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Significant Heterosis Detected from Hybridization of Parents with Agro-morphological Variability in Sesame (*Sesamum indicum* L.)

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Abstract Sesame is an important oilseed crop in Burkina Faso. However, varieties currently under cultivation are low yielding and susceptible to biotic or abiotic stresses. In such a context, an increase in sesame production would be possible either from an increase in the crop cultivation area or improvement of productivity traits. To create new and more productive varieties, seven lines from a local cultivar referred to as *Senekuru* were crossed with the improved and popular variety S42 during the dry season 2018-19, at Farakoba research station. Mid-parent heterosis, heterobeltiosis and the variability within the material were assessed during the rainy season 2019 using an Augmented Block Design. Standard agronomic practices were applied to the trials. The analysis of variance revealed highly significant differences among the genotypes for all the traits. Mid-parent heterosis and heterobeltiosis varied from cross to cross and from trait to trait. Concerning seed yield, the best value of mid-parent heterosis (87.44%) was obtained with Senekuru-3-1/S42, while Senekuru-2-1/S42 presented the best heterobeltiosis (40.34%). The main yield contributing traits in sesame production were plant height, branch number, and capsule number. Then, it was contended that hybrid seeds can significantly increase sesame productivity, provided that a practical hybridisation approach is applied.

Keywords: *hybrid seeds, breeding, cross, self-pollination, Burkina Faso*

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1. Introduction

The cultivated sesame (*Sesamum indicum* L.) is an important oil seed crop which may contain more than 50% oil content, and important components as proteins (23%) and antioxidants [1]. Sesame is used in human and animal diets thus providing many nutritional and medical benefits [2,3]. These uses of sesame seed made it a highly demanded crop around the world. The global sesame business was estimated over USD 12 billion in 2017 and is expected to reach about USD 18 billion by 2025 [4]. In Burkina Faso, sesame is the second most exported produce after cotton [5], bringing more than 100 million US dollars per year to the economy [6]. Although sesame productivity is relatively low (~600 kg/ha) [7,8] compared with the crop potential, this appeared to be better than the world average [8]. In many regions, the low productivity is attributable to several factors, including soil poverty, frequent occurrence of abiotic and/or biotic stresses, and the use of low yielding varieties. Genetic improvement is one of the most sustainable ways to face these constraints in order to increase domestic production. Previous researches conducted by the Oil and Oilseed Crops Research Institute (IRHO) led to development of some interesting varieties such as S42 in the 1970s [9]. Since then, S42 remained the most popular variety in the country. Despite its popularity due to seed whiteness and market demand, the variety is old and susceptible to many diseases [10]. Recently, the Institute of Environment and Agriculture Research (INERA) introduced some new varieties from Ethiopia (Wollega and Humera) with potential yields exceeding 1.5 t/ha [11]. Such introduction and current breeding efforts are conducive of sesame productivity improvement in Burkina Faso, through cultivar development, to provide farmers with new high-performing varieties. Therefore, widening the genetic base through strategic hybridization among available germplasms is crucial to create genetic variability that enables varietal selection. Hybridization can lead to the recombination of desirable traits from different varieties into a single crop line following generation advancement up to alleles’ fixation [12,13].

Enhanced sesame productivity can also be achieved by sustained use of best production techniques such as the application of pesticides and fertilizers, and possibly, the adoption of hybrid varieties. Hybrid seeds have been exploited worldwide for the increased productivity of many crop species, including cereals, fruits and vegetables, due to heterosis or hybrid vigour gained in F_1 generation [14,15,16]. Thus, the commercial use of hybrid varieties has driven many seed business worldwide. Hence, the development of hybrid cultivars is desirable to increase crop productivity. However, the application of hybrid seed technology has been overlooked in sesame production [13]. Yet, although sesame is a self-pollinated species, it presents many assets for the production of hybrid seeds: high rate of out crossing (up to 65 %) [17], availability of male sterility [18,19], easy mass hybridization technique [19,20], quantity of seeds produced per flower (Sapara et al. 2019). However, hybrid seeds are worth producing only if significant heterosis is present. With this in mind, the sesame variety S42 (also known as Jaaglon 128) was used to pollinate seven lines from a local population cultivar named *Senekuru*. Then, we assessed the agro-morphological diversity of all parental lines and the magnitude of heterosis of progenies from their cross with S42. Genotypes exhibited significant differences for all the traits that were assessed. Furthermore, mid-parent heterosis and heterobeltiosis varied depending on the hybrid and the trait. This article presents and discusses the main results of the study.

