Research Square

Preprints are preliminary reports that have not undergone peer review. They should not be considered conclusive, used to inform clinical practice, or referenced by the media as validated information.

Pattern of genetic inheritance of grain yield and grain related traits in *rabi* sorghum *Sorghum bicolor* (L.) Moench

Lokesh Kumar Verma Kumar Verma (vermal@uasd.in)
University of Agricultural Sciences Dharwad https://orcid.org/0000-0002-4741-4644

B. D. Biradar
UAS Dharwad: University of Agricultural Sciences Dharwad

Research Article

Keywords: Sorghum, grain size, grain yield, genetic inheritance, generation mean analysis

Posted Date: April 18th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1563283/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Abstract

Grain related and yield contributing traits greatly influences both grain size and grain yield. In present experiment four crosses *viz*., BJV 44 × DSMR-8, BJV 44 × DSMR-4, PKV Kranti × DSMR-8 and PKV Kranti × DSMR-4 were studied for inheritance pattern during rabi-2020. Both additive and dominance gene actions were found to be predominant for all the traits in the cross BJV 44 × DSMR-8, whereas rest of the crosses exhibited additive gene action for some traits and dominance for other traits. The majority of the crosses exhibited duplicate gene interactions for most of the traits and were found suitable for population improvement program whereas some crosses, showed complementary gene interaction and were found suitable for heterosis breeding. While two crosses *viz*., BJV 44 × DSMR-4 and PKV Kranti × DSMR-4 were found suitable for heterosis breeding for grain yield/plant. It is the first report on inheritance pattern of grain size viz., grain length, width, thickness and other grain related traits such as 100 grain volume and density studied using generation analysis.

Introduction

A C_4 plant with higher photosynthetic efficiency and abiotic stress tolerance (Nagy et al., 1995; Reddy et al., 2009), with center of origin in Africa, sorghum (*Sorghum bicolor* L. Moench) is adapted to a diverse set of environments ranging from arid and semiarid to tropical and temperate regions throughout the world. On world basis, sorghum is the fifth major cereal crop in the extent of production following wheat, rice, maize and barley. In addition to its significance as a food and fodder crop, sorghum plays an important role in supplying micronutrients at low cost (Rao et al., 2006; 2010). As a species, *sorghum bicolor* with 2n = 2x = 20 chromosome number belong to family *Poaceae*, sub family *panicoideae*, tribe *Andropogene* and is classified into five distinct races; bicolor, caudatum, durra, guinea and kafir, and an array of intermediate classes (Harlan and de Wet, 1972). Sorghum is an often cross pollinated crop with 5 to 10 *per cent* cross pollination and may exceed up to 40 per cent out crossing (Barnaud et al., 2008).

World's sorghum production of 57.50 million tones is produced from the area of 40.28 mha with the productivity of 1.43 tons per hectare in 2019-20 (Foreign Agricultural Service/USDA, 2020). India shares about 8 *per cent* of world sorghum production after USA and Nigeria and ranks third in area after Sudan and Nigeria.

In India, sorghum is primarily grown for food and fodder purposes in both rainy and post-rainy seasons. The total production and productivity of sorghum is of 4.63 million tons and around 1 ton per hectare, respectively from an area of 4.66 m ha (Indiastat, 2019–2020).

The grain related traits *viz*., grain length, grain width, grain thickness, 100 grain weight, 100 grain volume, grain density, grains/panicle and days to flowering showed positive and significant correlation with grain yield while path analysis also exhibited positive and significant direct & indirect effect on grain yield (Verma and Biradar, 2021). So, the genetic study is prerequisite for the improvement of these traits.

Knowledge of inheritance of these traits is critical to exploit the large variability identified in sorghum. Generation mean analysis provides information on the relative importance of additive effects, dominance deviations and effects due to non-allelic gene interactions, in determining genotypic values of the individuals and, consequently, means genotypic values of families and generations. Therefore, an attempt was made to

determine the inheritance pattern of grain yield and grain related traits using the generation mean analysis, trait heritability and type of gene action prevailing in *rabi* sorghum.

Material And Methods

Two promising varieties *viz.*, BJV 44 & PKV Kranti and two strong restorers such as DSMR-8 & DSMR-4 (Verma et al., 2022) were crossed to develop four crosses *viz.*, BJV 44 × DSMR-8, BJV 44 x DSMR-4, PKV Kranti × DSMR-8 and PKV Kranti × DSMR-4. Six generations, *i e.*, P_1, P_2, F_1, F_2, B_1 and B_2 were developed during *summer* and *kharif* seasons of 2020. In summer-2020 the F_1's of all the crosses generated and in kharif-2020 the B_1 and B_2 populations were generated by crossing the F_1's with their parents. Simultaneously, The F_1's were advanced to generate F_2 population. Since development of generations involve crossing and backcrossing in four different cross combinations, the seeds were not sufficient to evaluate in multiple seasons/year. Therefore only one season evaluation was carried out in post rainy season-2020. All the six generations were evaluated during post rainy season of 2020 at the Botany Garden, College of Agriculture, University of Agricultural Sciences, Dharwad, state of Karnataka, India. The experimental site is located at an altitude of 750 m above mean sea level, latitude of 15.46^{o}N and longitude of 75.01^{o}E.

To assess the six generations of all the four crosses, a trial was conducted without replications; the population size and characteristics of the parents is given in the Table 1. All the recommended package of practices were followed to raise a healthy crop. Data were recorded on days to flowering, grain yield/plant (g), grains/panicle, grain related traits *viz.*, grain width (mm), grain length (mm), grain thickness (mm), 100 grain weight (g), 100 grain volume (cc), grain density and plant height (cm). The grain size related traits were measured using the varnier caliper while, the volume of the 100 grains were measured based on the water displacement method.

Table 1
Characteristics of parents used and population size of the different generations of different crosses

Cross-1: BJV 44 × DSMR-8			Cross-2: BJV 44 x DSMR-4	
Sl. No	Generation	Population Size	Generation	Population Size
1	P_1 (BJV-44- High grain yield and quality)	20	P_1 (BJV-44- High grain yield and quality)	20
2	P_2 (DSMR-4- Strong restorer and bold seeds)	20	P_2 (DSMR-4- Strong restorer and bold seeds)	20
3	F_1	20	F_1	20
4	F_2	453	F_2	453
5	B_1	158	B_1	158
6	B_2	157	B_2	157
Cross-3: PKV Kranti × DSMR-8			Cross-4: PKV Kranti × DSMR-4	
1	P_1 (PKV Kranti- High grain yield and quality)	20	P_1 (PKV Kranti- High grain yield and quality)	30
2	P_2 (DSMR-8- Strong restorer and bold seeds)	22	P_2 (DSMR-4- Strong restorer and bold seeds)	24
3	F_1	19	F_1	22
4	F_2	455	F_2	453
5	B_1	156	B_1	156
6	B_2	154	B_2	158

Statistical analysis

The data obtained on different characters under study were subjected to generation mean analysis by following Mather (1949), scaling test (Hayman and Mather, 1955) for associated scaling test and (Cavalli, 1952) for joint scaling test and Hayman (1958) approach to find the significant non allelic interaction. The validity of this model for the scaling tests and non allelic interactions was examined using Indostat 9.1 software.

