *et al*. (2005) established plant population as playing a fundamental role in determining seed yield characters in sesame crop. Alam *et al*. (2011) reported that successful cultivation of any crop depends on several factors but plant population and sowing time are more essential for the seed production system of different crops. Also, Abdul –Rafiu (2015) observed that seed yield characters such as fruit weight per plant, unit fruit weight, number of seed per fruit, 100 seed weight, seed yield per plant and seed weight per fruit were significantly highest in cayenne pepper planted at low population density of 18,518 plants/ha.

On the performance of seed yield characters under the three plant densities, seed yield characters such as seed weight per plant, number of pods per plant, seed weight per pod and pod weight per plant were significantly highest in African yam beans planted at low population density of 10,000 plants per ha. However, number of seed per pod and seed production efficiency was not statistically affected by plant population. The result was similar with the work of De-Viloria *et al. (*2002*)* in bell pepper as well as Amnifard *et al.* (2010) and Abdul-Rafiu (2015) reports in Cayenne pepper. Yahaya (2008) also reported that the performance of C. *frutescens* was enhanced by wider spacing as the number of fruits per plant and fruit size were reduced at closer spacing. Ozer (2003) also reported that summer rapeseed (*Brasicca napus*) grown at higher plant density produced highest seed yield compared to the lower population density. Adebisi *et al*. (2005) also confirmed this in sesame with the genotypes performing better in terms of seed yield at medium population density of 166,667 plant/ha. However, the result was in contrast with the discoveries of Nerson (2002) who noticed that seed yield index varied with plant population densities in muskmelon (*Cucumis melo*) as seed highest yield was recorded at 12 plants per m^2 (from 0.5 to 16 plants per m^2), even though the fruits were relatively small. This implies that increased seed yield on per-hectare basis is attributable to a higher plant population density but results in lower seed production per plant. Higher plant population density really compensated for lower yield per plant and consequently resulted in increased seed yield per area.

Generally, highest seed yield was recorded in the lowest plant population density of 10,000 plants/ha in 2013. The result followed the same trend in the second cropping year of 2014. This implies that none of the plant populations is independent of changes in environmental conditions of the area of production. Also, the result showed that seed yield from 55,555 plant population density was lowest compared to 24,975 plant population ha^{-1}. Therefore, maintaining the plant population at 10,000 plants ha^{-1} still assures significant increase in seed yield per hectare. These findings are also supported by Adebisi *et al.* (2004) in sesame who reported that genotypes performed better (Seed yield) at medium population density of 166,667 plants per hectare.

A cursory observation of seed yield characters among the 18 AYB genotypes under the three plant population densities revealed that TSs86 had the highest seed weight per plant (70.38 – 100.87 g), highest pod weight/plant (115.89 -133.31 g) and highest number of seeds/pod (19.79-20.27) under the three plant population densities. The lowest seed weight/plant, as well as seed weight per pod and pod weight per plant were obtained in TSs370 and TSs94, respectively under 55,555 plants ha^{-1}. Genotypes TSs77, TSs50, TSs86 and TSs 83 were most outstanding in number of seed per pod, seed weight pod, number of pods per plant and seed production efficiency under 10,000 plants ha^{-1}. Also, other top seed yielding genotypes were TSs83, TSs331, TSs48 and TSs42.

Conclusion

AYB seed yield attributes were significantly influenced by plant population densities, genotypes and cropping years. Therefore, attention should be given to plant spacing, genotype and cropping years in seed production programme of African yam bean. Seed yield characters such as seed weight/plant, number of pods/plant, seed weight/pod and pod weight/plant were significantly highest at low density (10,000 plants ha^{-1}). Genotype TSs86 had the highest seed weight/plant (70.38 – 110.87g) pod weight/plant (115.89 – 133.31g) and number of seeds/pod (19.79 - 20.27g) under the three plant densities.