2. Material and Methods

2.1. Plant Material

The plant material included the variety S42 used as pollen parent, 7 lines extracted from a local cultivar *Senekuru*, used as female parents, and 7 hybrids from their crosses. The S42 variety is the most grown variety in Burkina Faso and has been very attractive due to its white seeds. The local cultivar *Senekuru* was a population variety, from which seven lines were isolated and were self-pollinated once before being used for hybridization.

2.2. Experiment Location

Experiments were conducted at Farakoba research station, located about 10 km away from Bobo-Dioulasso (11° 60’ N, 4° 20’ W, and 450 m above sea level). The area which presents ferruginous soils [21] is characterized by a dry- and a rainy- seasons [22]. The rainy season spreads from May to October and is characterized by an annual average rainfall of 1.200 mm [22].

2.3. Hybridizations and F_1 Evaluation

2.3.1. Hybridizations

Hybridizations were performed during the dry season (November 2018 to February 2019). To do so, seven lines derived from the so called local population *Senekuru*, were used as female parents and variety S42 was the male parent. Sesame hybridisation [23,24] consisted in the emasculation of female parents the afternoon and their hand pollination with the male parent S42 the next day in the morning.

2.3.2. Evaluation of F_1

The evaluation of hybrids (F_1) and parental lines was carried out during the rainy season (July – September 2019). This trial was performed using an augmented block design with S42 as a check and females and hybrids as test genotypes. Test genotypes were sown in single rows of 5 m long, considering each female and its hybrid as an experimental block. The check S42 appeared in each block. Seeds were sown with a spacing of 20 cm x 80 cm. The fertilizers NPK (14-23-14) and urea (46% nitrogen) were applied at the rate of 100 kg/ha and 50 kg/ha, respectively. Standard agronomic management practices and plant protection measures were applied to assure development of healthy plants.

2.4. Data Collection and Statistical Analysis

The sesame descriptor recommendations of IPGRI and NBPGR [25] was used. The data collection concerned traits such as days to 50% flowering, days to maturity, plant height, stem diameter, primary and secondary branches per plant, number of internodes, length of internodes, capsule length and width, seeds number per capsule, 1000 seed weight, seed yield per plant. Data measurements were carried out using five plants randomly selected in each entry row, except for characters like days to 50% flowering, days to maturity and 1000-seed weight, which were recorded on the plot basis. The grain yield was calculated according to the procedure described by Garfius [26] (1). The collected data were then subjected to analysis of variance to test the significance of differences between genotypes for each trait. Next, Student Newman Keuls test was used to compare means. Furthermore, mid-parent heterosis (2) and heterobeltiosis (3) were calculated according to Hayes, *et al.* [27].

$$W(g) = XYZ \tag{1}$$

(W: yield; X: number of capsules/plant; Y: number of seeds/capsule; Z: seed weight).

$$XMP(\%) = \left(\frac{XF1 - XMP}{XMP}\right) \tag{2}$$

(HMP: mid-parent heterosis; X_{F1}: mean of F_1; X_{MP}: mean of the two parents)

$$XBP(\%) = \left(\frac{XF1 - XBP}{XBP}\right) \tag{3}$$

(HBP: heterobeltiosis; X_{F1}: mean of F_1; X_{BP}: best parent).

3. Results

3.1. Phenotypic Variability

3.1.1. Phenology-Related Traits

The analyses of variance (ANOVA) of traits related to plant phenology showed significant differences among the genotypes. For traits such as 50% flowering and maturity dates, the ANOVA revealed highly significant ($P<0.0001$) differences between parental lines and the hybrids (Table 1). The S42 had the shortest duration among parental lines and hybrids. It reached 50% flowering 33 days after sowing (DAS) while hybrids and female lines reached their 50% flowering between 34 and 49 DAS. The female parent S4B-1 showed the latest date of 50% flowering (47 DAS). Depending on varieties, the days to maturity varied between 81 (S42) and 99 (Senekuru-4-3-2/S42) (Table 1).

