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GENETIC ANALYSIS OF DROUGHT TOLERANCE RELATED TRAITS IN F_3 POPULATIONS OF GROUNDNUT

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ABSTRACT

Groundnut (*Arachis hypogaea* L.) is a vital legume crop globally, particularly in semi-arid regions where drought stress significantly hampers yield and productivity. The inheritance of drought tolerance and yield-associated traits remains a key challenge in groundnut breeding programs. An investigation on genetic analysis of drought tolerance in F_3 populations of groundnut was undertaken during summer 2019 at MARS, UAS, Dharwad. Significant genetic variation was observed in F_3 populations study as evidenced by wider range and moderate to high PCV and GCV for most of the quantitative traits studied. High heritability and GAM were recorded for all studied and for most of the quantitative traits. For drought component traits like RWC, SPAD chlorophyll meter reading (SCMR), Moderate GCV and PCV and high heritability coupled with high GAM were estimated for RWC at all stages studied under two moisture regimes thus selection for this trait could be effective. But SCMR under water stress condition, low GCV and moderate PCV coupled with moderate heritability and GAM were estimated SCMR could serve as an index of selection for drought tolerance. Correlation analysis indicated that high RWC at pegging and pod development stage and high SCMR, had contributed for high drought tolerance index for maintenance pod yield under stress condition. Further, the ability of genotype to maintain physiological traits and yield components could aid groundnut genotypes in sustaining high pod yield under stress conditions. The reduction in mean performance of genotypes under moisture stress condition was observed. Superior recombinants identified for high pod yield with high oleic acid under water stress conditions were *viz.*, Dh-256×Dh-245-5-1, Dh-256×ICGV-02266-10-1 and Dh-257×ICGV-02266-35-1.
***Keywords* :** Groundnut, Drought tolerance, Well-watered and Water stress conditions, F_3 populations, Physiological traits, Yield components.

Introduction

Peanut (*Arachis hypogaea* L.) is an important legume and oilseed crop. It is grown globally on an area of 31.6 million hectares with a production of 53.6 million tons (FAOSTAT 2020) and productivity of 1699 kg/hectare. It is widely grown under rainfed conditions in more than 100 countries, which are characterized by inconsistent rainfall followed by severe drought especially in Asia and Africa. Water deficiency is known to reduce peanut yield by 70% (Manjonda *et al.,* 2018; Prasad *et al.,* 2010). Flowering and pod setting stages are considered most critical for water stress in peanut (Xiong *et al.,* 2016). Prolonged drought can cause reduction in root growth and density, curling of leaves, reduced inter-nodal length which in turn affect the absorption activity and efficient water usage resulting in delayed flowering and anthesis, reduced flower and pod number (Zhang *et al.,* 2012; Yang *et al.,* 2019a). Biochemically, photosynthesis and ATP biosynthesis are affected, which leads to a significant reduction in productivity (Liu *et al.,* 2013). Significant progress has been made in understanding the intrinsic mechanisms of drought tolerance in peanut through integrated approaches (see Shukla *et al.,* 2022; Yang *et al.,* 2019b; Gangurde *et* *al.,* 2019). Root traits are identified as drought adaptive traits; however, their use as selection criteria for drought resistance is limited as they require elaborate phenotyping protocols (Janila *et al.,* 2016). Transpiration efficiency (TE), specific leaf area (SLA), SPAD chlorophyll meter reading (SCMR) and relative water content (RWC) have been recognized as the important surrogate traits of water stress tolerance contributing to yield variation under drought stress in peanut (Krishnamurthy *et al.,* 2007). Efforts were also made to screen peanut genotypes for drought-tolerance based on yield and other traits. Genotypes performed differently in well-watered (WW) and water stressed (WS) conditions (Oppong-Sekyere *et al.,* 2018).

Materials and Methods

The experiment was carried out during *summer* 2019 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad situated in the northern transitional zone (Zone No. 8) of Karnataka with latitude of 15° 26^1 north, longitude of 76° 7^1 east at an altitude of 678 m above mean sea level (MSL). The soil type of the site was vertisol and pH in the range of 7.0 to 7.5. The experimental material consisted of F3 segregating populations evaluated for quantitative traits, physiological traits and quality traits. The details of F_3 populations used in the study are given below Table 1.

Table 1: Pedigree details of F_3 populations

Sl No.	Pedigree
1	Dh256 × Dh257
2	Dh-257 × TG-76
3	Dh257 × Dh245
4	Dh257 × ICGV2266
5	Dh256 × ICGV2266
6	Dh256 × Dh245
7	Dh257 × GM6000
8	Dh256 × TG76

Each genotype was sown in 1 m row with a plant spacing of 30 × 10 cm. Between WW and WS plots, two-meter space was left with a trench to avoid horizontal flow of water from WW to WS plots. Recommended package of practices was followed for raising a healthy crop. The crop in WW and WS was irrigated equally up to 65 days after sowing (DAS) (time of flowering). Water stress was induced during 65–85 days after sowing (DAS) coinciding with peg penetration and pod initiation stage in the WS plot. The crop was irrigated once on 85th DAS, and the moisture stress was again induced till physiological maturity in WS plot. Soil moisture content in WW and WS conditions was determined at a depth of 0–15 cm on 65, 85 and 110 DAS using the gravimetric method. The moisture content in dry weight basis can be calculated using the following formula (Black, 1965).

$$\text{Soil moisture content (\%)} = \frac{\text{Wet weight of the soil (gm)} - \text{Dry weight of the soil (gm)}}{\text{Dry weight of the soil (gm)}} \times 100$$

Wilting was scored using the 1–5 scale proposed by Ratnakumar *et al.* (2009). Observations on growth traits like plant height (PH) and number of primary branches per plant (NPB) were recorded at harvesting stage on five randomly selected plants. Similarly, the productivity traits like pod yield per plant (PY) and kernel yield per plant (KY) were recorded on five randomly selected plants, while shelling percentage (SP) and hundred seed weight (TW) were recorded from the whole plot. Relative water content (RWC) and SPAD chlorophyll meter reading (SCMR) were observed as physiological traits on 75 and 85 DAS. Drought tolerance index (DTI) was computed for PY as the ratio of PY under WS to PY under WW as suggested by Nautiyal *et al.* (2002). Field view of F_3 populations 20 days after stress in WW and WS condition during *summer* 2019 is shown in Plate 1.

Plate 1: Field view of well- watered and water-tress block at pod development stage

Data analysis

Analysis of variance (ANOVA) was performed for each trait across the years to test the significant difference among the genotypes using the "augmented RCBD" package of R (R Core Team 2021). Correlation between the traits was calculated using IBM SPSS software.

