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ESTIMATES OF GENETIC PARAMETERS FOR QUALITY OF WHEAT CULTIVARS GROWN IN LESOTHO

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ABSTRACT

Lesotho has embarked on wheat (*Triticum aestivum*) improvement programmes that increase productivity and quality. Among these is selection of superior genotypes. A study was conducted to estimate genetic variance, heritability, dominance, correlation and prediction ratio for wheat quality characteristics of five parents, F_1 and F_2 progeny. The characteristics were break flour yield, flour protein content, mixograph development time, Sodium Dodycel Sulphate sedimentation volume, kernel weight, kernel diameter and kernel hardness. General specific combining ability ratio in F_1 progeny showed non-additive gene action in all characteristics except one. In F_2 progeny, break flour yield, flour protein content, kernel hardness and mixograph development time were controlled by non-additive gene action. Sodium Dodycel Sulphate sedimentation volume, kernel weight and kernel diameter were controlled by additive gene action. Heritability in the broad sense was high for all characteristics in F_1 and F_2 progeny, whereas heritability in the narrow sense was high for F_2 and low for F_1 progeny. Positive and negative correlations were observed among characteristics in F_1 and F_2 progeny. In F_1 progeny, kernel hardness demonstrated highest prediction ratio. In F_2 progeny, seed diameter, seed weight, Sodium Dodecyl Sulphate sedimentation volume and break flour yield revealed high prediction ratio. Genetic variability exists and can be for improvement of wheat quality in Lesotho.

Key Words: Genetic variance, heritability, *Triticum aestivum*

RÉSUMÉ

Le Lesotho a embarqué sur des programmes d'améliorations du blé (*Triticum aestivum*), entre autre la sélection des génotypes à traits supérieurs, afin d'accroître la productivité et la qualié du blé. Une étude était conduite pour estimer la variance génétique, l'héritabilité, la dominance, la correlation et le taux de prédiction des caractéristiques de qualité de cinq parents, les progénies F_1 et F_2. Les dites caractéristiques étaient le rendement en farine, le contenu proténique de la farine, le temps de développement du mixographe, le volume de sédimentation du sulfate de sodium Dodycel, le poids de grains, le diamètre et la dureté des grains. Le rapport de la capacité de combinaison générale de la progénie F_1 a montré une action de gène non additif dans toutes les caractéristiques exceptée une seule. Dans la progénie F_2, le rendement en farine, le contenu protéinique de la farine, la dureté des grains et le temps de développement du mixographe étaient contrôlés par une action de gène non additif. Par contre, le volume de sédimentation du sulfate de sodium Dodecyl, le poids et le diamètre de grains étaient contrôlés par un gène additif. L'héritabilité au sens large était élevé pour toutes les caractéristiques dans les progénies F_1et F_2. Des correlations positives and négatives étaient observées parmi les caracteristiques dans les progénies F_1 et F_2. Dans F_1, la dureté de grains a démontré un rapport de prédiction plus élevé. Dans F_2, le diamètre de grains, le poids de grains, le volume de sédimentation du Sulfate de Sodium Dodecyl et le rendement en grains ont révélé un niveau du rapport de prédiction élevé. La variabilité génétique existe et peut servir dans l'amélioration de la qualité du blé au Lesotho.

Mots Clés: Variance génétique, héritabilité, *Triticum aestivum*

INTRODUCTION

The characteristics of economic importance in wheat (*Triticum aestivum*) which are of great concern to the wheat breeders express continuous variation. These characters are conferred by many genes, each having a small effect on the trait (Simmonds, 1991). The cumulative effect of these genes, combined with environmental effects, results in continuous variation in the phenotypic values of individual wheat cultivars (Falconer and Mackay, 1996). Where the variation is attributable to environment, selection of phenotypically superior individual plants does not show alteration in the next generation (Mangi *et al*., 2007; Dvojkovic *et al*., 2010). It is, therefore, necessary when drawing breeding plans to know the relative importance and magnitude of the genetic and environmental variation of the characters. Only phenotypic values of the trait can be directly measured; while the breeding value determines their influence on the next generation (Wricke and Weber, 1986).

