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HETEROSIS FOR YIELD AND ITS COMPONENTS IN SORGHUM HYBRIDS DEVELOPED BETWEEN WILD AND EXOTIC SORGHUM IN WESTERN KENYA

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Abstract

Hybrid breeding facilitates the development of high-yielding cultivars relative to one or both parents across a wider range of crops which is key to meeting future food demands. This study was conducted to determine the magnitude of hybrid vigour (heterosis) for selected traits in sorghum crosses. A total of 7 improved sorghum varieties obtained from Rongo University sorghum breeding program together with 7 sorghum wild relatives (SWRs) obtained from ICRISAT-Mali were crossed using North Carolina Mating design II. A total of 9 successful hybrid crosses together with their parents were evaluated at Kibos Research Station in Kisumu County in a Randomized Complete Block Design (RCBD) with three replications. Each entry was sown in a single row plot of 4 m length with a uniform spacing of 60 x 15 cm. Phenotypic data was collected throughout the growing period as per IPGRI, (1993) descriptors for sorghum on 15 randomly selected plants. The low number of crosses obtained was attributed to the partial incompatibilities between the SWRs and cultivated sorghum. Results showed high heterosis among the crosses for most of the selected traits. Heterosis for grain yield ranged from -31.48% to 194.27% and -49.39% to 137.89% for mid and better parent, respectively while for days to 50% Flowering, Average Heterosis ranged between -8.86% and 4.04% and that of better parent ranging from -6.49% to 7.46%. The best grain yield per plant heterotic cross combination identified was (RUC26 X 586) which expressed high positive heterosis over both mid and better parent (194.27% and 137.89%, respectively). This cross also showed significant positive average heterosis and heterobeltiosis for yield-contributing components. Likewise, RUMUK 154 X 586 was identified as the most promising cross combination recording -8.86% average heterosis and -6.49% heterobeltiosis in the case of days to 50% flowering. The negative average heterosis and heterobeltiosis expressed in this cross showed that it was very early maturing, a trait for escaping terminal drought in rainfed agriculture, characteristic of the Kenyan cultivation system. The results illustrate the potential of improving sorghum yield potential using Sorghum wild relatives.

Keywords: *Average heterosis, heterobeltiosis, sorghum, Sorghum wild relatives.*

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Introduction

Sorghum (*Sorghum bicolor L. Moench*) is a significant cereal crop in semi-arid regions of Africa. This is due to its resilience to environmental stresses such as water stress, low soil fertility, and high-temperature conditions. The crop is a staple food for over half a billion people in over 30 African countries (Wani, 2018). In Kenya sorghum is predominantly grown by smallholder farmers under rainfed cropping system with limited input use. It is mainly used as human food, animal feed and for industrial purposes. Sorghum is highly regarded for its high economic demand in Kenya for it is an integral ingredient in the production of sorghum beer. The increasing demand for beer has created a high demand for high-quality white sorghum for malting. Despite the increased demand sorghum yields in Kenya have continued to be poor (0.86 t/ha) (Egesa *et al.*, 2016; FAOSTAT, 2022; KNBS, 2017). The poor yields are attributed to biotic and abiotic stresses, lack of high-yielding and good quality sorghum varieties, inadequate adoption of improved varieties, inadequate post-harvest management practices among others (Kazungu *et al.*, 2023). Due to these production challenges, there is demand for new sorghum varieties that show improved resilience and productivity.

Heterosis, also known as hybrid vigour, is an experience where heterozygous hybrids show improved performance over their parents. Heterosis is highly valuable for plants in reproduction and adaptation to environmental changes. It is also of great importance in agriculture production, as hybrid breeding has been proven to be one of the most efficient ways to increase the grain yield of various crops (Paril *et al.*, 2024; Schnable and Springer, 2013).