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Conflict of Interests

None

Tables, Figures and Charts

Table 1: Mean square values for the seed yield characters evaluated in 18 AYB genotypes under three plant densities in 2013 and 2014 cropping years and combined cropping years

Source of Variation	DF	Seed weight / plant	No of pods/ plant	Seed weight /pod	Pod weight / plant	No of seeds/ pod	SPE
2013							
Rep	2	11.30**	98.74**	1.90	11641.10	2.25	289.55
Gen (G)	17	2451.12**	101.94**	5.08**	16417.04**	21.66	784.35**
Plt den (P)	2	12165.36**	420.80**	0.91	9025.77	25.58	1179.01**
G x P	34	480.00**	74.84**	2.87**	13476.17	27.95**	399.40**
Error	105	292.25	31.50	1.08	9711.28	15.33	199.97
2014							
Rep	2	11.30**	98.74**	1.90	11641.10	2.25	289.55
Gen(G)	17	2451.12**	101.94**	5.08**	16417.04**	21.66	784.35**
Plt den (P)	2	12165.36**	420.80**	0.91	9025.77	25.58	1179.01**
G x P	34	480.00**	74.84**	2.87**	13476.17	27.95**	399.40**
Error	105	292.25	31.50	1.08	9711.28	15.33	199.97
COMBINED							
Rep	2	415.67*	48.22	1.20	6375.04	1.03	329.54
Gen (G)	17	4143.54**	81.82**	7.99**	9664.88*	27.38*	1910.66**
Plt den (P)	2	13211.05**	494.58**	9.66**	8608.16*	31.23*	528.29*
G x P	34	355.06*	53.18**	2.79**	7049.02*	15.63	628.37**
Error	267	304.20	19.38	1.27	5989.95	13.92	342.55

** Significant at 1 % probability level *Significant at 5 % probability level No -Number
SPE – Seed Production Efficiency, Wt - Weight, plt-plant, G x P-Genotype x Population, Gen-genotype

Table 2: Effect of three plant densities on seed weight per plant in 18 AYB genotypes in 2013, 2014 and across cropping years

