African Crop Science Journal, Vol. 21, No. 4, pp. 283 - 289
ISSN 1021-9730/2013 $4.00


# HETEROTIC PERFORMANCE OF QUALITY CHARACTERISTICS OF BREAD WHEAT CULTIVARS

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*(Received 25 June, 2013; accepted 3 September, 2013)*

## ABSTRACT

Heterosis has made a significant contribution to the improvement of many crops regarding yield, quality and resistance to pests. The low wheat (*Triticum aestivum* L.) productivity in Lesotho has necessitated exploitation of heterosis in commercial cultivars. Heterotic performance of 38 $F_1$ and $F_2$ progenies from 5 x 5 diallel crosses of wheat cultivars were estimated for mid-parent and best-parent values. There were significant differences between $F_1$ and $F_2$ progenies for all characteristics. In $F_1$ progeny, a positive mid-parent heterosis was observed in Sodium dodecyl sulphate (SDS) sedimentation volume, kernel hardness, break flour yield and kernel weight. Positive best-parent heterosis was obtained in all the above parameters. In $F_2$ progeny, characteristics that showed positive mid-parent heterosis were mixograph development time, hardness index and SDS sedimentation volume; while positive best-parent heterosis was observed in mixograph development time, hardness index, kernel diameter and weight. A significant increase in mid-parent heterosis was observed for five characteristics in Sceptre x Wanda and SST124 x Nata. Another significant increase in mid-parent heterosis occurred for four characteristics in Nata x Wanda, Nata x Sceptre, Sceptre x Kariega, Sceptre x SST 124, Wanda x SST 124 and Sceptre x Nata. SST 124 x Sceptre, Nata x Wanda, SST 124 x Kariega and Kariega x Nata revealed a significant increase in best-parent heterosis for all characteristics.

*Key Words*: Best-parent heterosis, *Triticum aestivum*

## RÉSUMÉ

L'héterosis a significativement contribué à l'amélioration de beaucoup de cultures en terme de rendement, qualité et résistance aux pestes. La basse productivité du blé (*Triticum aestivum* L.) au Lesotho a nécessité l'exploitation de l'héterosis dans les cultivars commerciaux. La performance héterotique de 38 $F_1$ et progénies $F_2$ à partir des croisements des cultivars de blé diallèles 5 x 5 étaient estimée pour des valeurs des parents moyens et meilleurs parents. Des différences singnificatives étaient observées entre les progénies $F_1$ et $F_2$ pour toutes les caractéristiques. Dans la progénies $F_1$, une héterosis positive du parent moyen était observée dans le volume de sédimentation de Sulfate dodecyl de Sodium (SDS), la dureté de grains, le rendement en farine, le rendement et le poids de grains. L'héterosis de meilleurs parents était obtenue dans tous les paramètres ci-dessus. Dans la progénie $F_2$, caractéristiques qui ont manifesté l'héterosis positive des parents moyens était un temps de développement der mixographe, l'indice de dureté et le volume de sédimentation SDS; pendant que l'héterosis positive de meilleurs parents était observée dans le temps de développement du mixographe, l'indice de dureté, le diamètre et le poids de grains. Une augmentation significative dans l'héterosis des parents moyens était observée pour cinq caractéristiques dans Sceptre x Wanda et SST124 x Nata. Une autre augmentation dans l'héterosis des parents moyens était observée pour quatres caractéristiques dans Nata x Wanda, Nata x Sceptre, Sceptre x Kariega, Sceptre x SST 124, Wanda x SST 124 et Sceptre x Nata. SST 124 x Sceptre, Nata x Wanda, SST 124 x Kariega et Kariega x Nata ont révélé une augmentation sugnificative dans l'héterosis de meilleurs parents pour toutes les caractéristiques.