Results

Means and variances

The mean and variances for different traits in different generations are presented in Table 2. The experiment exhibited adequate variance for all the traits in all the crosses.

Adequacy of additive-dominance model

The scaling tests were performed to determine the efficacy of additive dominance model for the inheritance of grain yield and grain related traits. The scaling test values were found significantly differed from zero for all the studied traits in all the crosses except for grain density in PKV Kranti × DSMR-4, indicating the presence of non allelic gene interaction and dominance additive model is inadequate for explaining the inheritance of these traits (Table 3). Whereas, the additive dominant model found to be adequate for the grain density in PKV Kranti × DSMR-4. The joint scaling test also showed significant values and supported the inadequacy of the simple additive dominance model for all the traits in all the crosses except PKV Kranti × DSMR-4 for the grain density. These results are in harmony with earlier reports of Rao *et al*. (1994), Singh *et al*. (2007), Kumar *et al*. (2011), Salmi *et al*. (2019), Koubisy (2019) and Feltaous *et al*. (2020).

Gene effects

The six parameter model was followed to determine the nature and magnitude of gene effects involved in the genetic control of studied traits. The estimated mean effect parameter [m], which reflects the contribution due to the overall mean plus the locus effects and interactions of the fixed loci, was found to be significant for all the traits in all the crosses except for the grain density in PKV Kranti × DSMR-4, indicating that these characters are quantitatively inherited and showed the importance of non-allelic interactions.

The additive [d] gene effect was recorded negative and significant for grain length in BJV 44 x DSMR-4, for grain density in BJV 44 × DSMR-8 and for grain width in BJV 44 × DSMR-4 & PKV Kranti × DSMR-4. While, it was found to be non significant for grain volume in PKV Kranti × DSMR-4, for 100 grain weight in BJV 44 × DSMR-8 and PKV Kranti × DSMR-4, for grain width in PKV Kranti × DSMR-8 and for grain density in BJV 44 x DSMR-4. Rest of the traits of the crosses mentioned above showed significant additive effect. Interestingly, the traits, *viz.,* days to flowering, grain yield/plant, grain thickness, grains/panicle and plant height showed significant additive effects in all the crosses.

The dominance effect [h] was recorded significant for days to flowering, grain yield/plant, 100 grain weight, grain width, grain length, grain thickness, grain volume, grains/panicle and plant height in all the crosses. Whereas, it was non significant for grain width, and grain thickness in PKV Kranti × DSMR-4 and for grain density in PKV Kranti × DSMR-8.

Additive × additiveinteraction [i] was found to be significant in all the crosses for days to flowering, grain yield/plant, grain length, grain thickness, grains/panicle and plant height. Whereas, it was significant for 100 grain weight and volume in all the crosses except PKV Kranti × DSMR-4. The crosses *viz.,* PKV Kranti × DSMR-8 and BJV 44 × DSMR-8 were recorded significant while, rest of the crosses were non significant for grain density. In the crosses *viz.,* BJV 44 × DSMR-8 and BJV 44 × DSMR-4 the additive × additiveinteraction [i] was found to be significant for grain width whereas, it was non significant in rest of the crosses.

In all the crosses except PKV Kranti × DSMR-4 for days to flowering and 100 grain volume, in BJV 44 × DSMR-4 & PKV Kranti × DSMR-8 for 100 grain weight and grain length, in BJV 44 × DSMR-4 & PKV Kranti × DSMR-8 for 100 grain weight & grain length and in BJV 44 × DSMR-8 & BJV 44 × DSMR-4 for grain density and plant height the additive × dominance interaction [j] was found to be significant. Interestingly, it was significant in all the crosses for grain yield/plant and grains/panicle.

The dominance × dominance interaction [l] effect was noticed significant in all the studied crosses for days to flowering, grain yield/plant, 100 grain weight, grain width, grain thickness, 100 grain volume, grains/panicle and plant height. Whereas for grain length, it was significant in all the crosses except PKV Kranti × DSMR-8, while for grain thickness and grain density, it was significant in all the crosses except PKV Kranti × DSMR-4. Dominance × dominance interaction [l] effects were found to be higher than additive × dominance and additive × additiveinteractions for most of the crosses. These results are in harmony with the earlier reports of Vasudev Rao and Goud (1977), Hoshmand and Rezai (1997), Biradar *et al*. (2000), Pahuja (2003), Narain (2007), Singh *et al*. (2007), Prakash *et al*. (2010), Kumar *et al*. (2011), Shivani and Sreelakshmi (2013), Vyas (2014) and Aruna *et al*. (2015) Gaddameedi *et al*. (2018) and Rokade *et al*. (2021).

Types of epistasis

The type of epistasis is determined based on the signs of dominance [h] and dominance × dominance [l] interaction. When these effects are in same direction, the epistasis is complementary type if not it is duplicate type. The different type of epistasis observed in the present study for different characters in the different crosses and details are furnished in Table 4.

Most of the traits of all the crosses were controlled by duplicate type of interactions. Interestingly, all the traits of the cross BJV 44 × DSMR-8 exhibited duplicate type of gene interaction. These results are in agreement with the reports of Singh *et al*. (2007), Narain *et al*. (2007), Shivani and Sreelakshmi (2013), Vyas *et al*. (2014), Gaddameedi *et al*. (2018) and Mohammed *et al*. (2018).

Some traits *viz.,* days to flowering, grain yield/plant, grain/panicle in BJV 44 x DSMR-4, grain length, grain width and plant height in PKV Kranti × DSMR-8 and days to flowering, 100 grain weight, grain width, grain thickness & plant height in PKV Kranti × DSMR-4 exhibited complementary type of epistasis. Earlier workers such as Kumar *et al*. (2011) and Singh *et al*. (2007) reported the similar results.

Components of genetic variation

It can be seen from Table 5 that the additive variance (**σ^2a)** was recorded greater than the dominance variance (**σ^2d)** in all the crosses for days to flowering, grain yield/plant, 100 grain weight, grain width, grain length, grain thickness, grain density, grains/panicle and plant height. Whereas for 100 grain volume all the crosses except PKV Kranti × DSMR-4 exhibited higher additive variance than the dominance variance.

