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RESEARCH ARTICLE

SCMR: A More Pertinent Trait than SLA in Peanut Genotypes Under Transient Water Deficit Stress During Summer

K. A. Kalariya[1] · A. L. Singh[1] · K. Chakraborty[1] · B. C. Ajay[1] · P. V. Zala[1] · C. B. Patel[1] · R. N. Nakar[1] · Nisha Goswami[1] · Deepti Mehta[1]

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Abstract Peanut cultivation is habitually threatened by drought which affects the plant at all stages of development. The transient water deficit stress was imposed during 30–60 days after sowing (DAS) and 60–85 DAS in summer seasons of 2011 and 2012, respectively. As a surrogate of transpiration efficiency (TE), soil plant analytical development (SPAD) chlorophyll meter reading (SCMR) and specific leaf area (SLA) were evaluated and correlated with the pod yield (PY). The SCMR value increased at 60 and 85 DAS due to water deficit stress imposed during 30–60 DAS and 60–85 DAS, respectively. The SLA ranged from 129 to 156 $cm^2\ g^{-1}$ at 60 DAS and from 131 to 152 $cm^2\ g^{-1}$ at 85 DAS. Water deficit stress during 30–60 DAS did not affect the PY but, the water deficit stress during 60–85 DAS had resulted in 26 % PY loss as compared to normal irrigated crop. Variation in total dry matter (TDM) among peanut genotypes was observed. The positive correlation between SCMR and TDM; and SCMR and PY; at 60 and 85 DAS under water deficit conditions categorized the SCMR as a more pertinent trait than the SLA in peanut genotypes. Thus, it is advised to record SCMR at 85 DAS as a rapid technique to screen a large number of peanut genotypes submitted to water deficit stress during summer which can minimise the labour and work load of breeders during varietal development programs.

Keywords *Arachis hypogaea* L. · Pod yield · Soil plant analytical development chlorophyll meter reading · Specific leaf area · Water deficit stress

✉ K. A. Kalariya
kuldeep_ka@yahoo.co.in; kuldeep_ka@nrcg.res.in

[1] Basic Sciences Unit, Directorate of Groundnut Research, PB 5, Junagadh, Gujarat 362 001, India

Introduction

The rain-fed regions of the semi-arid tropics produce two-thirds of the global peanut (*Arachis hypogaea* L.) production where an erratic and insufficient rainfall causes an unpredictable drought stress which is the most important constraint for peanut production [1]. The profit-making peanut cultivation is mainly confined in Asian (47 % of the world peanut area contributing 60 % of the total world production), African (47 % area, 27 % production) and American (4.4 % area and 8 % production) countries whereas in India about 5.7 million ha is under the cultivation of peanut with average productivity of about 1300 kg ha^{-1} [2]. Drought affects plants at all the stages of development and, in some cases, sensitivity varies with particular growth stage of crop [3, 4]. Because peanut production is habitually affected by drought, elevation of transpiration efficiency (TE) is crucial to cope up with drought conditions. Soil plant analytical development (SPAD) chlorophyll meter reading (SCMR) and specific leaf area (SLA) are amongst easily assessable surrogates of TE that can be used in breeding and selection schemes in crop plants [5]. The chlorophyll density decides the photosynthetically active light-transmittance features of the leaf which is measured by the SCMR [6]. Significant positive correlations between SCMR and chlorophyll density [7] indicates that high SCMR value may have a higher photosynthetic activity per unit area. Studies piloted in greenhouse elucidate that SCMR increases and SLA reduces due to early season drought stress in peanuts but, with a smaller contribution to TE under well-watered and early season drought conditions [8]. Greenhouse condition does not always represent the real field situation which is fashioned by the nature because the drought is generated with advancement of time and not the incessantly