Thus, if a wheat breeder selects individuals to be the parents of the next generation based on their phenotypic values, success in improving the characters of the population can be predicted only from knowledge of degree of correlation between phenotypic values and breeding values; hence, prediction ratio is employed (Baker *et al*., 1971).

Prediction ratio enables the plant breeder to determine the transmitting ability of a wheat cultivar for the desired economic trait (Memon *et al*., 2007). It is of utmost importance to consider other characters besides the one that is being improved as most characters are correlated (Budak and Yildirum, 2002). As one trait is improved, the others may be affected negatively or positively due to pleiotropic effects of genes governing them. Genetic correlation is, therefore, important. The three genetic parameters explained above, namely heritability, prediction ratio and genetic correlation are of great significance in wheat breeding. These genetic parameters have not been estimated for wheat cultivars grown in Lesotho; which could assist breeders in choosing the mating systems and estimating genetic progression with high degree of accuracy.

The objective of this study was to estimate genetic variance, heritability, degree of dominance, prediction ratio and correlation from parents, F_1 and F_2 progeny.

MATERIALS AND METHODS

Experimental site. The study was conducted in Bloemfontein which is situated in the middle of the Republic of South Africa. It lies at an altitude of 1351m above sea level and at 29^0 06' South and $26^0$18'East. Average rainfall is 700 mm, most of which falls between October and April. Temperature in summer rise to the maximum of 31 ^{0}C, while winter temperature may reach as low as -4^{0}C.

The type of soil found in this area is red to yellow coloured sand with 10% montmorillonite clay. It exhibits little or no structure and is deemed freely draining. Soil depth is variable ranging from 600mm to 1200 and then 400 to 900 mm. It exhibits moderately low to low permeability.

Experimental procedure. Five wheat cultivars of breadmaking quality were used for the experiment (Table 1). Nata and Sceptre possessed poor quality, Wanda had medium; while SST124 and Kariega exhibited good quality. These cultivars were crossed in all possible combinations to produce F_1 progeny. The parents, together with their F_1 progeny, were grown in Bloemfontein.

The experiment was arranged in randomised complete block design with three replications. Each plot dimensions were 2 m x 1.8 m, with spacing between and within the rows being 45 cm and 10 cm, respectively.

The seed-bed was prepared using mould-board plough, after which it was harrowed to a fine tilth to facilitate germination. Seed was planted by hand at 25 kg ha^{-1}. Fertiliser was broadcast on the plots at the rate of 40 kg ha^{-1} nitrogen, 15 kg ha $^{-1}$ phosphorus and 12 kg ha^{-1} potassium. Weeding was done by handhoes. Seed from this experiment was harvested and grown to produce F_2 generation.

Seeds from F_1 generation were planted in the same manner as the previous generation in terms of agronomic practices and dimensions. At physiological maturity, seeds were harvested as

TABLE 1. Characteristics of wheat cultivars selected as parents for diallel cross

Parents	Quality characteristics				
	SDS (ml)	BLY (%)	FPC (%)	MDT (mins)	Rank
Kariega	92	57.3	14.9	4.5	Good
SST 124	74	59.2	15.5	2.5	Good
Wanda	90	58.9	10.5	3.1	Medium
Nata	47	54.5	7.7	2.3	Poor
Sceptre	51	56.3	7.8	3.5	Poor

SDS = sds-sedimentation volume, BLY = break flour yield, FPC = flour protein content, MDT = mixogram development time

F_2 generation, after which they were cleaned for quality analysis. The harvested F_1 and F_2 material with the parents were sent to the ARC-Small Grain Institute in Bethlehem, South Africa, for quality analysis.