*Mots Clés*: Héterosis de meilleurs parents, *Triticum aestivum*

## INTRODUCTION

Heterosis has made a significant contribution to the improvement of many crops for yield, quality and resistance to pests (Singh, 2006). Heterosis was coined by Shull (1908) when he intensively crossed inbred lines of maize (*Zea mays* L.) that resulted in higher performance than either of the parents or average of the parents. Shull was not the first person to deal with hybridisation of plants. Many plant breeders were involved in hybridisation before (Darwin, 1877; Johnson, 1891; McClear, 1892) as cited by Mather and Jinks (2007). David Fife developed an outstanding wheat cultivar called "Marquis" through hybridisation (Chahal and Gosal, 2001). Crops that have been extensively exploited for heterosis are barley (*Hordeum vulgate* L.), maize, oat (*Avena sativa* L.), rice (*Oryza vulgare* L.), soybean (*Glycine max* L. Merr.) and wheat (*Triticum aestivum* L. em. Thell.).

The phenomenon is brought about by the effect of dominance gene action (Falconer and Mackay, 1996). Physiological explanation indicated that crossing of genetically unrelated plants is less likely to possess the same detrimental or lethal recessive genes (Grant, 1975). The off-spring from such parents is likely to carry at least one normal gene resulting in the normal functioning of biochemical reactions. It seems to be expressed in plants because of a more efficient metabolic system resulting from normal functioning of many pairs of genes in the heterozygous individual (Chahal and Gosal, 2001). It involves crossing of two, three or four inbred lines to maximise genetic diversity and heterozygosity in the progeny (Sleper and Poehlman, 2006).

The exploitation of hybrid wheat has become more attractive than conventional plant breeding methods. In autogamous crops such as wheat, the effective use of heterosis relies upon the direction and magnitude of heterosis (Chahal and Gosal, 2001). Heterosis and inbreeding depression has a great influence on the breeding method to be used for improvement of a cultivar, e.g. where heterosis is high, hybrid breeding method is used whereas in inbreeding depression intensive outcrossing is performed (Singh, 2006). Heterosis also furnishes vital information about combining ability of the parents and usefulness in the breeding programme. In a large population, cultivars are crossed to one another and the ones that will consistently outperform the others in a particular trait are identified. Both general and specific combining ability are determined for each cultivar (Sharma *et al*. 1986; Borghi *et al*.1988). Estimation of heterosis over the better parent is important in determining true heterotic combinations.

Wheat hybridisation has been explored by many researchers with varying degree of heterosis. Borghi *et al*. (1986) achieved a maximum yield of 41%, while Zehr *et al*. (1997) obtained 35%. Nonetheless, some researcher attained 72 to 131% above mid-parent value (Bitzer *et al*.,1971). The increases were accounted for by the expression of heterosis. This study estimated heterotic potential of quality characteristics of wheat cultivars grown in Lesotho.

## MATERIALS AND METHODS

The study was carried out in Bloemfontein, located in the Republic of South Africa at 1351 m above sea level; and 26°18'East and 29°06' South. The site receives average rainfall of 700 mm mostly between October and April, with frequent thunderstorms. It experiences semi-arid climatic conditions with hot summer (32 °C) and cool, dry winters, often with frosts (-4 °C).

Mean monthly solar radiation ranges from 249 hr in winter to 319 hr in summer, and annual total hours being 3315.6 hr. The most dominant soil type is red to yellow sand comprising 10% montmorillonite clay. The depth of the top soil varies from 600 to 1200 mm and then sub soil from 400 to 900 mm.

Five commercial wheat cultivars were used as parents, of which two possessed good bread making quality, one had medium and the last two were poor. These were Kariega and SST 124 (good), Wanda (medium), Nata and Sceptre (poor). Parents were crossed in all combinations in an environmentally controlled greenhouse.

$F_1$ progeny obtained from the crosses and the parents were planted in the field in Bloemfontein, using randomised complete block design with three replications. Each plot was 2 m x 1.8 m, with the intra-row and inter-row spacings of 10 cm and 45 cm, respectively.