Results and Discussions

Identifying drought tolerant and drought susceptible genotypes

The soil moisture content was maintained at about 20% in the WW condition during 2018 and summer 2019 by providing artificial irrigation, while moisture stress was induced during two stages; peg penetration and pod initiation stage (65–85 DAS), and 95 DAS to physiological maturity in the WS condition. Soil moisture content during these stressed stages during 2019 ranged from 4 to 13%. Overall growth of the genotypes did not differ much between WW and WS conditions till 65 DAS. However, the crop in WS showed wilting up to 50% after induction of moisture stress. Analysis of variance for the growth, productivity and physiological traits showed significant differences among the genotypes and checks versus genotypes during summer 2019. Indicating the considerable amount of variability existing for all the characters studied and improvement can be achieved in these characters by selection and recombination Table 2.

Table 2: Analysis of variance for morpho-physiological, and yield component traits in groundnut F_3 segregating generation evaluated under WW and WS condition during *summer* 2019 at MARS, Dharwad

Source	Moisture levels	Df	Plant height (cm)	No of primary branches per plant	Pod number	Pod yield per plant (g)	Kernel yield per plant (g)	Shelling per cent	RWC at 70 DAS	RWC at 85 DAS	SCMR at 70 DAS	SCMR at 85 DAS
Entries (ignoring Blocks)	**WW**	166	53.2**	4.19**	83.06**	134.73**	51.68**	296.39**	131.72**	133.72**	48.44**	53.7**
	WS	166	46.88**	4.11**	90.53**	123.81**	44.53**	590.09**	65.8**	60.75**	83.14**	57.49**
Check	**WW**	18	37.53**	15.17**	230.78**	196.9**	62.04**	1051.21**	344.46**	385.32**	86.22**	105.09**
	WS	18	46.53**	16.32**	257.18**	159.1**	67.86**	1862.53**	300.48**	250.63**	327.5**	221.75**
Checks vs. Genotypes	**WW**	1	3036.01**	274.71**	2501.28**	7007.12**	2863.11**	13359.71**	7442.82**	6789.32**	55.68*	421.78**
	WS	1	2094.86**	256.33**	5301.78**	8533.92**	2636.16**	24598.86**	297.02**	53.16*	3391.59**	1008.63**
Genotypes	**WW**	147	34.83**	1.01**	48.52**	80.36**	31.29**	115.1 ns	55.94**	57.63**	43.77**	44.9**
	WS	147	32.99**	0.9 ns	34.67**	62.28**	24.04**	270.96**	35.49**	37.55**	30.72*	30.9**
Block (eliminating Treatments)	**WW**	3	1.75	0.08	1.01	3.26	0.67	3034.25	8.63	15.02	84.61**	36.75
	WS	3	0.73	0.29	0.21	2.08	3.64	23.27	14.18	86.68**	22.82	15
Error	**WW**	54	0.83	0.48	0.87	0.7	0.09	109.87	10.43	8.84	12.66	15.9
	WS	54	3.9	0.92	0.99	0.64	0.2	6.06	7.09	8.53	17.8	15.61

WW – Well watered, WS – Water stress

Mean, range and components of variation for quantitative and physiological traits

Table 3: Estimates of mean and range for morpho-physiological, and yield component traits in groundnut F_3 segregating generation evaluated under WW and WS conditions during *summer* 2019

Trait	Mean		Per cent reduction	Range		CD at 5% ($p = 0.05$)	
	WW	WS		WW	WS	WW	WS
Plant height (cm)	25.22	21.33	15.42	20.76-53.25	18.62-52.44	1.29	2.8
No. of primary branches per plant	4.11	3.92	4.62	2.08-8.52	1.83-10	0.98	1.36
Pod no.	18.68	16.77	10.22	3.25-42.34	1.62-38.4	1.32	1.41
Pod yield per plant (g)	20.28	17.01	16.12	1.94-57.93	1.36-53.49	1.18	1.13
Kernel yield per plant (g)	13.44	12.66	5.8	1.21-31.77	1.34-27.05	0.44	0.63
Shelling per cent	64.54	60.56	6.17	23.62-60.99	21.18-57.31	14.86	3.49
RWC-70	49.88	48.46	2.85	8.68-76.21	31.47-65.56	4.21	4.14
RWC-85	45.94	44.42	3.31	9.42-72.52	28.03-59.78	4.58	3.77
SCMR-70	49.92	45.36	9.13	14.87-63.13	26.73-59.27	5.65	5.6
SCMR-85	45.73	41.95	8.27	14.68-59.78	19.88-55.09	5.04	5.98

WW – Well watered, WS – Water stress

The mean performance of superior recombinants for various physiological, yield and its attributes varied due to soil moisture regimes during *summer* 2019. The results of the experiment are given in Tables 3-5 and are presented below (Fig. 1).