Laboratory analysis. Break flour yield was determined by milling wheat samples with a laboratory pneumatic mill, Bühler model MLU-202 (Bühler Bros., Inc., Uzwil, Switzerland). The AACC 26-21A method for milling hard wheat was followed (AACC, 2000). Protein content was quantified using a combustion method as described by the AACC 46-30 method (AACC, 2000). Hardness index, kernel diameter and kernel mass were measured using the AACC 55-31 method (AACC, 2000) with the SKCS model 4100 instrument. AACC 56-70 method was adopted to determine Sodium dodycel Sulphate sedimentation values. Mixing development time was estimated on a 35 g mixograph following AACC 54-40A method (AACC, 2000).

Analysis of variance, correlation and prediction ratio were performed using Agrobase (1999).

RESULTS

Genetic and phenotypic variance. Table 2 summarises estimates of all the genetic parameters. The results showed a high genetic variation for all characters studied, with exception of flour protein content and seed diameter in both F_1 and F_2. In addition, F_2 showed lower genetic variation in mixogram development time. Genetic variation is the sum of both additive and dominance. Phenotypic variation was high for seed hardness and Sodium Dodycel Sulphate sedimentation volume in both F_1 and F_2 progeny. The values of seed hardness were 350.33 and 303.42 for F_1 and F_2, respectively. Sodium Dodycel Sulphate sedimentation volume had the highest value of 233.96 and 154.10 in F_1 and F_2. Similarly, seed diameter in both F_1 and F_2 were low with values of 0.12 and 0.09.

The relative proportion of additive variance (δa) estimates to that of dominance (δ_d) greatly varied across the characteristics studied in F_1 progeny. The characteristic with the highest δ_a value was seed hardness, followed by Sodium dodycel Sulphate sedimentation volume, break flour yield and seed weight (Table 2). Mixograph development time, seed diameter and flour protein content had the least values.

The values for δ_d were high in Sodium Dodecyl Sulphate sedimentation volume, followed by seed hardness, seed weight, break flour yield and flour protein content. The characteristics with least values of δ_d were mixograph development time and seed weight. Three characteristics had high δ_a estimates; while δ_d was observed in four characteristics. The proportions of δ_a to δ_d were relatively high for break flour yield, flour protein content, SDS sedimentation, seed weight and seed diameter in F_2 progeny (Table 2). Seed hardness obtained the highest δ_a value, followed by SDDS sedimentation, seed and break flour yield. Flour protein content and seed diameter had a very low δ_a. However, mixograph development time and seed hardness had relatively higher δ_d than δ_a.

Heritability. Heritabilities of seven characteristics under study were partitioned into

TABLE 2. Estimates of genetic parameters for the wheat quality characteristics

Character		$\delta a=2\delta^2 gca$	$\delta_d=\delta^2 sca$	$\delta_g=\delta_a+\delta_d$	δ_e	$\delta p=\delta g+\delta e$	h^2_b	h^2_n	PR	$\sqrt{H/D}$
F_1	BFLY	14.48	10.83	25.32	1.34	26.66	0.95	0.54	0.57	1.22
	FPC	0.22	0.99	1.21	0.09	1.31	0.93	0.17	0.19	2.96
	MDT	0.02	0.22	0.24	0.06	0.30	0.81	0.07	0.09	4.48
	SDS	122.54	107.83	230.37	3.60	233.96	0.99	0.52	0.53	1.33
	SKCSW	10.93	22.40	33.36	3.70	37.05	0.90	0.30	0.33	2.02
	SKCSD	0.04	0.07	0.11	0.01	0.12	0.89	0.31	0.35	1.93
	SKCSH	274.41	69.03	343.44	6.89	350.33	0.98	0.78	0.80	0.71
F_2	BFLY	9.01	4.91	13.91	0.87	14.79	0.94	0.61	0.65	1.04
	FPC	0.52	0.29	1.05	0.04	1.09	0.96	0.48	0.50	1.05
	MDT	0.23	0.54	0.77	0.09	0.85	0.90	0.27	0.30	2.18
	SDS	111.88	36.54	148.42	5.68	154.10	0.96	0.73	0.75	0.81
	SKCSW	23.16	7.27	30.43	1.14	31.57	0.76	0.73	0.76	0.79
	SKCSD	0.07	0.02	0.08	0.01	0.09	0.96	0.77	0.81	0.69
	SKCSH	138.31	151.83	290.13	13.28	303.42	0.96	0.46	0.48	1.48

