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Combining Ability and Heterosis among Bottle Gourd [*Lagenaria siceraria* (Molina) Standl.] Selections for Yield and Related Traits under Drought-Stressed and Non-Stressed Conditions

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Abstract: Bottle gourd [*Lagenaria siceraria* (Molina) Standl.] is cultivated for multiple utilities, including as a leafy vegetable, for fresh and dried fruits and seeds. It is an under-researched and -utilized crop, and modern varieties are yet to be developed and deployed in sub-Saharan Africa (SSA). There is a dire need for pre-breeding and breeding of bottle gourds for commercialization in SSA. Therefore, this study aimed to determine the combining ability and heterosis among selected genotypes of bottle gourd for fruit yield and related traits under drought-stressed and non-stressed conditions to select the best parents and hybrids. Eight preliminarily selected and contrasting parents with drought tolerance were crossed using a half-diallel mating design. The 8 parents and 28 crosses were evaluated under non-stressed (NS) and drought-stressed (DS) conditions across two growing seasons (2020/21 and 2021/22) using a 6 × 6 alpha lattice design with three replicates. Data were collected on fruit yield and related traits and subjected to analysis of variance, combining ability and heterosis analyses. Significant ($p < 0.05$) specific combining ability (SCA) and general combining ability (GCA) effects were computed for fruit yield per plant (FYPP). The SCA × environment and GCA × environment interaction effects were highly significant ($p < 0.001$) for FYPP and SYPP. The results suggest that genetic effects were affected by the test environment. Parental genotypes BG-58 and GC recorded positive and significant GCA effects for FYPP under the DS condition, whereas GC recorded positive and significant GCA effects for FYPP under the NS condition. The two genotypes are ideal breeding parents for population development to select genotypes with high fruit and seed yields. Crosses BG-27 × BG-79, BG-79 × BG-52, BG-79 × BG-70, BG-80 × BG-70, BG-80 × GC, and BG-70 × GC recorded high and positive SCA effects for FYPP and SYPP under DS condition. Crosses BG-81 × BG-52, BG-81 × GC, BG-27 × BG-79, BG-27 × GC, BG-79 × GC, BG-80 × BG-70, BG-81 × BG-58, BG-27 × BG-80, BG-27 × BG-58, BG-79 × BG-52, BG-52 × BG-58, BG-80 × BG-58, and BG-58 × BG-70 recorded high and positive SCA effects for FYPP and SYPP under NS condition. Crosses BG-80 × BG-58, BG-27 × BG-79, BG-79 × BG-52, BG-27 × BG-52, and BG-52 × BG-80 showed high and positive mid- and better-parent heterosis under DS condition for FYPP and SYPP. Crosses BG-27 × GC, BG-79 × GC, BG-27 × BG-58, and BG-27 × BG-79 showed high and positive mid- and better parent heterosis under NS condition for FYPP and SYPP. The newly selected families are recommended for multi-environment evaluation forrelease and commercialization in South Africa or similar agroecologies.

Keywords: abiotic stress; bottle gourd; general combining ability; specific combining ability; gene action

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Citation: Mkhize, P.; Shimelis, H.; Mashilo, J. Combining Ability and Heterosis among Bottle Gourd [*Lagenaria siceraria* (Molina) Standl.] Selections for Yield and Related Traits under Drought-Stressed and Non-Stressed Conditions. *Diversity* **2023**, *15*, 925. https://doi.org/10.3390/d15080925

Academic Editor: Samir C. Debnath

Received: 6 July 2023
Revised: 3 August 2023
Accepted: 11 August 2023
Published: 14 August 2023

1. Introduction

Bottle gourd [*Lagenaria siceraria* (Molina) Standl., 2n = 2x = 22] is a multi-purpose crop belonging to the *Cucurbitaceae* family. It is a highly valued food security crop in Africa and Asia [1–5]. In Africa, the large and tender leaves are cooked and consumed as a leafy vegetable. The young, tender fruits are harvested and boiled until soft and consumed by adding sugar, peanuts, salt, or milk, depending on consumer preferences. The matured seeds extracted from dried fruits are processed to prepare livestock feed. The fruits of bottle gourd are an excellent source of essential macro- and micro-nutrients, including minerals (e.g., iron, phosphorus, potassium, calcium, and magnesium), vitamins B, C, and E, carbohydrates, and dietary fiber [1,3,4,6–11]. The fruits are also a good source of essential amino acids, including aspartic acid, threonine, serine, glutamic acid, alanine, valine, phenylalanine, lysine and arginine, and phytochemical compounds, including phenolics, flavonoids and terpenoids [9,10]. Wild fruits of the crop are bitter due to the presence of cucurbitacins, which possess pharmaceutical values including anti-cancer and anti-diabetes [10–12]. The leaves are a good source of essential nutrients such as zinc, nitrogen, manganese, and copper [8]. The seeds are a source of crude protein, crude lipids, crude fiber, and carbohydrates [13–15]. The seeds are valued for their antioxidants, sterols, and vitamins, including ascorbic acid, thiamine, riboflavin, niacin, pantothenic acid, and vitamin B-6 [13]. In addition, the seeds contain essential amino acids, including glutamic acid, leucine acid, arginine, lysine, and aspartic acid [16].

Bottle gourd is one of the widely used rootstocks for grafted watermelon. It confers desirable qualities such as better fruit yield and quality and resistance to biotic (e.g., fungal and viral diseases) and abiotic (heat and drought) stress factors in grafted watermelons [17–22]. In Africa, bottle gourd is cultivated using genetically unimproved landrace varieties that are phenotypically and genetically diverse with low yield potential [2,5,23]. In farmers' fields, different accessions are often planted in companion with the major crops, mainly maize, sorghum, soybeans, and rice. The landrace accessions display genetic variation and are selected by growers for their long handles/necks to make containers, and corrugated fruit with or without fruit necks are mainly for consumption. The round fruit-shaped gourds are used to make containers called "Kgapa" in the indigenous and local Sepedi language of South Africa. Planting diverse accessions in close proximity by farmers allows for cross-pollination, leading to high genetic recombination and genetic variation. The reported genetic diversity in different regions includes bottle gourd fruit having long curved-neck shapes, fruits with long straight-neck lengths, circular, oblate, pyriform, cavate, cylindrical fruit shapes, dark green fruit color and and other traits such as variation in the number of leaves and plant height [2,5,24–27]. In India, Turkey, India, China, and the USA, higher genetic variability of the crop has been reported [2,25,28–31]. The high genetic variation in bottle gourd allows for new variety designs with desirable consumer attributes, including high fruit and seed yields and other valuable traits such as fruit shape, size, color, and neck to enhance the crop's market value in Africa.

The phenotypic variability of bottle-gourd genetic resources is documented via agronomic and horticultural traits. These include aboveground plant traits (e.g., plant height, number of primary and secondary branches), flower traits (e.g., number of male and female flowers), fruit traits (e.g., fruit shape, fruit weight, fruit yield, fruit texture, fruit color, fruit with or without neck, fruit neck length, fruit neck bending) and seed traits (e.g., number of seeds per fruit, seed length, seed width, seed size, hundred seed weight, seed yield, seed coat color, seed texture) [2,25,27,28,32]. These traits are useful for targeted selection to develop new varieties targeting the various end-use values of the crop. For example, leaf traits such as leaf number, size, and plant height are essential to developing varieties suited for leaf vegetable and livestock fodder. Increasing the proportion of female than male flowers can aid the development of high-yielding hybrids. Increased fruit number and weight can improve fruit yield, whereas a high count of seeds per plant and increased seed weight are essential attributes to breeding high seed-yielding varieties. Some economic traits in bottle gourd are positively correlated and useful for selecting genotypes with better fruit and seed yields. For instance, fruit weight and fruit number have a direct positive effect on seed yield per fruit and fruit yield, suggesting their simultaneous selection and improvement [33,34]. These associations will allow for the breeding of bottle gourd varieties incorporating multiple traits.

Genotype selection with a desirable and complementary product profile requires progeny evaluation based on combining ability and heterosis analyses. Combining ability analysis has aided the selection of parental genotypes and progenies with high fruit yield for genetic advancement [33,35–38]. Fruit yield and related traits in bottle gourd were conditioned by non-additive gene action [31]. Complex gene action, including duplicate gene interaction, complimentary gene action, or non-allelic interaction, was reported for fruit yield in bottle gourd [38,39]. Refs. [40,41] reported high GCA compared to SCA effects for fruit yield, indicating the involvement of additive gene action conditioning their inheritance. Analysis of heterosis in bottle gourd identified the dominant form of heterosis for plant height, fruit length, and the number of branches, aiding the identification of hybrids for use in strategic breeding and variety release [40].

Presently, in Africa, bottle gourd is an under-researched and -utilized crop, and modern varieties are yet to be developed and deployed. There is a dire need for pre-breeding and breeding bottle gourds with increased fruit and seed yield to enhance the market value of the crop. In previous studies, Ref. [42] identified accessions of bottle gourd with desirable agronomic attributes, including high fruit and seed yields useful for hybrid breeding. Ref. [43] recently developed F_1 hybrids of bottle gourd derived from unimproved accessions for cultivation in the cooler environments of KwaZulu-Natal Province of South Africa. These newly developed hybrids performed better regarding fruit yield than the parental landrace accessions, indicating the possibility of developing cultivars with high yield potential and other desirable farmer-preferred traits. The next generation of improved bottle gourd varieties should comprise traits and attributes with multiple uses, including fodder, seed, and fruit, to serve varied value chains in the food, feed, and processing industries. Therefore, the objective of this study was to determine the combining ability and heterosis among selected genotypes of bottle gourd for fruit yield and related traits under drought-stressed and non-stressed conditions to select the best parents and hybrids for breeding.