Genotypes	Seed weight per plant (g)								
	55,555 plants ha^{-1}			24,975 plants ha^{-1}			10,000 plants ha^{-1}		
	2013	2014	Comb	2013	2014	Comb	2013	2014	Comb
TSs9	40.27^{de}	67.94^{c}	56.44^{c}	41.66^{fg}	35.26^{e}	59.42^{c}	43.50^{g}	97.33^{b}	72.28^{c}
TSs22	35.73^{ef}	71.55^{bc}	56.21^{c}	42.34^{fg}	42.60^{de}	61.17^{c}	49.75^{f}	91.65^{b}	71.36^{c}
TSs23	35.45^{ef}	85.89^{ab}	51.10^{c}	35.47^{hi}	44.19^{de}	53.38^{c}	48.44^{f}	99.02^{b}	78.73^{c}
TSs24	29.79^{fg}	40.20^{d}	68.02^{bc}	36.26^{hi}	56.64^{cd}	63.9^{c}	42.73^{g}	94.40^{b}	95.11^{bc}
TSs42	36.99^{e}	67.03^{c}	80.89^{bc}	49.14^{e}	64.59^{bc}	76.61^{bc}	56.54^{ef}	81.31^{c}	105.99^{ab}
TSs48	43.81^{cd}	67.28^{c}	88.09^{b}	49.53^{e}	63.90^{bc}	96.06^{ab}	57.29^{ef}	88.05^{b}	117.82^{ab}
TSs50	65.47^{b}	65.03^{c}	105.83^{ab}	83.27^{b}	94.06^{a}	107.14^{ab}	92.57^{f}	114.87^{a}	127.32^{a}
TSs77	34.58^{fg}	44.59^{d}	59.98^{bc}	40.00^{gh}	49.30^{cde}	76.17^{bc}	53.38^{f}	55.57^{c}	79.57^{c}
TSs81	34.43^{fg}	42.30^{d}	52.79^{c}	34.33^{i}	45.42^{d}	95.85^{ab}	33.79^{h}	63.22^{de}	104.55^{ab}
TSs82	33.70^{fg}	44.31^{d}	50.46^{c}	45.77^{ef}	46.51^{d}	61.99^{c}	45.50^{g}	65.43^{de}	71.73^{c}
TSs83	46.51^{c}	66.81^{c}	82.47^{bc}	63.28^{c}	81.63^{a}	104.24^{ab}	82.82^{c}	127.42^{a}	130.30^{a}
TSs86	72.10^{a}	88.67^{a}	115.89^{a}	91.84^{a}	93.89^{a}	116.28^{a}	101.54^{a}	120.19^{a}	133.31^{a}
TSs94	33.66^{fg}	40.61^{d}	51.67^{c}	33.72^{i}	42.29^{de}	53.98^{c}	36.27^{h}	46.68^{e}	65.97^{c}
TSs209	36.47^{e}	40.56^{d}	68.03^{bc}	37.54^{gh}	44.58^{de}	62.75^{c}	43.51^{g}	58.55^{e}	94.73^{bc}
TSs311	44.50^{cd}	82.32^{ab}	86.54^{bc}	54.00^{d}	63.98^{bc}	74.81^{bc}	59.26^{e}	91.16^{b}	85.80^{bc}
TSs331	47.24^{c}	65.67^{c}	80.07^{bc}	54.67^{d}	84.46^{a}	93.21^{ab}	64.03^{d}	94.44^{b}	106.66^{ab}
TSs349	44.07^{cd}	38.77^{d}	89.77^{b}	38.72^{gh}	54.26^{cd}	84.40^{bc}	52.97^{f}	64.87^{de}	121.01^{ab}
TSs370	21.79^{h}	45.80^{d}	80.03^{bc}	35.14^{h}	46.59^{de}	95.06^{ab}	42.51^{g}	63.43^{de}	101.85^{ab}
Mean	40.92	59.19	73.57	48.15	58.56	79.80	55.91	84.31	98.01
SE	2.98	9.87	6.42	2.98	9.87	6.42	2.98	9.87	6.42

Means followed by the same alphabets along the column are not significantly different from one another at 5 % probability level. Comb: Combined cropping years, Wt- Weight

Table 3: Effect of plant densities on number of pods/plant in 18 AYB genotypes in 2013, 2014 and across cropping years

