Diallel Analysis of White Pea Bean (Phaseolus vulegaris L.) Varieties for Yield and Yield Components

Tsegau Senbetay[1*] Abush Tesfaye[2]
1. Ethiopian Institute of Agricultural Research/Jimma Agricultural Research Center, ; P.O.B: 192, Jimma ,Ethiopia
2. Jimma University College of Agriculture and Veterinary Medicine; P.O.B- 307, Jimma, Ethiopia
corresponding author: tsegau2006@yahoo.com.

Abstract
Combining ability study provides very useful genetic information about the inheritance of quantitative traits that helps to determine the type of breeding procedure to be employed to improve the crop of interest. The objective of the study was to determine the type of gene actions involved in the inheritance of the most important quantitative traits in commercial white pea bean cultivars. Forty nine entries (7 parents and 42 F_2 diallel crosses) were grown in a simple lattice design with two replications at Jimma Agricultural Research Center, South Western Ethiopia. The results revealed significant mean squares in all of the characters. There were significant mean squares due to general combining ability, specific combining ability, reciprocal effects, maternal effects, and non-maternal effects in almost all of the characters. The relative contribution of specific combining ability was higher than general combining ability for all of the studied traits pod length and seed thickness.This indicating that the non-additive gene actions are influential in the expression of these traits which poses some difficulty as the non-additive gene actions are non-fixable. Thus, selfing should continue for more generation to fix the non-additive gene actions before undertaking selection. Starlight is good general combiner for pod size, seed size, 100-seed weight and grain yield. The other genotypes may also be good general combiner for other traits because they displayed positive and significant traits.
Keywords: Specific combining ability, general combining ability, reciprocal effects, maternal effects, Non-maternal effects.

1. Introduction

The white pea bean (*Phaseolus vulgaris* L.) is the most important food legume crop grown worldwide (Wortmann and Allen, 1994; Wortmann *et al*., 1998; Buruchara, 2006). Beans are considered by many to be the perfect food as they are nutrient dense with high contents of protein, micronutrients, vitamins, dietary fibre, and also have a low glycemic index (Wortmann and Allen, 1994; Bennink, 2005; Widers, 2006).

The crop is currently the second most important source of human dietary protein and the third most important source of calories next to soybean for over 100 million people in rural and poor urban communities in Africa (Buruchara, 2006). It is one of the most important pulse crops grown in many lowland areas of Ethiopia as a main crop and protein source. Green leaves, green pods, and immature and/or dry seeds may all be eaten, and they are very rich in iron and zinc (Kimani *et al*., 2006). Dry leaves, threshed pods, stalks and bean seeds that do not meet human food quality standards are fed to animals, or used as fuel for cooking, especially in Africa and Asia (Sperling *et al*., 1996; Buruchara, 2006).

In addition to contributing to protein requirement, haricot beans, particularly the white colored ones are very important to fetch additional income for farmers (Imru, 1985; Getahun and Yeshi, 1989; IAR, 1990). At present different types of beans are grown in Ethiopia both as a sole crop and intercropped with cereals (IAR, 1990; Kidane *et al*., 1990). These include, white pea beans as cash crop, different colored beans for local consumption, and climbing types to be used as green beans locally and other purposes.

According to CSA (2004), white pea bean has land area coverage of 209,534.89 hectares (2.38% of crop area) and a production of 1,521,66.062 tones (1.45% of total grain production) and a productivity of 7.26 quintal per hectare in Ethiopia,, which is very low. This low yield is attributed to several production constraints which include low number of improved varieties for the different agro-ecological zones, poor and untimely cultural practices, moisture stress and low soil fertility. A great loss of yield is also attributed to diseases such as rust, angular leaf spot, floury leaf spot, anthracnose, common bacterial blight and insects such as bean fly, aphids, stem maggots and bean bruchids (CIAT, 1986b; Amare, 1989; Habtu, 1990).

A coordinated pulse research program on varietal improvement and crop management was initiated in 1972 at Melkassa Agricultural Research Center (MARC) with the main emphasis given to haricot beans. The program so far depends up on evaluation of materials from introductions and some local collection. It has released several varieties (Imru, 1985; Amare and Haile, 1989; IAR, 1990).