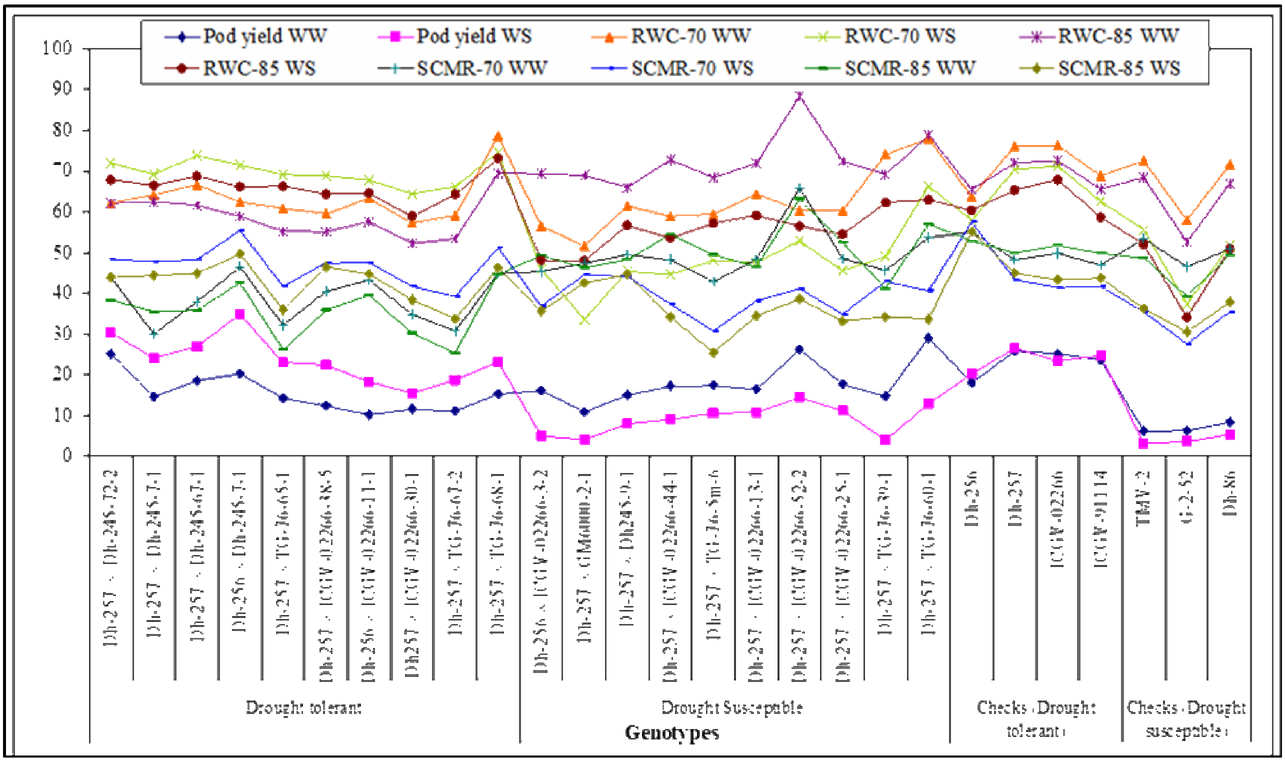

Fig. 1 : Mean performance of F_3 population for pod yield per plant (g), RWC (%) and SCMR under well-watered and water stress conditions during summer 2019

Table 4: Mean performance of superior recombinants identified for drought tolerance along with susceptible lines identified and compared with checks for plant height (cm), number of primary branches and number pods per plant under moisture stress conditions

Genotype and pedigree	Plant height (cm)		Per cent reduction by WS	No. of primary branches per plant		Per cent reduction by WS	No. Pod per plant		Percent reduction by WS
	WW	WS		WW	WS		WW	WS	
Drought tolerent genotypes									
Dh-257 × Dh-245-72-2	32.61	30.65	6.01	**4.21**	**3.83**	**9.03**	**25.34**	**31.94**	-26.05
Dh-257 × Dh-245-7-1	23.29	**21.63**	7.13	**7.08**	**6.32**	10.73	**15.62**	**16.82**	-7.68
Dh-257 × Dh-245-67-1	**29.97**	**25.98**	13.31	**4**	**3.56**	11.00	**25.36**	**27.94**	-10.17
Dh-256 × Dh-245-7-1	**24.31**	**24.04**	1.11	**4.72**	**4.07**	13.77	**33.42**	**38.11**	-14.03
Dh-257 × TG-76-65-1	22.87	**24.25**	**-6.03**	**5.32**	**4.26**	19.92	**10.92**	**13.82**	-26.56
Dh-257 × ICGV-2266-38-5	23.46	**24.54**	**-4.60**	**5.26**	**5.07**	**3.61**	**23.21**	**24.11**	-3.88
Dh-256 × ICGV-2266-11-1	**25.71**	**26.29**	**-2.26**	**5.12**	**4.32**	15.63	**18.34**	**19.11**	-4.20
Dh-257 × ICGV-2266-30-1	**25.87**	**21.32**	17.59	**4.23**	**3.68**	13.00	**11.01**	**17.11**	**-55.40**
Dh-257 × TG-76-67-2	**28.89**	**26.65**	7.75	**6.35**	**5.63**	11.34	**12.92**	**20.27**	**-56.89**
Dh-257 × TG-76-68-1	**24.76**	**22.15**	10.54	2.68	2.11	21.27	**22.2**	**26.67**	-20.14
Mean	25.38	23.63	6.90	4.9	4.29	12.45	19.83	23.59	-18.96
Drought susceptible genotypes									
Dh-256 × ICGV-2266-3-2	24.04	21.25	11.61	4.07	3.92	3.68	25.48	13.11	48.55
Dh-257 × GM-6000-2-1	26.37	21.23	19.49	4.99	4	19.8	10.9	5.89	45.96
Dh-257 × Dh-245-9-1	25.87	20.23	21.80	3	2.99	0.33	21.9	11.89	45.71
Dh-257 × ICGV-2266-44-1	31.79	24.21	23.84	3.92	2.07	**47.19**	23.34	9.11	**60.97**
Dh-257 × TG-76-5m-6	24.79	16.25	**34.45**	7.11	4.08	**42.61**	22.59	12.07	46.57
Dh-257 × ICGV-2266-13-1	26.32	19.98	**24.09**	3	1.83	**39.00**	24.84	10.94	**55.96**

Dh-257 × ICGV-2266-52-2	19.62	15.54	20.80	4	3.1	22.5	32.34	16.11	50.19
Dh-257 × ICGV-2266-25-1	14.71	9.62	**34.60**	2.92	2.07	29.10	27.34	12.71	53.51
Dh-257 × TG-76-39-1	**24.63**	**19.48**	20.91	2.11	2.08	1.42	26.07	17.92	31.26
Dh-257 × TG-76-60-1	28.95	23.65	18.31	3.08	2.36	23.38	41.26	20.32	50.75
Mean	25.51	20.26	20.58	3.37	3.29	2.43	25.61	13.01	49.20
Checks (Drought tolerent)									
Dh-256	22.00	21.12	4.00	4	3.75	6.25	28.59	29.4	**-2.83**
Dh-257	32.15	31.62	1.65	6.5	6.12	5.85	20.86	17.11	17.98
ICGV-02266	27.47	30.75	**-11.94**	10	8.51	3.2	16.06	18.02	**-12.20**
ICGV-91114	32.7	32.82	**-0.37**	6.37	5.1	9.03	11.64	13.2	-13.40
Mean	29.2	28.64	1.92	6.71	6.34	5.51	19.29	19.43	-0.73
Checks (Drought susceptible)									
TMV-2	29.55	20.40	**30.96**	7.47	6.5	**12.99**	7.61	4.56	40.08
G-2-52	27.65	21.43	**22.50**	7.53	6.85	9.03	4.26	2.35	**44.84**
Dh-86	27.55	22.90	16.88	6.87	6.5	5.39	8.34	5.11	38.73
Mean	28.25	21.58	23.62	7.06	6.84	3.12	6.74	4.01	40.50
Overall Mean	21.22	21.33	-0.52	4.11	3.92	4.62	45.97	28.92	37.09
CD5%	1.29	2.8		0.98	1.36		5.04	1.41	

Plant height of all the genotypes was reduced with progress of water stress. Similar results were reported by Boote *et al.* (1981). This indicated that moisture stress did not affect the growth of the plant in the drought tolerant genotypes.