2. Plant Material and Generation of Hybrids

The study used eight selected bottle gourd landrace accessions as parental genotypes for hybrid development. The selected bottle gourd accessions are widely grown in the Limpopo Province of South Africa by small-holder farmers for food (Table 1). The accessions are phenotypically and genetically divergent based on previous studies [27,32]. Additionally, the accessions exhibit varied responses to drought stress [42,44,45]. The Limpopo Department of Agriculture and Rural Development maintains the landrace accessions at Toowoomba Agricultural Development Centre (TADC), Bela-Bela, South Africa.

Table 1. List and attributes of selected bottle gourd genotypes used in the cross.

Accession Designation	Drought Response	Fruit Shape	Fruit Neck Length	Primary Fruit Color
BG-27	Tolerant	Cavate	Long	Dark green
BG-52	Tolerant	Cavate	Long	Medium green
BG-58	Susceptible	Elongated	Long	Dark green
BG-70	Susceptible	Elongated	No neck	Dark green
BG-79	Tolerant	Pyriform	Short	Light green
BG-80	Susceptible	Elongated	Short	Dark green
BG-81	Susceptible	Pyriform	No neck	Light green
GC	Tolerant	Pyriform	No neck	Light green

The eight parental accessions were grown in a 5 L capacity polyethylene plastic pots under glasshouse conditions at the University of Limpopo (−25°36′54″ S, 28°0′59.76″ E, 1312 m above sea level), South Africa. Five seeds per accession were sown in well-drained polyethylene plastic containing a loamy soil collected from the University of Limpopo, Syferskuil Experimental farm (−23°53′9.60″ S, 29°44′16.80″ E, 1312 m above sea level). Three plants were retained per accession in each pot two weeks after emergence and were watered daily to maintain soil moisture content approximately at field capacity (i.e., 40% *v*/*v*). Plants were allowed to grow until the development of male and female flowers, which occurred approximately 38 and 46 days after planting, respectively. The male flowers were brushed gently onto the female flower to ensure sufficient pollen for cross-pollination. The crosses were developed using a half-diallel mating design aiming for 28 crosses. The fully developed fruits from each of the crosses were labeled and sun-dried for up to four months. The seeds were extracted from the fruits, sun-dried, placed in labeled paper bags, and then stored in a dry, cool place for later use.

2.1. Study Site and Experimental Design

Field experiments were conducted at the University of Limpopo's Syferskuil research farm, Mankweng, South Africa, during the 2020/21 and 2021/22 growing seasons. The area is characterized by sandy and loamy soils. The average rainfall received during the 2020/21 and 2021/22 growing seasons were 243 and 198 mm, respectively. The maximum temperature and relative humidity ranged from 26 to 34.8 °C and 60% to 88% for both growing seasons. The 8 parental genotypes and 28 successful crosses were evaluated under non-stressed (NS) and drought-stressed (DS) conditions using a 6 × 6 α-lattice design with three replications. In each block, three plants were established for parental accessions and crosses. The two water conditions and growing seasons provided four testing environments. Parents and crosses were planted at an intra-and-inter row spacing of 5 × 5 m apart. Sprinkler irrigation was used to water the plants. In the first two weeks after planting, the second true leaf stage, plants under both DS and NS conditions were watered weekly with approximately 27 mm of water. Thereafter, supplemental irrigation of approximately 27 mm of water was applied per week for plants grown under NS condition, whereas plants under DS condition were rain-fed. The total amount of water received by the plants grown under the NS condition was approximately 670 mm, whereas those under the DS condition received approximately 256 mm during the 2020/21 growing season. During the 2021/22 growing season, plants under the NS condition received approximately 680 mm of water, whereas those under the DS condition received approximately 269 mm of water. The plants under DS condition experienced a drought stress intensity of about 0.7 during the first and second seasons, which was calculated using the following formula:

$$\mathrm{DSI} = \frac{\mathrm{Xns} - \mathrm{Xds}}{\mathrm{Xns}}$$

where DSI is drought stress intensity; Xns, mean fruit yield averaged across all the genotypes tested under NS condition; Xds mean fruit yield averaged across all the genotypes tested under DS condition [46,47].

2.2. Data Collection

Data were collected on a single randomly selected and tagged plant out of the three plants in each block for parental genotypes and crosses. The following agronomic traits were measured: total number of male and female flowers per plant, sex ratio calculated as the total number of male flowers per plant to the total number of female flowers per plant, number of leaves per plant, plant height measured from the base of the plant to the tip of the main vine in meters, number of fruits per plant, single fruit weight of dried fruit (kg), fruit circumference (cm) measured as the horizontal distance around the boundary of the fruit, fruit yield per plant (kg), number of seeds per fruit, hundred seed weight (g) and seed yield per plant (kg). The fruit-related traits were measured on a single fully developed fruit per plant.

2.3. Data Analysis

2.3.1. Analysis of Variance

Analysis of variance was performed using GenStat version 18 [48]. The Least Significant Difference (LSD) test was computed to compare treatment means at the 5% level of significance.

2.3.2. Estimates of Best Linear Unbiased Predictors

Best Linear Unbiased Predictors (BLUPs) were calculated using META-R (Multi Environment Trail Analysis with R for Windows) Version 6.0 [49]. The BLUPs estimates were computed based on the lattice design procedure using the following linear model:

$$Y_{ijkl} = \mu + Loc_i + Rep_j(Loc_i) + Block_k(Loc_iRep_j) + Gen_l + Loc_i \times Gen_l + \varepsilon_{ijkl}$$

where,

Y_{ijkl} = the trait of interest,
μ = overall mean effect,
Loc_i = effects of the ith environment,
Rep_j = effects of the jth replicate,
$Block_k$ (Rep_i) = effects of the kth incomplete block within the jth replicate,
$Loc_i \times Gen_l$ = environment $\times$ genotype interaction,
Gen_j = effects of the lth genotype,
ε_{ijkl} = error associated with the ith replication, jth incomplete block and the kth genotype, which is assumed to be normally and independently distributed, with mean zero and homocedastic variance σ^2. Genotypes, environment, and interactions were treated as random factors effects to calculate BLUPs.

2.4. Estimates of the GCA and SCA Effects

The significant tests for GCA and SCA effects were estimated using PBTools version 1.4 [47]. The GCA and SCA effects and genetic variance components were estimated using AGD-R (Analysis of Genetic Designs in R) Version 5.0 [50] using a half-diallel mating design, method II, and model I. The analysis was performed using the following fixed-effect model:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

where,

Y_{ijk} = value for the ijth cross in the kth replication
μ = the population mean,
g_i and g_j = GCA effects for the ith and jth parents
s_{ij} = the SCA effect of the cross of the ith and jth parents
e_{ijk} = error term associated with the cross of the ith and jth parents in the kth replication

2.5. Gene Action and Heritability Estimates

Broad sense heritability (h^2B), narrow sense heritability (h^2n), additive variance (σ^2A), and dominance variance (σ^2D) were calculated according to [49,51] using the following formula:

$$h^2B = \frac{\sigma^2 g}{\sigma^2 g + \frac{\sigma^2 ge}{nLoc} + \sigma^2\varepsilon/(nLoc \times nRep)}$$

where,

σ^2 g = genotypic variance,
$\sigma^2\varepsilon$ = error variance,
$nRep$ = number of replicates,
$\sigma^2 ge$ = G $\times$ E interaction variance,
$nLoc$ = number of environments in the analysis

$$h^2n = \frac{\sigma^2 A}{\sigma^2 A + \sigma^2 D + \sigma^2 E}$$

where,
$\sigma^2 A$ = additive variance component,
$\sigma^2 D$ = dominance variance component,
$\sigma^2 E$ = environmental variance

$$\sigma^2 A = 4\sigma^2 gca$$

where *gca* = general combining ability effect

$$\sigma^2 D = 4\sigma^2 sca$$

where *sca* = specific combining ability effect

2.6. Heterosis Estimates

Mid-parent heterosis (*MPH*) and better-parent heterosis (*BPH*) were computed according to the following equations [52]:

$$MPH = 100 \times \left(\frac{F1 - MP}{MP}\right) \quad \text{and}$$
$$BPH = 100 \times \left(\frac{F1 - BP}{BP}\right)$$

where,
$F1$ = mean performance of $\boldsymbol{F}_1$,
MP = mean of the two parents making the cross and
BP = mean of the better parent for that particular cross.

2.7. Correlation Analysis

The BLUPs estimates were used to compute Pearson correlation coefficients to determine the associations between assessed agronomic traits using SPSS version 25 (SPSS Inc., Chicago, IL, USA, 2018).

3. Results

3.1. Genotype, Water Condition, and Their Interaction Effects

Analysis of variance showing the main effects of genotype, water conditions, and their interaction for the studied agronomic traits are shown in Table 2. Significant genotypic effects ($p < 0.001$) were recorded for all traits except for SR. The effects of water conditions were highly significant ($p < 0.001$) for all the traits. Genotype × environment interaction effects were significant ($p < 0.001$) for all assessed traits.

3.2. Performance of Bottle Gourd Parents and Hybrids for Assessed Traits

BLUPs estimates for the assessed traits for parents and their hybrids under DS and NS conditions across the two growing seasons are presented in Tables 3 and 4, respectively. An approximately 50% increase in the performance of the different parental genotypes and hybrids was recorded for NMF, NFF, PH, NFPP, FC, NSPF, and SYPP under the NS condition compared to the DS condition. Under DS condition, a high FYPP of >0.4 kg was recorded for crosses BG-52 × BG-58, BG-79 × BG-52, BG-80 × BG-58, and BG-80 × GC, while a low FYPP of <0.2 kg was recorded for approximately 18% of the crosses. Higher FYPP of >0.4 kg was recorded for parental genotypes GC, and low FYPP of <0.2 kg was recorded for five parental genotypes, including BG-27, BG-52, BG-79, BG-80, and BG-81. Under NS condition crosses, BG-27 × BG-52 recorded a higher FYPP of >9.5 kg, whereas BG-80 × BG-70 recorded the least FYPP of 0.4 kg. Parents BG-70 and GC recorded high FYPP of 1.6 and 2.8 kg, respectively, whereas all the other parents recorded a low FYPP of <1 kg.