Genotypes	Number of pods per plant								
	55,555 plants ha^{-1}			24,975 plants ha^{-1}			10,000 plants ha^{-1}		
	2013	2014	Comb	2013	2014	Comb	2013	2014	Comb
TSs9	16.53^{c}	21.33^{abc}	18.93^{a}	12.20^{ef}	15.00^{bcde}	13.60^{cd}	16.07^{ef}	19.33^{cd}	17.70^{cd}
TSs22	12.73^{ef}	23.33^{ab}	18.03^{ab}	10.40^{f}	17.33^{ab}	13.87^{cd}	19.67^{bc}	14.33^{cd}	17.00^{cd}
TSs23	14.00^{def}	21.67^{ab}	17.84^{ab}	17.33^{ab}	14.00^{bcde}	15.67^{bc}	16.40^{ef}	18.33^{bc}	17.37^{cd}
TSs24	11.60^{fghi}	26.00^{a}	18.80^{ab}	11.33^{ef}	18.00^{ab}	14.67^{bc}	21.80^{b}	17.33^{bcd}	19.57^{bc}
TSs42	9.17^{i}	15.33^{de}	12.25^{cde}	13.23^{de}	14.00^{bcde}	13.62^{cde}	16.07^{ef}	17.33^{bcd}	16.70^{cd}
TSs48	10.00^{ghi}	17.67^{bcd}	13.84^{cd}	13.37^{cd}	15.00^{abcde}	14.19^{cde}	15.17^{fg}	18.33^{bcd}	16.75^{cd}
TSs50	15.47^{cd}	18.00^{bcd}	16.74^{bc}	17.43^{ab}	18.33^{ab}	17.88^{ab}	20.47^{b}	21.33^{ab}	20.90^{b}
TSs77	12.23^{efg}	9.00^{f}	10.62^{e}	12.20^{ef}	14.00^{bcde}	13.10^{cde}	13.00^{g}	17.33^{bcd}	15.17^{de}
TSs81	20.00^{ab}	16.67^{cd}	18.34^{ab}	15.13^{bc}	16.33^{ab}	15.73^{bc}	15.67^{fg}	17.00^{bcd}	16.34^{cd}
TSs82	18.13^{bc}	18.00^{bcd}	18.07^{ab}	17.27^{ab}	15.00^{bcde}	16.14^{bc}	13.53^{g}	12.33^{d}	12.93^{e}
TSs83	14.33^{de}	11.00^{ef}	12.67^{cde}	16.00^{b}	17.67^{ab}	16.84^{bc}	17.77^{cd}	20.67^{ab}	19.22^{bc}
TSs86	15.90^{cd}	16.33^{cde}	16.12^{bc}	19.13^{a}	19.67^{a}	19.40^{a}	25.13^{a}	26.00^{a}	25.57^{a}
TSs94	22.47^{a}	18.33^{bcd}	20.40^{a}	15.80^{bc}	10.67^{e}	13.24^{cde}	17.00^{cd}	19.00^{bc}	18.00^{bc}
TSs209	9.60^{hi}	11.33^{ef}	10.62^{e}	11.20^{ef}	11.33^{de}	11.27^{e}	14.13^{fg}	16.67^{bcd}	15.40^{de}
TSs311	10.97^{ghi}	21.00^{abcd}	15.99^{bc}	15.33^{bcd}	15.00^{abcde}	15.17^{bc}	16.27^{ef}	15.67^{cd}	15.97^{de}
TSs331	12.20^{efg}	12.00^{ef}	12.10^{cde}	15.40^{bcd}	16.67^{abcd}	16.04^{bc}	16.87^{de}	17.67^{bcd}	17.27^{cd}
TSs349	11.03^{ghi}	19.00^{bcd}	15.02^{c}	13.13^{de}	18.33^{abc}	15.73^{bc}	13.67^{fg}	16.00^{bcd}	14.84^{de}
TSs370	19.20^{b}	16.00^{cde}	17.60^{ab}	13.20^{de}	15.00^{abcde}	14.10^{cde}	15.10^{f}	14.67^{cd}	14.89^{de}
Mean	14.20	17.33	15.78	14.39	15.63	15.07	16.87	17.74	17.31
SE	1.48	3.24	2.36	1.48	3.24	2.36	1.48	3.24	2.36

Table 4: Effect of plant densities on seed weight/pod in 18 AYB genotypes in 2013, 2014 and across cropping years