Heterosis has both genetic and epigenetic bases (Groszmann *et al.*, 2011; Shen *et al.*, 2017; Sinha *et al.*, 2020). There are three hypotheses that have been proposed to explain the genetic basis of heterosis. The dominance hypothesis which was proposed by Davenport (1908) proposes that 'undesirable recessive alleles are masked or complemented by their desirable dominant counterparts. It predicts that the inbred lines will be similar to hybrids in terms of performance given that the undesirable recessive alleles can be eliminated through recombination breaking-up linkage'. The overdominance hypothesis proposed by (East, 1908; Shull, 1908) proposes 'that a heterozygous locus is superior to both homozygous states as a result of non-additive intra-locus allelic effects'. The epistasis hypothesis proposed by (Jinks and Jones, 1958) is where complex, non-additive interactions between alleles over multiple loci across the genome generate heterosis. The potential of sorghum hybrids is estimated from the percentage increase or decrease of their performance over the mid parent (average heterosis) and better parent (heterobeltiosis) (Hochholdinger and Hoeckenger, 2007). The degree of heterosis in crops varies based on the genetic distance of the parents, their reproductive mode, the traits investigated (Zhou *et al.*, 2012), the developmental stage of the plants (Groszmann *et al.*, 2013), and the environment. Several studies have been conducted on heterosis using various quantitative traits. These include days to 50% flowering, plant height, panicle length, panicle width, number of primary branches per panicle, fodder yield, biomass yield, 100 seed weight, panicle exertion, and grain yield per plant (Begna *et al.*, 2024; Mindaye *et al.*, 2016; Silva *et al.*, 2020; Veldandi *et al.*, 2021a). These studies consistently focussed on hybrids developed from exotic parental lines and local check varieties. However, some of the hybrids developed lacked the adaptive traits for diverse local environments due to narrow genetic base. The development of heterotic pools with wide genetic base is one solution to overcome the challenges of adaptation to climate change, resistance to pests and diseases, and local farmers' end use requirements. Development of Hybrid crosses with wild sorghum relatives offers the much-needed genetic potential that could be tapped from the wild sorghum in order to enhance diversity, resilience and adaptation to climate change for improved productivity. Estimation of the amount of heterosis in such crosses can indicate

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how much genetic gain could be available and this information is useful in guiding the breeding process. The potential use of wild sorghum relatives in sorghum improvement programs has been documented by various researchers. Some example are *S. bicolor subsp. Verticilliflorum* being used to improve sorghum yield, *S. halepense* being used to introduce perennialism and *S. propinquum* being used to increase height and earliness of development (Duncan *et al.*, 1991); (Cox *et al.*, 1984; Jordan *et al.*, 2004). However, in Kenya, the benefits of such efforts are scarcely available. Therefore, objectives of the present study were to develop potential crosses between selected Kenyan sorghum and sorghum wild relatives and then to determine the extent of heterobeltiosis and average heterosis in 9 sorghum crosses developed between Kenyan-adapted lines and sorghum wild relatives. The findings from this study will provide insights into the potential of improving sorghum yield using Sorghum wild relatives by various sorghum breeding programs in the region.

Materials and Methods

The study was conducted at Kibos research station which is located at 0^0 53'S, and 34^0 52'E in Kisumu County. The area has an altitude of 1679 m above sea level (a.s.l). It receives a mean annual rainfall of between 1200 – 1300 mm with a mean minimum temperature range of between 16^0C – 19^0C while the mean maximum range is between 27^0C – 30^0C. The soils are classified as vertisols with dark greyish brown to dark brown sandy clay loam, texture underlain by brownish to greyish brown clay loam to light clay (Jaetzold *et al.*, 1985; KESREF, 2001). The plant genetic materials used in the study are presented in Table 1

Table 1

Materials used in Crossing

Recurrent Parents			Donor Parents		
No.	Entry	Source	No.	Entry	Source
1	RUT53B	Rongo University	1	466	ICRISAT-Mali
2	RUMUK 154	Rongo University	2	586	ICRISAT-Mali
3	RUE32	Rongo University	3	514	ICRISAT-Mali
4	RUC26	Rongo University	4	588	ICRISAT-Mali
5	RUT30b	Rongo University	5	504	ICRISAT-Mali
6	KENSORG 5	Rongo University	6	565	ICRISAT-Mali
7	RUMUK 60	Rongo University	7	560	ICRISAT-Mali