Table 2. Analysis of variance showing mean squares and significant tests for the parental genotypes and their crosses evaluated for agronomic/horticultural traits under non-stressed and drought-stressed conditions across two growing seasons in South Africa.

Source of Variation	Traits												
	df	NMF	NFF	SR	NL	PH	NFPP	FW	FC	FYPP	NSPF	HSW	SYPP
Incomplete Block (IB)	5	8922.00 **	432.2 **	12.94 *	11,562.00 ^{ns}	15.68 ^{ns}	16.9 ^{ns}	0.01 ^{ns}	3292.20 **	0.39 ^{ns}	157,280.00 **	24.83 ^{ns}	0.15 ^{ns}
IB × Replication (Reps)	10	4309.00 ^{ns}	129.90 ^{ns}	7.45 ^{ns}	4050.00 ^{ns}	68.71 ^{ns}	5.39 ^{ns}	0.00 ^{ns}	114.3 ^{ns}	0.09 ^{ns}	9818.00 ^{ns}	16.31 ^{ns}	0.01 ^{ns}
Reps	2	62.00 ^{ns}	55.10 ^{ns}	2.92 ^{ns}	24,012.00 ^{ns}	57.91 ^{ns}	30.68 ^{ns}	0.00 ^{ns}	196.2 ^{ns}	0.69 ^{ns}	82,067.00 ^{ns}	21.45 ^{ns}	0.01 ^{ns}
Genotype (Gen)	35	2691.80 **	157.34 **	7.45 ^{ns}	27,966 **	76.65 **	23.68 **	0.03 **	1409.70 **	0.69 **	128,815.00 **	24.24 **	5.24 **
Environment (Env)	3	25,075.00 **	2958.70 **	31.41 **	774,455 **	749.79 **	683.71 **	0.04 **	7604.5 **	12.46 **	1,149,414.00 **	115.08 **	9.54 **
Gen × Env	105	2219.2 **	104.68 **	5.43 ^{ns}	16,872 **	61.67 *	11.08 **	0.02 **	1061.6 **	0.31 **	75,629.00 **	15.22 **	12.12 **
Residual	287	1607	60.49	5.55	19,681	45.46	4.11	0.04	674.6	0.07	62,491	10.77	4.47

Note: df, degrees of freedom; * and ** denote significant differences at 5 and 1% probability levels, respectively; ns, non significant; NMF, number of male flowers per plant, NFF; the number of female flowers per plant; SR, sex ratio, NL = the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant, FW = fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

Table 3. BLUPs estimates of bottle gourd parents and their hybrids for assessed traits evaluated under drought-stressed conditions across two growing seasons in South Africa.

Genotype	Traits											
	NMF	NFF	SR	NL	PH	NFPP	FW	FC	FYPP	NSPF	HSW	SYPP
Crosses												
BG-27 × BG-52	47.64	8.92	6.88	88.68	4.26	2.88	0.07	59.89	0.21	144.78	15.53	0.1
BG-27 × BG-58	64.24	12.28	6.4	96.11	4.01	3.36	0.07	58.16	0.29	320.74	16.63	0.29
BG-27 × BG-70	67.73	14.78	6.14	119.84	4.54	3.52	0.08	48.12	0.35	334.75	16.38	0.24
BG-27 × BG-79	64.24	11.42	6.63	87.88	5.47	4.16	0.07	47.94	0.31	364.69	16.07	0.24
BG-27 × BG-80	88.53	11.7	7.27	59.95	2.33	2.08	0.04	41.25	0.14	359.86	16.31	0.14
BG-27 × GC	44.57	9.11	6.47	71.25	2.02	2.08	0.05	59.29	0.14	194.04	16.88	0.11
BG-52 × BG-58	72.9	10.94	7.05	144.69	7.27	5.92	0.08	58.63	0.52	459.52	16.95	0.52
BG-52 × BG-70	76.94	11.7	6.40	136.3	6.25	4.48	0.08	51.98	0.41	444.38	16.34	0.33
BG-52 × BG-80	67.17	11.8	6.51	85.94	2.46	2.72	0.07	81.99	0.20	268.1	16.49	0.16
BG-52 × GC	66.2	11.22	6.38	113.86	3.63	2.56	0.07	57.8	0.20	406.39	15.43	0.15
BG-58 × BG-70	80.99	12.86	6.54	148.57	6.41	4.96	0.07	85.92	0.39	419.27	16.95	0.4
BG-58 × GC	88.94	15.54	6.38	115.16	4.79	4.16	0.08	47.83	0.38	289.83	16.26	0.23
BG-70 × GC	59.64	9.97	6.72	106.6	2.85	2.08	0.06	35.41	0.14	227.04	16.53	0.12
BG-79 × BG-52	83.64	12.38	6.75	122.74	5.83	4.96	0.08	53.4	0.49	482.38	16.35	0.48
BG-79 × BG-58	63.54	10.65	6.59	86.59	2.99	2.4	0.06	51.67	0.18	208.05	16.86	0.12

Table 3. *Cont.*

Genotype	Traits											
	NMF	**NFF**	**SR**	**NL**	**PH**	**NFPP**	**FW**	**FC**	**FYPP**	**NSPF**	**HSW**	**SYPP**
BG-79 × BG-70	79.18	15.45	6.48	123.71	2.65	3.04	0.07	40.67	0.24	201.61	16.74	0.14
BG-79 × BG-80	46.66	9.4	6.43	118.55	4.34	3.84	0.06	53.43	0.27	144.94	16.2	0.11
BG-79 × GC	43.73	8.53	7.04	143.56	5.01	4.00	0.08	66.59	0.37	186.31	16.89	0.14
BG-80 × BG-58	61.59	11.8	6.09	143.4	7.26	5.76	0.09	71.71	0.59	224.47	17.02	0.23
BG-80 × BG-70	59.64	10.07	6.82	96.59	3.06	3.52	0.07	50.88	0.27	317.84	16.53	0.21
BG-80 × GC	81.97	14.01	6.34	124.19	6.64	5.28	0.09	65.61	0.49	273.57	16.8	0.29
BG-81 × BG-27	89.64	15.26	6.34	105.96	4.9	3.68	0.07	55.11	0.28	311.73	15.39	0.17
BG-81 × BG-52	86.71	17.47	6.21	143.89	3.24	4.16	0.07	47.71	0.29	483.18	15.35	0.30
BG-81 × BG-58	62.15	11.42	6.36	76.09	3.05	2.72	0.06	49.71	0.28	242.34	15.88	0.13
BG-81 × BG-70	41.08	8.63	6.42	124.36	4.79	3.52	0.08	51.74	0.28	150.8	16.41	0.12
BG-81 × BG-79	71.36	13.24	6.48	55.43	1.99	2.08	0.05	33.41	0.13	351.17	16.55	0.13
BG-81 × BG-80	92.43	15.93	6.72	109.35	4.62	3.36	0.07	52.13	0.25	441.81	16.68	0.25
BG-81 × GC	63.41	10.17	6.78	150.18	5.46	3.84	0.09	51.67	0.42	360.99	15.96	0.24
Parents												
BG-27	52.38	10.36	6.58	74.32	2.73	2.4	0.05	43.26	0.14	208.05	15.85	0.12
BG-52	59.36	11.9	6.19	98.21	2.77	1.92	0.04	34.57	0.13	264.23	16.59	0.11
BG-58	66.2	11.61	6.4	122.26	4.79	3.84	0.07	51.42	0.31	269.55	16.18	0.18
BG-70	50.85	9.59	6.6	98.21	3.33	4	0.06	64.24	0.21	197.42	16.04	0.14
BG-79	50.15	9.49	6.57	107.73	2.83	2.88	0.05	49.66	0.17	199.19	16.65	0.14
BG-80	73.73	12.28	6.42	132.75	4.07	3.84	0.06	73.45	0.19	269.87	16.97	0.21
BG-81	73.59	12.86	6.52	87.88	2.66	2.4	0.07	66.92	0.18	228.33	17.29	0.14
GC	94.81	16.79	6.17	187.47	6.97	5.6	0.07	77.87	0.49	432.15	16.81	0.32
Mean	67.71	11.99	6.53	111.34	4.23	3.56	0.07	55.31	0.29	296.76	16.41	0.21
LSD (%)	38	8.49	1.47	59.4	2.89	2.34	0.03	17.99	0.28	210.96	2.36	0.27
CV (%)	52.71	80.87	35.95	47.35	56.63	58.62	34.91	24.65	89.75	63.18	20.26	122.95
p-value	>0.05	<0.05	>0.05	<0.05	>0.05	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05

NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg). CV, coefficient of variation; LSD, least significant difference.

Table 4. BLUPs estimates of bottle gourd parents and their hybrids for assessed traits evaluated under non-stressed condition across two growing seasons in South Africa.