restricted/limited water supply. Several studies are conducted to show a relationship between SLA and SCMR in greenhouse or pot experiments but, there are only a limited experiments conducted to establish the relationship of SCMR, SLA and pod yield (PY) in field conditions where, except the irrigation water disposal, all other weather parameters are natural. Through such limited field experiments, attempts have been made to identify the most appropriate time to record SCMR and SLA. Based on the literature survey, the most appropriate time to record SCMR and SLA in peanut is 60 days after sowing (DAS) [5], 85 DAS [9] and 30, 60 and 90 days after emergence (DAE) [10]. In addition, the experimental material itself decides the fate of usefulness of SCMR as normally distribution of SCMR value is reported in recombinant inbred lines (RILs). Due to the poor regression coefficients (r2) the SCMR is not considered adequately robust enough as a reliable surrogate of TE in peanut RILs [11]. Most drought resistant traits were not correlated with PY and yield components except for SCMR with pod number per plant. Further, the heritability estimates of SLA and SCMR in early segregating population is difficult and evaluation should be carried out in more advanced populations [12]. Assessment of water use efficiency (WUE) in peanut developing material and cultivars is needed not only across different growing regions, but also during different growing conditions [13]. It is useful to guide breeders to modify varieties for improvement in WUE [14]. Measurement of SLA needs a high skilled labour requirement and more time but, through SCMR a large number of samples can be tested in short time which is very much needed while testing a large population of advanced breeding lines. In peanuts, stage specificity intolerance and susceptibility to water deficit condition is documented for photosynthetic characteristics [15]. SCMR is negatively correlated with SLA and information on specific responses at a particular stage during which water deficit condition leads to economic yield loss is required. If SCMR is found to have any stage specific responses then it can be used as a rapid screening technology during a particular growth stage and can reduce the work load of a breeder during varietal development procedure. Comparing responses of a specific trait in contrasting genotypes for the same trait under a particular environment is one of the approaches that characterizes the behaviour of a particular trait. Thus, this study was targeted to unravel the changes in SCMR and SLA in contrasting Spanish peanut genotypes (for base SCMR values) to assess their influence on PY and yield components in two summer seasons under water deficit stress imposed during different growth periods in field conditions.

Material and Methods

Field Trails and Plant Materials

Field experiments were conducted during summer seasons (January–June) of 2011 and 2012 at the research farm of Indian Council of Agricultural Research-Directorate of Groundnut Research, Junagadh, Gujarat, India (lat 21°31′N, Long 70°36′E) in the Vertic Ustochrept soil with field capacity 30.3, pH 7.5 and the electrical conductivity of 0.16 dsm^{-1}. The trial was laid out in a factorial randomized block design with main treatments of three irrigation treatments viz. T_1—normal irrigation (well watered), T_2—transient water deficit stress during 30–60 days after sowing (DAS) and T_3—transient water deficit stress during 60–85 DAS and sub treatment comprising of six peanut Spanish varieties. Mean SCMR value (during 45–60 DAS) reported in previous experiments under normal condition during Kharif 2010 (data not presented) was considered for the selection of varieties namely, ICGV 86031, ICGS 44 and SG 99 (for high SCMR value >38) and TAG 24, DRG 1 and AK 159 (for low SCMR value <32). Seeds were procured from the plant physiology department of the directorate. The net plot size was 4 × 3 m^2 with nine effective lines/plot at 45 cm row to row and 10 cm plant to plant spacing. Before sowing, fertilizers (40 N:50 P:50 K) were applied in furrows. Sowing was carried out in the last week of January in year 2011 and the first week of the February in year 2012 keeping a population density of 22 plants m^{-2} and suggested agronomic and plant protection measures were followed carefully. In normal irrigated control-T_1, the irrigation was continued to replenish 100 % pan evaporation at 7–8 days interval. In T_2 (water deficit stress during 30–60 DAS followed by adequate water supply), the last irrigation was given on 24 DAS so as to achieve the palpable water deficit period to start from 30 DAS (beginning of bloom) by skipping a total of four irrigations and next irrigation was given on 61st DAS to relieve a 30 days long stress period on 61st DAS (beginning seed). In T_3 (water deficit stress during 60–85 DAS followed by adequate water supply) a 25 days long drought period was imposed between beginning of seed to beginning of maturity.

Soil Moisture and Plant Water Relations

For determination of soil moisture content by gravimetric method, soil samples were taken from two soil depths; 0–15 and 15–30 cm from each treatment plots periodically. Relative water content (RWC %), SCMR and SLA were measured during 28–30 DAT (days after treatment) in T_2

and 23–25 DAT in T_3 in each replicas and compared with T_1. The RWC was calculated as under.

$$\text{RWC } (\%) = [(\text{FW}-\text{DW})/(\text{TW}-\text{DW})] \times 100$$

where, FW is fresh weight, DW is dry weight and TW is turgid weight. Second fully opened leaf from the apex of the main stem of the plant was selected to record SCMR by SPAD-502 meter (Minolta Konica Co. Ltd., Japan). Care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina and the inferences from veins and midribs could be avoided. The SLA was measured from the second fully opened leaf randomly selected in each treatment in the morning hours (08:00–09:30). Leaf area of these leaves was measured with a LI 3100 leaf area meter (LI-COR Inc., Lincoln, NE, USA), leaves were then oven-dried at 60 °C for 72 h and weighed and specific leaf area (cm^2g^{-1}) was calculated as under.

$$\text{SLA} = \text{Leaf area}\left(\text{cm}^2\right)/\text{Leaf dry wt (g)}$$

Mean of five readings of SCMR and mean of two readings of SLA was used to represent one replication in each treatment.