At physiological maturity, seeds from $F_1$ plants were harvested, cleaned and planted to produce $F_2$ progeny. The same agronomic practices used in $F_1$ progeny were followed. The trials were irrigated with 50mm of water thrice a week usingportable sprinkler irrigation system. Fertilisation was done at rates of 40 kg $ha^{-1}$ nitrogen, 15kg $ha^{-1}$ phosphorus and 12 kg $ha^{-1}$ potassium as basal dressing. Seed was planted by hand at the rate of 25 kg $ha^{-1}$. Weeds were controlled using hand-hoes. The harvested $F_1$ and $F_2$ materials, together with the parents were sent to the ARC-Small Grain Institute in Bethlehem for quality analysis.

Methods developed by American Association Cereal Chemists (AACC) (2000) for determination of wheat quality were adopted for this study. The laboratory pneumatic mill, Bühler model MLU-202 (Bühler Bros., Inc., Uzwil, Switzerland) was used to mill wheat samples and determine break flour yield. The AACC 26-21A procedure for milling hard wheat was employed.

Protein content was determined by combustion method according to AACC 46-30. Hardness index, kernel diameter and kernel mass were measured using AACC 55-31 method with the SKCS model 4100 instrument. AACC 56-70 procedure was performed to establish Sodium dodycel Sulphate sedimentation values. Mixing development time was measured on a 35 g mixograph according to the AACC 54-40A method.

Mid-parent and best parent heterosis were estimated for break flour yield, flour protein content, mixograph development time, seed hardness, seed diameter, seed weight and Sodium dodecyl sulphate sedimentation volume using Equations 1 and 2, respectively (Fehr,1987).

Mid-parent heterosis (%) = 100 x ($F_1$ –MP) MP ……………………………………………… Equation 1

Best-parent heterosis (%) = 100 x ($F_1$- HP) HP ……………………………………………… Equation 2

Where $F_1$ = $F_1$ hybrid performance, MP = (P1+P2)/ 2. P1 and P2 are the performance of inbred parents. HP = Highest performing parent. Analysis of variance was performed using Agrobase Generation 11 establish the differences among the crosses. Mean separation was done using Least Significant Difference at 5% level.

## RESULTS

**Estimates of heterosis.** The mean square of the mid-parent and best parent heterosis for seven characteristics in $F_1$ and $F_2$ progeny are presented in Tables 1 and 2. The analysis showed highly significant (P<0.01) differences among the hybrids for all the seven characteristics studied. Both negative and positive heterosis were observed in all characteristics. There was a great variation in the expression of heterosis. Some hybrids showed high heterotic values either positive or negative, while others expressed little or none.

In $F_1$ progeny, the maximum positive mid-parent heterosis was observed in SDS sedimentation, followed by seed hardness, break flour yield and seed weight. The maximum positive best parent heterosis was obtained in SDS sedimentation, seed hardness, break flour yield and seed weight (Table 3).

TABLE 1. Mean squares for mid-parents

| Source | Df | Fly | Fpc | Mdt | SDS | Skcsw | Skcsh | Skcsd |
|---|---|---|---|---|---|---|---|---|
| Genotypes | 18 | 66.608** | 3.438** | 1.534** | 187.401** | 52.532** | 162.393** | 8.887** |
| Error | 38 | 0.335 | 0.217 | 0.207 | 0.344 | 3.904 | 1.944 | 3.361 |
| Total | 56 | | | | | | | |

Fly=break flour yield, fpc=flour protein content, mdt=mixogram development time, SDS=SDS-sedimentation volume, skcsw=kernel weight, skcsd=kernel diameter, skcsh=kernel hardness, **P<0.01