The number of primary branches per plant of all the genotypes reduced from well-watered to water stress but reduction was more in drought susceptible genotypes, *viz.* Dh-257 × ICGV-2266-44-1 (47.19 %), Dh-257 × TG-76-5m-6 (42.61 %) and Dh-257 × ICGV-2266-13-1 (39.00 %) and less in drought tolerant genotypes (3.61-21.27%) of which the genotypes, *viz.* Dh-257 × TG-76-67-2 (6.35 and 5.63) and Dh-257 × Dh-245-7-1 (7.08 and 6.32) recorded higher number of primary branches per plant in both well-watered and water stress conditions. Similar kind of results was recorded by Mahesh and Khan, 2019. This was another growth parameter that was least affected in drought tolerant genotypes under water stress condition.

Majority of the drought tolerant genotypes had higher number of pods per plant compared to drought susceptible genotypes, Dh-257 × ICGV-2266-44-1 and Dh-257 × ICGV-2266-13-1 which also recorded higher reduction (60.97 % & 55.96 %) in number of pods per plant respectively from well-watered to water stress condition. However, the genotypes, Dh-257 × ICGV-2266-30-1 (-55.40 %) and Dh-257 × TG-76-67-2 (-56.89 %) recorded increased number of pods per plant from well-watered to water stress condition. The drought tolerant genotype Dh-256 × Dh-245-7-1 (33.42 & 38.11) recorded highest number of pods per plant in well-watered and water stress conditions. Similar results were recorded by Meisner and Karnok (1992) and Vorasoot *et al.,* (2003). These superior genotypes can be employed efficiently in breeding programmes.

Table 5: Mean performance of superior recombinants identified for drought tolerance along with susceptible lines identified and compared with checks for pod yield per plant (g) , kernel yield per plant (g), shelling per cent and oil per cent under moisture stress conditions

Genotype and pedigree	Pod yield per plant (g)		DTI PY	Per cent reduction by WS	Kernel yield per plant (g)		Per cent reduction by WS	Shelling per cent		Per cent reduction by WS	Oil per cent		Percent reduction by WS
	WW	WS			WW	WS		WW	WS		WW	WS	
Drought tolerant genotypes													
Dh-257 × Dh-245-72-2	25.07	30.34	1.21	-21.02	12.53	18.83	-50.28	61.23	63.74	-4.10	49.27	48.36	1.85
Dh-257 × Dh-245-7-1	14.62	24.05	1.65	-64.50	12.13	14.91	-22.92	63.63	65.08	-2.28	50.81	47.47	6.57
Dh-257 × Dh-245-67-1	18.62	26.84	1.44	-44.15	13.52	19.13	-41.49	60.35	73.37	-21.57	48.45	49.28	-1.71
Dh-256 × Dh-245-7-1	20.21	34.91	1.73	-72.74	15.62	21.83	-39.76	71.32	60.59	15.04	43.97	46.8	-6.44
Dh-257 × TG-76-65-1	14.23	22.87	1.61	-60.72	9.23	14.29	-54.82	62.35	63.05	-1.12	51.87	50.4	2.83
Dh-257 × ICGV-02266-38-5	12.40	22.31	1.80	-79.92	8.69	16.23	-86.77	65.32	69.55	-6.48	50.72	47.01	7.31
Dh-256 × ICGV-02266-11-1	10.24	18.34	1.79	-79.10	9.62	12.86	-33.68	70.14	66.48	5.22	46.01	48.96	-6.41
Dh257 × ICGV-02266-30-1	11.57	15.54	1.34	-34.31	8.36	11.63	-39.11	61.25	69.77	-13.91	53.27	49.94	6.25
Dh-257 × TG-76-67-2	11.12	18.70	1.68	-68.17	8.69	12.85	-47.87	62.54	70.17	-12.20	53.62	48.47	9.60
Dh-257 × TG-76-68-1	15.26	23.12	1.52	-51.51	13.23	20.59	-55.63	64.51	66.14	-2.53	51.57	47.37	8.14
Mean	15.33	23.70		-54.57	11.16	16.32		64.26	66.79		49.96	48.41	

Drought Susceptible genotypes													
Dh-256 × ICGV-02266-3-2	16.14	5.01	0.31	68.96	12.45	2.63	78.88	45.54	39.70	12.82	48.9	47.45	2.97
Dh-257 × GM6000-2-1	10.88	4.02	0.37	63.05	8.32	3.26	60.82	71.09	42.81	39.78	51.96	50.33	3.14
Dh-257 × Dh245-9-1	15.01	8.02	0.53	46.57	12.31	6.48	47.36	75.14	46.51	38.10	57.02	55.23	3.14
Dh-257 × ICGV-02266-44-1	17.24	9.06	0.53	47.45	12.34	7.68	37.76	60.29	48.27	19.94	46.27	49.17	-6.27
Dh-257 × TG-76-5m-6	17.38	10.62	0.61	38.90	14.25	7.79	45.33	72.44	43.10	40.50	48.84	46.67	4.44
Dh-257 × ICGV-02266-13-1	16.49	10.84	0.66	34.26	15.32	7.86	48.69	67.44	44.28	34.34	49.9	50.43	-1.06
Dh-257 × ICGV-02266-52-2	26.13	14.41	0.55	44.85	18.19	9.48	47.88	60.88	55.78	8.38	48.89	47.02	3.82
Dh-257 × ICGV-02266-25-1	17.74	11.19	0.63	36.92	16.47	8.03	51.24	64.76	47.82	26.16	51.58	52.32	-1.43
Dh-257 × TG-76-39-1	14.76	3.98	0.27	73.04	10.92	6.90	36.81	65.11	37.13	42.97	51.47	52.77	-2.53
Dh-257 × TG-76-60-1	28.97	12.82	0.44	55.75	30.32	12.46	58.91	52.73	50.16	4.87	51.47	53.37	-3.69
Mean	18.07	9.00		50.22	24.39	8.26	66.14	63.54	45.56	28.31	50.63	50.48	0.30
Checks (Drought tolerant)													
Dh-256	18.01	20.23	1.12	**-12.33**	12.26	15.77	-28.63	67.32	**73.49**	-9.17	48.76	50.37	-3.30
Dh-257	**25.74**	26.44	1.03	-2.72	16.72	15.00	10.29	70.12	72.31	-3.12	47.68	44.52	6.63
ICGV-02266	25.08	23.26	0.93	7.26	15.68	15.42	1.66	70.35	68.34	2.86	51.35	50.37	1.91
ICGV-91114	23.60	24.63	1.04	-4.36	17.45	16.16	7.39	71.21	70.74	0.66	49.29	47.48	3.67
Mean	23.11	23.64		-2.30	15.53	15.59	-0.39	69.75	71.22	-2.11	49.27	48.19	2.20
Checks (Drought susceptible)													
TMV-2	**6.18**	**3.14**	0.51	**49.19**	5.55	3.70	33.33	63.21	60.13	4.87	49.29	45.51	7.67
G-2-52	6.30	3.58	0.57	43.17	4.22	2.72	35.55	64.31	61.23	4.79	45.59	44.53	2.33
Dh-86	8.35	5.34	0.64	36.05	7.01	4.98	28.96	62.21	60.74	2.36	52.31	50.35	3.75
Mean	6.94	4.02		42.10	5.59	3.80	32.06	63.24	60.70	4.02	49.06	46.80	4.62
Overall Mean	13.44	19.01		-41.44	20.28	12.66	37.57	68.68	64.56	6.00	51.05	48.97	4.07
CD5%	0.44	1.13			1.18	0.63		1.32	3.49		0.11	0.13	