Seven adapted Kenyan sorghum lines and Seven selected SWRs were crossed in a North Carolina II design (Comstock and Robinson, 1952) mating design during the short rains of 2022 (September) at KALRO center in Kibos for the development of experimental material for estimation of heterosis. Nine successful crosses were developed. The small number of crosses produced was mainly due to self-pollination of the recurrent parents and to some extent partial self-incompatibilities between the SWR genotypes and the recurrent parents (Johnston *et al.*, 2005) . Nine F1 hybrids developed were evaluated during the long rain season of 2023 along with parents. Each entry was sown in a single row of 4 m long with a uniform spacing of 60 x 15 cm in a Randomized Complete Block Design (RCBD), replicated three times. Planting was carried out at the onset of long rains and standard agronomic practices were carried out as recommended. The data was collected on fifteen randomly selected plants in each plot and mean observations were taken. A total of five agronomic traits were evaluated in this experiment as per the IPGRI, (1993) descriptors for sorghum. These included; days to 50 percent flowering, plant height, number of primary branches per panicle, panicle breadth, panicle

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exertion, panicle length, 100 seed weight, and grain yield per plant.

The mean performance of parents, as well as hybrids, were subjected to statistical analysis using R statistical software. Heterobeltiosis (Better parent heterosis), Average heterosis, and significance of heterosis were calculated according to Prasuna (2012).

Heterosis over Average Parent: Heterosis was expressed as the percentage increase or decrease observed in the F1 over the mid-parent using the following formula (Prasuna, 2012; Ramesh *et al.*, 2018). Average heterosis (%);

$$H1 = \frac{\overline{F1} - \overline{MP}}{\overline{MP}} X\ 100$$

Where;

$\overline{F1}$ = Mean of F1

$\overline{MP}$ = Mean of parents

Heterosis over Better Parent: This was expressed as a percentage increase or decrease observed in F1 over the better parent according to the following formula. Heterobeltiosis (%) (H2);

$$H2 = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} X\ 100$$

Where;

$\overline{F1}$ = Mean of F1

$\overline{BP}$ = Mean of better parent

For the characters like days to 50% flowering, earliness is desirable so the early parents were taken as better parents.

Test of Significance of Heterosis: To test the significance for different types of heterosis computation of standard error (SEm) for average heterosis and heterobeltiosis were calculated based on error mean squares (EMS) from the ANOVA tables consisting of parents and crosses. The significance of heterosis *i.e.* average heterosis, and heterobeltiosis was then tested by comparing the calculated 't'- value with the tabulated student's 't'- value for appropriate error degrees of freedom at 5 percent and 1 percent level of significance (0.05 and 0.01 level of probability), respectively (Prasuna, 2012; Ramesh *et al.*, 2018)

$$t_{calc} \text{ for BP and MP} = \frac{\overline{F1} - \overline{BP}/\overline{MP}}{SEm}$$

Where $SEm = \sqrt{\frac{2EMS}{r}}$

EMS = Error mean of squares

r = Number of replications

Results and Discussions

Data on mean monthly temperature, rainfall and relative humidity for Kibos is presented in Table 2. In general, the weather was warm, humid and with good rainfall amount and intensity favorable for sorghum cultivation.

Table 2

Mean climatic information during the 2023 cropping season

	March	April	May	June	July
Rainfall amount (mm)	200.9	312.68	226.81	42.68	18.78
Temperature (^{0}C)	23.3	23	23.2	23.2	23.6
Humidity (%)	69.1	73.9	71.3	67.9	61.2

Mean Performance of hybrid Crosses and Parental Lines

The analysis of variance of parents and hybrids for yield and yield components is presented in Table 3.