There is wide genetic variability in white pea beans in growth habit (determinate vs. indeterminate), in days to maturity, in seed size, color and quality (cookability and palatability), in vegetative and reproductive growth, pigmentation, and leaf size, shape and orientation and resistance to pests (Leakey, 1970). The choice of promising genotypes from diverse genetic base, and their subsequent utilization for hybridization is one of the strategies for improving the productivity of any crop including beans. A systematic study of the hybrids (F_1s) and their behavior in subsequent generations of selfing (F_2, F_3, etc.) can generate basic genetic information about the type of gene action governing the inheritance of quantitative traits such as yield. The effort made to develop recombinant inbred lines inorder to identify superior recombinant inbred lines has been very limited on commercial white pea bean cultivars in the country. The Ethiopian bean improvement program has focused on screening of introductions and could not generate basic genetic information. Effective selection for seed yield and its components requires information on the magnitude of useful genetic variance present in the population, combining ability, heterosis, and correlation of component traits. Hence, it is necessary to systematically test the performance of parental lines in order to identify superior and complementary genotypes for hybridization. A suitable means to achieve this goal is the use of diallel mating system, a method where the progeny performance can be statistically separated in to components relating to general combining ability (GCA) and specific combining ability (SCA). General and specific combining abilities are a measure of the additive and non-additive genetic variation of parents, respectively (Sprague and Tatum, 1942). Combining ability analysis is one of the powerful tools in identifying the best combiners, which may be hybridized to exploit trasngressive segregants that help in identifying superior recombinant inbred lines. It is also useful to elucidate the nature of gene action involved.

It is recommended that high yielding heterotic crosses with low inbreeding depression and showing transgressive segregation (development of a character in excess of either parent) in the F_2 generation should be considered for further breeding work. Replicated yield trials can be undertaken in the F_2 and F_3 and selection be done only in large populations and among families of high yielding crosses (Singh, 1989). Thus it is desirable to study combiningability of the released varieties of white pea beans and elite genotypes.

Although studies on combining ability and the expression of heterosis have been made in various crops, including the white pea bean in various parts of the world, little effort has been made on beans in Ethiopia.

Therefore, this study was conducted with the objective of determining general combining ability (GCA) and specific combining ability (SCA) of seven lines of export quality white pea bean genotypes and their diallel crosses.

2. MATERIALS AND METHODS

The experiment was conducted in the experimental field of Jimma Agricultural Research Center. Jimma is located in the South West of Ethiopia at about 355 km from Addis Ababa, and Jimma Agricultural Research Center is 14km away from Jimma town. The area is characterized by one long rainy season (May to October) with mean annual rainfall of 900-1754 mm, and an altitude of 1750 m.a.s.l. The minimum and maximum air temperature for the area is 11^{o}C and 26^{o}C, respectively.

Seven white pea bean varieties (Avanti, OR-04-DH, ARGENE, ER-04-AJ, TA-04-JI, Crest wood and Starlight) were used in this study. These varieties were used for commercial and canning purpose. A complete diallel including reciprocal was obtained giving 49 combinations consisting of seven parents (n), 21F2s [n (n-1)] and 21F2s reciprocals. The selection of parental lines was mainly based on their observed yield potential, some qualitative traits including quality of seed and distinct morphological characteristics. Crossing was made among the seven parents in all possible combinations in a full diallel fashion at Jimma agricultural research center.

Full diallel (including reciprocals) were produced at Jimma Agricultural Research Centre during August to September 2011/12 during the rainy period, and furrow irrigation was provided when the rain stopped, October to November 2011/12. Artificial pollination was conducted in the morning (7:00 AM to 10:00 AM). Plants were hybridized using emasculation with protected rubbing or hook methods where the fertilized stigma of the male parent that carried ample pollen was hooked onto the stigma of the female parent. Sepals were kept intact to protect the bud, and pollination quickly followed (CIAT, 1977).

The experiment was laid out in a simple lattice design with two replications. A spacing of 40 cm between rows was used to facilitate supplemental irrigation, and plants were spaced 20 cm apart within the row. To ascertain full stand in a plot, two seeds per hill were planted and thinned to appropriate stand 10 days after emergence. A plot of four rows each 4 m long (1.6X4m) were used, and 100 kg/ha DAP fertilizer was applied at the time of planting. All necessary agronomic practices were done uniformly as per the recommendations. The correct stand count (80 plants per plot) was maintained after thinning. Stand count at harvest was also done.