The pod yield per plant varied from 10.24 g (Dh-256 × ICGV-02266-11-1) to 25.74 g (Dh-257) under well-watered condition, from 3.14 g (TMV-2) to 30.34 g (Dh-257 × Dh-245-72-2) under water stress and with an average of 13.44 g, and 19.01 g pod yield per plant, respectively. While, majority of drought tolerant genotypes recorded increase in pod yield per plant with of higher number of pods per plant, from well-watered to water stress conditions, of which, Dh-257 × TG-76-39-1 (73.04 %), Dh-256 × ICGV-02266-3-2 (68.96 %) and Dh-257 × GM-6000-2-1 (63.05 %), were found promising. Similar results were recorded by Vadez and Ratnakumar (2016), and Aninbon *et al*, (2021). The reduction in pod yield from well-watered to water stress was more significant because of less number of pods per plant in drought susceptible genotypes Dh-257 × ICGV-02266-38-5 (-79.92 %), Dh-256 × ICGV-02266-11-1 (-79.10 %) and Dh-257 × TG-76-67-2 (-68.17 %). The genotypes with low pod yield had less number of matured pods under water stressed conditions due to less number of flowers and pegs (Songsri *et al.,* 2008).

The reduction in kernel yield per plant from well-watered to water stress was more significant in drought susceptible genotypes, *viz.* Dh-257 × TG-76-39-1 (78.88 %), Dh-256 × ICGV-02266-3-2 (60.82 %) and Dh-257 × GM-6000-2-1 (63.05 %), while, majority of drought tolerant genotypes recorded increase in pod yield per plant, of which, genotypes *viz.* Dh-257 × ICGV-02266-38-5 (-86.77 %), Dh-257 × TG-76-68-1 (-55.63 %) and Dh-257 × TG-76-65-1 (-54.82 %) were promising. Increase in pod yield per plant was associated with increase in number of pods per plant under water stress conditions. Higher kernel yield per plant was recorded by genotypes, *viz.* Dh-256 × Dh-245-7-1 (21.83 g), Dh-257 × TG-76-68-1 (20.59 g) and Dh-257 × Dh-245-67-1 (19.13 g). Similar results were recorded by Madukwe *et al.,* (2011), Khan *et al.,* (2012) and Carvalho *et al.,* (2017). Least reduction in pod yield per plant coupled with least reduction in shelling per cent would help to get genotypes with less reduction in kernel yield per plant.

Higher shelling per cent indicates good source-sink relation. It is also a good indicator to assess drought tolerance capacity of genotypes. In the present study, shelling per cent was increased from well-watered to water stress condition in drought tolerant genotypes. However, reduction in shelling per cent was more significant in drought susceptible genotypes, *viz.* Dh-257 × TG-76-39-1 (42.97 %), Dh-257 × TG-76-5m-6 (40.50 %) and Dh-257 × GM-6000-2-1 (39.78 %). Most of drought tolerant genotypes, recorded increased shelling per cent and, Dh-257 × Dh-245-67-1 (73.37 %) and Dh-256 (73.49 %) recorded higher shelling per cent compared to other genotypes under water stress condition. These results were similar to those reported by Carvalho *et al.* (2017) and Thakur *et al.* (2013).

There was no significant reduction in overall mean oil per cent of genotypes from well-watered to water stress condition. Higher oil per cent was recorded in genotypes, *viz.* Dh-257 × Dh245-9-1 (55.23 %), Dh-257 × TG-76-60-1 (53.37 %) and Dh-257 × TG-76-39-1 (52.77 %) under water stress condition. Similar results were recorded by Srivalli (2015). This could be advantage in breeding for drought tolerance without any reduction in main output, oil content of the produce.

Table 6: Mean performance of superior recombinants identified for drought tolerance along with susceptible lines identified and compared with checks for RWC at 70 DAS, RWC at 85 DAS, SCMR at 70 DAS and SCMR at 85 DAS under moisture stress conditions