Table 1. Analysis of variance for phenology-related traits

Genotypes	Filiation	50%DF	DM
S42	PM	33^{a}	81^{a}
S4B-1	PF	47^{abc}	97^{abc}
S4B-1/S42	F_1	46^{abc}	97^{bc}
Senekuru-1-2	PF	39^{ab}	93^{ab}
Senekuru-1-2/ S42	F_1	38^{ab}	96^{abc}
Senekuru-2-1	PF	39^{ab}	93^{ab}
Senekuru-2-1/ S42	F_1	34^{ab}	95^{abc}
Senekuru-3-1	PF	43^{ab}	95^{abc}
Senekuru-3-1/ S42	F_1	42^{ab}	95^{abc}
Senekuru-4-2	PF	42^{ab}	96^{abc}
Senekuru-4-2/ S42	F_1	43^{c}	93^{ab}
Senekuru-4-3-1	PF	39^{ab}	90^{a}
Senekuru-4-3-1/ S42	F_1	39^{ab}	94^{ab}
Senekuru4-3-2	PF	42^{ab}	90^{a}
Senekuru-4-3-2/S42	F_1	46^{bc}	99^{c}
F		118.6	121.548
P value		<0.0001	< 0.0001

50%DF: Days to 50% flowering; DM: Days to maturity; PM: male parent, PF: female parent.

3.1.2. Morphological Traits

Genotypes were significantly different for the number of primary and secondary branches ($P < 0.0001$). Parental line Senekuru-4-3-2 had the highest number (11) of primary branches. However, the lowest number of branches (3) was presented by the parental line Senekuru-2-1 (Table 2). Significant differences were also recorded for the plant height at maturity ($P < 0.0001$) and stem diameter ($P = 0.0013$). The tallest plant was the hybrid Senekuru-3-1/S42 (188.2 cm) and the shortest plant was S42 with 135.3 cm (Table 2). Also, stem diameters varied significantly ($P = 0.0013$) between 14.75 mm (S42) and 18.9 mm (Senekuru-3-1).

3.1.3. Yield and Yield Components

Sesame capsules showed significant differences for length ($P = 0.0027$) and width ($P = 0,007$). There was also significant variation ($P < 0.0001$) in the number of capsules per plant across genotypes. The highest number of capsules per plant was recorded with the line S4B-1 (485.8) and the lowest with S42 (67.28). The number of seeds per capsule varied significantly ($P < 0.0001$) among genotypes, between 33.8 (Senekuru-4-3-1/S42) and 65 (Senekuru-4-2/S42) seeds per capsules. The variation in 1000-seeds' weight, which was also significant ($P = 0.0284$), ranged between 2.8 g (S4B-1) and 4.1 g (Senekuru-1-2/ S42). Grain yields were significantly different ($P < 0.0001$). The best performing genotype for seed yield per plant was S4B-1 (74.5 g/plant) and the worst genotype was S42 (13.35 g/plant). The boxplots show the pattern of grain yields depending on genotypes (Figure 1).

3.2. Correlation between Traits

The Pearson's correlation coefficients revealed variable types of correlations between evaluated traits (Table 4), some of which were significant. Thus, there was a positive and significant correlation ($r = 0.83$) between days to 50% flowering and days to maturity. In addition, grain yields were positively and significantly correlated with traits such as number of primary and secondary branches, plant height, and number of capsules per plant. The 1000 seeds' weight was significantly but negatively correlated with number of capsules per plant ($r = -0.45$) and with number of secondary branches ($r = -0.46$). In addition, plant height was positively correlated with number of capsules ($r = 0.55$) (Table 4).