The degree of dominance was recorded lower than unity in all the crosses except BJV 44 × DSMR-8 for days to flowering and grain width. For grain yield/plant it was greater than unity in all the crosses except PKV Kranti × DSMR-8. For 100 grain weight, grain thickness, 100 grain volume and grains/panicle all the crosses except PKV Kranti × DSMR-4 showed degree of dominance greater than unity. All the crosses except BJV 44 × DSMR-4 recorded degree of dominance greater than unity for grain length. For grain density two crosses *viz.,* BJV 44 × DSMR-8 and PKV Kranti × DSMR-8 showed degree of dominance greater than unity whereas for rest of the crosses it was lower than unity. The degree of dominance was found to be lower than unity for all the crosses except PKV Kranti × DSMR-4 for plant height.

Heritability

The traits *viz.,* days to flowering and plant height exhibited moderate broad sense heritability whereas it was high for rest of the traits in BJV 44 × DSMR-8 (Table 5). In BJV 44 × DSMR-4 the traits *viz.,* 100 grain weight, grain thickness and grain density exhibited moderate heritability whereas for grain width it was low. Rest of the traits in the cross showed high heritability. All the traits in PKV Kranti × DSMR-8 showed high heritability while the traits *viz.,* grain thickness and plant height exhibited moderate heritability. Four traits such as grain width, grain length, grain thickness and plant height showed moderate heritability while rest of the traits showed high heritability. On the other hand, the narrow sense heritability was found to be high for all the traits in BJV 44 × DSMR-8 and PKV Kranti × DSMR-8. In BJV 44 x DSMR-4, all the traits expressed high narrow sense heritability except for grain width where it was moderate. In the cross PKV Kranti × DSMR-4 the 100 grain volume showed low heritability whereas rest of the traits showed high heritability.

For all the traits in all the crosses except for 100 grain volume in PKV Kranti × DSMR-4 the narrow sense heritability was in the range of moderate to high whereas it was found to be low for 100 grain volume. These results are in agreement with those reported previously by Abd El-Hamid and Ghareeb (2018) and Koubisy (2019).

Discussion

The information of inheritance pattern, heritability and gene action helps considerably for the improvement of traits and ultimately yield. Hayman's generation mean analysis provides information on the relative importance of additive effect, dominance effect and non-allelic gene interactions, to determining genotypic values of the individuals and consequently, mean genotypic values of families and generations. This experiment showed considerable variance in the different families of different crosses, revealing the existence of genetic diversity in the parental material used for the experiment (Table 2). The present experiment based on the significant values of different scales and joint scale test indicated the presence of gene interaction for all the traits in all the crosses except in PKV Kranti × DSMR-4 for the grain density. The gene effect such as [m] indicated that all the traits in all the crosses are quantitatively inherited and showed the importance of non allelic interactions. The significant [d] additive effects for most of the traits in majority of the crosses indicting the possibility of improvement through selection in early segregating generations. Similarly, significant dominance effect [h] suggesting to postpone the selection for late generations to increase homozygosity. The results indicated that both additive and dominance effects have important contributions in the inheritance of the studied traits, suggesting that selection for desirable traits might be effective in early generations. However, it is better to postpone it to later segregating generations. The significance of additive × dominance [j] and dominance × dominance [l] gene interactions indicates that the traits are greatly affected by additive × dominance, dominance and non allelic interactions. Therefore, it is advisable to delay selection for later segregating generation till the populations attain of homozygosity. The present results suggesting that all type of epistasis *viz*., additive × additive, additive × dominance and dominance × dominance playing role for the expression of all the studied traits.

Based on the results of present study, it is advisable to delay selection for most of the traits in most of the crosses and interestingly for all the traits in the cross BJV 44 × DSMR-8 as these were showing duplicate type of epistasis. This study reveals the presence of duplicate type of epistasis for most of the traits and it would limit the range of variability (Kearsy and Pooni, 1996) and delay in the selection until the attainment of homozygosity

would be better to exploit the transgressive segregants. Whereas, it is advisable to go for heterosis breeding for the traits showing complementary gene interaction (Table 4). It would be rewarding to exploit heterosis in the crosses *viz*., BJV 44 × DSMR-4 and PKV Kranti × DSMR-4 for grain yield/plant. For the traits in the crosses such as for days to flowering in BJV 44 × DSMR-4 & PKV Kranti × DSMR-4, For grain yield in BJV 44 x DSMR-4, for grain width in PKV Kranti × DSMR-8 & PKV Kranti × DSMR-4, for grain length in PKV Kranti × DSMR-8, for grains/panicle in BJV 44 × DSMR-4 and for plant height in PKV Kranti × DSMR-8 the complementary epistasis was in desirable direction and this increases the heterosis in the desirable direction. Thus, heterosis breeding would be worthwhile for these crosses for the concerned traits. While, the crosses exhibiting duplicate gene interaction (Table 4) can not be used directly for heterosis exploitation as this gene action reduces the heterosis. Therefore, for the characters to improve the concerned cross should be subjected to recurrent selection (Comstock et al., 1949) or bi parental matting to accumulate favorable genes followed by selection in the subsequent generations. Liang and Walter, 1968 suggested delaying selection until the genotypes are stabilized in homogenous dominance condition, so that superior dominant allelic combinations can be selected.

The results of the present experiment reveals that all the traits in all the crosses except for 100 grain volume in PKV Kranti × DSMR-4 is under the control of additive gene action (Table 6) and selection in the early generation would be rewarding. Whereas for the 100 grain volume in PKV Kranti × DSMR-4 delayed selection would be good. The traits of the crosses showing degree of dominance less than unity reveals the role of partial dominance gene effects and selection in the later segregating generation would be meaningful. The degree of dominance greater than unity for most of traits in most of the crosses revealing the role of over dominance. These results suggest that the delayed selection to later generation would be rewarding.