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Table 3

Analysis of variance for yield and yield components for parents and crosses

Source of Variation	df	Days to 50% flow	Plant height	Panicle length	Panicle breadth	Primary branches	Panicle exertion	100 sdwt	GY per plant
Rep	2	0.788	3.82	1.511	0.2339	6.011	0.4091	0.01636	4.42
Treatment	21	46.708**	10616.38**	112.696**	4.791**	154.325**	199.6169**	0.66798**	3591.27**
Error	42	1.169	41.87	2.126	0.2458	4.369	0.8853	0.01474	14.92

* Significant at 5% level ** Significant at 1% level

The results showed that there were highly significant differences among hybrids and parents for all the characters evaluated under study indicating some considerable amount of variability present among genotypes for various characters measured. The means for parents and hybrids for yield and yield components are presented in Table 4.

Table 4

Mean performance of parents and crosses for yield and yield contributing characters in sorghum

Entry	Days to 50% flow	Plant height (cm)	Panicle length (cm)	Panicle breadth (cm)	Primary branches	Panicle exertion (cm)	100 sdwt (g)	GY per plant (g)
466	86	230.5	25.5	6	50.5	6	2.01	31.48
504	85	276	27	5	49.5	6	2.41	37.08
514	82	240	31.5	4.5	55.5	13	3.11	33.48
560	76	310	32.33	6	54	10	3.17	72.39
565	80	370	28.5	5	44.5	18	2.82	19.08
586	81	370	29.5	4.75	56	25	2.48	17.49
588	85	307	26	4.5	42.5	25	2.4	26.03
RUC26	76	195	22	6	40	1	2.22	28.19
RUE32	76	185	17	7	49	4	1.66	37.3
KENSORG 5	80	230	22.5	8	40	18	1.69	65.29
RUMUK 154	77	165.5	19.67	8.5	31.5	1	1.32	70.21
RUT30B	80	256.7	20	7	42.5	2	2.12	82.68
RUT53B	81	279	18	7	32.5	2	2.27	96.98
RUC26 X 586	81.67	372	31	7	47	9	2.59	133.88
RUE32 X 565	73	310	31	6	54	25	2.45	37.84
KENSORG 5 X 588	84	318	20	8.5	44	18	2.02	121.67
RUMUK 154 X 466	78	220	25	7	50	4	1.99	71.86
RUMUK 154 X 586	72	273	26.5	8	41	13	2.95	86.09
RUMUK 154 X 514	82	228	34	6.5	45	10	2.7	35.53
RUT30B X 504	83	308	34	6.333	56	16	2.66	78.95
RUT30B X 560	75	320	39	8	55	5	1.98	105.14
RUT53B X 466	78	314	35.5	7.5	50	2	2.3	97.35
Grand Mean	79.62	276.26	27.07	6.55	46.82	10.59	2.33	63
CV %	1.4	2.3	5.4	7.6	4.5	8.9	5.2	6.1
Sed	0.88	5.28	1.19	0.4	1.71	0.77	0.1	3.15

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Mean performance for crosses was higher than those of parents for all the traits measured except for days to 50% flowering. For grain yield mean ranged from 35.53-133.9 g per plant for crosses compared to 17.5- 96.9 g for parentals. The average yield for crosses was 85.4 g compared to 47.5 g for Parents. For 100 seed weight mean ranges were from 1.9-2.7 g for crosses compared to 1.7- 3.2 g for parents with averages of 2.4 g for crosses and 2.3 g for Parents. Similar trends were observed with plant height where mean ranges were higher for crosses (220-372 cm) compared to parentals (165.5- 370 cm). For days to 50% flowering crosses took fewer days to flower (72- 84 days) compared to parents (76- 86 days) (Table 4).