Genotypes	Seed weight/pod (g)								
	55,555 plants ha^{-1}			24,975 plants ha^{-1}			10,000 plants ha^{-1}		
	2013	2014	Comb	2013	2014	Comb	2013	2014	Comb
TSs9	3.60^{de}	4.58^{cd}	4.09^{d}	4.07^{de}	4.44^{c}	4.26^{cd}	5.67^{bc}	5.53^{bc}	5.60^{b}
TSs22	3.48^{d}	3.79^{de}	3.64^{de}	3.86^{def}	4.80^{bc}	4.33^{cd}	5.49^{bc}	3.95^{ef}	4.72^{cd}
TSs23	4.38^{bcd}	6.37^{a}	5.38^{b}	3.75^{ef}	4.09^{cd}	3.92^{d}	5.36^{bc}	4.25^{de}	4.81^{cd}
TSs24	4.63^{bc}	5.04^{bc}	4.33^{bc}	5.06^{bc}	5.52^{ab}	5.29^{ab}	4.99^{cd}	5.54^{bc}	5.22^{bc}
TSs42	4.30^{bcd}	5.61^{bc}	4.95^{bc}	4.38^{de}	4.78^{bc}	4.58^{c}	6.84^{a}	5.01^{cd}	5.93^{b}
TSs48	3.62^{cd}	3.95^{de}	3.79^{d}	5.04^{bc}	5.51^{ab}	5.28^{ab}	5.75^{bc}	6.26^{b}	6.01^{b}
TSs50	6.01^{a}	7.13^{a}	6.57^{a}	3.16^{f}	6.25^{a}	4.71^{bc}	6.81^{a}	7.21^{a}	7.01^{a}
TSs77	4.07^{bcd}	3.29^{de}	3.68^{de}	4.39^{de}	3.45^{d}	3.92^{d}	4.81^{cd}	3.66^{efg}	4.24^{d}
TSs81	3.15^{de}	4.43^{cd}	3.79^{d}	5.35^{bc}	5.85^{ab}	5.60^{a}	5.94^{ab}	5.39^{bc}	5.67^{b}
TSs82	3.04^{e}	3.31^{de}	3.18^{de}	4.55^{cd}	4.96^{bc}	4.76^{bc}	4.71^{cd}	4.20^{de}	4.46^{cd}
TSs83	4.07^{bcd}	3.88^{de}	3.98^{d}	5.59^{b}	5.19^{bc}	5.39^{ab}	5.13^{bc}	6.03^{bc}	5.58^{bc}
TSs86	4.73^{bc}	5.55^{bc}	5.14^{b}	3.34^{ef}	6.11^{a}	4.73^{bc}	4.79^{cd}	6.44^{ab}	5.62^{b}
TSs94	2.90^{e}	3.16^{e}	3.03^{e}	3.37^{ef}	3.01^{d}	3.49^{d}	5.22^{bc}	5.69^{bc}	5.46^{bc}
TSs209	3.79^{cd}	5.46^{bc}	4.63^{bc}	4.21^{de}	3.67^{cd}	3.94^{d}	6.20^{ab}	3.73^{ef}	4.97^{cd}
TSs311	3.43^{de}	4.83^{cd}	4.13^{c}	3.55^{ef}	3.83^{cd}	3.69^{d}	2.66^{e}	2.88^{g}	3.47^{e}
TSs331	3.06^{e}	5.15^{bc}	4.11^{c}	3.50^{ef}	5.16^{bc}	4.33^{cd}	4.64^{cd}	3.09^{fg}	3.87^{de}
TSs349	4.57^{bc}	3.91^{de}	4.24^{c}	4.26^{de}	5.87^{ab}	5.07^{ab}	5.33^{bc}	4.18^{de}	4.76^{cd}
TSs370	4.33^{bcd}	4.98^{c}	4.66^{bc}	6.55^{a}	4.65^{bc}	5.60^{a}	6.02^{ab}	5.81^{bc}	5.92^{b}
Mean	3.95	4.69	4.29	4.33	4.84	4.61	5.35	4.94	5.18
SE	0.58	0.59	0.59	0.58	0.59	0.59	0.58	0.59	0.59

Means followed by the same alphabets along the column are not significantly different from one another at 5 % probability level. Comb: Combined cropping years,

Table 5: Effect of three plant densities on pod weight per plant in 18 AYB genotypes in 2013,2014 and across cropping years