Table 6
Identified gene actions for the different traits in different crosses

6. 100 grain volume				
σ^2g	0.10	0.251	0.157	0.132
σ^2a	0.14	0.360	0.275	0.029
σ^2d	-0.03	-0.109	-0.118	0.104
σ^2p	0.14	0.284	0.205	0.157
σ^2b	0.71	0.884	0.769	0.841
σ^2h	0.94	1.267	1.345	0.182
Degree of dominance	2.40	2.208	1.666	-4.283
7. **Grain density**				
σ^2g	0.03	0.011	0.007	0.009
σ^2a	0.06	0.025	0.011	0.014
σ^2d	-0.03	-0.014	-0.004	-0.005
σ^2p	0.04	0.021	0.010	0.010
σ^2b	0.81	0.537	0.702	0.836
σ^2h	1.50	1.176	1.066	1.338
Degree of dominance	1.38	-5.025	1.155	-0.950
8. **Number of grains per panicle**				
σ^2g	8472.09	63738.36	8375.67	7170.84
σ^2a	14081.05	124523.90	14692.34	9052.41
σ^2d	-5608.97	-60785.54	-6316.66	-1881.57
σ^2p	12303.59	100894.52	11970.35	11469.14
σ^2b	0.69	0.63	0.70	0.63
σ^2h	1.14	1.23	1.23	0.79
Degree of dominance	2.58	2.19	-2.22	1.75
10. Plant height				
σ^2g	19.59	44.52	22.27	25.25

6. 100 grain volume				
σ^2a	23.47	55.06	30.69	29.31
σ^2d	-3.89	-10.55	-8.42	-4.06
σ^2p	34.98	73.81	42.53	48.47
σ^2b	0.56	0.60	0.52	0.52
σ^2h	0.67	0.75	0.72	0.61
Degree of dominance	-1.26	-0.70	-0.80	1.10

Traits	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
Days to 50 per cent flowering	A & D	D	D	D
Grain yield per plant	A & D	A & D	D	A & D
100 grain weight	A & D	A & D	A & D	D
Grain width	A & D	D	D	D
Grain length	A & D	D	A & D	A & D
Grain thickness	A & D	A & D	A & D	D
100 Grain volume	A & D	A & D	A & D	D
Grain density	A & D	D	A & D	*
Number of grains per panicle	A & D	A & D	D	A & D
Plant height	D	D	D	D
* Trait showed absence of non allelic interaction.				
Where,				
A- Additive gene action, D- Dominance gene action				
and A&D- both Additive and Dominance gene action.				

The estimates of heritability in the broad sense suggests a high portion of the phenotypic variation and is attribute to genetic variation for all the crosses except for grain width in BJV 44 × DSMR-8 as the broad sense heritability observed between moderate to high. The magnitude of narrow sense heritability shows that the additive effects have a higher role than the dominance effect in controlling all the traits except 100 grain volume. The present study indicates that the selection process will be effective, which result in a higher response but delaying selection would be more rewarding.

Conclusion

The current investigation indicated the significant influence of all the two types of gene actions *viz.*, additive, dominance and interaction components in the expression of almost all the traits. The crosses showing complementary gene interaction can be improved through heterosis breeding while reciprocal and biparental matting strategies can be adopted to accumulate favorable genes in crosses for concerned traits showing duplicate gene interaction. This is a first report on using generation mean analysis to study the inheritance pattern of grain width, grain length, grain thickness, grain volume and grain density in sorghum. The information from the present study could be helpful for further study of the grain yield and grain related traits.

Declarations

Acknowledgements

The author is thankful to Sorghum scheme of Dr. PDKV, Akola, India for providing the promising verity PKV Kranti and Dr. B. D. Biradar for providing the promising variety BJV 44.

Conflict of Interest

The authors have no conflict of interest

References

1. Abd El-Hamid EAM, Ghareeb ZE (2018) Generation mean analysis for estimating some genetic parameters in four bread wheat crosses. In *Proceeding of the Seventh Field Crops Conference, Giza, Egypt*, 18, 17–29
2. Aruna C, Swarnalatha M, Kumar PP, Devender V, Suguna M, Blümmel M, Patil JV (2015) Genetic options for improving fodder yield and quality in forage sorghum. Trop Grasslands-Forrajes Tropicales 3(1):49–58
3. INDIASTAT (2020) Economic Survey. Ministry of Finance, Economic Division, Government of India. Pp. S16-18
4. FAOSTAT (2020) Food and Agricultural Organization of the United Nations,STAT Citation. http://www.faostat.fao.org
5. Barnaud A, Trigueros G, McKey D, Joly HI (2008) High outcrossing rates in fields with mixed sorghum landraces: how are landraces maintained? Heredity 101(5):445–452
6. Biradar BD, Vastrad SM, Balikai RA, Nidagundi JM (2000) Combining ability studies in rabi sorghum. Karnataka J Agricultural Sci 13(3):721–723
7. Cavalli LL (1952) An analysis of linkage in quantitative inheritance. An analysis of linkage in quantitative inheritance. HMSC, London, pp 135–144
8. Comstock RE, Robinson HF, Harvey PH (1949) A breeding procedure designed to make maximum use of both general and specific combining ability. J Agron 41:360–367
9. Feltaous YM, Soliman GMM, El-Rawy MA (2020) Genotyping and phenotyping for some bread wheat genotypes terminal heat stress. Egypt J Plant Breed 24(1):195–223
10. Gaddameedi A, Ravikiran KT, Mohammed R, Phuke RM, Sadaiah K, Kishor PK, Kumar AA (2018) Inheritance studies on grain iron and zinc concentration and agronomic traits in sorghum [*Sorghum bicolor* (L.)

Moench]. J Cereal Sci 83:252–258

11. Harlan JR (1972) deWet JWJ: A simplified classification of sorghum. Crop Sci 12:172–176
12. Hayman BI, Mather K (1955) The description of genic interactions in continuous variation. Biometrics 11(1):69–82
13. Hayman BI (1958) The separation of epistasis from additive and dominance variation in generation mean. Heredity 12:371–390
14. Hoshmand S, Rezai A (1997) Type of gene action and heritability estimates for some agronomic traits in seventeen crosses of grain sorghum [*Sorghum bicolor* (L.) Moench].Iranian Journal of Agricultural Sciences (Iran Islamic Republic)
15. Kumar S, Reddy KHP, Srinivasa Rao P, Sanjana Reddy P, Reddy BV (2011) Study of gene effects for stalk sugar yield and its component traits in sweet sorghum [*Sorghum bicolor* (L.) Moench] using generation mean analysis. J Rangel Sci 1(2):133–142
16. Koubisy YSI (2019) Generation mean analysis of two bread wheat crosses under normal and late sowing date conditions. Egypt J Agric Res 97(2):589–607
17. Kearsey MJ, Pooni HS, Bulmer M (1996) The Genetical Analysis of Quantitative Traits. Genet Res 68(2):183
18. Mather K (1949) Biometrical genetics. Dover publication Inc., New York
19. Mohammed R, Are AK, Munghate RS, Gaddameedi A, Polavarapu Bilhan KK, Sharma HC (2018) Pattern of genetic inheritance of morphological and agronomic traits of sorghum associated with resistance to sorghum shoot fly. Atherigona soccata Euphytica 214(2):1–20
20. Nagy Z, Tuba Z, Zsoldos F, Erdei L (1995) CO2-exchange and water relation responses of sorghum and maize during water and salt stress. J plant physiol 145(4):539–544
21. Narain V, Singh PK, Kumar N, Singh VS (2007) Gene effects for grain yield and related traits in sorghum [*Sorghum bicolor* (L.) Moench]. Indian J Genet Plant Breed 67(1):34–36
22. Rao PP, Basavaraj G, Ahmed W, Bhagavatula S (2010) An analysis of availability and utilization of sorghum grain in India. *SAT eJournal*, *8*
23. Rao PP, Birthal PS, Reddy BV, Rai KN, Ramesh S (2006) Diagnostics of sorghum and pearl millet grains-based nutrition in India. Int sorghum millets Newsl 47:93–96
24. Pahuja SK, Yadav R, Grewal RPS (2003) Genetics of fodder yield and its components in multi-cut x single cut forage sorghum crosses. Forage Res 29(3):139–141
25. Prakash R, Ganesamurthy K, Nirmalakumari A, Nagarajan P (2010) Combining ability for fodder yield and its components in Sorghum (Sorghum bicolor L). Elect J Plant Breed 1(2):124–128
26. Reddy BV, Ramesh S, Reddy PS, Kumar AA (2009) Genetic enhancement for drought tolerance in sorghum. Plant Breed Reviews 31:189
27. RAO MG, Patil SJ, Giriraj K (1994) Generation mean analysis of grain yield and some panicle characters in two exotic x Indian rabi sorghum crosses. Indian J Genet Plant Breed 54(02):158–163
28. Rokade RC, Kusalkar DV, Shinde GC, Shinde MS (2021) Inheritance of drought tolerance in post rainy season sorghum [*Sorghum bicolor* [L.] Moench]. J Pharmaco Phytochem 10(2):1032–1034
29. Salmi M, Benmahammed A, Benderradji L, Fellahi ZEA, Bouzerzour H, Oulmi A, Benbelkacem A (2019) Generation means analysis of physiological and agronomical targeted traits in durum wheat (*Triticum*