Pod length (PDL) (cm): The length of 5 randomly taken pods from each of the 5 randomly selected plants. Pod diameter (PDD) (cm): The diameters of the 5 randomly selected pods from each of 5 randomly selected plants were measured using caliper. Seed length (mm):-The average length in millimeter of 10 seeds from five plants each measured parallel to the hillium using vernier caliper. Seed thickness (mm):- Average thickness in millimeter of 10 seeds measured parallel to the seed diameter using vernier caliper. Seed diameter in millimeter of 10 seeds was also measured using vernier caliper.

The height of the plant was determined as the length of the stem from the base of the plant to the topmost flower bud. The average number of pods per plant was computed by dividing the total number of pods by the number of plants. The average number of seeds per plant were also taken. Harvesting was done and 100 seed weight and grain yield per plot were also measured.

Diallel analysis was carried out according to Griffing (1956) Method one, Model one (fixed effects), which involved parents and one-way F2 hybrids (including reciprocals). Griffing portioned the total sum of squares due to the genotypes with p(p-1)/2 –1 degree of freedom into sum of squares due to GCA with p-1 degree of freedom and sum of squares due to SCA with p(p-1)/2 degree of freedom. Here the experimental material itself was the population about which inferences were drawn and hence the estimates obtained from the analysis were applied to those genotypes only. Combining ability analyses was carried out using SAS computer software. Relative importance of GCA, SCA, and the reciprocal cross effects were computed as a proportion of cross effects sum squares. Similarly relative importance of maternal and non-maternal effects was computed as a proportion of reciprocal cross effects sum of squares.
Combining ability was computed using the mathematical model:

$$x_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc}\sum_k \sum_l e_{ijkl} \begin{cases} i.j = 1,..., p, \\ k = 1,..., b, \\ l = 1,..., c. \end{cases}$$

Where μ is the population mean, gi (gj) is the g.c.a. effect, sij the s.c.a. effect, such that sij = sji, and eijkl is the effect peculiar to the ijklth observation, p,b and c are number of parents, blocks and sampled plants. The restrictions

$$\sum_i g_i = 0, and \sum_j s_{ij} + s_{ii} = 0$$

for each i are imposed

Where Sij is specific combining ability of a cross between the ith and jth parent and Sii is the specific combining ability of a parent selfed. Such linear model for analysis of variance helps to determine whether there is a significant difference among the genotypes tested using the F – ratio as:

$$F = \frac{MSv}{MSe}$$

If the effect of genotypes is significant, the sum of squares due to genotypes will be partitioned in to GCA, SCA and reciprocal effects. Then the additive leaner model for diallel analysis can be written as:

$$\times_{ij} = \mu + g_i + S_{ij} + r_{ij} + \sum \quad \sum e_{ijkl} \; / \; bc$$

g = GCA
S = SCA
r = reciprocal effects
b = no. of blocks
c = no. of individuals
e = effects of environmental factors
μ = overall means

Diallel analysis is limited to the following conditions:

$$S_{ij} = S_{ji} \qquad \sum g_i = 0$$

$$r_{ij} = -r_{ij} \qquad \sum S_{ij} = 0_i$$

3. Result

Analysis of variance (ANOVA) revealed highly significant (P<0.001) variation among the 49 genotypes for the traits investigated (table 1). Crosses Avanti X Starlight displayed the highest hundred seed weight(37.85gram). However, the reciprocal cross displayed (23.02 gram). This implies that Avanti is best parent when used as male and Starlight as female for this trait. The cross ER-04-AJ X Starlight displayed 36.24 gram for hundred seed weight (table2). This implies that Starlight is best genotype for hundred seed weight. Moreover, the cross Avanti X Starlight Was also displayed the highest pod length, pod diameter, seed length, seed diameter and seed thickness (table 2). This indicating that Starlight is the best parent when used as female for larger seed size in every cross.

The forward cross ER-04-AJ X Starlight exhibited the largest pod length (9.78cm). However, the reciprocal cross; Starlight X ER-04-AJ displayed 9.15 cm. This is due to the maternity effect of the crop. Moreover, this hybrid ER-04-AJ X Starlight have the largest pod diameter (1.12cm). It also exhibited the largest seed length (12mm), seed diameter (7.86mm) and seed thickness (5.85mm). This implies that reciprocal effect in commercial white pea bean (phaseolus Vugaris L.) varieties contributed. Generally, the cytoplasmic reciprocal effect had the maximum contribution for inheritance of yield and yield components. That is why the seeds of the forward cross should not be mixed with the seeds of reciprocal cross.