Genotypes	Pod weight/plant (g)								
	55,555 plants ha^{-1}			24,975 plants ha^{-1}			10,000 plants ha^{-1}		
	2013	2014	Comb	2013	2014	Comb	2013	2014	Comb
TSs9	48.43^{de}	64.45^{ef}	56.44^{c}	52.68^{def}	66.15^{fg}	59.42^{c}	72.16^{def}	72.39^{h}	72.28^{c}
TSs22	44.01^{de}	68.41^{e}	56.21^{c}	45.90^{efg}	76.43^{ef}	61.17^{c}	64.06^{f}	78.66^{h}	71.36^{c}
TSs23	47.12^{de}	55.07^{g}	51.10^{c}	50.75^{def}	56.00^{g}	53.38^{c}	85.06^{cd}	72.39^{h}	78.73^{c}
TSs24	46.53^{d}	89.50^{d}	68.02^{bc}	45.48^{efg}	82.32^{e}	63.9^{c}	80.43^{cde}	109.78^{ef}	95.11^{bc}
TSs42	59.20^{bcd}	102.58^{c}	80.89^{bc}	61.99^{cde}	91.23^{de}	76.61^{bc}	67.23^{ef}	144.74^{c}	105.99^{ab}
TSs48	85.22^{a}	90.96^{cd}	88.09^{b}	92.88^{a}	99.24^{cd}	96.06^{ab}	91.37^{bc}	144.26^{c}	117.82^{ab}
TSs50	80.29^{ab}	131.37^{b}	105.83^{ab}	91.57^{a}	122.71^{b}	107.14^{ab}	95.74^{bc}	158.90^{b}	127.32^{a}
TSs77	66.00^{bc}	53.95^{f}	59.98^{bc}	78.34^{b}	74.00^{ef}	76.17^{bc}	85.45^{cd}	73.69^{h}	79.57^{c}
TSs81	44.63^{de}	60.98^{ef}	52.79^{c}	98.43^{a}	93.27^{cd}	95.85^{ab}	104.16^{ab}	104.93^{efg}	104.55^{ab}
TSs82	41.90^{e}	59.02^{ef}	50.46^{c}	43.41^{fg}	80.56^{e}	61.99^{c}	42.26^{g}	101.20^{fg}	71.73^{c}
TSs83	76.17^{ab}	88.76^{d}	82.47^{bc}	90.87^{a}	117.60^{bc}	104.24^{ab}	105.03^{ab}	155.57^{bc}	130.30^{a}
TSs86	76.81^{ab}	154.96^{a}	115.89^{a}	85.87^{ab}	146.68^{a}	116.28^{a}	95.02^{bc}	170.60^{a}	133.31^{a}
TSs94	37.98^{e}	65.36^{ef}	51.67^{c}	39.48^{g}	68.48^{fg}	53.98^{c}	38.87^{g}	93.06^{g}	65.97^{c}
TSs209	42.12^{c}	93.93^{cd}	68.03^{bc}	43.49^{fg}	82.00^{e}	62.75^{c}	45.13^{g}	144.33^{c}	94.73^{bc}
TSs311	53.48^{cd}	119.60^{b}	86.54^{bc}	61.42^{cde}	88.20^{de}	74.81^{bc}	68.01^{ef}	103.58^{efg}	85.80^{bc}
TSs331	68.93^{bc}	91.20^{cd}	80.07^{bc}	81.30^{b}	105.12^{c}	93.21^{ab}	98.33^{bc}	114.98^{de}	106.66^{ab}
TSs349	84.61^{ab}	94.92^{cd}	89.77^{b}	84.75^{ab}	84.04^{e}	84.40^{bc}	118.47^{a}	123.54^{d}	121.01^{ab}
TSs370	69.88^{ab}	90.17^{c}	80.03^{bc}	71.89^{bc}	118.23^{bc}	95.06^{ab}	96.88^{bc}	106.89^{ef}	101.85^{ab}
Mean	59.63	87.51	73.57	67.81	91.79	79.80	80.76	115.19	98.18
SE	9.73	7.74	8.74	9.73	7.74	8.74	9.73	7.74	8.74

Means followed by the same alphabets along the column are not significantly different from one another at 5 % probability level. Comb: Combined cropping years,

Table 6: Effect of three plant densities on seed production efficiency (SPE) in 18 AYB genotypes in 2013, 2014 and across cropping years