TABLE 2. Mean squares for best parent heterosis

| Source | Df | Fly | Fpc | Mdt | SDS | Sd | Sw | Sh |
|---|---|---|---|---|---|---|---|---|
| Genotypes | 18 | 25.108** | 1.836** | 0.235** | 165.643** | 5.576** | 26.180** | 261.468** |
| Error | 38 | 1.014 | 3.779 | 0.158 | 2.581 | 8.246 | 3.734 | 2.933 |
| Total | 56 | | | | | | | |

FLY = break flour yield, FPC = flour protein content, MDT = mixogram development time, SDSS = SDS-sedimentation volume, Skcsw = kernel weight, Skcsd = kernel diameter, Skcsh = kernel hardness, **P<0.01

In $F_2$ progeny, the characteristics that showed highest positive mid-parent heterosis were mixograph development time, followed by hardness index and SDS sedimentation volume; while the highest positive best parent heterosis was observed in mixograph development time, hardness index, seed diameter and weight (Table 4). A large number of hybrids exhibited positive mid-parent heterosis in mixograph development time and hardness, followed by break flour yield. Positive best parent heterotic effects were expressed in hardness index, mixograph development time and break flour yield. The characteristics that showed low heterotic effects were SDS sedimentation and seed diameter in best parent heterosis, while seed weight and diameter had the lowest values in mid-parent heterosis.

**$F_1$ and $F_2$ progenies.** Significant differences between $F_1$ and $F_2$ progeny were found in all wheat quality characteristics (Tables 1 and 2). Significant increase in mid-parent heterosis (MPH) was observed for five characteristics (FLY, SKCSD, SKCSW, SKCSH and SDSS) in two crosses (Sceptre x Wanda and SST 124 x Nata). Another significant increase in MPH occurred for four characteristics in seven crosses, namely; Nata x Wanda, Nata x Sceptre, Sceptre x Kariega, Sceptre x SST 124, Wanda x SST 124 and Sceptre x Nata. Two crosses revealed a significant increase in best parent heterosis (BPH) for all the characteristics studied, namely; SST 124 x Sceptre and Nata x Wanda, followed by SST 124 x Kariega and Kariega x Nata with six and characteristics, respectively (Table 4).

## DISCUSSION

A large number of hybrids showed high mid-parent heterosis in seed weight, followed by seed hardness and break flour yield; while in high best parent heterosis, it was seed hardness, followed seed weight, break flour yield and mixograph development time (Table 3). With mixograph development time and seed diameter, the hybrids showed very low mid-parent and best parent heterosis.

Briggle (1963) noted that all parental combinations did not result in expression of hybrid vigour in wheat quality as some did not perform as well as either parent, involved in hybridisation. Johnson and Schmidt (1968) indicated that some $F_1$ hybrids out-performed their parents, while others were out-performed by their parents in wheat quality studies. Sayed (1978) observed a heterotic effect of 7.5% above high parent and about 44 – 48% hybrid showed heterosis with 40.7% being the maximum. He further indicated a maximum high parent heterosis ranging from 14.2 to 74% depending on the wheat quality characteristic being studied.

A large number of crosses (6) exhibited an increase in four and three characteristics (Tables 3 and 4). According to Mackey (1976), expression of heterosis may result from one or two of the following circumstances; namely (a) accumulation of favourable dominant genes dispersed among two parents, and (b) favourable allelic and non-allelic interaction (over-dominance) or complementary interaction of additive dominance on recessive genes at different loci (epistatis).

TABLE 3. Estimation of mid-parent and best parent heterosis for seven characteristics of wheat quality in $F_1$ progeny