Significant GCA and SCA Mean Squares were observed in all of the traits. This implies that both additive and non-additive genetic gene actions are important for the inheritance of these traits. However, the additive gene action more important than the dominance gene action since the variance due to GCA is greater than the variance due to SCA in all of the traits. Significant reciprocal effects were observed in all of these traits except pod diameter and pod length. Significant Mean Squares due to Maternal effects were observed in all of the traits except pod diameter. This implies that the reciprocal cytoplasmic gene is important for the inheritance of these traits. Moreover, significant mean squares due to non-maternal effects were exhibited in all of the traits except pod diameter and pod length. This implies that the inter action between cytoplasm and nuclear genes are important for the inheritance of these traits.

4.Discussion

Analysis of variance (ANOVA) revealed that there is a highly significant ($P<0.01$) difference among the genotypes for pod length, pod diameter, seed length, seed diameter, 100-seed weight, grain yield and seed thickness. This finding is similar with the finding of Arunga *et al*. (2010) who reported highly significant ($P<0.001$) mean squares among 25 genotypes for days to flowering, plant height at flowering, number of pods per plant, pod weight per plant, pod length, and pod diameter in snap bean. Machado *et al* (2002) also reported similar result that highly significant mean squares for grain yield in F2 segregating population in a 9 X 9 diallel cross in common bean. Mukankusi *et al*. (2011) reported that additive gene action was far more important in determining resistance to Fusarium root rot than the non-additive gene action in common bean. Significant GCA and SCA mean Squares were reported by (Rameah *et al*, 2000) in corn inbred lines using diallel crosses. Moreover, (Mc Phee et al, 2002) reported significant GCA, SCA and reciprocals for nutritional parameters such as sucros, Raffinose, stachyose, total sugar, and total oligosaccharides in common bean.

Arunga *et al.*(2010) has also reported significant GCA, SCA and reciprocal effects for pod length, pod diameter, and pod weight which is similar with this finding. Thus, hybrid combinations with high means, favorable SCA estimates and involving at least one of the parents with high GCA, would tend to increase the concentration of favorable alleles. Moreover, it was observed that parents having low GCA might show good potential in varietal combinations. Adel *et al.*(2012) reported significant GCA and SCA effects for number of spikes per plant, spike weight per plant and grain yield per plant in six diallel cross of wheat. Roberto *et al.*(2011) has reported similar results that significant GCA and SCA effects for pod length, plant height, pod diameter, total number of pods, number of pods per plant, number of grains per plant, total grin weight in common bean and snap bean. However, he has reported non-significant SCA effect for dry mass of the aerial part and pod length for this crop. This implies that The additive and non-additive gene effects have the maximum contribution for the inheritance of commercial white pea bean varieties. Especially the reciprocal effect of this crop haricot bean is very important to considered for quantitative and qualitative traits. When we observed from this experiment, for seed and pod length and diameter; there is high maternity and paternity effect. Moreover, the inter action of the reciprocal cytoplasmic and nuclear gene have contributed for the inheritance of yield and yield related traits in common bean. Arunga *et al.*(2010) reported non-significant maternal effects for pod length, pod diameter, pod weight, days to flowering and number of pods per plant in snap bean.

Crosses Avanti X Starlight, OR-04-DH X Starlight, Argane X Starlight, ER-04-AJ X Starlight, TA-04-AJ X Starlight, Starlight X ER-04-AJ and Starlight X OR-04-AJ had displayed large hundred seed weight (table 2). Therefore, Starlight is good general combiner using as female and male parent for seed weight and seed size in general. Similar results reported that small seeded types (less than 25gm/100 seeds), medium seed types (between 25 to 40gm/100 seeds) and the large seed types (more than 40gm/100 seeds) (vanschoonhoven *et al*.1991). Seed size and growth habit appear to be correlated. large and medium seeded types are most frequently found in growth habit I and IV, while small seeded ones are found predominantly in type II and III (vanschoonhoven *et al*.1991).