Genotype and pedigree	RWC-70		Per cent reduction by WS	RWC-85		Per cent reduction by WS	SCMR-70		Per cent reduction by WS	SCMR-85		Percent reduction by WS
	WW	WS		WW	WS		WW	WS		WW	WS	
Drought tolerant genotypes												
Dh257 × Dh245-72-2	62.08	71.94	-15.88	62.01	67.84	-9.40	43.94	48.38	-10.10	38.35	43.92	-14.52
Dh257 × Dh245-7-1	64.06	69.18	-7.99	62.36	66.39	-6.46	29.96	47.83	-59.65	35.53	44.43	-25.05
Dh257 × Dh245-67-1	66.62	73.81	-10.79	61.57	68.74	-11.65	37.93	48.31	-27.37	35.85	44.92	-25.30
Dh256 × Dh245-7-1	62.29	71.47	-14.74	58.86	66.15	-12.39	46.43	55.43	-19.38	42.57	49.72	-16.80
Dh-257 × TG-76-65-1	60.86	69.09	-13.52	55.15	66.24	-20.11	32.11	41.71	-29.90	26.13	35.93	-37.50
Dh257 × ICGV2266-38-5	59.49	68.86	-15.75	55.11	64.25	-16.59	40.46	47.47	-17.33	35.89	46.47	-29.48
Dh256 × ICGV2266-11-1	63.32	67.70	-6.92	57.54	64.51	-12.11	43.29	47.51	-9.75	39.51	44.77	-13.31
Dh257 × ICGV2266-30-1	57.22	64.39	-12.53	52.18	58.88	-12.84	34.77	41.73	-20.02	30.18	38.38	-27.17
Dh-257 × TG-76-67-2	59.06	66.15	-12.00	53.32	64.21	-20.42	30.74	39.18	-27.46	25.33	33.74	-33.20
Dh-257 × TG-76-68-1	78.68	74.61	5.17	69.42	73.01	-5.17	44.87	51.19	-14.09	44.68	46.26	-3.54
Mean	63.37	69.72	-10.02	58.75	66.02	-12.37	38.45	46.87	-21.91	35.40	42.85	-21.05
Drought susceptible genotypes												
Dh256 × ICGV2266-3-2	56.47	45.87	18.77	69.31	48.08	**30.63**	45.39	36.84	18.84	49.32	35.62	27.78
Dh257 × GM6000-2-1	51.60	33.53	**35.02**	68.90	48.03	**30.29**	47.41	44.56	6.01	46.31	42.59	8.03
Dh257 × Dh245-9-1	61.45	45.44	26.05	65.94	56.63	14.12	49.56	44.23	10.75	48.31	44.62	7.64
Dh257 × ICGV2266-44-1	58.86	44.63	24.18	72.73	53.50	26.44	48.24	37.30	22.68	54.39	34.17	37.18
Dh-257 × TG-76-5m-6	59.40	48.11	19.01	68.33	57.11	16.42	42.88	30.74	**28.31**	49.53	25.38	**48.76**
Dh257 × ICGV2266-13-1	64.31	47.57	26.03	71.90	59.06	17.86	48.27	38.12	21.03	46.49	34.42	25.96
Dh257 × ICGV2266-52-2	60.33	52.85	12.40	88.36	56.42	**36.15**	65.82	41.19	**37.42**	63.13	38.53	38.97
Dh257 × ICGV2266-25-1	60.22	45.58	24.31	72.37	54.41	24.82	48.56	34.88	28.17	52.46	33.13	36.85
Dh-257 × TG-76-39-1	74.07	49.03	**33.81**	69.19	62.21	10.09	45.69	42.89	6.13	41.21	34.18	17.06
Dh-257 × TG-76-60-1	77.93	66.30	14.92	78.77	62.88	20.17	53.60	40.62	24.22	56.92	33.65	**40.88**
Mean	62.46	47.89	23.33	72.58	55.83	23.07	49.54	39.14	21.00	50.81	35.63	29.87
Checks (Drought tolerant)												
Dh-256	63.74	57.98	9.04	65.44	60.32	7.82	55.04	57.48	-4.43	52.86	55.09	**-4.22**
Dh-257	76.03	70.37	7.44	72.01	65.32	9.29	48.31	43.32	10.33	49.95	44.99	9.93
ICGV-02266	76.21	71.26	6.50	72.52	67.85	6.44	49.87	41.44	16.90	51.83	43.32	16.42
ICGV91114	68.85	62.51	9.21	65.50	58.62	10.50	46.97	41.67	11.28	49.94	43.78	12.33
Mean	68.87	58.20	15.50	72.97	60.43	17.19	51.49	42.51	17.43	52.12	40.26	22.77
Checks (Drought Susceptible)												
TMV-2	72.47	55.55	23.35	68.43	51.97	24.05	53.42	35.41	**33.71**	48.68	36.24	**25.55**
G-2-52	57.96	37.38	**35.51**	52.60	34.02	**35.32**	46.56	27.56	**40.81**	39.28	30.53	22.28
Dh-86	71.62	51.76	**27.73**	66.94	50.88	23.99	50.96	35.48	30.38	49.36	37.85	23.32
Mean	69.47	58.13	16.33	67.05	56.18	16.22	50.33	40.61	19.31	49.25	41.51	15.73
Overall Mean	45.94	48.46	-5.49	64.54	44.42	31.17	42.73	45.36	-6.15	49.88	41.95	15.90
CD5%	4.21	3.77		14.86	4.14		5.65	5.98		4.58	5.60	

RWC at 70 DAS was increased from well-watered to water stress condition in drought tolerant genotypes and it was reduced in drought susceptible genotypes. However, the reduction was more significant in drought susceptible genotypes, *viz.* G-2-52 (35.51 %), Dh257 × GM6000-2-1 (35.02 %) and Dh-257 × TG-76-39-1 (33.81 %). The genotypes with less reduction in RWC are regarded as drought tolerant genotypes. In present study, less reduction in RWC was observed with moisture stress during pegging stage. The results were on par with Khan *et al.* (2012), Chakraborty *et al.* (2015) and Ranganayakulu *et al.* (2015). On contrary, drought tolerant genotypes *viz* Dh257 × Dh245-72-2 (-15.88 %) and Dh257 × ICGV2266-38-5 (-15.75 %) recorded increase in RWC at 70 DAS compared to other genotypes and checks under water stress condition.

RWC at 85 DAS increased from well-watered to water stress condition but it was reduced in drought susceptible genotypes, *viz.* Dh257 × ICGV2266-52-2 (36.15 %), G-2-52 (35.32 %), Dh256 × ICGV2266-3-2 (30.63 %) and Dh257 × GM6000-2-1 (30.29 %). The genotypes with less reduction in RWC are regarded as drought tolerant genotypes. In present study, significantly higher reduction was observed during terminal stress. The results were on par with Khan *et al.* (2012), Chakraborty *et al.* (2016) and Ranganayakulu *et al.* (2015). On contrary, drought tolerant genotypes, *viz.* Dh-257 × TG-76-65-1 (-20.11 %) and Dh-257 × TG-76-67-2 (-20.42 %) recorded increase in RWC at 85 DAS compared to other genotypes under water stress condition. Among the drought tolerant recombinants, Dh-257 × TG-76-68-1 (73.01 %), Dh257 × Dh245-72-2 (67.84 %), and Dh257 × Dh245-67-1 (68.74 %) recorded higher RWC at 85 DAS compared to checks under water stress conditions, indicating their ability to maintain water content in leaves even under water stress conditions.

In present study, SPAD and chlorophyll content increased with water stress and similar results were reported by Nigam *et al.* (2008). Chlorophyll content increased with water stress there was minimal reduction in leaf water potential under stress and higher photosynthetic rate in genotypes with lower specific leaf area (Rao *et al.,* 2001). SCMR at 70 DAS increased from well-watered to water stress condition in drought tolerant genotypes and in drought susceptible genotypes it was reduced. However, the reduction was more significant in drought susceptible genotypes, *viz* G-2-52 (40.81 %), TMV-2 (33.71 %), Dh257 × ICGV2266-52-2 (30.38 %), and Dh-257 × TG-76-5m-6 (28.31 %). The drought tolerant genotypes *viz.* Dh257 × Dh245-7-1 (-59.65 %), Dh-257 × TG-76-65-1 (-29.90 %) and Dh-256 (-4.43 %) recorded higher increase in SCMR at 70 DAS under water stress conditions.

SCMR at 85 DAS of the drought tolerant genotypes increased from well-watered to water stress condition, whereas, it was reduced in drought susceptible genotypes, *viz.* TMV-2, Dh-257 × TG-76-5m-6 and Dh-257 × TG-76-60-1 which also have shown higher reduction (25.55 %, 48.76 % and 40.88 %, respectively) in SCMR at 85 DAS from well-watered to water stress condition. These results were in agreement with Saravanan *et al.,* (2018). On contrary, the genotypes *viz.* Dh-257 × TG-76-67-2 (-33.20 %), Dh-257 × TG-76-65-1 (-37.50 %), and Dh257 × ICGV2266-38-5 (-29.48 %) recorded higher increase in SCMR at 85 DAS from well-watered to water stress condition indicating their ability to withstand drought by maintaining photosynthetic rate for normal growth and development under moisture stress condition.