Table 2. Analysis of variance for morphological traits

Genotypes	NBP	NBS	NEN	HP (cm)	DC (mm)	LgE (cm)
S42	4.6^{a}	2.8^{b}	23.4^{a}	135.3^{a}	14.75^{a}	9.08^{a}
S4B-1	9.8^{d}	9.4^{f}	31.75^{a}	174.2^{h}	17.32^{abc}	11.4^{ab}
S4B-1/s42	6^{b}	2.2^{b}	28^{a}	144.4^{b}	17.5^{bc}	10.2^{ab}
Senekuru-1-2	5.8^{b}	3.8^{bcd}	36.2^{b}	160.2^{d}	16.54^{ab}	9.6^{a}
Senekuru-1-2/ S42	6.6^{b}	2^{b}	30^{a}	150^{c}	16.56^{ab}	10^{ab}
Senekuru-2-1	3.6^{a}	0.4^{a}	26.2^{a}	148.4^{c}	16.36^{ab}	7.8^{a}
Senekuru-2-1/ S42	4^{a}	0.2^{a}	32.6^{a}	170.4^{g}	17.2^{abc}	9.4^{a}
Senekuru-3-1	6.2^{b}	0.6^{a}	29.6^{a}	167.8^{f}	18.9^{bc}	12^{bc}
Senekuru-3-1/ S42	4^{a}	3.2^{bc}	40.8^{c}	188.2^{j}	20.04^{c}	10.2^{ab}
Senekuru-4-2	9.4^{d}	4.6^{cde}	29.2^{a}	164.6^{e}	17.48^{bc}	13.2^{c}
Senekuru-4-2/ S42	7.6^{c}	5.5^{de}	32.2^{a}	163.8^{e}	17.44^{bc}	10.6^{ab}
Senekuru-4-3-1	5.8^{ab}	5^{cde}	33.8^{a}	184^{i}	17.32^{bc}	6.6^{a}
Senekuru-4-3-1/ S42	6^{b}	3.6^{bcd}	33.4^{a}	144.8^{b}	17.74^{bc}	8^{a}
Senekuru4-3-2	11.2^{e}	14.5^{g}	33.6^{a}	149.4^{c}	16.2^{ab}	12^{abc}
Senekuru-4-3-2/S42	6.4^{b}	6.2^{e}	36.2^{ab}	163^{e}	17.78^{bc}	10.2^{ab}
F	224	109.5	377.5	1237.1	15.9	27.9
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0013	0.0002

NBP: number of primary branches, NBS: number of secondary branches, NEN: number of internodes; HP: plant height; DC: stem diameter; LgE: internode length; PM: male parent, PF: female parent.

Table 3. Analysis of variance for yield and yield components

Genotypes	LgC (cm)	LrgC (cm)	NCP	NGC	P1000G (g)
S42	2.58^{ab}	0.86^{a}	67.28^{a}	59.37^{g}	3.34^{ab}
S4B-1	2.5^{a}	0.88^{ab}	485.8^{l}	54.8^{ef}	2.8^{a}
S4B-1/s42	2.56^{ab}	0.98^{abc}	219.8^{k}	57.4^{efg}	3.4^{ab}
Senekuru-1-2	2.74^{abc}	1.12^{c}	88.2^{c}	54^{e}	3.4^{ab}
Senekuru-1-2/ S42	2.82^{abc}	1.02^{abc}	82.4^{b}	49.2^{d}	4.1^{b}
Senekuru-2-1	2.7^{ab}	1.04^{bc}	96.4^{d}	44.2^{b}	3.2^{ab}
Senekuru-2-1/ S42	2.82^{abc}	0.98^{abc}	100.8^{e}	58.2^{fg}	3.3^{ab}
Senekuru-3-1	2.94^{abc}	1.02^{abc}	173^{h}	47.6^{cd}	3.3^{ab}
Senekuru-3-1/ S42	3.14^{c}	1^{abc}	200^{j}	54^{e}	3.4^{ab}
Senekuru-4-2	2.52^{ab}	0.92^{abc}	134.8^{f}	50.6^{d}	3.6^{ab}
Senekuru-4-2/ S42	2.88^{abc}	0.94^{abc}	147.4^{g}	65^{h}	3.2^{ab}
Senekuru-4-3-1	2.72^{ab}	0.96^{abc}	148.8^{g}	45.4^{bc}	2.9^{a}
Senekuru-4-3-1/ S42	2.56^{ab}	0.94^{abc}	137.4^{f}	33.8^{a}	2.8^{a}
Senekuru4-3-2	2.94^{abc}	1.02^{abc}	199.2^{j}	55.8^{ef}	2.9^{a}
Senekuru-4-3-2/S42	3.14^{bc}	1^{abc}	183.2^{i}	63.4^{h}	3.3^{ab}
F	12.3	8.7	9687.1	140.6	5
P (5%)	0.0027	0.007	<0.0001	<0.0001	0.0284

LgC: capsule length; LrgC: capsule width; NCP: number of capsules per plant; NGC: number of seeds per capsule; P1000G:1000-seeds weight.