Fly = break flour yield, fpc = flour protein content, mdt = mixogram development time, sds = sds-sedimentation volume, skcsw = kernel weight, sckcsd = kernel diameter, scksh = kernel hardness

heritability in the narrow sense (h_n^2) and heritability in the broad sense (h_b^2) (Table 2). All characteristics showed very high h_b^2; ranging from 0.81 to 0.99 in F_1 progeny. This showed that the combinations of genes in this particular generation were favourable for the characteristics obtained under the present study. SDS sedimentation had the highest h_b^2, followed by seed hardness, break flour yield, flour protein content, seed weight, seed diameter, then mixograph development time. A wide range from 0.07 to 0.78 was obtained in h_n^2 across the characteristics in F_1 progeny. Seed hardness had the highest value; followed by break flour yield, SDS sedimentation, seed diameter, seed weight, flour protein content and mixograph development time (Table2).

In F_2 progeny, h_b^2 ranged from 0.76 to 0.96 with characteristics having high values being seed hardness, seed diameter, SDS sedimentation and flour protein content. Break flour yield followed, then mixograph development time and seed weight. The h_n^2 ranged from 0.27 to 0.77 with the highest value obtained from seed diameter, followed by seed weight and SDS - sedimentation, break flour yield, flour protein content, seed hardness and mixograph development time (Table 2).

The h_b^2 in F_1 and F_2 were higher than h_n^2 in both progeny (Table 2). The range between these two progeny was not much different. However, h_n^2 in F_1 progeny in some characteristics were very low compared to h_n^2 in F_2 progeny. Both of them obtained the same high value.

Prediction ratio. In F_1 progeny, seed hardness was the only characteristic of that demonstrated a high prediction ratio closer to unity. Two of the seven characteristics showed moderate prediction ratios, while others showed a low to very low prediction ratio. In F_2 progeny, seed diameter, seed weight, Sodium Dodecyl Sulphate sedimentation volume and break flour yield exhibited a high prediction ratio; while for flour protein content was moderate. Low prediction ratio was observed in mixograph development time and seed hardness. The characteristics with high h_b^2 and h_n^2 showed a high prediction ratio as well, while those with low h_b^2 and h_{n2} revealed a low prediction ratio. The high prediction ratio, which was closer to unity, showed the relative importance of general and specific combining ability in determining progeny performance (Table 2).

Degree of dominance. In F_1 progeny, all the characteristics, except one; indicated over-dominance (Table 2). Mixograph development time had the highest value above unity, followed by flour protein content, seed weight, seed diameter, Sodium Dodecyl Sulphate sedimentation and break flour yield. Seed hardness exhibited partial dominance (value below unity). F_2 progeny demonstrated varying degree of dominance with break flour yield and flour protein content exhibiting complete dominance. Mixograph development time and seed hardness expressed over-dominance, while Sodium Dodecyl Sulphate sedimentation volume, seed weight and seed diameter had partial dominance (Table 2). The characteristics cut across all degrees of dominance.

Correlation. Table 3 depicts correlation matrix for characteristics in F_1 and F_2 progeny. In F_1, flour protein content exhibited negative correlation with most characteristics such as mixograph development time (r = -0.0311), kernel weight (r = -0.0475), kernel diameter(r = -0.1173) and kernel hardness (r = -0.0140), and positive correlation with Sodium Dodecyl Sulphate sedimendation volume only. Similarly, mixograph development time was negatively correlated with Sodium Dodecyl Sulphate sedimendation volume (r = -0.1501), kernel weight (r = -0.3526) and kernel diameter (r =-0.2144); but positively correlated with kernel hardness (r =0.4273). Sodium Dodecyl Sulphate sedimendation volume expressed negative correlation with kernel weight, kernel diameter and kernel hardness. Lastly, kernel diameter and kernel hardness were negatively correlated.