Crestwood and starlight have displayed the highest hundred seed weight. Moreover, they also displayed good grain yield, pod length, pod diameter, seed length and seed diameter. This implies that these parents are good general combiner for seed and pod size even for yield in general. Alghamdi *et al.*(2009) reported significant GSA and SCA effects for days to flowering, plant height, number of branches per plant, number of pods per plant, 100-seed weight, number of seeds per plant and seed yield per plant in faba bean crossing. He explained the importance of additive and non-additive gene effect for the in heritance of this traits which is similar with the present finding. Machado *et al*. (2002) also reported Significant GCA and SCA for grain yield in common bean. He was reported that the genetic variance for additive effects (GCA) is reduced, increasing the relative importance of the non-additive genetic effects (Sprague and Tatum, 1942; Lonquist and Gardner, 1961; Allard, 1971; and Vencovsky, 1980). Using adapted and non-adapted common bean cultivars with a wide genetic variation, Abreu (1997) observed that, both for GCA and SCA, there were significant effects of similar magnitude. Londero *et al.*(2005) reported significant SCA,GCA and reciprocal effects for fiber content in common bean grains. It can therefore be indicated for the use in programs of controlled hybridization, aiming at the increase of the dietary fiber content since the estimates of the effects of provide information on the concentration of predominantly additive genes and are highly useful for the indication of parents in intrapopulational improvement programs (Cruz and Regazzi 1997). Thus, a crossing by identifying male and female parents should be potentially superior in the selection of lines, due to the higher value (Ramalho *et al.* 1993). Although the effects of the specific combining ability are useful for the indication of the best hybrid combinations, they do not specify which one of the parents should be used as male or female in the specific crossing; reciprocal effects are used to obtain this information (Cruz and Regazzi 1997).

In the improvement of autogamous plants the cost/ benefit relation often makes the production of hybrid seeds unfeasible. Thus, the estimates (highest and positive) are not only considered for the acquisition of superior hybrids, but also for its values per se. The breeder is therefore interested in combinations with the most favorable estimates of specific combining ability, which involve at least one parent that presented the most favorable effect of the general combining ability (Cruz and Regazzi 1997). This way, selection in the population resulting from the parents crestwood and starlight in every cross using for and reciprocal cross is very effective for identifying pod and seed size in common bean. Therefore, Identifying female and male parents and using their reciprocal crosses in common been breeding is very important for yield and yield components, quality, disease resistance and other desirable traits.

5. Conclusion

The present study revealed that there is genetic variability in white pea bean genotypes for pod and seed size. Selecting common bean genotypes as male and female parent is important for farther breeding program. There is high reciprocal effect in crossing of common bean especially for pod and seed sizes. Crestwood and starlight are good combiner parents for every cross that contributed on the seed size inheritance of this crop. Thus, the seeds of reciprocal cross should not be mixed with the seeds of forward cross since there is cytoplasm reciprocal effect. Moreover, there is also the interaction of cytoplasm and nuclear gene for the inheritance of yield and yield components.

Acknowledgement

Jimma Agricultural Research Center is duly acknowledged for funding this research project. I would like to express my sincere gratitude to my major advisor, Dr. Abush Tesfaye for the guidance, daily follow up and advice in carrying out the thesis research and providing me bean materials used in the study. The author would also like to thank technical assistants in JARC and JUCAVM students of the Department of plant breeding, Jimma University College of Agriculture and veterinary medicine for their all rounded support.

Reference

Abreu A de FB (1997) Predição do potencial genético de populações segregantes do feijoeiro utilizando genitores inter-raciais. Doctoral thesis, Universidade Federal de Lavras, Lavras, MG.

Allard RW (1971) Princípios de melhoramento genético das plantas. Editora Edgard Blucher, São Paulo. pp 381.

Adel, M. M., and E. A. Ali. "Gene Action and Combining Ability in a Six Parent Diallel Cross of Wheat." *Asian Journal of Crop Science* 5.1 (2012): 14-23.

Alghamdi, Salem S. "Heterosis and Combining Ability in a Dia Ilei Cross of Eight Fab a Bean (Vicia faba L.) Genotypes." *Asian Journal of Crop Science*1.2 (2009): 66-76.

Arunga, Edith Esther, Henk A. Van Rheenen, and James Otieno Owuoche. "Diallel analysis of Snap bean (Phaseolus vulgaris L.) varieties for important traits." *African Journal of Agricultural Research* 5.15 (2010): 1951-1957.

Cruz CD and Regazzi AJ (1997) Modelos biométricos aplicados ao melhoramento genético. Editora UFV, Viçosa, 390p.