| Progeny | Fly | | Fpc | | Mdt | | SDS | | SKCSW | | SKCSD | | SKCSH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph |
| Sceptre x Wanda | 6.43 | 2.67 | -2.07 | -2.14 | -0.59 | -0.70 | -9.17 | -23.00 | 13.05 | 9.84 | 0.64 | 0.46 | -22.16 | -30.46 |
| Kariega x Nata | 13.10 | 11.91 | -0.38 | -0.53 | -0.35 | -0.53 | 18.50 | 10.34 | 6.63 | 2.29 | 0.28 | 0.16 | -15.56 | -26.28 |
| SST124 x Sceptre | 6.03 | 2.2 | 0.51 | -0.24 | -0.26 | -0.34 | -18.17 | -18.17 | 1.73 | 1.54 | 0.16 | 0.15 | 9.85 | 7.65 |
| Nata x Wanda | 1.81 | 0.66 | 0.15 | -0.53 | -0.17 | -0.20 | 22.66 | 16.00 | 2.59 | -0.81 | 0.09 | -0.08 | -23.89 | -34.39 |
| Nata x Sceptre | 5.20 | 2.59 | 1.66 | 1.63 | 0.64 | 0.54 | -7.50 | -21.33 | 10.39 | 7.31 | 0.65 | 0.49 | 0.17 | -8.73 |
| Sceptre x Kariega | 3.87 | 0.07 | -2.35 | -2.50 | -0.02 | -0.20 | -3.17 | -12.00 | 3.60 | -0.74 | 0.23 | -0.01 | -4.39 | -15.11 |
| Sceptre x SST124 | 3.29 | -0.54 | 1.43 | 0.90 | -0.32 | -0.32 | 8.16 | 6.00 | 2.36 | 1.42 | 0.08 | 0.01 | -5.67 | -5.88 |
| SST124 x Nata | 0.64 | -0.58 | 0.25 | 0.07 | 0.08 | -0.20 | -18.00 | -23.00 | -1.68 | -2.94 | -0.05 | 0.12 | 16.68 | 14.86 |
| SST 124 x Kariega | -1.12 | -1.18 | -1.5 | -1.53 | -0.56 | -0.75 | -7.17 | -9.33 | 2.11 | 1.17 | 0.13 | 0.06 | 3.21 | 3.00 |
| Nata x SST 124 | 0.46 | -1.68 | -0.57 | -0.64 | 1.35 | 1.24 | -4.17 | -18.00 | -2.11 | -5.32 | 0.02 | -0.16 | 6.20 | -2.10 |
| Wanda x Sceptre | 1.83 | -1.93 | -0.82 | -0.04 | 0.00 | -0.33 | -3.33 | -3.53 | 1.95 | -3.08 | -0.06 | -0.30 | -4.30 | -6.71 |
| SST124 x Wanda | -2.09 | -2.16 | -2.18 | -2.37 | 0.90 | 0.60 | -14.66 | -19.66 | -3.67 | -4.80 | -0.11 | -0.17 | 13.14 | 10.73 |
| Wanda x SST124 | -1.92 | -2.06 | -2.11 | -2.14 | 0.28 | 0.27 | -25.00 | -26.20 | -0.05 | 0.37 | 0.19 | 0.18 | 10.07 | 9.48 |
| Wanda x Kariega | -2.79 | -2.83 | 0.11 | -0.64 | 1.58 | 1.50 | -6.87 | -14.00 | 4.02 | -4.66 | 0.19 | 0.18 | 15.83 | 13.63 |
| Wanda x Nata | -1.75 | -2.90 | -0.82 | -1.05 | 0.17 | 0.14 | -4.01 | -4.21 | 11.01 | 7.99 | 0.21 | 0.04 | 3.37 | -7.13 |
| Scepter x Nata | -1.49 | -1.12 | -1.97 | -2.00 | 0.01 | 0.00 | -29.00 | -29.00 | -1.72 | -1.59 | 0.10 | 0.09 | 16.14 | 15.55 |
| Kariega x Wanda | -4.45 | -4.49 | -1.02 | -1.73 | 1.10 | 1.03 | -14.17 | -21.33 | -7.46 | -7.78 | -0.26 | -0.26 | 17.09 | 15.49 |
| Nata x Kariega | -4.62 | -5.81 | -1.55 | -1.73 | 0.15 | -0.13 | -4.33 | -9.33 | -0.81 | -2.07 | -0.07 | 0.01 | -18.16 | -19.98 |
| Kariega x SST124 | -7.16 | -7.18 | -0.22 | -0.93 | 0.60 | 0.53 | -12.84 | 20.00 | 0.41 | 0.09 | 0.19 | 0.20 | 0.77 | -0.83 |
| LSD (0.05) | 1.69 | 1.44 | 0.75 | 0.32 | 0.09 | 0.11 | 2.31 | 2.73 | 1.11 | 1.37 | 0.19 | 0.22 | 2.12 | 1.99 |