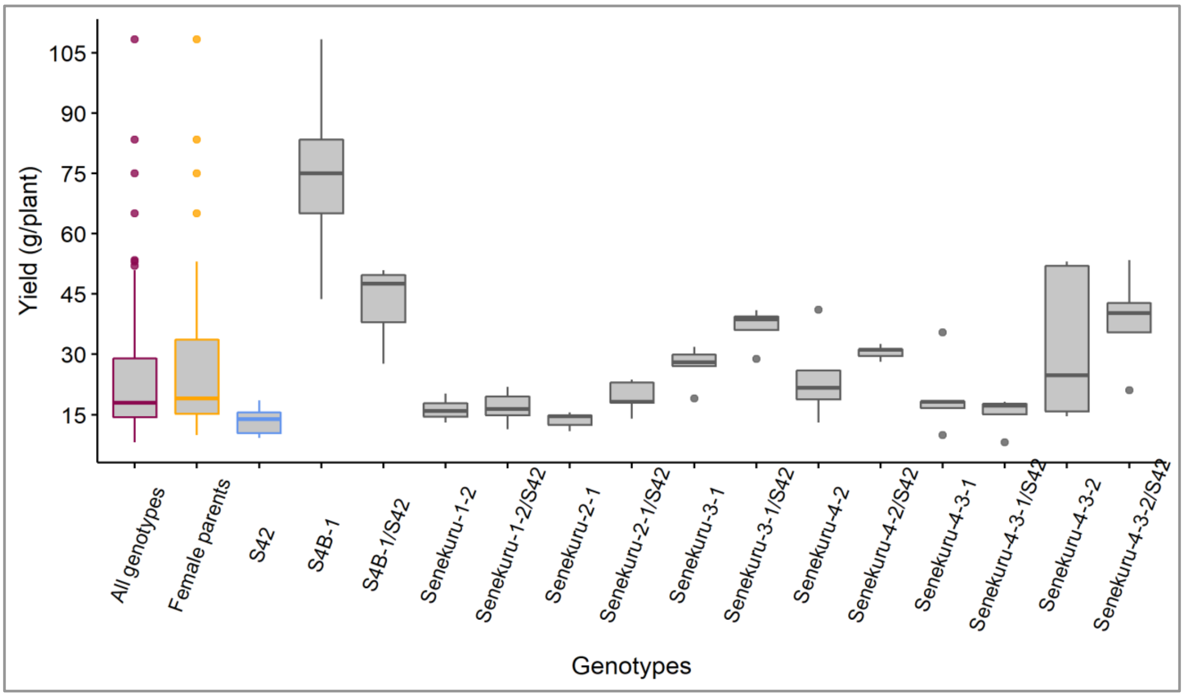

Figure 1. Boxplot of seed yield per plant (g) of hybrids and parental lines

Table 4. Correlation coefficients for yield and yield-contributing traits

Traits	50%DF	NBP	NBS	HP	LgC	LrgC	DM	NCP	NGC	P1000G	DC	W
50%DF	1											
NBP	0.59**	1										
NBS	0.41	0.82***	1									
HP	0.62**	0.27	0.18	1								
LgC	0.45*	0.05	0.16	0.54**	1							
LrgC	0.48*	0.14	0.03	0.47*	0.58**	1						
DM	0.83***	0.43	0.14	0.71***	0.45*	0.67**	1					
NCP	0.71***	0.61**	0.54**	0.55**	0.09	0.09	0.57**	1				
NGC	-0.09	-0.05	0.12	-0.22	0.11	-0.33	-0.35	-0.08	1			
P1000G	-0.19	-0.24	-0.46*	-0.18	0.07	0.09	-0.01	-0.45*	0.22	1		
DC	0.77***	0.25	0.06	0.83***	0.59**	0.58**	0.84***	0.52**	-0.37	-0.09	1	
W	0.76***	0.58**	0.52**	0.53**	0.18	0.09	0.59**	0.96***	0.12	-0.30	0.52**	1

50%DF: Days to 50% flowering; DM: Days to maturity; NC: number of carpella; NBP: number of primary branches; NBS: number of secondary branches; HP: plant height; DC: stem diameter; LgC: capsule length; LrgC: capsule width; NCP: number of capsules per plant; NGC: number of seeds per capsule; P1000G: 1000-seeds weight; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Table 5. Mid-parent heterosis (HMP) and heterobeltiosis (HBP) of the 7 sesame hybrids for variable traits