durum Desf.) cross. Revista Facultad Nacional de Agronomía Medellín 72(3):8971–8981

30. Singh A, Singh B, Singh R (2017) Genetic analysis of yield and yield component traits in three crosses of Pennisetum typhoides in India. Int J Crop Breed Genet 3(1):72–82
31. Shivani D, Sreelakshmi C (2013) Components of genetic variance and degree of dominance for grain and fodder yields in sorghum (*Sorghum bicolor* L. Moench). Elect J Plant Breed 4(2):1129–1132
32. Rao VMJ, Goud JV (1977) Inheritance of plants height and maturity in sorghum and their components. Mysore J Agricultural Sci 11:269–275
33. Verma LK, Biradar BD, Patil SS, Chattannavar SN, Kubsad VS (2022) Comparative analysis of restoration behavior of *milo* (104A, 401A) and *maldandi* (M31-2A) based male sterile lines in sorghum [*Sorghum bicolor* (L.) Moench].Genet. Resour. Crop Evol.,1–8
34. Verma LK, Biradar BD (2021) Correlation and path analysis for grain yield and yield attributes in rabi sorghum [*Sorghum bicolor* (L.) Moench]. Pharma Innov J 10(10):1211–1214
35. Vyas M, Chaudhary L, Ranwal RB (2014) Generation mean analysis for grain yield and its components in sorghum [*Sorghum bicolor* [L.] Moench] grown under two different environments. Int J Plant Sci 9(2):381–384

Tables

Table 2: Mean and variance of four crosses for different characters under study

Cross	BJV 44 × DSMR-8		BJV 44 × DSMR-4		PKV Kranti × DSMR-8		PKV Kranti × DSMR-4	
Pedigree	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
1. Days to 50 *per cent* flowering								
P_1	70.45	1.88	70.40	1.73	70.10	1.78	70.57	1.63
P_2	67.15	2.03	60.30	1.91	67.45	2.93	60.88	2.03
F_1	67.41	1.87	61.65	1.19	68.79	1.06	62.55	1.12
F_2	67.22	3.48	64.40	7.04	69.55	6.69	66.31	9.05
BC_1	70.18	2.08	66.16	2.75	70.22	1.81	68.21	3.07
BC_2	67.20	2.38	63.66	2.71	65.26	3.15	63.34	3.82
2. Grain yield per plant								
P_1	81.37	10.49	77.15	11.23	91.94	12.87	94.83	10.28
P_2	80.64	11.49	50.70	12.97	81.85	11.23	60.47	11.10
F_1	96.54	11.82	94.20	11.89	124.84	12.82	105.19	10.47
F_2	92.52	42.06	71.18	37.14	118.56	47.20	86.81	36.25
BC_1	116.53	20.07	78.11	12.24	120.02	20.54	103.12	17.23
BC_2	104.74	18.14	69.58	16.52	88.36	18.52	82.11	19.10
3. 100 grain weight								
P_1	3.942	0.106	3.887	0.116	4.440	0.108	4.412	0.112
P_2	3.830	0.112	4.034	0.120	4.073	0.111	4.242	0.110
F_1	3.613	0.037	3.477	0.103	3.721	0.012	3.878	0.005
F_2	3.578	0.348	3.681	0.243	3.946	0.279	4.311	0.197
BC_1	4.072	0.110	4.061	0.118	4.984	0.113	4.325	0.129
BC_2	4.031	0.117	3.894	0.121	4.325	0.118	4.284	0.122
4. Grain width								
P_1	3.843	0.018	3.984	0.019	4.101	0.019	4.182	0.018
P_2	3.980	0.014	4.187	0.024	4.06	0.014	4.298	0.015
F_1	3.723	0.016	4.339	0.015	4.300	0.014	4.304	0.018

F_2	3.862	0.057	4.228	0.026	4.110	0.051	4.199	0.043
BC_1	4.110	0.022	4.216	0.022	4.108	0.025	4.188	0.025
BC_2	4.051	0.021	4.314	0.017	4.117	0.022	4.227	0.021
5. Grain length								
P_1	4.813	0.028	4.836	0.056	4.985	0.030	4.979	0.027
P_2	4.661	0.026	5.035	0.051	4.758	0.027	4.884	0.030
F_1	4.831	0.024	5.052	0.055	5.382	0.019	4.987	0.029
F_2	4.692	0.094	4.887	0.232	4.883	0.087	4.599	0.070
BC_1	5.070	0.035	5.021	0.063	5.069	0.041	4.949	0.034
BC_2	4.832	0.033	5.106	0.057	4.890	0.033	4.885	0.037
6. Grain thickness								
P_1	2.846	0.016	2.808	0.021	3.088	0.016	3.103	0.018
P_2	2.781	0.015	2.863	0.027	2.834	0.018	2.854	0.025
F_1	2.644	0.016	2.803	0.022	2.953	0.016	2.758	0.021
F_2	2.753	0.041	2.758	0.053	2.851	0.031	2.841	0.046
BC_1	2.973	0.019	2.934	0.024	3.14	0.021	2.960	0.022
BC_2	2.812	0.019	2.833	0.030	2.841	0.023	2.793	0.029

Contd….