Estimates of Heterosis

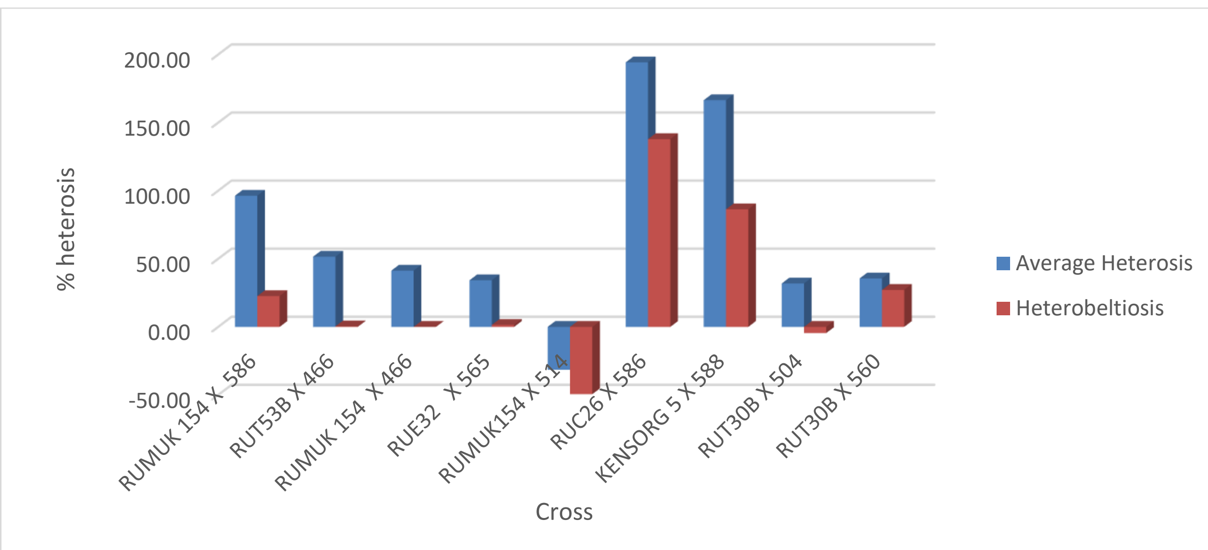
Average heterosis and heterobeltiosis for five important attributes are presented in Table 5. In general, the F1s showed positive, negative, and no heterosis for the traits studied.

Grain Yield per Plant (g)

Heterosis for grain yield per plant ranged from -31.48% (RUMUK 154 X 514) to 194.27% (RUC26 X 586) and -49.39% (RUMUK 154 X 514) to 137.89% (RUC26 X 586) both over mid parent and better parent, respectively. The cross RUC26 X 586 expressed high positive heterosis over both mid-parent and better parent (194.27% and 137.89%, respectively) Figure1 and Table 5.

Figure 1

Graphical presentation of the nine cross combinations for heterosis for grain yield



100-Seed Weight (g)

For 100-seed weight, heterosis ranged from -25.28% (RUT30B X 560) to 55.26% (RUMUK 154 X 586) and from -37.54% (RUT30B X 560) to 18.95% (RUMUK 154 X 586) over mid parent and better parent, respectively. (RUMUK 154 X 586) exhibited high heterosis both over mid parent (55.26%) and better parent (18.95%) for this trait (Table 5).

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Table 5

Estimates of Average heterosis (H1) and heterobeltiosis (H2) for Grain yield per plant, 100 seed weight. Days to 50% flowering, and Plant height

Cross	Grain Yield per plant		100 seed weight		Days to 50% flowering		Plant height	
	H1	H2	H1	H2	H1	H2	H1	H2
RUMUK 154 X 586	96.33**	22.62**	55.26**	18.95**	-8.86**	-6.49**	1.96**	-26.22**
RUT53B X 466	51.56*	0.38	7.48	1.32	-6.59**	-3.70**	23.26**	12.54**
RUMUK 154 X 466	41.33**	0.02	19.16**	-1	-4.29**	1.3	11.11**	-4.55
RUE32 X 565	34.23**	1.45	9.38*	-13.12**	-6.41**	-3.95**	11.71**	-16.22**
RUMUK154 X 514	-31.48**	-49.39**	21.08**	-13.18**	3.14**	6.49**	12.45**	-5.00*
RUC26 X 586	194.27**	137.89**	10.21*	4.44	4.04**	7.46**	31.68**	0.54
KENSORG 5 X 588	166.47**	86.35**	-1.22	-15.83**	1.82	5.00**	18.44**	3.58*
RUT30B X 504	31.85**	-4.51	17.18**	10.37*	0.61	3.75**	15.64**	11.59**
RUT30B X 560	35.59**	27.16**	-25.28**	-37.54**	-3.85**	-1.32	12.93**	3.25