Machado, Cristina de Fátima, et al. "Choice of common bean parents based on combining ability estimates." *Genetics and Molecular Biology* 25.2 (2002): 179-183.

Jinks JL (1954). The analysis of heritable variation in a diallel cross of *Nicotiana rustica* varieties. Genetics. 39: 767-788.

Khehra AS, Bhalla SK (1976). Cytoplasmic effects on quantitative characters in maize (*Zea mays* L.). Theor. Appl. Genet., 47: 271–274.

Ramalho MAP, Santos JB and Zimmermann MJO (1993) Genética quantitativa em plantas autógamas: aplicações ao melhoramento genético do feijoeiro. Editora UFG, Goiânia, 271p.

Rameeh, V., A. Rezai, and A. Arzani. "Estimates of genetic parameters for yield and yield components in corn inbred lines using diallel crosses." *Journal of science and technology of agriculture and natural resources* 4.2 (2000): 95-104.

dos Santos Trindade, Roberto, et al. "Combining ability for morphoagronomic traits in common bean and snap bean." *African Journal of Agricultural Research*6.29 (2011): 6240-6245.

Lonquist JH and Gardner CO (1961). Heterosis in inter-varietal crosses in maize and its implication in breeding procedure. Crop Science 1:179-183.

Londero, Patrícia Medianeira Grigoletto, et al. "Genetic variability for dietary fiber content in common bean populations." *Crop Breeding and Applied Biotechnology* 5.1 (2005): 86-90.

McPhee, Kevin E., et al. "Genetic analysis of the raffinose family oligosaccharides in common bean." *Journal of the American Society for Horticultural Science* 127.3 (2002): 376-382.

Mukankusi, Clare, et al. "Genetic analysis of resistance to Fusarium root rot in common bean." *Euphytica* 182.1 (2011): 11-23.

Sprague GF, and Tatum LA (1942) General vs specific combining ability in single crosses of corn. Journal American Society Agronomy 34:923-932.

van Schoonhoven, Aart, and Oswaldo Voysest, eds. *Common beans: research for crop improvement*. CIAT, 1991.

Vencovsky R (1980) Herança quantitativa. In: Paterniani E e Veigas, G. Melhoramento e produção de milho no Brasil. 2.ed. Campinas: Fundação Cargill, ESALQ, Piracicaba, pp122-199.

Table 1. Mean squares due to genotypes and error for yield and yield related traits of 7*7 full diallel crosses of white pea bean (ANOVA)

Parameters	**Replication**	**Genotype**	**Error**
GY	338590	396711***	104399
HSWT	45.53ns	56.87***	15.41
PDL	8.45	0.71***	0.23
PD	0.09	0.02**	0.01
SL	0.00	2.22***	0.58
SD	0.02	0.47***	0.04
ST	0.02ns	0.10***	0.02
Degree of freedom	1	48	48

Where, GY=grain Yield, HSWT=Hundred Seed Weight,PDL= Pod length, PD=Pod diameter, SL=Seed length, SD=Seed Diameter, ST=Seed thickness

Table 3. GCA, SCA, reciprocals, maternal and non-maternal mean squares for Seed length, Seed diameter, pod length, pod diameter, Seed thickness, hundred seed weight, and grain yield

PARAMTERS	**MEAN SQUARES**				
	GCA	SCA	REC	MAT	NMAT
SL	6.47***	2.42***	1.43**	1.71*	1.32*
SD	1.62***	0.59***	0.27***	0.40***	0.23***
PDL	2.10***	0.49*	0.39ns	0.63*	0.29ns
HSWT	164.11***	54.58***	33.31**	31.21*	34.28**
GY	343718.96*	318384.47**	223852.66*	436162.71**	157661.64ns
PDD	0.04**	0.02*	0.01ns	0.01ns	0.01ns
ST	0.40***	0.08**	0.07**	0.10**	0.06*

* Significant at $p < 0.05$; *** Significant at $p < 0.001$., Where, HSWT=Hundred seed weight, GY=grain yield, PDL=pod length, pod diameter, SL=Seed length, SD=Seed diameter, Seed thickness