Cross	BJV 44 × DSMR-8		BJV 44 × DSMR-4		PKV Kranti × DSMR-8		PKV Kranti × DSMR-4	
Pedigree	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
7. 100 Grain volume								
P_1	3.215	0.048	3.043	0.042	3.720	0.059	4.402	0.056
P_2	3.112	0.043	3.404	0.036	3.448	0.045	4.242	0.039
F_1	2.982	0.038	3.078	0.027	3.561	0.043	3.253	0.003
F_2	2.962	0.144	3.108	0.284	3.429	0.205	3.608	0.157
BC_1	3.634	0.084	3.415	0.108	3.994	0.070	3.608	0.101
BC_2	3.311	0.070	3.258	0.100	3.525	0.064	3.543	0.185
8. Grain density								
P_1	1.2106	0.0029	1.2377	0.0081	1.1937	0.0033	1.1984	0.0012
P_2	1.2241	0.0025	1.8549	0.0179	1.1876	0.0032	1.2073	0.0018
F_1	1.1928	0.0116	1.1302	0.0067	1.0448	0.0029	1.1890	0.0019
F_2	1.2123	0.0380	1.2059	0.0213	1.1937	0.0103	1.1981	0.0105
BC_1	1.1224	0.0094	1.2134	0.0109	1.2466	0.0052	1.1987	0.0037
BC_2	1.2212	0.0096	1.1968	0.0067	1.2268	0.0044	1.2092	0.0033
9. Number of grains per panicle								
P_1	2075.20	4528.14	2002.43	45899.13	2082.55	4374.91	2163.48	4354.68
P_2	2119.09	4118.54	1264.55	17311.53	2016.90	3941.52	1481.63	4510.71
F_1	2683.28	3339.66	2731.26	42706.99	3356.93	3031.14	2713.51	4163.90
F_2	2467.63	12303.58	1968.45	100894.50	3058.92	11970.35	2035.32	11469.14
BC_1	2891.16	5602.36	1959.02	36390.93	2439.54	4894.45	2398.59	6605.38
BC_2	2627.30	4923.76	1802.79	40874.21	2041.13	4353.92	1936.55	7280.49
10. plant height								
P_1	281.06	16.57	284.56	32.26	298.40	21.43	299.47	24.39
P_2	241.81	17.81	235.70	39.35	251.23	19.66	235.61	31.15
F_1	250.20	13.60	268.91	22.78	253.46	19.98	276.29	18.66

F_2	270.38	34.98	262.27	73.81	270.44	42.53	253.41	48.47
BC_1	276.55	23.17	267.74	43.37	291.59	28.71	277.76	29.64
BC_2	244.16	23.32	247.35	49.18	245.25	25.66	244.76	37.99

Table 3: Scaling test and gene effects for grain yield and grain related traits

Cross	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
1. **Days to 50 *per cent* flowering**				
Scaling test				
A	2.51**±0.48	0.28±0.46	1.55*±0.44	3.30**±0.43
B	-0.16±0.50	5.36**±0.47	-5.73**±0.52	3.26**±0.48
C	-3.55**±0.81	3.58**±0.82	3.07**±0.83	8.72**±0.81
D	-2.95**±0.25	-1.03**±0.31	3.63**±0.30	1.08**±0.35
Joint Scaling test	237.31**	171.29**	136.42**	270.88**
Genetic parameters				
m	67.28**±0.09	64.40**±0.13	69.55**±0.12	66.31**±0.14
d	2.99**±0.17	2.51**±0.19	4.96**±0.18	4.86**±0.21
h	4.50**±0.61	-1.64*±0.70	-7.24**±0.69	-5.34**±0.76
i	5.89**±0.49	2.06**±0.62	-7.25**±0.60	-2.16**±0.70
j	2.67**±0.55	-5.08**±0.57	7.27**±0.59	0.04±0.56
l	-8.23**±1.06	-7.70**±1.11	11.43**±1.09	-4.40**±1.17
2. Grain yield per plant (g)				
Scaling test				
A	55.15**±1.24	-15.14**±1.21	23.28**±1.36	6.22**±1.12
B	32.30**±1.26	-5.73**±1.29	-29.97**±1.29	-1.45±1.19
C	14.99**±2.17	-31.51**±2.21	50.78**±2.35	-18.43**±2.00
D	-36.24**±0.79	-5.32**±0.72	28.74**±0.82	-11.60**±0.74
Joint Scaling test	3240.99**	255.16**	2626.16**	287.83**
Genetic parameters				
m	92.52**±0.31	71.19**±0.29	118.56**±0.32	86.81**±0.28
d	11.79**±0.50	8.52**±0.43	31.66**±0.50	21.01**±0.48
h	88.01**±1.82	40.92**±1.71	-19.53**±1.91	50.75**±1.70
i	72.47**±1.58	10.64**±1.43	-57.48**±1.63	23.21**±1.49
j	22.85**±1.43	-9.41**±1.39	53.24**±1.47	7.66**±1.32
l	-159.93**±2.95	10.22**±2.80	64.17**±3.09	-27.98**±2.77

3. 100 grain weight (g)				
Scaling test				
A	0.589**±0.097	0.758**±0.118	1.807**±0.094	0.359**±0.085
B	0.620**±0.102	0.276*±0.119	0.857**±0.093	0.449**±0.089
C	-0.686**±0.172	-0.151±0.202	-0.169±0.151	0.836**±0.127
D	-0.947**±0.068	-0.592**±0.061	-1.417**±0.063	0.014±0.058
Joint Scaling test	214.96**	117.75**	717.07**	56.14**
Genetic parameters				
m	3.578**±0.028	3.681**±0.023	3.946**±0.025	4.311**±0.021
d	0.041±0.039	0.167**±0.039	0.659**±0.039	0.040±0.040
h	1.621**±0.150	0.701**±0.151	2.297**±0.138	-0.476**±0.125
i	1.894**±0.135	1.185**±0.121	2.833**±0.126	-0.027±0.115
j	-0.03±0.13	0.48**±0.13	0.95**±0.13	-0.09±0.12
l	-3.103**±0.231	-2.219**±0.255	-5.498**±0.216	-0.781**±0.204

Contd….