* Significant at 5% level   ** Significant at 1% level

Days to 50 percent flowering

Regarding days to 50% Flowering, Average Heterosis ranged between -8.86% and 4.04% and that over better parent ranged from -6.49% to 7.46%. Most of the Fl's exhibited negative heterosis (preferred) for this trait, both over better parent and mid-parent. The cross (RUMUK 154 X 586) had the best-preferred heterosis both over mid-parent (-8.86%) and better parent (-6.49%) for this trait (Table 5).

Plant Height

For plant height average heterosis varied from 1.96% (RUMUK 154 X 586) to 31.68% (RUC26 X 586) whereas heterobeltiosis for the same traits ranged between -26.22% (RUMUK 154 X 586) to 12.54% (RUT53B X 466). Crosses that exhibited negative heterobeltiosis for this trait were (RUMUK 154 X 466), (RUMUK 154 X 586), (RUMUK 154 X 514) and (RUE32 X 565) (Table 5).

Panicle Length

Regarding panicle length, heterosis ranged from 0.11% (RUMUK 154 X 466) to 63.22% (RUT53B X 466) and -23.06% (KENSORG 5 X 588) to 39.22% (RUT53B X 466) over mid parent and better parent, respectively (Table 5). Crosses (RUT53B X 466) and (RUT30B X 504) recorded high positive heterosis over both mid parent and better parent for this trait (Table 6, Fig 2a and 2b).

Figure 2a *Heterosis for panicle length*

Figure 2b *Heterosis for panicle length*

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Number of Primary Branches per Panicle

Heterosis for number of primary branches per panicle ranged from -8.16% (RUMUK 154 X 514) to 21.74% (RUT30B X 504) and -26.79% (RUMUK 154 X 586) to 13.13% (RUT30B X 504) over mid parent and better parent, respectively. Of the crosses (RUT30B X 504) exhibited high heterosis over both the mid parent (21.74%) and better parent (13.13%) (Table 6).

Table 6

Estimates of Average heterosis (H1) and heterobeltiosis (H2) for panicle length, primary branches, panicle exertion, and panicle breadth

Cross	Panicle length		Primary branches		Panicle exertion		Panicle breadth	
	H1	H2	H1	H2	H1	H2	H1	H2
RUMUK 154 X 586	7.77	-10.17*	-6.29	-26.79**	-45.8	-48.00**	20.66**	-5.88
RUT53B X 466	63.22**	39.22**	20.49**	-0.99	-50.00*	-66.67**	15.38*	7.14
RUMUK 154 X 466	0.11*	39.21	21.95**	-0.99	14.29	-33.33*	-3.45	-17.64**
RUE32 X 565	36.26**	8.77*	15.51**	10.20**	127.27**	38.89**	0	-14.29*
RUMUK154 X 514	17.23**	7.94*	3.45	-18.92**	42.86**	-23.08**	0	-23.53**
RUC26 X 586	20.39**	5.08	-2.08	-16.07**	-30.77**	-64.00**	30.11**	16.67*
KENSORG 5 X 588	17.53**	-23.08**	6.67	3.53	-16.28**	-28.00**	36.00**	6.25
RUT30B X 504	44.68**	25.92**	21.74**	13.13**	300.00**	166.67**	5.00**	-9.57
RUT30B X 560	49.03**	20.63**	13.99**	1.85	-6.67	-50.00**	23.08**	14.29*

Panicle Exertion

For panicle exertion heterosis ranged from -50% (RUT53B X 466) to 300% (RUT30B X 504) and -66.67% (RUT53B X 466) to 166.67% (RUT30B X 504) over mid parent and better parent, respectively. (RUT30B X 504) had the highest significant positive heterosis over both the mid parent and better parent for this trait (Table 6).