	Senekuru-4-3-2/S42		S4B-1/S42		Senekuru-3-1/S42		Senekuru-2-1/S42		Senekuru-4-2/S42		Senekuru-4-3-1/S42		Senekuru-1-2/S42	
Traits	HMP (%)	HB P(%)	HMP (%)	HBP (%)	HMP (%)	HBP (%)	HMP (%)	HBP (%)	HMP (%)	HBP (%)	HMP (%)	HBP (%)	HMP (%)	HBP (%)
50%DF	25.33	11.90	15.00	0.00	13.16	0.00	-4.23	-12.82	25.33	11.90	8.33	0.00	5.56	-2.56
NBP	-17.95	-42.86	-16.67	-38.78	-25.93	-35.48	-4.76	-16.67	8.57	-19.15	17.65	3.45	24.53	13.79
NBS	-27.49	-57.24	-63.33	-76.60	128.57	45.45	-88.89	-93.75	44.74	19.57	-7.69	-28.00	-42.86	-47.37
HP	14.71	9.10	-6.96	-17.11	24.55	12.16	20.00	14.82	9.20	-0.49	-9.39	-21.30	1.49	-6.37
LgC	15.02	6.80	0.00	-2.29	13.36	6.80	6.02	4.44	10.34	6.67	-2.66	-5.88	7.22	2.92
LrgC	7.53	-1.96	10.11	8.89	5.26	-1.96	5.38	-5.77	4.44	2.17	3.30	-2.08	0.99	-8.93
DM	15.79	10.00	8.99	0.00	7.95	0.00	9.20	2.15	5.08	-3.13	9.94	4.44	10.34	3.23
NCP	37.13	-8.03	-20.36	-54.76	66.25	15.61	21.89	4.56	46.67	9.35	26.75	-7.66	6.87	-6.58
NGC	11.03	8.56	0.17	-4.01	1.12	-8.78	13.01	-1.02	16.91	7.26	-35.25	-42.71	-13.53	-17.73
P1000G	4.76	-2.94	9.68	0.00	7.94	3.03	0.00	-2.94	-8.57	-11.11	-11.11	-17.65	20.59	20.59
W	67.61	18.91	-2.51	-42.45	87.44	35.12	41.16	40.34	60.54	24.86	-21.74	-33.62	12.26	2.64
DC	18.14	9.75	7.30	1.04	20.14	6.03	10.82	5.13	7.26	-0.23	9.71	2.42	5.48	0.12

50%DF: Days to 50% flowering; DM: Days to maturity; NBP: number of primary branches, NBS: number of secondary branches, HP: plant height; DC: stem diameter, PM: male parent, PF: female parent; LgC: capsule length; LrgC: capsule width; NCP: number of capsules per plant; NGC: number of seeds per capsule; P1000G: 1000-seeds weight.

3.3. Estimation of Heterosis

Mid-parent heterosis and heterobeltiosis were estimated for seven hybrids based on 12 traits (Table 5). Mid-parent heterosis ranged from -88.89% to 128.57 % and heterobeltiosis ranged from -93.75 % to 45.45 %. Both heterosis and heterobeltiosis were dependent on crosses and traits. High and positive mid-parent heterosis was recorded for the plant duration to maturity, and the highest value was obtained with the hybrid Senekuru-4-3-2/S42 (Table 5). The heterobeltiosis for this trait varied between -3.13 % and 10.00%. Six hybrids had positive mid-parent heterosis for 50% flowering time; however, only two hybrids had positive heterobeltiosis.

Furthermore, mid-parent heterosis varied between -9.39 and 24.55% for plant height, and between 5.48 and 20.14% for stem diameter in all hybrids. Four hybrids showed positive heterosis for plant height, with Senekuru-3-1/S42 presenting the highest value (24.55%). For this trait, heterobeltiosis varied between -21.30 % and 14.82 % for plant height and between -0.23 % and 9.75 % for stem diameter. Additionally, the mid-parent heterosis for the number of primary branch was the highest with the hybrid Senekuru-1-2/S42 (24.53%) and the lowest with Senekuru-3-1/S42 (-25.93%). For the same trait, heterobeltiosis ranged from -42.86 % to 13.79 %. Regarding the length of capsules, all the hybrids showed positive mid-parent heterosis. With regards to 1000-seeds' weight, the mid-parent heterosis and heterobeltiosis fall in the range between -11.11 % to 20.59 % and -42.71 % to 8.56 %, respectively. For seed yield, the best value of mid-parent heterosis (87.44%) was recorded by Senekuru-3-1/S42 while Senekuru-2-1/S42 recorded the best heterobeltiosis (40.34%).