Cross	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
4. Grain width (mm)				
Scaling test				
A	0.654**±0.046	0.110*±0.048	-0.184**±0.048	-0.111*±0.045
B	0.398**±0.045	0.102*±0.049	-0.128**±0.044	-0.147**±0.045
C	0.180*±0.080	0.063±0.078	-0.326**±0.079	-0.292**±0.078
D	-0.436**±0.028	-0.074**±0.022	-0.007±0.027	-0.017±0.026
Joint Scaling test	367.25**	14.67**	20.11**	15.34**
Genetic parameters				
m	3.862**±0.011	4.228**±0.008	4.109**±0.011	4.199**±0.010
d	0.060**±0.017	-0.098**±0.016	-0.009±0.017	-0.040*±0.017
h	0.683**±0.065	0.402**±0.057	0.231**±0.064	0.098±0.062
i	0.872**±0.056	0.148**±0.044	0.013±0.055	0.034±0.052
j	0.26**±0.05	0.01±0.06	-0.05±0.05	0.04±0.05
l	-1.925**±0.105	-0.360**±0.100	0.299**±0.105	0.224*±0.104
5. Grain length (mm)				
Scaling test				
A	0.497**±0.057	0.154*±0.085	-0.229**±0.059	-0.067±0.055
B	0.173**±0.057	0.127±0.082	-0.360**±0.055	-0.101*±0.059
C	-0.369**±0.101	-0.424**±0.157	-0.974**±0.098	-1.440**±0.099
D	-0.519**±0.036	-0.352**±0.053	-0.193**±0.035	-0.636**±0.033
Joint Scaling test	243.09**	44.63**	104.72**	440.79**
Genetic parameters				
m	4.692**±0.014	4.887**±0.023	4.883**±0.014	4.599**±0.012
d	0.238**±0.021	-0.086**±0.028	0.179**±0.022	0.064**±0.021
h	1.132**±0.083	0.821**±0.124	0.895**±0.081	1.328**±0.078
i	1.038**±0.072	0.704**±0.106	0.385**±0.070	1.272**±0.065
j	0.32**±0.07	0.027±0.09	0.14*±0.07	0.03±0.06
l	-1.707**±0.132	-0.985**±0.192	0.203±0.132	-1.103**±0.131

6. Grain thickness				
Scaling test				
A	0.457**±0.044	0.259**±0.052	0.239**±0.046	0.058±0.046
B	0.199**±0.044	0.001±0.057	-0.105*±0.047	-0.026±0.053
C	0.098±0.076	-0.243*±0.094	-0.425**±0.078	-0.107±0.084
D	-0.279**±0.025	-0.251**±0.028	-0.280**±0.024	-0.070*±0.027
Joint Scaling test	190.87**	100.38**	192.69**	9.67*
Genetic parameters				
m	2.753**±0.010	2.758**±0.011	2.851**±0.008	2.841**±0.010
d	0.161**±0.016	0.101**±0.018	0.299**±0.017	0.167**±0.018
h	0.389**±0.060	0.470**±0.070	0.551**±0.059	-0.081±0.065
i	0.558**±0.050	0.503**±0.057	0.559**±0.047	0.140*±0.054
j	0.26**±0.05	0.26**±0.06	0.34**±0.05	0.08±0.05
l	-1.214**±0.099	-0.762**±0.119	-0.693**±0.103	-0.172±0.111

Contd….

Cross	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
7. 100 grain volume				
Scaling test				
A	1.072**±0.078	0.710**±0.079	0.706**±0.083	-0.438**±0.068
B	0.529**±0.076	0.034±0.075	0.042±0.077	-0.409**±0.080
C	-0.441**±0.128	-0.169±0.139	-0.575**±0.146	-0.719**±0.098
D	-1.021**±0.048	-0.456**±0.062	-0.661**±0.052	0.064±0.057
Joint Scaling test	515.50**	117.39**	218.06**	90.65**
Genetic parameters				
m	2.962**±0.018	3.108**±0.025	3.429**±0.021	3.608**±0.019
d	0.323**±0.032	0.157**±0.036	0.468**±0.029	0.065±0.043
h	1.861**±0.109	0.766**±0.133	1.299**±0.119	-1.197**±0.118
i	2.043**±0.096	0.912**±0.124	1.322**±0.103	-0.128±0.113
j	0.54**±0.09	0.68**±0.01	0.66**±0.09	-0.03±0.10
l	-3.644**±0.180	-1.655**±0.201	-2.070**±0.187	0.975**±0.197
8. Grain density				
Scaling test				
A	-0.159**±0.030	0.059*±0.032	0.255**±0.021	0.010±0.015
B	0.026±0.030	-0.591**±0.037	0.221**±0.020	0.022±0.016
C	0.029±0.061	-0.530**±0.058	0.304**±0.036	0.009±0.029
D	0.081**±0.022	0.001±0.017	-0.086**±0.012	-0.012±0.012
Joint Scaling test	62.12**	292.94**	207.02**	6.15^{NS}
Genetic parameters				
m	1.212**±0.009	1.206**±0.007	1.194**±0.005	
d	-0.099**±0.011	0.017±0.011	0.020*±0.008	
h	-0.187**±0.049	-0.419**±0.043	0.026±0.029	
i	-0.162**±0.043	-0.003±0.035	0.172**±0.025	
j	-0.18**±0.03	0.65**±0.04	0.03±0.02	
l	0.295**±0.076	0.536**±0.072	-0.648**±0.048	

9. Number of grains per panicle				
Scaling test				
A	1023.84**±22.47	-815.65**±73.16	-560.40**±22.45	-79.82**±22.45
B	452.24**±22.08	-390.23**±63.58	-1291.58**±21.26	-322.04**±23.70
C	309.68**±38.15	-855.67**±123.55	1422.39**±38.17	-930.88**±38.67
D	-583.20**±13.36	175.10**±37.17	1637.19**±12.84	-264.51**±13.77
Joint Scaling test	3200.74**	132.99**	17689.97**	772.81**
Genetic parameters				
m	2467.63**±5.22	1968.45**±14.92	3058.92**±5.129	2035.32**±5.03
d	263.86**±8.32	156.23**22.15	398.41**±7.72	462.04**±9.40
h	1752.53**±31.12	747.56**±91.93	-1967.17**±30.31	1419.97**±32.11
i	1166.40**±26.71	-350.21**±74.34	-3274.37**±25.68	529.02**±27.55
j	571.60**±26.24	-425.41**±71.58	731.17**±25.23	242.22**±26.20
l	-2642.47**±50.63	1556.09**±152.04	5126.35**±49.11	-127.15*±53.94

Contd….