Panicle Breadth

For panicle breadth, heterosis ranged from 0% (RUT30B X 504) to 36% (KENSORG 5 X 588) and -14.29% (RUT30B X 504) to 33.33% (RUT30B X 560) over mid parent and better parent, respectively. (RUT30B X 504) and (RUE32 X 565) exhibited no positive heterosis over both mid parent and better parent while (RUT30B X 560) showed highest positive heterosis over both the mid parent (33.33%) and better parent (33.33%) (Table 6).

Discussion

Results showed that most of the hybrids derived from locally adapted genotypes and sorghum wild relatives had higher grain yield and yield components that were evaluated except for days to 50% flowering which were reflected in the expression of heterosis. This demonstrated that there is potential in improving sorghum yields and its components by using hybrids derived from wild sorghum relatives. The average heterosis and heterobeltiosis in crosses varied significantly and this was due to the genetic diversity of parents used to generate the crosses as the parental materials were of diverse origins and to some extent from different races and gene pools. Similar findings have been reported by Ringo *et al.* (2015), Zhang *et al.* (2024) and Demisse (2023). The high positive heterobeltiosis (67%) and average heterosis (89%) for grain yield exhibited by the majority of the F1s is attributed to positive transgressive inheritance where the offspring's exhibited improved

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performance over the parents. This was expected due to high genetic diversity of the parental lines.

The cross (RUC26 X 586) expressed the highest positive heterosis over mid and better parent for grain yield per plant. The positive significant heterobeltiosis for grain yield per plant could have been contributed by the high scores for 100 seed weight and long panicle length. This finding also compares well with several other studies such as Rachman *et al.* (2022), Sheunda (2019), Schaffasz *et al.* (2019), Ouma *et al.* (2012), and Zhang *et al.* (2024) who have reported Significant positive heterosis for grain yield per plant and on other agronomic traits.

For days to 50% flowering, 40% of the F1s had negative heterobeltiosis in comparison with parental genotypes while 60% of the F1s had negative average heterosis as compared to parental genotypes. This was expected as the F1s had reduced flowering time compared to the parents which implies faster maturity and reduction of the crop reproductive cycle. Earliness is one of the key traits contributed by the wild sorghum which is an important contribution to sorghum adaptation and resilience to water stress which is predominant in the western and Eastern Kenya regions. These findings compare well with those of Sheunda *et al.* (2019), Crozier *et al.* (2020) and Veldandi *et al.* (2021b) who reported significant and negative heterotic values for this trait in sorghum. Further, these result are in agreement with the work of (Tiruneh *et al.*, 2013) who reported negative heterosis in others crops such as common bean genotypes. The Lowest values for average heterosis and heterobeltiosis were expressed in RUMUK 154 X 586 which showed that this was among the top early maturing crosses. The early maturity in sorghum crosses has been attributed to additive gene effects (Makanda *et al.* (2009).

Most of the crosses showed positive heterosis and heterobeltiosis for plant height. The cross RUT53B X 466 and RUC26 X 586 particularly stood out for this trait probably because of the four possible patterns of dominance, over dominance, pseudo-over dominance, and epistasis (Li *et al.*, 2015). Similar results have been reported by Deosarkar *et al.* (2021), El-Mottaleb and Asran (2004) and El-Dardeer *et al.* (2011).