Genotype	Traits											
	NMF	**NFF**	**SR**	**NL**	**PH**	**NFPP**	**FW**	**FC**	**FYPP**	**NSPF**	**HSW**	**SYPP**
Crosses												
BG-27 × BG-52	119.07	15.60	7.84	201.55	8.70	8.96	1.08	61.54	9.63	574.16	14.38	0.64
BG-27 × BG-58	145.99	25.34	6.77	419.92	10.65	8.80	0.14	51.24	1.26	554.98	15.79	0.67
BG-27 × BG-70	144.85	18.79	7.75	209.55	8.82	7.80	0.09	50.44	0.74	773.20	13.73	0.70
BG-27 × BG-79	170.49	27.90	7.19	322.53	9.74	8.96	0.11	90.07	1.01	469.99	14.40	0.55
BG-27 × BG-80	150.41	18.79	8.19	282.54	9.59	6.97	0.09	48.55	0.77	330.24	15.09	0.30
BG-27 × GC	150.98	23.10	7.20	213.95	9.07	9.13	0.18	61.53	1.64	402.98	12.80	0.41
BG-52 × BG-58	181.88	24.70	7.60	221.55	8.98	7.97	0.13	85.21	1.06	436.98	15.98	0.45
BG-52 × BG-70	164.94	23.26	7.42	291.14	10.09	8.96	0.10	67.91	0.94	391.91	15.91	0.56
BG-52 × BG-80	133.89	17.19	7.88	328.13	8.80	7.13	0.08	53.18	0.60	546.48	16.60	0.62
BG-52 × GC	178.89	24.86	7.74	240.55	9.18	8.80	0.10	73.15	0.86	692.16	13.73	0.72
BG-58 × BG-70	145.85	19.27	7.80	201.55	9.38	8.46	0.08	55.73	0.79	354.95	15.47	0.39
BG-58 × GC	150.12	20.23	7.83	208.15	8.85	5.64	0.07	109.78	0.44	486.20	15.74	0.34
BG-70 × GC	183.17	30.93	6.98	168.16	8.67	7.97	0.14	80.08	1.09	387.56	14.07	0.42
BG-79 × BG-52	155.11	23.58	7.16	206.15	9.20	8.30	0.10	77.29	0.86	372.15	17.22	0.50
BG-79 × BG-58	156.82	21.35	7.56	301.94	18.42	9.30	0.10	78.74	0.98	574.95	13.75	0.67
BG-79 × BG-70	160.09	18.63	8.34	145.96	8.15	7.97	0.10	67.49	0.77	824.99	12.52	0.67
BG-79 × BG-80	140.72	17.35	8.80	328.93	9.49	10.79	0.11	59.93	1.26	370.96	14.19	0.51
BG-79 × GC	162.37	25.98	7.05	186.81	8.69	10.13	0.13	75.89	1.36	334.00	14.89	0.44
BG-80 × BG-58	166.79	24.54	7.28	323.53	9.71	10.96	0.11	87.89	1.22	533.24	12.13	0.61
BG-80 × BG-70	160.52	21.99	7.62	213.35	8.81	8.13	0.10	72.90	0.79	524.34	15.34	0.56
BG-80 × GC	161.94	23.58	7.33	332.53	10.02	8.46	0.12	84.15	0.99	573.96	15.06	0.67
BG-81 × BG-27	176.04	29.50	6.92	368.53	10.22	9.13	0.12	77.01	1.06	668.64	14.15	0.71
BG-81 × BG-52	165.22	25.50	7.58	387.52	11.09	7.97	0.12	81.55	0.95	668.44	12.65	0.54
BG-81 × BG-58	146.70	23.58	7.06	184.56	9.65	9.13	0.11	70.61	1.00	595.31	13.25	0.62
BG-81 × BG-70	147.84	23.26	7.12	374.33	10.40	11.29	0.13	79.49	1.53	272.13	14.09	0.41
BG-81 × BG-79	143.57	22.15	7.53	382.72	10.13	9.79	0.08	52.42	0.94	347.64	15.66	0.46
BG-81 × BG-80	162.09	26.14	7.17	302.34	10.77	10.46	0.11	72.84	1.17	598.47	13.44	0.74
BG-81 × GC	179.32	27.90	7.14	363.13	10.48	10.29	0.15	80.06	1.60	687.61	12.13	0.71
Parents												
BG-27	144.00	18.47	8.02	351.93	8.59	6.97	0.09	56.60	0.67	355.94	16.14	0.36
BG-52	133.17	17.19	7.71	290.94	8.88	7.47	0.11	68.41	0.84	400.81	15.42	0.48
BG-58	164.94	23.58	7.42	267.94	9.04	9.30	0.10	76.98	0.96	438.76	14.02	0.51
BG-70	179.89	26.14	7.38	422.92	10.26	12.29	0.12	80.78	1.59	306.13	14.76	0.52

Table 4. *Cont.*

Genotype	Traits											
	NMF	**NFF**	**SR**	**NL**	**PH**	**NFPP**	**FW**	**FC**	**FYPP**	**NSPF**	**HSW**	**SYPP**
BG-79	132.89	21.83	6.93	148.36	8.38	6.47	0.09	60.21	0.61	326.68	14.81	0.32
BG-80	157.24	20.39	7.95	176.56	8.23	7.80	0.12	85.57	0.91	407.92	15.41	0.52
BG-81	158.67	23.10	7.35	185.75	9.04	8.30	0.08	55.38	0.69	580.48	16.51	0.81
GC	184.02	26.78	7.37	441.32	11.22	13.78	0.16	80.20	2.48	364.44	14.02	0.65
Mean	157.24	22.85	7.50	277.70	9.70	8.89	0.11	71.41	1.28	486.94	14.59	0.55
LSD (%)	39.12	7.81	1.79	125.73	7.33	3.28	0.03	28.16	0.57	213.28	3.60	0.25
CV (%)	23.38	30.50	30.02	34.46	98.75	31.90	25.66	34.48	45.03	33.73	24.41	38.79
p-value	>0.05	<0.05	>0.05	<0.05	>0.05	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05

NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg). CV, coefficient of variation; LSD, least significant difference.

3.3. The GCA and SCA Effects

The ANOVA summary showing mean squares and significant tests for GCA and SCA effects for the assessed traits across the two growing seasons are presented in Table 5. The environmental effect was significant for all traits except for HSW. The genotypic effect was significant for all traits except for SR, PH, FC, and SYPP. The genotypic $\times$ environmental effect was significant for all traits except for SR, FW, FC, and NSPF. The GCA effects were significant for NFF, NFPP, FW, FC, and FYPP, whereas SCA effects were significant for NMF, NFF, NL, NFPP, FYPP, HSW, and SYPP. The GCA $\times$ environment interaction effects were significant for NMF, NFF, NL, NFPP, FYPP, HSW, and SYPP, whereas SCA $\times$ environment effects were significant for NMF, NFF, NL, PH, NFPP, FYPP, HSW, and SYPP.

3.3.1. General Combining Effects of Parental Genotypes

General combining effects of the parental genotypes for yield and related traits under DS and NS conditions across the two growing seasons are presented in Table 6. The parental lines exhibited varied GCA effects for the different assessed traits. Significant positive and high positive GCA effects were considered desirable for the different traits. Under the DS condition, BG-58 and GC were the best-performing parental genotypes that recorded high positive and significant GCA effects for NL, PH, NFPP, FW, and FYPP. In addition, BG-58 recorded a high positive and significant GCA effect of 0.24 for SYPP. Under the NS condition, parental genotype GC recorded significant and high positive and GCA effects of 18.3, 3.7, 1.4, 0.02, and 0.5 for NMF, NFF, NFPP, FW, and FYPP, in that order. BG-52 and BG-79 recorded a high and negative GCA effect of −0.1 for SYPP.

3.3.2. Specific Combining Ability Effects of the Crosses

Specific combining ability effects of the crosses for the assessed traits under DS and NS conditions across the two growing seasons are presented in Tables 7 and 8, respectively. The SCA effect varied widely among the 28 hybrids. Under DS condition, positive and significant SCA effects of 0.4, 0.5, and 0.7 for FYPP were recorded for BG-79 $\times$ BG-52, BG-27 $\times$ BG-79, and BG-79 $\times$ BG-70, in that order. In addition, positive and significant SCA effects of 0.6 for SYPP were recorded for BG-80 $\times$ BG-70. Under NS condition, BG-81 $\times$ BG-52, BG-27 $\times$ BG-79, and BG-79 $\times$ GC recorded positive and significant SCA effects of 0.5, 0.6, and 1 for FYPP, in that order. Positive SCA effects of 0.2, 0.3, and 0.4 for SYPP were recorded for BG-81 $\times$ BG-58, BG-79 $\times$ BG-52, and BG-27 $\times$ GC, in that order.

3.4. Gene Action and Heritability Estimates

There were differences in the gene action and heritability among the assessed traits under the DS and NS conditions (Table 9). Under the DS condition, the broad-sense heritability (h^2B) was higher than the narrow-sense heritability (h^2n) for all traits. Under the DS condition, h^2B varied from 0.76 to 0.94 for all traits except for SR and HSW, which recorded h^2B of 0.13 and 0.23, respectively. A h^2n of zero was recorded for all traits except for NL. Similarly, under the NS condition, the h^2B was higher than the h^2n for all traits. Overall, the dominance variance (σ^2D) was higher compared to the additive variance (σ^2A) for all traits.

Table 5. Analysis of variance showing mean squares and significant tests for parental genotypes and their hybrids for the assessed traits across two growing seasons in South Africa.

Source of Variation	Traits												
	df	NMF	NFF	SR	NL	PH	NFPP	FW	FC	FYPP	NSPF	HSW	SYPP
Environment (Env)	3.00	25,074.90 **	4125.34 **	31.79 *	1,009,293.0 **	785.16 **	684.26 **	0.051 **	10,863.87 **	13.17 **	1,269,586.00 **	125.94 ns	3.23 **
Env(Rep)	6.00	269.09 ns	42.93 ns	2.60 ns	10,572.48 **	31.45 ns	12.10 **	0.00 ns	412.96 ns	0.21 **	25,322.75 ns	38.04 **	0.07 **
Env (RepBlock)	40.00	2112.83 **	145.49 **	6.93 ns	8314.86 **	48.66 ns	7.05 **	0.00 ns	876.45 ns	0.19 **	53,420.55 ns	14.54 *	0.09 **
Genotype (Gen)	35.00	3966.34 *	157.33 *	7.45 ns	27,965.56 *	76.65 ns	23.68 **	0.03 **	1409.69 ns	0.69 **	128,815.50 *	24.53 *	0.15 ns
Gen × Env	105.00	2219.24 **	104.68 **	5.43 ns	16,872.5 **	61.67 *	23.78 **	0.00 ns	1061.55 ns	0.31 **	75,628.94 ns	15.21 **	0.12 **
GCA	7.00	4839.62 ns	229.01 *	7.99 ns	13,288.07 ns	52.32 ns	11.08 **	0.03 *	2902.99 *	1.02 *	100,802.40 ns	11.54 ns	0.11 ns
SCA	28.00	3748.02 *	139.42 ns	7.32 ns	31,634.94 *	82.73 ns	25.67 *	0.02 *	1036.37 ns	0.61 **	135,818.70 *	27.78 **	0.16 ns
GCA × Env	21.00	2513.755 **	96.00 **	4.66 ns	16,083.49 **	39.91 ns	23.18 **	0.00 ns	936.45 ns	0.31 **	53,004.61 ns	20.88 **	0.14 **
SCA × Env	84.00	2145.60 **	106.84 **	5.62 ns	17,081.00 **	67.10 *	11.65 **	0.00 ns	1092.80 ns	0.31 **	81,285.03 ns	13.79 *	0.11 **
Residual	100.00	30,125.06	26.92	5.05	464.46	43.97	2.88	0.00	−174.76	0.02	−950.83	8.75	0.01

Note: GCA, general combining ability; SCA, specific combining ability; df, degrees of freedom; * and ** denote significant difference at 5 and 1% probability levels; ns, non-significant; NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

Table 6. General combining effects for the assessed traits among the parental genotypes evaluated under drought-stressed and non-stressed conditions across two growing seasons in South Africa.