Cross	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
10. Plant height				
Scaling test				
A	21.84**±1.41	-17.99**±1.96	31.31**±1.69	-20.25**±1.56
B	-3.70*±1.46	-9.92**±2.09	-14.20**±162	-22.38**±1.76
C	58.25**±2.32	-9.00**±3.28	25.21**±2.77	-74.04**±2.69
D	20.06**±0.79	9.45**±1.11	4.05**±0.85	-15.71**±0.93
Joint Scaling test	1205.93**	125.73**	690.91**	823.51**
Genetic parameters				
m	270.38**±0.28	262.27**±0.40	270.44**±0.31	253.41**±0.33
d	32.39**±0.55	20.39**±0.77	46.34**±0.59	33.00**±0.66
h	-51.35**±1.87	-10.12**±2.64	-29.45**±2.11	40.17**±2.19
i	-40.11**±1.57	-18.90**±2.23	-8.10**±1.70	31.41**±1.85
j	25.54**±1.69	-8.07**±2.43	45.51±1.84	2.13±1.96
l	21.98**±3.20	46.80**±4.49	-9.02*±3.64	11.22**±3.76

Table 4. Identified different gene interaction for the traits under study in four different crosses

Sl. No.	Crosses / Characters	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
1.	Days to 50 % flowering	Duplicate	Complementary	Duplicate	Complementary
2.	Grain yield / plant (g)	Duplicate	Complementary	Duplicate	Duplicate
3.	100 grain weight (g)	Duplicate	Duplicate	Duplicate	Complementary
4.	Grains/ panicle	Duplicate	Complementary	Duplicate	Duplicate
5.	100 grains volume (cc)	Duplicate	Duplicate	Duplicate	Duplicate
6.	Grain density	Duplicate	Duplicate	Duplicate	**No interaction**
7.	Grain length (mm)	Duplicate	Duplicate	Complementary	Duplicate
8.	Grain width (mm)	Duplicate	Duplicate	Complementary	Complementary
9.	Grain thickness (mm)	Duplicate	Duplicate	Duplicate	Complementary
10.	Plant height (cm)	Duplicate	Duplicate	Complementary	complementary

Table 5. Estimates of various genetic parameters for the traits under study

Cross	BJV 44 × DSMR-8	BJV 44 × DSMR-4	PKV Kranti × DSMR-8	PKV Kranti × DSMR-4
1. **Days to 50 *per cent* flowering**				
$\sigma^2 g$	1.56	5.54	4.98	7.58
$\sigma^2 a$	2.49	8.61	8.43	11.22
$\sigma^2 d$	-0.92	-3.07	-3.44	-3.64
$\sigma^2 p$	3.48	7.04	6.69	9.05
$\sigma^2 b$	0.45	0.79	0.75	0.84
$\sigma^2 h$	0.72	1.22	1.23	1.24
Degree of dominance	1.23	-0.81	-1.21	-1.05
2. Grain yield per plant (g)				
$\sigma^2 g$	30.65	25.14	34.77	25.67
$\sigma^2 a$	45.91	45.52	55.34	36.18
$\sigma^2 d$	-15.25	-20.38	-20.57	-10.51
$\sigma^2 p$	42.06	37.14	47.20	36.25
$\sigma^2 b$	0.73	0.68	0.74	0.71
$\sigma^2 h$	1.09	1.23	1.17	1.00
Degree of dominance	2.73	2.19	-0.79	1.55
1. **100 grain weight (g)**				
$\sigma^2 g$	0.28	0.13	0.22	0.139
$\sigma^2 a$	0.47	0.25	0.33	0.143
$\sigma^2 d$	-0.19	-0.11	-0.11	-0.004
$\sigma^2 p$	0.35	0.24	0.28	0.197
$\sigma^2 b$	0.79	0.55	0.78	0.705
$\sigma^2 h$	1.35	1.02	1.17	0.727
Degree of dominance	6.32	2.05	1.87	-3.436

1. **Grain width (mm)**				
$\sigma^2 g$	0.04	0.007	0.036	0.026
$\sigma^2 a$	0.07	0.011	0.055	0.040
$\sigma^2 d$	-0.03	-0.004	-0.019	-0.015
$\sigma^2 p$	0.06	0.026	0.051	0.043
$\sigma^2 b$	0.72	0.285	0.710	0.595
$\sigma^2 h$	1.24	0.449	1.082	0.938
Degree of dominance	3.39	-0.029	-5.059	-1.572
1. **Grain length (mm)**				
$\sigma^2 g$	0.07	0.178	0.063	0.041
$\sigma^2 a$	0.12	0.344	0.099	0.068
$\sigma^2 d$	-0.05	-0.166	-0.036	-0.027
$\sigma^2 p$	0.09	0.232	0.087	0.070
$\sigma^2 b$	0.73	0.766	0.729	0.588
$\sigma^2 h$	1.27	1.483	1.144	0.980
Degree of dominance	2.18	-3.091	2.236	4.544
1. **Grain thickness**				
$\sigma^2 g$	0.03	0.030	0.015	0.024
$\sigma^2 a$	0.04	0.053	0.019	0.040
$\sigma^2 d$	-0.01	-0.023	-0.004	-0.016
$\sigma^2 p$	0.04	0.053	0.031	0.046
$\sigma^2 b$	0.62	0.565	0.471	0.534
$\sigma^2 h$	1.07	0.999	0.601	0.877
Degree of dominance	1.55	2.152	1.356	-0.696

Contd….

1. **100 grain volume**				
σ^2g	0.10	0.251	0.157	0.132
σ^2a	0.14	0.360	0.275	0.029
σ^2d	-0.03	-0.109	-0.118	0.104
σ^2p	0.14	0.284	0.205	0.157
σ^2b	0.71	0.884	0.769	0.841
σ^2h	0.94	1.267	1.345	0.182
Degree of dominance	2.40	2.208	1.666	-4.283
1. **Grain density**				
σ^2g	0.03	0.011	0.007	0.009
σ^2a	0.06	0.025	0.011	0.014
σ^2d	-0.03	-0.014	-0.004	-0.005
σ^2p	0.04	0.021	0.010	0.010
σ^2b	0.81	0.537	0.702	0.836
σ^2h	1.50	1.176	1.066	1.338
Degree of dominance	1.38	-5.025	1.155	-0.950
1. **Number of grains per panicle**				
σ^2g	8472.09	63738.36	8375.67	7170.84
σ^2a	14081.05	124523.90	14692.34	9052.41
σ^2d	-5608.97	-60785.54	-6316.66	-1881.57
σ^2p	12303.59	100894.52	11970.35	11469.14
σ^2b	0.69	0.63	0.70	0.63
σ^2h	1.14	1.23	1.23	0.79
Degree of dominance	2.58	2.19	-2.22	1.75
10. Plant height				
σ^2g	19.59	44.52	22.27	25.25
	23.47	55.06	30.69	29.31

σ^2a				
σ^2d	-3.89	-10.55	-8.42	-4.06
σ^2p	34.98	73.81	42.53	48.47
σ^2b	0.56	0.60	0.52	0.52
σ^2h	0.67	0.75	0.72	0.61
Degree of dominance	-1.26	-0.70	-0.80	1.10