Variability in yield and physiological traits:

Table 7: Estimates of genetic parameters for morpho-physiological, and yield component traits in groundnut F_3 segregating generation evaluated under WW and WS conditions during *summer* 2019

Trait	GCV (%)		PCV (%)		h^2 b.s. (%)		GAM (%)	
	WW	WS	WW	WS	WW	WS	WW	WS
Plant height (cm)	27.48	25.29	27.82	26.93	97.63	88.17	56.02	48.99
No. of primary branches per plant	18.53	17.22	25.63	24.17	52.26	51.23	27.63	25.21
Pod no.	36.94	30.92	37.28	31.37	98.2	97.14	75.53	62.87
Pod yield per plant (g)	44	41.31	44.2	41.52	99.13	98.97	90.39	84.78
Kernel yield per plant (g)	41.54	38.57	41.61	38.73	99.7	99.19	85.57	79.25
Shelling per cent	23.54	25.21	16.62	25.5	94.54	97.76	51.56	51.42
RWC at 70 DAS	13.52	11	14.99	12.29	81.35	80.04	25.17	20.3
RWC at 85 DAS	15.21	12.13	16.53	13.79	84.66	77.28	28.86	21.99
SCMR at 70 DAS	12.14	7.93	14.41	12.22	71.07	42.06	21.12	10.6
SCMR at 85 DAS	12.6	9.32	15.68	13.25	64.58	49.47	20.89	13.53

WW – Well watered, WS – Water stress

In the present F_3 recombinants evaluation, yield components like pod number per plant, pod yield per plant, kernel yield per plant and shelling per cent recorded high heritability with moderate to high genetic advance as per cent mean (Table 6 and Fig 2) and this could serve as an index for selection to high yield (John *et al.,* 2008 and Sowmya and Nadaf, 2022). The indirect selection for yield through yield components that have high heritability seems to be much more rewarding than direct selection for yield alone. Hence, genetic improvement of these traits would be possible (Paniwadee *et al.,* 2009) through simple selection under water stress conditions.

Under both the moisture regimes, moderate to high level of GCV, PCV were estimated for shelling per cent these traits indicate the substantial contribution of additive genetic variance in the expression of these characters and high heritability coupled with high GAM were estimated which suggested selection will also be effective for these traits. The results were in accordance with the reports of Yadav *et al.* (2014), Mahalakshmi *et al.* (2018), Bhargavi *et al.* (2017).

Physiological traits

Moderate range of variability in terms of GCV and PCV and high heritability coupled with high GAM were estimated for RWC at two stages under two moisture regimes thus selection for this trait could be affective.

For the trait, SCMR at two stages moderate GCV, PCV along with high heritability and high GAM were estimated under well-watered condition, but under water stress condition, low GCV and moderate PCV coupled with moderate heritability and GAM was estimated indicating the influence of environment in the expression of SCMR. In contrast to present experiment in groundnut, Krishnamurthy *et al.* (2007) used RIL's TAG 24 × ICGV 86031 as experimental material and found the heritability of the SCMR quite similar across different experimental sites and water regimes which indicated that SCMR was less prone to environmental effect on this trait.

The physiological traits RWC and SCMR measured at these stages indicated low to moderate genetic variation in the recombinants (F_3) and difference between PCV and GCV for this trait indicated prevalence of environmental influence on these traits during both the seasons. In contrast to these results, significant genotypic variation for the traits related to drought tolerance was reported in numerous reports depending upon the material used for their study by Vorasoot *et al.* (2003) and Painawadee *et al.* (2009).

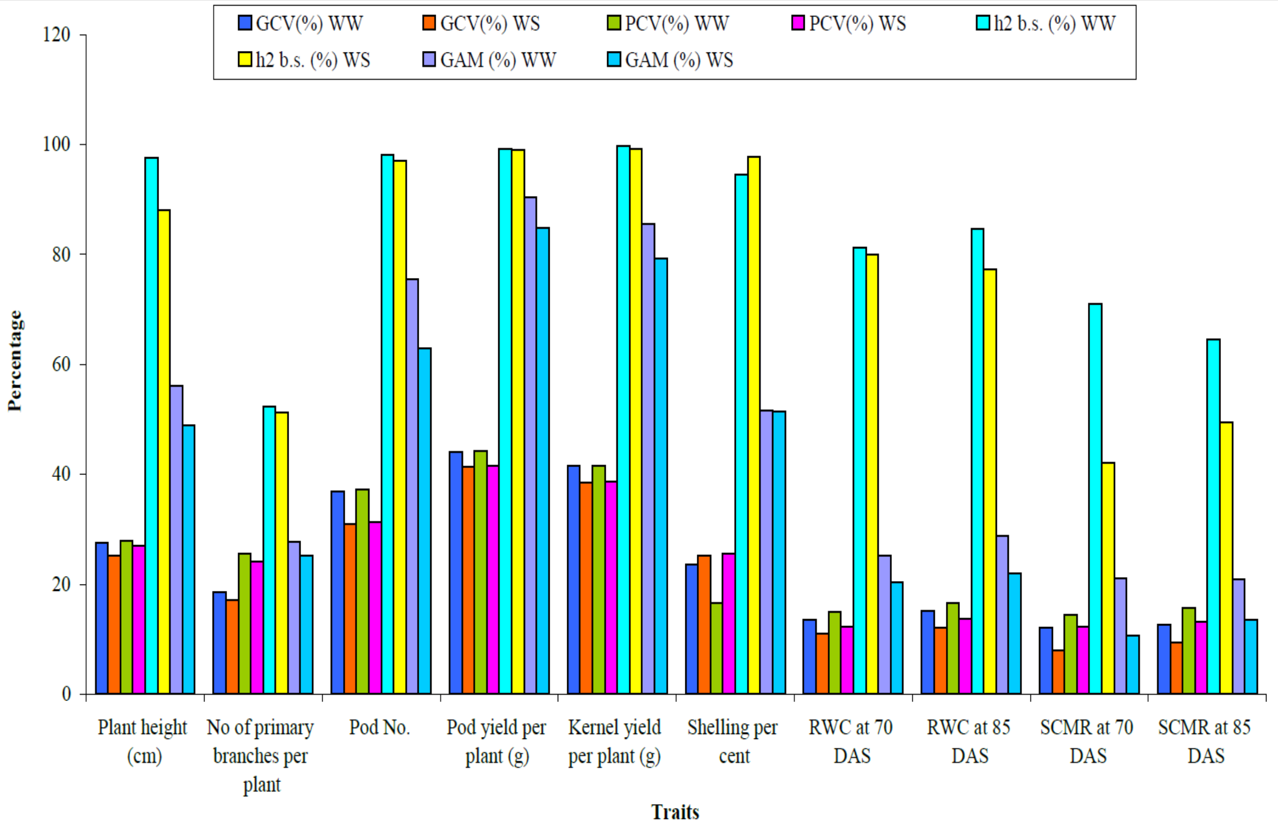

Fig. 2: Genetic variability parameters for quantitative and physiological characters in F_3 segregating population during summer 2019