Parents	Traits											
	NMF	NFF	SR	NL	PH	NFPP	FW	FC	FYPP	NSPF	HSW	SYPP
						Drought-stressed						
BG-81	15.44 ns	6.39 **	−0.72 ns	−10.09 ns	−1.04 **	−1.01 **	0.00 ns	−1.41 ns	−0.11 ns	35.55 ns	−1.80 **	−0.11 ns
BG-27	−14.51 ns	−0.11 ns	−0.49 ns	−15.54 **	−0.83 ns	−0.76 ns	−0.01 **	−2.36 ns	−0.10 ns	−60.72 ns	−1.01 ns	−0.06 ns
BG-79	−13.96 ns	−3.16 ns	0.18 ns	−17.14 **	−0.70 ns	−0.46 ns	−0.01 **	−6.13 **	−0.07 ns	−29.17 ns	0.67 ns	−0.04 ns
BG-52	8.14 ns	1.09 ns	0.09 ns	−5.49 ns	−0.27 ns	−0.36 ns	0.00 ns	0.31 ns	−0.02 ns	71.03 ns	0.11 ns	0.11 ns
BG-80	−1.71 ns	−1.16 ns	0.37 ns	−6.39 ns	−0.22 ns	−0.12 ns	0.00 ns	4.32 ns	−0.04 ns	−62.27 ns	0.97 ns	−0.08 ns
BG-58	16.39 ns	1.54 ns	−0.12 ns	23.76 **	1.93 **	1.19 **	0.01 **	4.16 ns	0.16 **	17.43 ns	1.44 ns	0.24 **
BG-70	−13.76 ns	−3.13 ns	0.42 ns	−1.69 ns	−0.34 ns	0.44 ns	0.00 ns	−2.75 ns	−0.02 ns	−52.05 ns	−0.27 ns	−0.01 ns
GC	3.99 ns	−1.26 ns	0.27 ns	32.56 **	1.46 **	1.19 **	0.02 **	3.85 ns	0.19 **	80.18 ns	−0.10 ns	0.04 ns
						Non-stressed						
BG-81	7.24 ns	3.49 **	−0.65 **	56.38 **	2.26 **	1.03 ns	0.00 ns	−3.53 ns	0.14 ns	171.58 **	−0.76 ns	0.27 ns
BG-27	−5.91 ns	−0.31 ns	−0.15 ns	5.63 ns	−0.07 ns	−0.98 ns	0.00 ns	−0.31 ns	−0.14 ns	30.73 ns	1.28 ns	0.02 ns
BG-79	−7.26 ns	−0.96 ns	0.20 ns	−13.78 ns	−0.84 ns	0.08 ns	−0.01 **	−1.55 ns	−0.07 ns	−91.13 **	0.06 ns	−0.11 **
BG-52	−24.46 **	−3.41 **	−0.02 ns	−35.58 **	−1.15 **	−1.78 **	−0.02 **	1.20 ns	−0.37 **	−26.23 ns	1.97 **	−0.07 **
BG-80	6.09 ns	−1.46 ns	0.62 **	−26.83 ns	−0.94 ns	−0.53 ns	0.01 **	1.43 ns	−0.02 ns	−44.48 ns	0.33 ns	−0.03 ns
BG-58	3.29 ns	0.09 ns	−0.04 ns	−14.23 ns	−0.22 ns	−0.18 ns	0.00 ns	2.07 ns	−0.06 ns	19.53 ns	−0.94 ns	−0.02 ns
BG-70	2.69 ns	−1.11 ns	0.44 ns	3.28 ns	0.13 ns	0.98 ns	0.00 ns	−0.29 ns	0.06 ns	−26.08 ns	−0.56 ns	−0.05 ns
GC	18.34 **	3.69 **	−0.39 ns	25.13 ns	0.83 ns	1.38 **	0.02 **	0.97 ns	0.47 **	−33.93 ns	−1.39 ns	0.01 ns

Notes: ** denote significant at 1% probability level of t-values based on a two-tailed test, respectively; ns, non-significant; NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

Table 7. Specific combining effects for the studied agronomic traits among the crosses evaluated under drought-stressed conditions across two growing seasons in South Africa.