4. Discussion

The extent and direction of heterosis are important for breeding programmes, and these usually stem for genetic variability of parents involved. In this study, the ANOVA revealed significant differences between parental genotypes and hybrids for all the traits. Such phenotypic variability among the parents involved in the crosses and their breeding values are highly conducive of heterotic response of F_1 hybrids [28]. Heterosis for commercially important traits is attributable to simultaneous expression of many genes modulating agro-morphologic component traits, which favourable alleles interact in hybrid individuals [29], resulting in additive or synergistic effect on target traits [30,31,32,33].

Traits pertaining to plant phenology are very important in plant breeding and can be used to develop new cultivars with durations perfectly adapted to local ecological conditions. The variety S42 proved to be the most early-maturing variety with the shortest duration to 50% flowering and to maturity. The earliness of S42 was reported previously [11,34], and may explain the massive adoption of this variety in Burkina Faso. For such a trait, negative heterosis was desirable. However, none of the hybrids presented a better earliness than parents, indicating that traits related to the plant phenology may not be appropriate target for hybrid production. However, this result might be dependent on parental varieties, because negative heterosis had been attained for earliness in previous studies [35,36,37]. More generally, negative heterosis is sought for traits like earliness and disease susceptibility [38]. Despite the absence of negative heterosis, since five out of seven F_1 progenies were earlier than their parents presenting the longest duration, such hybrids can still be useful by providing some developmental benefits to the crop, be it small.

The hybrids usually exhibited more robust morphologies than parental lines, attributable to heterosis. Sesame plants' robustness was measured through plant height and stem diameter, which are two important traits for the crop breeding. Indeed, plant height and branch number are known to be positively correlated with yield [39,40], due essentially to the capacity of tall and tillered plants to produce more capsules and thus resulting in more seed yields. The indeterminate growth habit in sesame provides permanent branching and capsule production [39], however, such a trait is not always practical in farming, since it results in progressive seed maturation. Setbacks of progressive seed maturation include lodging, which commonly causes important yield loss. Therefore, determinate growth habit is desirable to obtain grouped crop maturation, facilitate harvest and minimise lodging.

Although only one hybrid showed a positive mid-parent heterosis for 1000-seeds' weight, this is sufficient to conclude that this trait can be enhanced through hybrid seeds. The negative correlations detected between 1000-seeds' weight and number of capsules per plant and number of secondary branches, shows that capsule abundance results in reduced seed size. Similar correlations between these traits were reported previously [41]. Yet, in the present study, the highest heterosis was recorded for the number of branches per plant, which correlated well with seed yields. Thus, accrued attention must be observed when selecting simultaneously for seed yield and seed size, to minimise the loss of one target trait for the other. To improve the yield components that have negative association with one another, suitable recombinants should be developed through strategic mating design. Based on mid-parent heterosis value for plant height, female parents like Senekuru-2-1, Senekuru-4-3-2, Senekuru-3-1, Senekuru-4-2, Senekuru-1-2 should be ideal to improve this trait. In the same way, Senekuru-3-1 would make a perfect parent to provide heterosis for number of capsules per plant in combination with variety S42. However, these assumptions are dependent on their combining ability with provisional mating parents.

Concerning seed yield, four out of seven hybrids exhibited positive heterosis, with Senekuru-3-1/S42 exhibiting the best value of mid-parent heterosis (87.44%), while Senekuru-2-1/S42 presented the best heterobeltiosis (40.34%). With this much level of heterosis, hybrid seeds of sesame have the potential to confer near two folds productivity to the crop. This conclusion is also supported by the high and positive heterosis for capsules number per plant, which is an important yield component trait. The present results corroborate with many studies previously conducted elsewhere [42,43].

To conclude, the present study was conducted to assess the magnitude of heterosis in hybrids resulting from genetically diverse genotypes. A high phenotypic diversity was found among genotypes. This diversity within the plant materials was certainly crucial for the expression of heterosis in F_1 progenies. Thus, the cross between local lines and S42 provided good hybrid vigour for several traits, despite the variability in their combining abilities. However, traits do not present heterosis in the same direction in hybrid plants. Therefore, a trade-off is needed between the most targeted traits for the development of the ideal hybrid variety. Mid-parent heterosis and heterobeltiosis varied from cross to cross and showed that overall, hybrid seeds can significantly enhance agro-morphological traits in sesame. As a self-pollinated crop, the challenge would be to develop an efficient and practical cross-pollination method to be commercially viable.

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Statement of Competing Interests

The authors declare that they have no competing interests.

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