In F_2 progeny, break flour yield positively correlated with flour protein content (r =0.3240), Sodium Dodecyl Sulphate sedimendation volume (r = 0.4954), kernel weight (r = 0.4320) and kernel diameter; but negatively correlated with mixograph development time (r = -0.2042) and kernel hardness (r =-0.1998). Flour protein content was positively correlated to Sodium Dodecyl Sulphate sedimendation volume, kernel weight and kernel diameter, and negatively correlated to mixogram development time and kernel hardness. Mixograph development time revealed a negative correlation with Sodium Dodecyl Sulphate sedimendation volume, kernel weight and kernel diameter; but was positively correlated with kernel hardness. Similarly, Sodium Dodecyl Sulphate sedimendation volume exhibited negative correlation with kernel diameter and kernel hardness, but positive correlation with kernel weight. Kernel weight was positively correlated with kernel diameter and negatively correlated with kernel hardness. Lastly, kernel diameter and kernel hardness showed negative correlation.

TABLE 3. Correlation among wheat quality characteristics in F_1 and F_2 progeny

		FIY	FPC	MDT	SDS	SKCW	SKCD
F_1	FPC	0.1560					
	MDT	-0.2992*	-0.0311				
	SDS	0.3344**	0.3450**	-0.1501			
	SCSKW	0.5006**	-0.0475	-0.3526**	-0.0178		
	SCSKD	0.3935**	-0.1173	-0.2144	-0.2204	0.9444**	
	SCSKH	-0.2379*	-0.0140	0.4273**	-0.6740**	-0.3457**	-0.1176
F_2	FPC	0.3240					
	MDT	-0.2042*	-0.1850				
	SDS	0.4954**	0.4652**	-0.1504			
	SCSKW	0.4320**	0.3190	-0.5614**	0.1253		
	SCSKD	0.3963**	0.2380	-0.3191	-0.0442	0.8920**	
	SCSKH	-0.1998*	-0.1002	0.3465	-0.4972	-0.2948**	-0.4309

FLY = break flour yield, FPC = flour protein content, MDT = mixogram development time, SDS = Sodium Dodecyl Sulphate-sedimentation volume, SKCSW = seed weight, SCKCSD = Seed diameter, SCKSH = seed hardness
*Significant at P<0.05, **Significant at P<0.01

DISCUSSION

Genetic and phenotypic variance. High genetic variation in most wheat quality characters studied (Table 2) suggests that there is a large gene-pool from which wheat breeders can select superior genes for improvement in the breeding programme. The high variations in quality characters are useful in designing better effective breeding strategies in wheat cultivars (Wricke and Weber, 1986; Falconer and Mackay, 1996). These variations will enhance improvement much faster, particularly because the difference in the mean of parents and superior offspring is large. The quality characters that expressed high variations in F_1 and F_2 were seed hardness and Sodium Dodecyl Sulphate sedimentation volume; while the least variation was obtained in seed diameter and mixogram development time. From the least genetic variation, significant improvement cannot be realised or else it will take longer time to improve these wheat quality characters. Hence, there would be need for outsourcing the wheat cultivars with a higher genetic variation in the characters and be incorporated in the breeding programme.

Phenotypic variation was also high in some characters such as seed hardness and Sodium Dodecyl Sulphate sedimentation volume in both F_1 and F_2 progeny (Table 2). Seed diameter and mixogram development time exhibited least phenotypic variation. The difference between genotypic and phenotypic variation was minimal, indicating that environment has little influence over the characters studied, and most of the characters observed are due to genetic expression. The results of genotypic and phenotypic variation obtained suggest that there is a good scope for wheat quality characteristics through phenotypic selection.

Progress for selection depends on genetic variability existing in the population and selection is more effective when the genetic variation in relation to environmental variation is high (Falconer and Mackay, 1996). Genetic variability estimate gives good implication for genetic potential in crop improvement through selection. These results are consistent with the findings of previous researchers, who found a high genetic and phenotypic variation in the wheat quality characters (Ojo *et al*., 2006; Jalata *et al*., 2011).