Table 2. Mean values of yield and yield related traits:

treatments	HSWT (gm)	GY (kg)	PDL (cm)	PDD (cm)	SL (mm)	Sd (mm)	ST (mm)
1 × 1	19.89	1000	8.03	1.00	8.67	6.27	4.98
1 × 2	20.87	1299	8.13	0.91	8.29	6.30	5.22
1 × 3	22.41	1580	7.77	0.86	7.75	6.12	5.17
1 × 4	18.29	1781	8.34	1.00	7.76	6.14	5.35
1 × 5	15.19	1700	7.07	0.91	7.34	6.22	5.14
1 × 6	18.35	1335	8.56	0.87	8.06	5.83	5.25
1 × 7	37.85	1405	9.55	1.21	11.69	7.84	5.99
2 × 1	18.39	1686	8.21	0.90	9.01	6.24	4.98
2 × 2	19.29	1285	8.70	0.98	9.52	6.31	5.21
2 × 3	15.48	1341	8.48	0.95	7.53	5.92	4.69
2 × 4	20.08	2110	8.67	0.92	11.89	6.12	5.11
2 × 5	18.63	1445	8.20	0.94	8.41	6.32	4.96
2 × 6	20.71	1886	8.48	0.87	8.33	6.40	5.29
2 × 7	27.56	2044	8.96	1.10	9.22	6.66	5.44
3 × 1	23.99	1320	7.39	0.78	8.06	6.45	5.32
3 × 2	21.76	1300	8.63	1.01	9.10	5.84	4.89
3 × 3	20.47	1748	8.37	0.83	9.00	6.08	4.77
3 × 4	15.91	1250	8.44	0.96	7.39	5.81	4.97
3 × 5	14.33	875	7.96	0.96	8.52	5.79	4.83
3 × 6	15.55	1371	8.43	0.96	8.02	6.28	5.39
3 × 7	26.01	2441	9.09	1.06	10.52	7.36	5.16
4 × 1	17.48	1800	7.22	0.87	8.12	6.05	4.95
4 × 2	15.12	1375	8.20	0.89	8.84	6.27	5.18
4 × 3	16.30	1200	8.07	0.96	7.95	6.14	4.82
4 × 4	16.67	1078	8.31	1.01	8.72	6.35	5.39
4 × 5	25.93	1809	8.10	0.94	8.09	6.13	5.27
4 × 6	13.65	1200	8.05	0.90	7.47	6.42	5.33
4 × 7	36.24	1520	9.78	1.12	12.00	7.86	5.85
5 × 1	18.07	1441	7.35	0.87	8.76	6.37	5.18
5 × 2	16.56	1257	8.64	0.94	9.32	6.12	5.20
5 × 3	24.84	1300	8.89	0.95	9.81	6.71	5.43
5 × 4	16.20	1505	8.23	0.98	8.52	6.08	5.17
5 × 5	14.34	1511	8.07	0.88	8.12	6.01	5.09
5 × 6	18.34	1175	8.06	0.93	8.94	6.14	5.26
5 × 7	29.43	3621	9.17	1.00	10.87	7.24	5.55
6 ×1	18.49	1789	8.36	0.99	7.38	6.19	5.17
6 × 2	18.74	1365	8.64	0.96	7.95	6.31	5.27
6 ×3	15.62	1759	7.53	0.73	7.24	5.16	4.68
6 ×4	20.38	1168.	8.05	0.92	8.51	5.98	5.06
6 × 5	20.82	1421	8.33	0.96	8.84	6.46	5.55
6 × 6	42.36	1425.	9.45	1.16	11.79	7.86	5.78
6 ×7	16.21	1714	8.28	0.82	8.64	6.15	5.16
7 × 1	23.02	1158	8.08	0.89	8.49	6.31	5.32
7 × 2	27.16	1512	9.64	0.95	10.13	6.28	5.16
7 × 3	30.60	2045	8.95	1.05	10.25	6.95	5.25
7 × 4	31.32	1600	9.15	1.11	7.76	7.53	5.32
7 × 5	23.31	1659.	7.93	0.93	9.84	6.05	5.32
7 × 6	24.63	705	8.200	0.99	9.04	6.42	5.53
7 × 7	36.18	1601	8.880	1.10	10.91	7.19	5.63
S.E	18.16	21.1	0.4824	0.09	0.76	0.20	0.16
L.S.D	5.218	323.1	0.9698	0.19	2.10	0.55	0.43
C.V	10.77	658.2	5.7	9.90	8.54	3.16	3.01

HSWT=Hundred seed weight, GY=grain yield, PDL=pod length, pod diameter, SL=Seed length, SD=Seed diameter, Seed thickness.