However, in Western Kenya, previous studies such as Gudu *et al.* (2013) have shown that majority of farmers prefer medium to short sorghum plants varieties compared to the tall ones. This is due to the fact that Short sorghums require a relatively shorter period to maturity compared to taller ones and withstand lodging as well as easiness during harvesting (Hashimoto *et al.*, 2021); Madhusudhana and Patil (2013). In this case therefore, higher heterobeltiosis for plant height did not necessarily translate to positive outcome for the small holder farmers of western Kenya. Therefore, crosses such as RUMUK 154 X 586, RUMUK 154 X 466 and RUMUK 154 X 514 were the most promising for plant height as they had negative transgressive inheritance and were shorter than their parents. These findings compare well with those of Gaddameedi *et al.* (2020) who also reported negative transgressive inheritance for plant height in selected sorghum lines. Results for panicle Length showed that 78% of the F1s exhibited positive heterobeltiosis and the rest showed average heterosis. A longer panicle is generally associated with a greater number of grains and this is one of the attributes for higher grain yields in sorghum hybrids. These results compare well with those of Mengistu *et al.* (2020), Sheunda (2019), Deosarkar *et al.* (2021) and (Kanbar *et al.*, 2011) who reported positive heterosis and heterobeltiosis for panicle length. However they are contrary to those reported by Premalatha *et al.* (2006) and Rachman *et al.*, 2022 who reported negative heterosis for this trait although the reason for such results could not be established immediately. Heterosis of 100 seed weight show that 44% of the F1s showed positive heterobeltiosis and 78% of the F1s showed positive average heterosis. The cross (RUMUK 154 X 586) expressed high heterosis over mid and better parent for 100 seed weight. Significant

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better parent heterosis for 100-seed weight was reported by (Gaddameedi *et al.*, 2020; Yimer and Jin, 2020).

Heterosis for panicle Breadth revealed 44% of the F1s showed positive heterobeltiosis and 67% of the F1s showed average heterosis for this trait. A Broader panicle is generally associated with a greater number of grains and this is one of the attributes for higher grain yields in sorghum hybrids. Similar positive heterosis for panicle breadth was reported by Ingle *et al.* (2018). Wirnas *et al.* (2021) stated that panicle breadth was one of the important morphological ideotypes related to high grain yield in sorghum.

44% of the F1s showed positive heterobeltiosis and 78% of the F1s showed positive average heterosis for Number of primary branches per panicle. The cross (RUT30B X 504) expressed high heterosis over mid and better parent for number of Primary branches per panicle. Significant positive heterosis for Number of primaries per panicle was also reported by Deosarkar *et al.* (2021) Prasuna (2012) and Ingle *et al.* (2018). Heterosis of Panicle exertion show that 22% of the F1s showed positive heterobeltiosis and 44% of the F1s showed positive average heterosis. Panicle exertion is an important attribute that often determines the quality of the grains. Poorly exerted panicle has the leaf sheath covering the panicle thus provides favorable conditions for fungi and insects to develop at the base of the panicle. The preferred well-exerted panicles were in two crosses (RUT30B X 504) and (RUE32 X 565). Similar results on positive heterobeltiosis and standard heterosis on panicle exertion was also reported by Ringo *et al.* (2015) and Wagaw *et al.* (2020)

Conclusion and Recommendations

Sorghum hybrids developed using locally adapted genotypes and sorghum wild relatives exhibited higher grain yield performance than their parents. This was reflected in considerable amounts of heterosis for grain yield and its selected components. This study has determined the magnitude of heterosis in selected crosses for selected traits and showed that a considerable amount of mid-parent and better-parent heterosis existed for grain yield per plant alongside other yield components among the hybrids which has demonstrated that there is potential in improving sorghum yields and its components by using hybrids derived from wild sorghum relatives. The most heterotic cross combination identified for grain yield was (RUC26 X 586) which exhibited high positive heterosis over both mid-parent and better parent (194.27% and 137.89%, respectively). This cross also showed significant positive average heterosis and heterobeltiosis for yield-contributing components. Likewise, RUMUK 154 X 586 was identified as the most promising cross combination for early maturity recording -8.86% average heterosis and -6.49% heterobeltiosis in case of days to 50% flowering.

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The author(s), while preparing this work, did not use any AI tool and assume(s) full responsibility for the publication's content.

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Otieno K: Writing – review & editing, Writing – original draft, Methodology, Data curation. **Ouma E:** Writing – review & editing, Conceptualization. **Kiplagat O:** Writing – review & editing, Conceptualization.

Declaration of Conflict of Interest

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