Out of seven wheat quality characteristics, four were conferred by additive gene action, while the remaining three were under the influence of dominance effects (Table 2). The characters controlled by additive effects were break flour yield, Sodium Dodecyl Sulphate sedimentation volume, seed hardness and seed weight. Flour protein content, mixogram development time and seed hardness are conferred by dominance gene action. Additive gene action is cumulative over generations and is the main source of genetic variation exploited by most wheat breeders (Baker *et al*., 1971). Dominance effect occurs as a result of interaction between alleles on the same locus. The levels of additive and dominance genetic variance in characters important for wheat breeding programmes have a great impact on determination of breeding strategies. Estimates of genetic parameters reported in this research are specific for each population because they depend on the additive and dominance effects of segregating loci which differ among populations.

The overall results of the study showed that both dominance and additive effects were equally important for expression of wheat quality characteristics; whereas additive effects were more important in some characters but least important to others. Similarly, dominance gene action had a perceptible influence on some characters where additive gene action did not show any expression, which is in agreement with the results that have been reported for maize population (Haullauer and Miranda, 1981).

Heritability. Generally, heritability was high for all wheat quality characteristics studied in F_1 and F_2 progeny. Heritability is partitioned into h_b^2 and h_n^2. Both of them are classified by Dabholkar (1992) as low (0.05 - 0.10), medium (0.1 - 0.3) and high (0.30 and above). Sodium Dodecyl Sulphate sedimentation obtained the highest h_b^2, followed by seed hardness, break flour yield, flour protein content, seed weight, seed diameter, and then mixograph development time in F_1 progeny. In terms of h_n^2, seed hardness had the highest value; followed by break flour yield, Sodium Dodecyl Sulphate sedimentation, seed diameter, seed weight, flour protein content and lastly, mixograph development time in F_1 progeny.

H_b^2 is not important in breeding as it is comprised of additive and dominance effects. Dominance changes from one generation to the other; hence, cannot be selected for in the breeding programme (Falconer and Mackay, 1996). The highly heritable characters are selected at an early generation stage of breeding cycle (Falconer and Mackay, 1996). Similarly, low heritable characters are selected at a later generation stage. Since the h_n^2 estimates were low in some characteristics, it implied that to obtain high estimates, the number of breeding cycles have to be performed. Similar results were found in a study by Silva *et al.* (2004) in Brazil in which characters of wheat quality showed a wide range from highly heritable to low heritable values, and selection was performed on highly heritable characters controlled by additive gene effects. These findings are also consistent with reports from Baker *et al.* (1971) and Jalaluddin and Harrison (1989).

Degree of dominance. All the characteristics except one showed over-dominance in F_1 progeny while in F_2 progeny varying degree of dominance was obtained. As already indicated, degree of dominance changes from one generation to the other due to change in the genes occupying a particular locus, unlike in the genes conferring traits that have additive effect which are fixed to a locus. No character conferred by dominance genes can be selected since it changes; therefore, in the breeding programme it is excluded. Where character shows over-dominance, it performs much higher than complete or additive dominance and it can be considered for that particular generation and not the next one. Estimate of the average levels of dominance is in partial (0.71) to overdominance range (4.48) in F_1 and F_2 progeny. Partial dominance is 0.69 to overdominance of 2.18. MDT had the highest degree of over-dominance; while seed hardness was partial in F_1 progeny, followed by seed weight and SDS. These estimates are comparable to those reported by Silvia *et al.* (2004) who worked on estimates of genetic variance and level of dominance in Brazil.

Correlation. In F_1 progeny, differences were observed in correlation coefficients in terms of magnitude and direction (Table 3). Sodium Dodecyl Sulphate sedimentation, flour protein content, kernel weight, kernel diameter and kernel hardness exhibited positive correlations with flour break yields. This suggests that as one of these traits increases others also increases, but at different rates as their coefficients differs greatly. Less effort is required to improve on other traits if the wheat breeders' interest is focusing on specific few traits, simultaneously other positively related will improve. This also enables selection to be done simultaneously.