Fpc = Flour protein content; Mdt = Mixogram development time; SDS = Sodium dodecyl sulphate; SKCSW = Seed weight; SKCSD = Seed diameter; SKCSH = Seed hardness Mph = Mid-parent heterosis; Bph = Best parent heterosis

TABLE 4. Estimation of mid-parent and best parent heterosis for seven characteristics of wheat quality of $F_2$ progeny

| Progeny | Fly | | Fpc | | Mdt | | SDS | | SKCSW | | SKCSD | | SKCSH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph | Mph | Bph |
| Sceptre x Wanda | 9.71 | 0.07 | -3.33 | -3.33 | 0 | 0 | 9.21 | -2.35 | 5.13 | 4.62 | 4.13 | 2.86 | -3.68 | -3.73 |
| Kariega x Nata | -0.02 | -2.56 | -0.41 | -3.15 | 20.76 | 18.52 | -1.91 | -4.94 | 3.77 | 2.84 | -11.34 | -12.75 | 13.03 | 8.20 |
| SST124 x Sceptre | 10.20 | 0.50 | 0.82 | 1.64 | 24.14 | 12.50 | 3.36 | -6.09 | -6.16 | -9.07 | -2.14 | -4.18 | 17.93 | 15.14 |
| Nata x Wanda | -0.02 | -0.03 | -0.04 | -0.04 | 19.2 | 19.2 | -22.98 | -27.06 | 20.37 | 4.51 | 1.61 | 0.40 | 14.59 | 14.06 |
| Nata x Sceptre | 9.09 | 5.69 | 5.00 | 5.00 | -19.23 | -19.23 | 20.28 | 13.16 | 6.30 | 1.57 | 10.00 | 1.59 | -16.29 | 16.72 |
| Sceptre x Kariega | 0.04 | 0.01 | 1.21 | 3.93 | 39.62 | 37.04 | -5.41 | -13.58 | -5.67 | -6.99 | -3.73 | -4.53 | 17.11 | 16.51 |
| Sceptre x SST124 | 0.04 | 0.02 | 0 | -1.61 | 37.93 | 25.0 | 14.09 | 3.66 | -17.39 | -19.95 | -11.97 | -13.81 | 5.52 | 3.28 |
| SST124 x Nata | 2.16 | 1.22 | 9.02 | 1.21 | 11.54 | -9.38 | 13.92 | 9.76 | -0.63 | -5.85 | -2.08 | -6.38 | -14.54 | -16.92 |
| SST 124 x Kariega | -3.19 | 3.93 | 0.40 | -0.79 | 18.6 | 9.38 | -6.75 | -7.32 | -3.17 | -3.5 | -0.85 | -3.70 | 9.97 | 8.25 |
| Nata x SST 124 | 1.35 | 0.42 | -5.74 | -11.81 | 10.35 | 9.38 | -3.80 | -7.59 | -6.36 | -11.28 | -2.50 | -6.77 | 3.31 | 0.43 |
| Wanda x Sceptre | 2.88 | 0.63 | -8.92 | -8.81 | 50.00 | 50.00 | 0 | -0.11 | -16.28 | -16.69 | -9.50 | -10.61 | 14.95 | 14.89 |
| SST124 x Wanda | 0.03 | 0.02 | 2.46 | 0.81 | -6.70 | -15.63 | -8.98 | -10.59 | -5.82 | -8.29 | -1.27 | -4.49 | 11.27 | 8.65 |
| Wanda x SST124 | 0.09 | 0.09 | -3.69 | -5.24 | 31.03 | 18.75 | 0.60 | -1.18 | -12.51 | -14.46 | -7.17 | -10.20 | 25.72 | 22.77 |
| Wanda x Kariega | -0.04 | 0.469 | -0.08 | -10.24 | 43.40 | 40.74 | -15.66 | -17.68 | -17.86 | 18.60 | -9.02 | -9.39 | 21.81 | 17.13 |
| Wanda x Nata | 2.37 | 1.37 | 4.17 | 4.17 | 11.54 | -9.38 | 13.92 | 9.76 | -0.63 | -5.85 | -2.08 | -6.38 | -14.54 | -16.92 |
| Scepter x Nata | 0.01 | -4.44 | -3.58 | -3.58 | 30.77 | 30.77 | -5.29 | -10.53 | -13.89 | -15.87 | -6.53 | -8.77 | 17.11 | 16.51 |
| Kariega x Wanda | -2.58 | -3.33 | -9.31 | -11.81 | 39.62 | 40.71 | -19.28 | -21.18 | -9.74 | -10.55 | -3.69 | -4.01 | 17.05 | 12.55 |
| Nata x Kariega | -0.03 | -0.05 | -18.22 | -20.47 | 58.49 | 55.56 | -10.83 | -13.58 | -19.35 | -22.28 | -10.53 | -11.95 | 16.26 | 11.29 |
| Kariega x SST124 | -8.57 | -9.23 | -15.54 | -16.54 | -15.25 | -21.88 | -6.75 | -7.32 | -18.55 | -19.97 | -21.24 | -26.75 | -68.30 | -68.80 |
| LSD (0.05) | 0.09 | 0.05 | 1.90 | 2.23 | 3.42 | 2.67 | 1.53 | 2.34 | 1.97 | 2.22 | 1.31 | 2.86 | 3.54 | 3.06 |