Cross	Traits											
	NMF	**NFF**	**SR**	**NL**	**PH**	**NFPP**	**FW**	**FC**	**FYPP**	**NSPF**	**HSW**	**SYPP**
BG-81 × BG-27	−6.50 ^{ns}	−6.40 ^{ns}	0.80 ^{ns}	−38.09 **	−1.45 ^{ns}	−0.71 ^{ns}	−0.01 ^{ns}	5.44 ^{ns}	−0.08 ^{ns}	−242.12 **	4.12 **	0.00 ^{ns}
BG-81 × BG-79	49.95 **	7.60 ^{ns}	−0.71 ^{ns}	35.86 ^{ns}	3.63 **	2.54 **	0.01 ^{ns}	4.82 ^{ns}	0.22 ^{ns}	−21.85 ^{ns}	−5.28 **	0.02 ^{ns}
BG-81 × BG-52	37.90 ^{ns}	8.65 ^{ns}	−0.17 ^{ns}	−45.54 **	−2.57 ^{ns}	−1.26 ^{ns}	−0.02 **	−8.69 ^{ns}	−0.15 ^{ns}	386.60 **	3.02 ^{ns}	0.03 ^{ns}
BG-81 × BG-80	21.30 ^{ns}	15.90 **	−1.12 ^{ns}	−19.69 ^{ns}	−2.54 ^{ns}	−1.36 ^{ns}	−0.02 **	−10.42 ^{ns}	−0.18 ^{ns}	77.40 ^{ns}	−3.33 ^{ns}	−0.19 ^{ns}
BG-81 × BG-58	38.65 ^{ns}	15.15 **	−1.16 ^{ns}	21.71 ^{ns}	1.31 ^{ns}	0.49 ^{ns}	0.00 ^{ns}	2.85 ^{ns}	0.01 ^{ns}	317.20 **	−0.79 ^{ns}	0.19 ^{ns}
BG-81 × BG-70	−28.45 ^{ns}	−6.05 ^{ns}	0.12 ^{ns}	−14.44 ^{ns}	−2.07 ^{ns}	−1.41 ^{ns}	−0.03 **	−8.77 ^{ns}	−0.27 ^{ns}	−207.50 ^{ns}	−0.81 ^{ns}	−0.22 ^{ns}
BG-81 × GC	−74.30 **	−15.70 **	0.04 ^{ns}	27.01 ^{ns}	2.28 ^{ns}	0.84 ^{ns}	0.01 ^{ns}	7.57 ^{ns}	0.09 ^{ns}	−253.32 **	0.26 ^{ns}	−0.10 ^{ns}
BG-27 × BG-79	−32.05 ^{ns}	−12.75 ^{ns}	1.41 ^{ns}	71.26 **	2.87 ^{ns}	1.59 ^{ns}	0.06 ^{ns}	1.75 ^{ns}	0.45 **	185.75 ^{ns}	−1.32 ^{ns}	0.27 ^{ns}
BG-27 × BG-52	−20.10 ^{ns}	−5.40 ^{ns}	0.74 ^{ns}	−22.19 ^{ns}	−1.72 ^{ns}	−1.21 ^{ns}	−0.01 ^{ns}	0.26 ^{ns}	−0.11 ^{ns}	−128.58 ^{ns}	0.09 ^{ns}	−0.12 ^{ns}
BG-27 × BG-80	42.35 ^{ns}	6.15 ^{ns}	−0.63 ^{ns}	60.91 **	6.12 ^{ns}	3.49 **	0.02 **	1.68 ^{ns}	0.25 ^{ns}	185.37 ^{ns}	−2.23 ^{ns}	0.18 ^{ns}
BG-27 × BG-58	−66.25 **	−14.10 **	0.92 ^{ns}	−16.24 ^{ns}	−0.04 ^{ns}	−0.61 ^{ns}	0.00 ^{ns}	0.73 ^{ns}	−0.11 ^{ns}	−306.83 **	1.41 ^{ns}	−0.29 ^{ns}
BG-27 × BG-70	38.60 ^{ns}	−1.85 ^{ns}	2.79 **	−50.84 **	−3.14 ^{ns}	−1.76 ^{ns}	−0.04 ^{ns}	−25.26 **	−0.20 ^{ns}	173.47 ^{ns}	0.52 ^{ns}	−0.04 ^{ns}
BG-27 × GC	−12.00 ^{ns}	0.95 ^{ns}	0.02 ^{ns}	16.51 ^{ns}	−0.43 ^{ns}	0.34 ^{ns}	0.01 ^{ns}	9.45 ^{ns}	0.05 ^{ns}	304.77 **	−0.19 ^{ns}	0.36 ^{ns}
BG-79 × BG-52	44.65 ^{ns}	21.80 **	−3.41 **	66.96 **	2.41 ^{ns}	1.59 ^{ns}	0.04 ^{ns}	−4.85 ^{ns}	0.42 **	194.25 ^{ns}	1.65 ^{ns}	0.24 ^{ns}
BG-79 × BG-80	−57.10 **	−9.75 ^{ns}	−0.47 ^{ns}	−68.79 **	−5.10 **	−3.16 **	−0.03 ^{ns}	12.91 ^{ns}	−0.40 **	−271.98 **	3.94 **	−0.22 ^{ns}
BG-79 × BG-58	−25.20 ^{ns}	−3.30 ^{ns}	−0.44 ^{ns}	−29.99 ^{ns}	−2.62 **	−1.81 ^{ns}	−0.02 **	−13.40 **	−0.20 ^{ns}	−160.18 ^{ns}	−1.93 ^{ns}	−0.16 ^{ns}
BG-79 × BG-70	65.70 **	6.45 ^{ns}	1.09 ^{ns}	108.36 ^{ns}	6.57 ^{ns}	4.59 **	0.06 ^{ns}	22.57 **	0.69 **	627.62 ^{ns}	0.48 ^{ns}	0.96 ^{ns}
BG-79 × GC	−60.95 **	−9.30 ^{ns}	−0.32 ^{ns}	27.26 ^{ns}	1.84 ^{ns}	1.44 ^{ns}	0.03 **	2.85 ^{ns}	0.15 ^{ns}	−191.58 ^{ns}	−1.59 ^{ns}	−0.11 ^{ns}
BG-52 × BG-80	−7.05 ^{ns}	−2.00 ^{ns}	0.26 ^{ns}	−66.39 **	−4.35 **	−3.46 **	−0.02 **	7.72 ^{ns}	−0.40 **	−189.28 ^{ns}	3.97 **	−0.33 ^{ns}
BG-52 × BG-58	38.10 ^{ns}	5.85 ^{ns}	−0.12 ^{ns}	−39.44 ^{ns}	−3.47 **	−1.71 ^{ns}	−0.04 ^{ns}	−12.07 ^{ns}	−0.25 ^{ns}	−167.80 ^{ns}	0.76 ^{ns}	−0.19 ^{ns}
BG-52 × BG-70	−65.65 **	−9.20 ^{ns}	0.77 ^{ns}	14.81 ^{ns}	1.11 ^{ns}	0.54 ^{ns}	0.02 **	12.75 ^{ns}	0.11 ^{ns}	−330.53 **	−0.55 ^{ns}	−0.22 ^{ns}
BG-52 × GC	−33.90 ^{ns}	−0.30 ^{ns}	−2.50 **	−58.29 **	−3.53 **	−2.01 ^{ns}	−0.05 ^{ns}	−28.64 ^{ns}	−0.30 **	−350.58 **	1.32 ^{ns}	−0.44 **
BG-80 × BG-58	−30.05 ns	−7.05 ^{ns}	0.83 ^{ns}	−24.89 ^{ns}	−3.37 **	−2.16 **	0.00 ^{ns}	23.12 **	−0.24 ^{ns}	−220.78 **	−0.07 ^{ns}	−0.25 ^{ns}
BG-80 × BG-70	20.85 ns	−1.75 ^{ns}	1.51 ^{ns}	61.96 **	5.32 **	3.44 **	0.02 **	6.00 ^{ns}	0.37 **	272.52 **	3.08 ^{ns}	0.63 **
BG-80 × GC	62.00 **	3.60 ^{ns}	1.40 ^{ns}	60.41 **	5.51 **	3.69 **	0.04 ^{ns}	8.19 ^{ns}	0.53 **	266.50 **	−1.44 ^{ns}	0.34 ^{ns}
BG-58 × BG-70	−5.75 ^{ns}	−2.45 ^{ns}	0.37 ^{ns}	−53.34 **	−4.38 **	−3.56 **	−0.01 ^{ns}	7.09 ^{ns}	−0.45 ^{ns}	−15.23 ^{ns}	−2.78 ^{ns}	−0.33 ^{ns}
BG-58 × GC	10.80 ^{ns}	−0.30 ^{ns}	0.07 ^{ns}	5.01 ^{ns}	−0.77 ^{ns}	−0.81 ^{ns}	−0.01 ^{ns}	1.84 ^{ns}	−0.13 ^{ns}	−50.48 ^{ns}	1.00 ^{ns}	−0.02 ^{ns}
BG-70 × GC	−26.30 ^{ns}	−4.50 ^{ns}	−2.73 ^{ns}	39.86 ^{ns}	4.29 **	3.29 **	0.02 **	10.63 ^{ns}	0.44 **	−89.18 ^{ns}	−0.05 ^{ns}	−0.02 ^{ns}

Note: ** denote significant differences at 1% probability level of t-values based on a two-tailed test, respectively; ns, non-significant; NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

Table 8. Specific combining effects for the studied agronomic traits among the crosses evaluated under non-stressed condition across two growing seasons in South Africa.

Cross	Traits											
	NMF	**NFF**	**SR**	**NL**	**PH**	**NFPP**	**FW**	**FC**	**FYPP**	**NSPF**	**HSW**	**SYPP**
BG-81 × BG-27	−8.32 ^{ns}	−3.66 ^{ns}	0.45 ^{ns}	−149.11 **	−5.04 **	−0.91 ^{ns}	−0.04 **	−3.56 ^{ns}	−0.47 **	−64.07 ^{ns}	5.27 **	0.36 ^{ns}
BG-81 × BG-79	51.33 **	6.14 ^{ns}	0.22 ^{ns}	30.14 ^{ns}	1.16 ^{ns}	−3.41 **	0.01 ^{ns}	0.86 ^{ns}	−0.37 ^{ns}	201.28 **	0.82 ^{ns}	−0.01 ^{ns}
BG-81 × BG-52	1.18 ^{ns}	5.79 ^{ns}	−1.47 **	96.04 **	2.98 **	4.04 **	0.01 ^{ns}	−0.83 ^{ns}	0.52 **	−375.87 ^{ns}	1.09 ^{ns}	−0.38 **
BG-81 × BG-80	29.38 ns	10.24 **	−1.21 ^{ns}	102.84 **	3.34 **	−2.11 ^{ns}	0.01 ^{ns}	−0.43 ^{ns}	−0.21 ^{ns}	332.73 **	−4.86 **	−0.07 ^{ns}
BG-81 × BG-58	−15.17 ^{ns}	−5.21 ^{ns}	1.01 ^{ns}	76.09 ^{ns}	2.31 ^{ns}	2.64 ^{ns}	0.00 ^{ns}	−3.02 ^{ns}	0.35 ^{ns}	10.98 ^{ns}	−0.58 ^{ns}	0.22 **
BG-81 × BG-70	−43.37 **	−8.26 **	0.65 ^{ns}	−115.51 **	−3.02 **	−2.71 ^{ns}	−0.02 ^{ns}	1.05 ^{ns}	−0.42 ^{ns}	107.98 ^{ns}	−3.62 ^{ns}	−0.22 **
BG-81 × GC	−0.27 ^{ns}	1.44 ^{ns}	−0.52 ^{ns}	61.49 ^{ns}	1.84 ^{ns}	1.64 ^{ns}	0.03 **	10.48 ^{ns}	0.51 **	−402.42 ^{ns}	1.32 ^{ns}	−0.41 ^{ns}
BG-27 × BG-79	−6.42 ^{ns}	−2.86 ^{ns}	0.43 ^{ns}	47.14 ^{ns}	1.46 ^{ns}	1.74 ^{ns}	0.03 **	−0.98 ^{ns}	0.57 **	253.43 **	−4.72 **	0.14 ^{ns}
BG-27 × BG-52	28.98 ^{ns}	−0.06 ^{ns}	0.96 ^{ns}	−49.11 ^{ns}	−1.87 ^{ns}	2.09 ^{ns}	−0.02 ^{ns}	−0.58 ^{ns}	0.14 ^{ns}	−263.37 **	1.27 ^{ns}	−0.16 **
BG-27 × BG-80	33.33 ^{ns}	10.09 **	−1.26 ^{ns}	57.29 ^{ns}	2.31 ^{ns}	2.04 ^{ns}	0.01 ^{ns}	23.44 **	0.27 ^{ns}	−116.52 **	−1.69 ^{ns}	0.01 **
BG-27 × BG-58	−92.97 ^{ns}	−11.46 **	−0.18 ^{ns}	10.09 ^{ns}	0.90 ^{ns}	−0.61 ^{ns}	−0.03 **	2.63 ^{ns}	−0.18 ^{ns}	197.08 **	−0.45 ^{ns}	0.19 **
BG-27 × BG-70	17.48 ^{ns}	0.09 ^{ns}	0.79 ^{ns}	4.84 ^{ns}	−0.82 ^{ns}	0.64 ^{ns}	0.04 ^{ns}	−8.60 ^{ns}	0.42 ^{ns}	−300.17 **	−0.06 ^{ns}	−0.33 **
BG-27 × GC	−24.72 ^{ns}	−0.96 ^{ns}	−0.98 ^{ns}	116.24 **	4.13 **	0.29 ^{ns}	0.06 ^{ns}	−4.52 ^{ns}	0.55 **	254.83 **	2.99 ^{ns}	0.38 **
BG-79 × BG-52	−31.62 ^{ns}	−5.76 ^{ns}	0.27 ^{ns}	−96.26 **	−3.29 **	−2.36 ^{ns}	−0.03 **	−11.59 ^{ns}	−0.45 ^{ns}	442.93 ^{ns}	−1.87 ^{ns}	0.33 **
BG-79 × BG-80	−10.77 ^{ns}	1.94 ^{ns}	−0.77 ^{ns}	−24.11 ^{ns}	−0.65 ^{ns}	−0.76 ^{ns}	−0.03 **	−1.07 ^{ns}	−0.51 **	−152.72 ^{ns}	−2.28 ^{ns}	−0.25 ^{ns}
BG-79 × BG-58	−29.32 ^{ns}	−4.76 ^{ns}	−0.12 ^{ns}	−96.81 **	−4.23 **	−5.01 **	−0.04 ^{ns}	−13.04 **	−0.75 **	−0.67 ^{ns}	0.57 ^{ns}	−0.09 ^{ns}
BG-79 × BG-70	33.88 ^{ns}	5.19 ^{ns}	−0.56 ^{ns}	−54.01 ^{ns}	1.04 ^{ns}	1.84 ^{ns}	0.01 ^{ns}	8.58 ^{ns}	0.24 ^{ns}	−148.07 ^{ns}	3.47 ^{ns}	−0.03 ^{ns}
BG-79 × GC	23.33 ^{ns}	0.24 ^{ns}	0.57 ^{ns}	138.74 **	4.10 **	4.09 **	0.05 ^{ns}	4.43 ^{ns}	1.00 **	−90.82 ^{ns}	−0.87 ^{ns}	0.00 ^{ns}
BG-52 × BG-80	13.63 ^{ns}	−0.31 ^{ns}	0.50 ^{ns}	53.14 ^{ns}	2.64 ^{ns}	2.74 ^{ns}	0.01 ^{ns}	−9.57 ^{ns}	0.31 ^{ns}	272.18 **	−3.74 ^{ns}	0.43 ^{ns}
BG-52 × BG-58	−54.77 **	−11.11 **	2.14 **	−87.36 ^{ns}	−3.63 **	−2.91 ^{ns}	−0.01 ^{ns}	−4.07 ^{ns}	−0.45 ^{ns}	595.78 ^{ns}	−4.64 **	0.33 **
BG-52 × BG-70	8.08 ^{ns}	−0.41 ^{ns}	0.31 ^{ns}	−10.21 ^{ns}	−0.98 ^{ns}	−1.81 ^{ns}	0.01 ^{ns}	4.10 ^{ns}	−0.39 ^{ns}	−135.37 ^{ns}	5.24 **	−0.17 ^{ns}
BG-52 × GC	−38.92 **	−7.36 ^{ns}	0.57 ^{ns}	−47.21 ^{ns}	−3.52 **	−0.81 ^{ns}	0.01 ^{ns}	6.62 ^{ns}	0.04 ^{ns}	−218.97 **	−1.60 ^{ns}	−0.22 **
BG-80 × BG-58	5.53 ^{ns}	−0.31 ^{ns}	0.29 ^{ns}	−33.46 ^{ns}	−1.50 ^{ns}	−0.56 ^{ns}	−0.03 **	−4.70 ^{ns}	−0.22 ^{ns}	218.78 **	3.00 ^{ns}	0.32 **
BG-80 × BG-70	58.83 **	5.64 ^{ns}	0.65 ^{ns}	67.44 ^{ns}	1.37 ^{ns}	1.59 ^{ns}	0.05 ^{ns}	10.47 ^{ns}	0.61 **	−239.72 **	5.93 **	−0.10 ^{ns}
BG-80 × GC	20.43 ^{ns}	2.34 ^{ns}	−0.08 ^{ns}	15.94 ^{ns}	1.53 ^{ns}	1.44 ^{ns}	0.00 ^{ns}	−21.73 **	0.17 ^{ns}	−220.62 **	−0.41 ^{ns}	−0.14 ^{ns}
BG-58 × BG-70	22.78 ^{ns}	3.04 ^{ns}	−0.04 ^{ns}	−14.41 ^{ns}	0.38 ^{ns}	0.04 ^{ns}	−0.03 **	−8.07 ^{ns}	−0.49 ^{ns}	297.73 **	−3.49 ^{ns}	0.28 **
BG-58 × GC	−10.52 ^{ns}	0.24 ^{ns}	−0.47 ^{ns}	−49.71 ^{ns}	−2.64 **	−2.31 ^{ns}	0.00 ^{ns}	5.37 ^{ns}	−0.33 ^{ns}	−197.97 **	1.15 ^{ns}	−0.28 **
BG-70 × GC	24.28 ^{ns}	5.69 ^{ns}	−0.68 ^{ns}	−9.31 ^{ns}	2.86 **	2.34 ^{ns}	−0.01 ^{ns}	10.23 ^{ns}	0.20 ^{ns}	154.03 ^{ns}	−6.76 **	0.04 ^{ns}