The results are consistent with the finding of Woldegiorgis (2003), who worked on genetic variability of Ethiopian wheat cultivars. Among the traits that showed increase with others is kernel hardness, which is undesirable in both milling and baking industry as more energy is expended to break the grain during milling process. Nonetheless, negative correlations were found between flour protein content and mixogram development time, kernel weight, kernel diameter and hardness. This is attributed to the fact that protein synthesis process utilises more energy at an expense of kernel weight, kernel diameter and kernel hardness. Similarly, mixogram development time had a negative correlation with Sodium Dodecyl Sulphate sedimentation, kernel diameter and kernel hardness. Sodium Dodecyl Sulphate sedimentation volume also revealed negative correlation with kernel hardness, weight and diameter. This shows an inverse relationship suggesting that as one increase the other decreases. It is of paramount importance to know the direction of other traits as some are being improved. Regression in some important traits may be experienced which may delay progression in the breeding of going back to improve the ones that regressed. This observation is in consonance with results of several workers (Kosmolak and Dyck, 1981; Basset *et al.*, 1989; Groger *et al.*, 1997). In F_2 progeny, all quality traits except mixograph development time and kernel hardness exhibited positive correlation with break flour yield.

Similarly, flour protein content showed positive correlation with Sodium Dodecyl

Sulphate sedimentation volume excluding mixograph development time and kernel hardness. This implied that as protein content is increased the volume of the Sodium Dodecyl Sulphate sedimentation volume is also increased. Sodium Dodecyl Sulphate sedimentation volume is used as a rapid method for determining protein quality which could either be strong or of good quality. In this case, the wheat cultivars have good quality. These results are similar to those of Baker *et al.* (1971) and Djojkovic *et al.* (2010) . Conversely, mixograph development time was negatively correlated to all quality traits except kernel hardness. Sodium Dodecyl Sulphate sedimentation volume is also negatively correlated with kernel diameter and kernel hardness. Kernel hardness, kernel weight and kernel diameter have inverse relationship. The findings are consistent with other researchers (Baker *et al.*, 1971; Gaines, 1991).

Prediction ratio. In F_1 progeny, kernel hardness and break flour yield had the highest prediction ratios suggesting that they are easily transferred to the offspring and early generation selection can be practiced; hence, progress can be made within a shorter period of time. Nonetheless, low prediction ratios were obtained for mixograph development time and flour protein content, which implies that it will take time for these traits to improve necessitating many generations before improvement is realised. In F_2 progeny, kernel diameter and kernel weight exhibited high prediction ratios; while the rest revealed moderate to near high prediction ratio. In this progeny, improvement of quality traits can be achieved earlier with very few generations. Baker *et al.* (1971) emphasized the importance of prediction ratio in determining the rate of transmission of traits and the rate of improvement in some traits due to high rate of transmission. This study shows that there is a wide genetic variability in the material used which could be explored to improve wheat quality characteristics.

CONCLUSION

General and specific combining ability ratio in F_1 progeny showed non-additive gene action in all characteristics except one. In F_2 progeny, break flour yield, flour protein content, kernel hardness and mixograph development time were controlled by non-additive gene action. Sodium Dodycel Sulphate sedimentation volume, kernel weight and kernel diameter were controlled by additive gene action. Heritability in the broad sense was high for all characteristics in F_1 and F_2 progeny, whereas heritability in the narrow sense was high for F_2 and low for F_1 progeny. Positive and negative correlations were observed among characteristics in F_1 and F_2 progeny. In F_1 progeny, kernel hardness demonstrated highest prediction ratio. In F_2 progeny, seed diameter, seed weight, Sodium Dodecyl Sulphate sedimentation volume and break flour yield revealed high prediction ratio. Genetic variability exists and can be for improvement of wheat quality in Lesotho.

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