Genotypes	SPE (%)								
	55,555 plants ha^{-1}			24,975 plants ha^{-1}			10,000 plants ha^{-1}		
	2013	2014	Comb	2013	2014	Comb	2013	2014	Comb
TSs9	83.81^{ab}	54.90^{cd}	69.35^{b}	81.16^{abc}	41.20^{d}	61.18^{c}	60.81^{cd}	68.57^{bc}	64.69^{cd}
TSs22	81.23^{ab}	53.57^{d}	67.40^{bc}	92.26^{a}	57.50^{c}	74.88^{ab}	79.04^{ab}	65.50^{bc}	72.27^{bc}
TSs23	75.45^{bc}	57.70^{cd}	66.57^{c}	71.08^{bc}	80.47^{ab}	75.77^{ab}	63.43^{cd}	60.57^{bc}	62.00^{cd}
TSs24	63.69^{cd}	28.87^{e}	46.28^{d}	79.74^{abc}	62.33^{b}	74.67^{ab}	60.05^{cd}	69.60^{bc}	61.19^{cd}
TSs42	64.02^{cd}	67.66^{ab}	65.85^{bc}	79.80^{abc}	74.37^{ab}	77.08^{ab}	84.21^{ab}	80.73^{a}	82.47^{ab}
TSs48	51.35^{de}	72.57^{ab}	61.96^{c}	53.65^{de}	69.60^{abc}	61.62^{c}	62.59^{cd}	80.63^{a}	71.61^{bc}
TSs50	81.52^{ab}	74.37^{ab}	77.94^{ab}	90.85^{ab}	79.67^{ab}	85.26^{a}	97.29^{a}	78.87^{ab}	88.08^{a}
TSs77	56.94^{d}	65.70^{b}	68.00^{b}	51.06^{de}	73.70^{ab}	58.38^{c}	62.39^{cd}	79.07^{ab}	68.05^{c}
TSs81	90.42^{a}	72.28^{ab}	81.35^{a}	39.34^{e}	31.70^{d}	35.52^{d}	40.34^{e}	59.80^{cd}	50.07^{e}
TSs82	80.48^{ab}	75.37^{ab}	77.92^{ab}	97.69^{a}	38.00^{d}	72.85^{ab}	87.68^{ab}	81.00^{a}	84.34^{a}
TSs83	60.84^{c}	75.63^{ab}	68.24^{bc}	70.16^{bcd}	68.03^{bc}	69.10^{bc}	79.04^{abc}	81.13^{a}	80.09^{ab}
TSs86	92.43^{a}	74.57^{ab}	83.50^{a}	88.17^{ab}	81.77^{a}	84.67^{a}	86.98^{ab}	76.23^{ab}	81.61^{ab}
TSs94	88.42^{ab}	67.03^{bc}	77.73^{ab}	85.42^{abc}	65.70^{bc}	75.56^{ab}	93.45^{a}	50.03^{d}	71.74^{bc}
TSs209	86.92^{ab}	63.43^{b}	75.18^{ab}	86.70^{abc}	55.53^{c}	71.12^{b}	97.15^{a}	74.53^{ab}	85.84^{a}
TSs311	83.50^{ab}	80.70^{a}	82.10^{a}	88.04^{ab}	72.13^{abc}	80.09^{ab}	87.63^{ab}	87.80^{a}	87.72^{a}
TSs331	70.32^{bc}	73.17^{a} b	71.74^{ab}	67.79^{cd}	80.20^{ab}	73.99^{ab}	65.14^{cd}	82.10^{a}	73.62^{bc}
TSs349	52.13^{d}	58.10^{cd}	55.11^{c}	49.50^{de}	82.83^{a}	66.17^{bc}	51.17^{de}	89.20^{a}	70.18^{bc}
TSs370	31.19^{e}	47.23^{d}	39.32^{d}	53.37^{de}	59.67^{c}	56.62^{c}	43.97^{de}	69.97^{b}	55.92^{de}
Mean	71.93	64.60	68.64	73.65	65.24	69.70	72.35	74.19	72.86
SE	12.20	8.16	10.18	12.20	8.16	10.18	12.20	8.16	10.18

Means followed by the same alphabets along the columns are not significantly different from one another at 5 % probability level. SPE – Seed production efficiency. Comb: Combined cropping years,

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