Note: ** denote significant differences at 1% probability level of t-values based on a two-tailed test; respectively, ns non-significant; NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

3.5. Heterosis under Drought-Stressed and Non-Stress Conditions

Heterosis estimates for the studied traits amongst the F_1 bottle gourd evaluated under DS and NS conditions across the two growing seasons are presented in Supplemental Table S1. High positive heterosis was considered desirable for the assessed traits. Under DS condition, high and positive mid-parent heterosis (MPH) of 298%, 101%, 91%, 58% and 86% for FYPP was recorded for crosses BG-80 × BG-58, BG-27 × BG-79, BG-79 × BG-52, BG-27 × BG-52 and BG-52 × BG-80, whereas better-parent heterosis (BPH) of 184%, 70%, 59%, 51% and 32% for FYPP was recorded for the same crosses, respectively. High and positive MPH of 244% and 265% and BPH of 236% and 174% for SYPP were recorded for crosses BG-70 × GC and BG-79 × BG-52, in that order. Under the NS condition, high and positive MPH of 58% and 52%, and BPH of 50% and 31% for FYPP were recorded for crosses BG-27 × GC and BG-79 × GC, in that order. At the same time, BPH of 52% and 59% for SYPP were recorded for crosses BG-27 × BG-58 and BG-27 × BG-79. In addition, MPH of 29% and 34% for SYPP were recorded for crosses BG-27 × BG-58 and BG-27 × BG-79, respectively.

Table 9. Gene action and heritability estimates for the assessed traits under drought-stressed and non-stressed conditions across two growing seasons in South Africa.

Traits	σ^2A	σ^2D	h^2B	h^2n
		Drought-stressed		
NMF	0.00	1825.33	0.85	0.00
NFF	0.00	75.25	0.76	0.00
SR	0.08	0.84	0.13	0.01
NL	758.15	3548.41	0.86	0.15
PH	0.00	14.06	0.91	0.00
NFPP	0.04	7.65	0.88	0.00
FW	0.00	0.00	0.87	0.01
FC	12.35	755.56	0.94	0.02
FYPP	0.00	0.09	0.89	0.00
NSPF	0.00	69,636.26	0.89	0.00
HSW	0.00	1.42	0.23	0.00
SYPP	0.00	0.09	0.85	0.00
		Non-stressed		
NMF	248.28	1292.97	0.82	0.0.13
NFF	10.84	64.27	0.86	0.12
SR	0.50	1.53	0.23	0.06
NL	0.00	42,735.77	0.95	0.00
PH	0.00	7.81	0.08	0.00
NFPP	0.35	15.35	0.89	0.02
FW	0.00	0.03	0.93	0.00
FC	83.30	988.20	0.88	0.06
FYPP	0.06	0.60	0.93	0.08
NSPF	0.00	118,919.20	0.95	0.00
HSW	0.00	15.45	0.82	0.00
SYPP	0.00	0.10	0.90	0.00

Note, σ^2A, additive variance; σ^2D, dominance variance; h^2B, broad-sense heritability; h^2n, narrow-sense heritability; NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference (cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

3.6. Associations of the Agronomic Traits under Drought and Non-Stressed Conditions

Pearson's correlation coefficients showing the associations between the assessed traits under DS and NS conditions across the two growing seasons are presented in Table 10. A highly significant and moderate positive correlation was recorded between several traits. Under DS condition, significant and positive correlations were recorded between FW with FYPP (r = 0.8) and SYPP (r = 0.7). Additionally, a significant and positive correlation was recorded between FYPP and SYPP (r = 0.8). Whereas under NS condition, high and positive correlations were recorded between NFPP with FW (r = 0.8) and SYPP (r = 0.8). NFPP exhibited a significantly low correlation with FYPP (r = 0.3). FW positively correlated with FYPP (r = 0.6) and SYPP (r = 0.9). A moderate and positive correlation was recorded between FYPP and SYPP (r = 0.5).

Table 10. Pearson correlation coefficients showing associations between assessed traits among the parental genotypes and their crosses under drought-stressed (upper diagonal) and non-stressed (lower diagonal) conditions across two growing seasons in South Africa.