Table 8: Estimates of correlation coefficients for morpho-physiological, and yield component traits in groundnut F_3 segregating generation evaluated under WW and WS condition during *summer* 2018-19

Characters	Moisture levels	Plant height (cm)	No. of primary branches per plant	Pod no.	Kernel yield per plant (g)	Shelling per cent	RWC-70	RWC-85	SCMR-70	SCMR-85	DTI	PY(g)
Plant height (cm)	WW	1										
	WS	1										
No. of primary branches per plant	WW	0.311**	1									
	WS	0.263**	1									
Pod no.	WW	-0.131	-0.152	1								
	WS	-0.205**	-0.332**	1								
Kernel yield per plant (g)	WW	-0.223**	-0.27**	0.799**	1							
	WS	-0.241**	-0.364**	0.252**	1							
Shelling per cent	WW	-0.127	-0.112	0.026	0.146	1						
	WS	-0.271**	-0.351**	0.818**	0.389**	1						
RWC-70	WW	0.297**	0.425**	0.367**	0.389**	-0.123	1					
	WS	0.014	0.054	0.488**	0.048	0.598**	1					
RWC-85	WW	0.294**	0.404**	0.376**	0.411**	-0.045	0.982**	1				
	WS	-0.012	-0.002	0.524**	0.06	0.634**	0.972**	1				
SCMR-70	WW	0.071	0.043	0.59**	0.589**	0.001	0.647**	0.66**	1			
	WS	-0.17	-0.303**	0.688**	0.293**	0.673**	0.595**	0.639**	1			
SCMR-85	WW	0.158	0.217**	0.481**	0.496**	-0.001	0.764**	0.788**	0.942**	1		
	WS	-0.067	-0.13	0.581**	0.179	0.585**	0.63**	0.646**	0.941**	1		
DTI	WW	-0.115	-0.103	-0.367**	-0.336**	0.038	-0.472**	-0.468**	-0.461**	-0.504**	1	
	WS	-0.114	-0.118	0.39**	0.013	0.402**	0.297**	0.307**	0.338**	0.33**	1	
PY (g)	WW	-0.144	-0.265**	0.81**	0.917**	-0.057	0.343**	0.355**	0.55**	0.44**	0.329**	1
	WS	-0.214**	-0.263**	0.735**	0.177**	0.876**	0.572**	0.606**	0.598**	0.51**	0.442**	1

WW – Well watered, WS – Water stress

Character association of quantitative, physiological traits and oil quality traits in two different moisture regimes.

Character association at genotypic level among yield and yield attributing traits along with physiological traits were studied in groundnut F_3 segregating generation evaluated under well-watered and water stress conditions and the results of genotypic correlation coefficients are given in Table 7. The results of correlation studies are presented hereunder.

Correlations analysis for pod yield and other traits

Under water stress conditions, pod yield per plant had significant positive genotypic correlation with shelling per cent. These results are consistent with Faye *et al.,* 2015 report. Similar findings of the present study of significant positive correlation between pod yield per plant and SCMR at all stages studied were reported earlier by Achirou *et al.* (2019) and Abady *et al.* (2021), with RWC at all stages studied by (Abady *et al.,* 2021), with kernel yield per plant by Oppong-Sekyere *et al.* (2019), with DTI by Srivalli (2015) with pod number. These correlations indicated that it is possible to derive the superior recombinants considering the combination of above traits under water stress conditions.

However, pod yield per plant had significant negative association with number of primary branches per plant and plant height. This could be due to the fact that under moisture stress condition, plant may not afford to have more vegetative growth to sustain under stress condition.

Conclusion

In the present F_3 recombinants evaluation, for number of primary branches per plant, there was moderate GCV and PCV and moderate heritability in broad sense coupled with high GAM under both the moisture regimes. High GCV and PCV and wide range of variation were estimated for most of the quantitative traits coupled with high heritability and high genetic advance as per cent mean for plant height, pod number per plant, pod yield per plant and kernel yield per plant under both moisture regimes.

Moderate GCV and PCV and high heritability coupled with high GAM were estimated for RWC at all stages studied under two moisture regimes thus selection for this trait could be effective. For the trait, SCMR at all stages studied moderate GCV, PCV along with high heritability and high GAM were estimated under well-watered condition, but under water stress condition, low GCV and moderate PCV coupled with moderate heritability and GAM were estimated SCMR could serve as an index of selection for drought tolerance. Oil content there was low GCV, PCV but high heritability with low GAM under well-watered and water stress conditions. Low variation in the population for these traits could be due to the less variation for these traits in the parents. This indicates that the phenotypic variability in F_3 recombinants reflected genotypic variability and thus not affected much by environmental fluctuations.

In the F_3 populations studied under water stress conditions, pod yield per plant had significant positive genotypic correlation with pod number per plant, shelling per cent, SCMR at all stages studied and kernel yield per plant. Kernel yield per plant recorded significant positive correlation with pod number per plant, shelling per cent SCMR at 70 DAS and plant drought tolerance index. RWC at 85 DAS had significant positive correlation with shelling per cent, RWC at 70 DAS, SCMR at all stages studied, and drought tolerance index. DTI recorded significant positive correlation with shelling per cent, indicating the significance of these traits for drought tolerance to improve pod yield under water stress condition.

Among F_3 populations studied, top 10 superior recombinant lines were identified for significant high yield under both well watered and water stress conditions compared to drought tolerant checks, and were on par with the checks *viz.* Dh257 × Dh245-72-2, Dh257 × Dh245-7-1, Dh257 × Dh245-67-1, Dh256 × Dh245-7-1, Dh-257 × TG-76-65-1, Dh257 × ICGV2266-38-5, Dh256 × ICGV2266-11-1, Dh257 × ICGV2266-30-1, Dh-257 × TG-76-67-2 and Dh-257 × TG-76-68-1.

Superior recombinants identified for high pod yield per plant with better oil quality traits such as oil content, protein content, oleic acid content and O/L ratio under water stress conditions. The genotypes *viz.* Dh-256 × Dh-245-5-1, Dh-256 × ICGV-02266-10-1 and Dh-257 × ICGV-02266-35-1 had significantly higher oleic acid and pod yield per plant under water stress conditions compared to checks, GM-6000 and Dh-245.

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