Fpc = Flour protein content; Mdt = Mixogram development time; SDS = Sodium dodecyl sulphate; SKCSW = Seed weight; SKCSD = Seed diameter; SKCSH = Seed hardness; Mph = Mid-parent heterosis; Bph = Best parent heterosis

However, some crosses expressed a significant reduction in both MPH and BPH (Table 4). The cross that showed decline for all characteristics in MPH was Kariega x SST 124, followed by Kariega x Nata exhibiting decline in five characteristics. Likewise, a large number of crosses showed a decline in four to three wheat quality characteristics. Kariega x SST 124 expressed inbreeding depression in both MPH and BPH (Table 4). Decline in both MPH and BPH is accounted for by inbreeding depression, which is expressed when dominance interaction effect disappeared in $F_2$ generation due to reduced heterozygosity and increase in homozygosity.

The crosses indicating either heterosis in $F_1$ generation and decline in $F_2$ generation should be used to produce hybrid cultivars; while ones which showed consistent heterosis in $F_1$ and $F_2$ generation should be utilised in cultivar development programmes. Crosses such as Sceptre x Wanda, SST 124 x Sceptre, SST 124 x Kariega, Kariega x Nata, Sceptre x Wanda and SST 124 x Nata could be used in cultivar development, while Nata x Wanda, Nata x Sceptre, Sceptre x Kariega, Sceptre x SST 124, SST 124 x Nata, SST 124 x Kariega, Nata x SST 124, Wanda x Sceptre, SST 124 x Wanda, Nata x SST 124, Wanda x Kariega, Wanda x Nata and Kariega x Wanda could be utilised in hybridisation programme.

## ACKNOWLEDGEMENT

The authors extend sincere gratitude to National Research Foundation for providing funding to execute the research. Dr. Hilka Marteens and Mrs. Saidy Geldenhys are appreciated for guidance, administrative and technical support.

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