Traits	NMF	NFF	SR	NL	PH	NFPP	FW	FC	FYPP	NSPF	HSW	SYPP
NMF		0.866 **	0.00 ^{ns}	0.277 **	0.365 **	0.378 **	0.00 ^{ns}	0.20 ^{ns}	−0.06 ^{ns}	0.611 **	−0.03 ^{ns}	−0.11 ^{ns}
NFF	0.525 **		0.12 ^{ns}	0.333 **	0.350 **	0.401 **	−0.06 ^{ns}	0.11 ^{ns}	−0.17 ^{ns}	0.577 **	0.05 ^{ns}	−0.20 ^{ns}
SR	0.04 ^{ns}	0.21 ^{ns}		0.04 ^{ns}	0.11 ns	0.06 ^{ns}	−0.14 ^{ns}	−0.03 ^{ns}	−0.248 *	0.00 ns	0.19 ^{ns}	−0.17 ^{ns}
NL	0.431 **	0.08 ^{ns}	−0.15 ^{ns}		0.772 **	0.712 **	−0.18 ^{ns}	0.453 **	−0.285 *	0.405 **	0.12 ^{ns}	−0.251 **
PH	−0.500 **	0.333 **	0.286 *	−0.398 **		0.861 **	−0.24 ^{ns}	0.462 **	−0.339 **	0.533 **	0.03 ^{ns}	−0.22 ^{ns}
NFPP	−0.24 ^{ns}	0.511 **	0.307 *	−0.12 ^{ns}	0.866 **		−0.23 ^{ns}	0.401 **	−0.361 **	0.453 **	0.05 ^{ns}	−0.266 *
FW	−0.474 **	0.334 **	0.382 **	−0.438 **	0.946 **	0.783 **		−0.17 ^{ns}	0.839 **	−0.04 ^{ns}	−0.02 ^{ns}	0.683 **
FC	0.690 **	0.403 **	−0.08 ^{ns}	0.598 **	−0.335 **	−0.02 ^{ns}	−0.356 **		−0.282 **	0.20 ^{ns}	−0.06 ^{ns}	−0.23 ^{ns}
FYPP	−0.13 ^{ns}	0.22 ^{ns}	0.22 ^{ns}	−0.22 ^{ns}	0.443 **	0.293 *	0.631 **	−0.12 ^{ns}		−0.12 ^{ns}	0.08 ^{ns}	0.830 **
NSPF	0.17 ^{ns}	−0.04 ^{ns}	0.07 ^{ns}	0.02 ^{ns}	−0.21	−0.254 *	−0.17 ^{ns}	0.06 ^{ns}	−0.13 ^{ns}		−0.18 ^{ns}	−0.12 ^{ns}
HSW	−0.02 ^{ns}	0.320 **	0.07 ^{ns}	−0.14 ^{ns}	0.375 **	0.357 **	0.327 **	−0.23 ^{ns}	0.02 ^{ns}	−0.14 ^{ns}		0.19 ^{ns}
SYPP	−0.545 **	0.295 *	0.313 **	−0.476 **	0.981 **	0.827 **	0.969 **	−0.400 **	0.463 **	−0.19 ^{ns}	0.19 ^{ns}	

Notes: * and ** denote significant at 5 and 1% probability level of t-values based on a two-tailed test, respectively; ns, non-significant; NMF, number of male flowers per plant; NFF, the number of female flowers per plant; SR, sex ratio; NL, the number of leaves per plant; PH, plant height (m); NFPP, the number of fruits per plant; FW, fruit weight (kg/fruit); FC, fruit circumference(cm); FYPP, fruit yield per plant (kg); NSPF, the number of seeds per fruit; HSW, hundred seed weight (g/100 seed); SYPP, seed yield per plant (kg).

4. Discussion

Bottle gourd has niche market opportunities in SSA, requiring the breeding of new, well-adapted, and high-yielding varieties that possess good agronomic and horticultural traits and acceptable market standards. The present study determined the combining ability and heterosis of fruit yield and related traits among South African bottle gourd accessions under drought-stressed and non-stressed conditions for breeding and variety release.

Analysis of variance revealed significant genotypic effects (Table 2), suggesting substantial differences among the parental genotypes and their progenies for economic traits, including fruit and seed yields (Tables 4 and 5). Bottle gourd is a morphologically diverse crop with variations reported for agronomic traits, including male and flowering capacity, fruit yield and related traits, and seed yield and related traits [2,25,27,28,32,42,53]. Drought stress reduced flowering and fruit capacity (Tables 4 and 5). Fruit and seed yield were reduced by 71 and 62% across the tested genotypes, respectively. These indicated that bottle gourd can grow under drought-stressed environments and produce reasonable yields. The increasing drought episodes in SSA require concerted efforts to develop drought-resilient bottle gourd varieties. The variation observed in the present study will allow for selecting of desirable genotypes for new variety design and commercialization. For example, crosses BG-52 × BG-58, BG-79 × BG-52, BG-80 × BG-58, BG-80 × GC, BG-81 × BG-80, and BG-81 × GC were high fruit yielders and are recommendable for further selection. Additionally, crosses BG-52 × BG-58, BG-79 × BG-52, BG-27 × BG-52, BG-27 × BG-58, BG-27 × BG-70 and BG-52 × BG-80 were the best performers for seed yield. These are ideal families for gene introgression, genetic advancement, and variety release. The significant genotype-by-environment interaction effects for the studied traits suggested environmental influence on the performance of genotypes requiring multi-environment testing to identify and recommend genotypes with specific and wide adaptation in targeted production environments.

The significant SCA effect indicated non-additive gene action for fruit and seed yield and some related agronomic traits (Tables 7 and 8). The non-additive gene action is non-fixable and challenging to transform, suggesting that such crosses should be used in direct production to increase the fruit and seed yield of bottle gourd in South Africa. There were significant GCA × environment effects for fruit and seed yields (Table 6). This indicated that the effects are dependent on the environment for their expression. A significant SCA × environment interaction effect existed for fruit and seed yields, suggesting that the environment played a significant role in expressing the effects. Therefore, multi-environment testing of the parents and hybrids is crucial to categorize each genotype's performance and identify genotypes with adaptation to certain environments to optimize the fruit and seed yield.

In the present study, crosses such as BG-27 × BG-79 and BG-79 × BG-70 with high and significant SCA for fruit yield per plant were derivatives of parental genotypes BG-27, BG-70, and BG-79. Interestingly, these parents had low and non-significant GCA effects on fruit yield per plant. Previous studies in bottle gourd revealed crosses with significant SCA effects for fruit yield and yield-related traits that are derived from both or at least a parent that is a good combiner for the trait [38,39,41,54]. The recorded high SCA effects in the current study may be due to dominant × dominant non-allelic gene interaction producing over-dominance, thus challenging to modify using breeding programs [55,56]. In addition to dominance and epistasis, the SCA variation includes aberrations due to genotype × environment interactions [57]. In the current study, crosses such as BG-81 × BG-80 had a high positive and significant SCA effect for the number of female flowers. This cross manifested from good × poor general combiner parents for the trait may be attributed to favorable additive gene effects of the good general combiner parent (BG-81) and non-additive effects of the poor general combiner (BG-80) [56]. Parental genotypes such as BG-58 and GC (Table 6) with high GCA effects for fruit and seed yield serve as valuable germplasm for future breeding. Crosses such as BG-81 × BG-52, BG-81 × GC, BG-27 × BG-79, BG-27 × GC, BG-79 × GC, BG-80 × BG-70, BG-81 × BG-58, BG-27 × BG-80, BG-27 × BG-58,

BG-79 × BG-52, BG-52 × BG-58, BG-80 × BG-58, and BG-58 × BG-70 (Tables 7 and 8) with the high positive SCA effect for fruit and seed yield are potential genetic resources for further selection and multi-environment testing for release and commercialization in South Africa.

Heritability analysis is useful to provide information about the potential transmissibility of traits from parents to offspring [58,59]. The larger broad-sense heritability compared to narrow-sense heritability for all traits (Table 9) indicates that additive gene action is conditioning these traits in bottle gourd, showing that genetic gains are achievable using selection.

The exploitation of heterosis via intensive evaluation of hybrids identifies diverse genetic donors and allows for the identification of heterotic crosses [37,38]. High and positive mid- and better-parent heterosis observed in the cross BG-80 × BG-58, BG-27 × BG-79, BG-79 × BG-52, BG-27 × BG-52, and BG-52 × BG-80 for fruit yield per plant and cross, BG-70 × GC and BG-79 × BG-52 for seed yield per fruit. Hence, these crosses are essential for strategic breeding and variety release in South Africa.

Trait correlation analyses aid in the simultaneous selection of multiple traits. The positive correlations between the number of female flowers per plant with the number of fruits per plant and the number of fruits per plant with the number of seeds per fruit, fruit yield per plant, and seed yield per fruit suggested simultaneous improvement in these traits is possible. Additionally, these suggested the linkages of desirable genes controlling the expression of the studied traits [60,61]. Therefore, these traits are recommended for further selection in the newly developed bottle gourd hybrids to deliver varieties that meet market needs and standards and multiple crop characteristics required by sub-Saharan African growers.

5. Conclusions

The current study assessed the combining ability and heterosis for fruit yield and related traits. Crosses were made using genetically distant parents of South African bottle gourd accessions under non-stressed and drought-stressed conditions to select drought-tolerant parents and new hybrids for production under water-stressed environments in South Africa or similar agroecologies globally. Drought stress reduced flowering and fruit capacity, fruit and seed yields in the presently assessed bottle gourd populations. Nevertheless, the studied genotypes produced reasonable yield levels under drought-stressed conditions, indicating the possibility of breeding for enhanced drought tolerance in bottle gourds. Parental genotypes BG-58 and GC were identified as valuable germplasm for future breeding targeting high fruit and seed yields in water-limited environments. The newly bred F_1 hybrids BG-81 × BG-52, BG-81 × GC, BG-27 × BG-79, BG-27 × GC, BG-79 × GC, BG-80 × BG-70, BG-81 × BG-58, BG-27 × BG-80, BG-27 × BG-58, BG-79 × BG-52, BG-52 × BG-58, BG-80 × BG-58, and BG-58 × BG-70 with high fruit and seed yields were drought-tolerance and are recommended for release and commercialization in South Africa following multi-environment testing.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15080925/s1, Table S1: Estimates of mid parent and better parent heterosis for the studied agronomic traits under drought stress and non-stress conditions across two growing seasons in South Africa.

Author Contributions: Conceptualization, P.M., H.S., and J.M.; methodology, P.M., H.S., and J.M.; validation, P.M., H.S., and J.M.; formal analysis, P.M., and J.M.; investigation, P.M.; resources, P.M., and J.M.; data curation, P.M.; writing—original draft preparation, P.M.; writing—review and editing, P.M., H.S., and J.M.; supervision, H.S., and J.M.; project administration, P.M., H.S., and J.M.; funding acquisition, P.M., H.S., and J.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The University of KwaZulu-Natal (UKZN), the University of Limpopo (UL), and the Limpopo Department of Agriculture and Rural Development (LDARD) are acknowledged for support provided during this study. P. Ndwambi is acknowledged for assisting with trial implementation and management. M. Malatji and the rest of the University of Limpopo farm employees are acknowledged for their assistance and guidance during the trial.

Conflicts of Interest: The authors declare no conflict of interest.

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