Measuring Pod Yield and Yield Attributes

The crop was harvested at full maturity and the pods were allowed to dry under the sun till the moisture content of the kernel reaches 8–10 %. This produce was further used to measure PY, total dry matter (TDM) and shelling (%) of the data PY and TDM were used to calculate HI. Mean of five records was used to represent value of 100 seed mass (g) and shelling (%). Shelling (%) was calculated as under.

$$\text{Shelling } (\%) = [(\text{weight of kernels}/\text{weight of pods})] \times 100.$$

The stress tolerance index was calculated through formula given by Fernandez as under.

$$\text{STI} = \frac{\text{YiYs}}{(\grave{\text{Y}})^2} \times 100$$

where Yi is the PY of well-watered (T_1) plots, Ys is the PY of stressed plots (T_3) and $\grave{\text{Y}}$ is the PY average for the population [16].

Weather Parameters

Weather parameters were recorded during cropping season of both years (Fig. 1). Minimum temperature ranged from 14.1 to 27.4 °C and the maximum temperature from 30.1 to 40.6 °C during cropping season in 2011. During 2012, the minimum and maximum temperatures ranged between 11.2 to 27.1 °C and 27.5 to 40.5 °C, respectively. Relative humidity ranged between 48 and 85 % in 2011 and 37 and 85 % during 2012. Evaporation ranged from 3.2 to 10.6 mm with an average of 7.8 mm in 2011 and from 5.7 to 10.7 mm with an average of 8.5 mm in 2012.

Statistical Analysis

The data obtained from both the years were analysed using two-way repeated measure ANOVA in excel with DSAASTAT add-on with the year as fixed effect with three replicas and the least significant differences were calculated to assess the significance of treatment means where the "F" test was found significant at $P < 0.05$. Correlation between different traits at 60 and 85 DAS was studied using PAST (ver. 2.17c) statistical software.

Results and Discussion

Soil–Water–Plant Relations

During 30–85 DAS, mean soil moisture content (SMC) in T_1 plots remained above 14 and 15 % in 0–15 cm and 15–30 cm soil-layer, respectively (Table 1). Overall, the SMC was higher in 15–30 cm soil (lower) layer than the 0–15 cm soil (upper) layer irrespective of the treatment. In T_2 and T_3 plots, SMC decreased in a linear fashion and after a rehydration through irrigation it remained above 14.0 % till 85 DAS which was maintained till harvest (data not presented). The percentage decrease in SMC in T_2 accounted 41 % in both upper and lower soil layers as compared to T_1 at 60 DAS, whereas in T_3, the percentage decrease in SMC was 56 % in upper soil layer and 37 % in lower soil layer as compared to T_1 at 85 DAS. In T_3 plots the SMC reached to as low as 6.2 % at 85 DAS. The mean relative water content (RWC) was 94.5 in T_1 and 87.8 in T_2 at 60 DAS whereas, at 85 DAS it was 93.1 % in T_1 and 83.7 % in T_3 (Table 2). There was a significant effect of irrigation treatment on RWC (%) (Table 3).

SCMR and SLA

Over the years, significant variation was reported in SCMR due to irrigation treatments. The SCMR also varied due to genotypic differences with the highest in SG 99 (45.3) at 60 DAS and in ICGV 86031 (45.3) at 85 DAS. The interaction irrigation x genotype was significant at both growth stages in year 2011. At 60 DAS, the interaction effects year × genotype and at 85 DAS, irrigation × year and year × genotype were significant for SCMR values (Table 3). T_2 and T_3 have reduced the SLA. It was 152 cm^2g^{-1} in T_1 and 138 cm^2g^{-1} in T_2 at 60 DAS whereas it was 153 cm^2g^{-1} in T_1 and 128 cm^2g^{-1} in T_3 at 85 DAS. Among peanut genotypes, the leaf thickness in

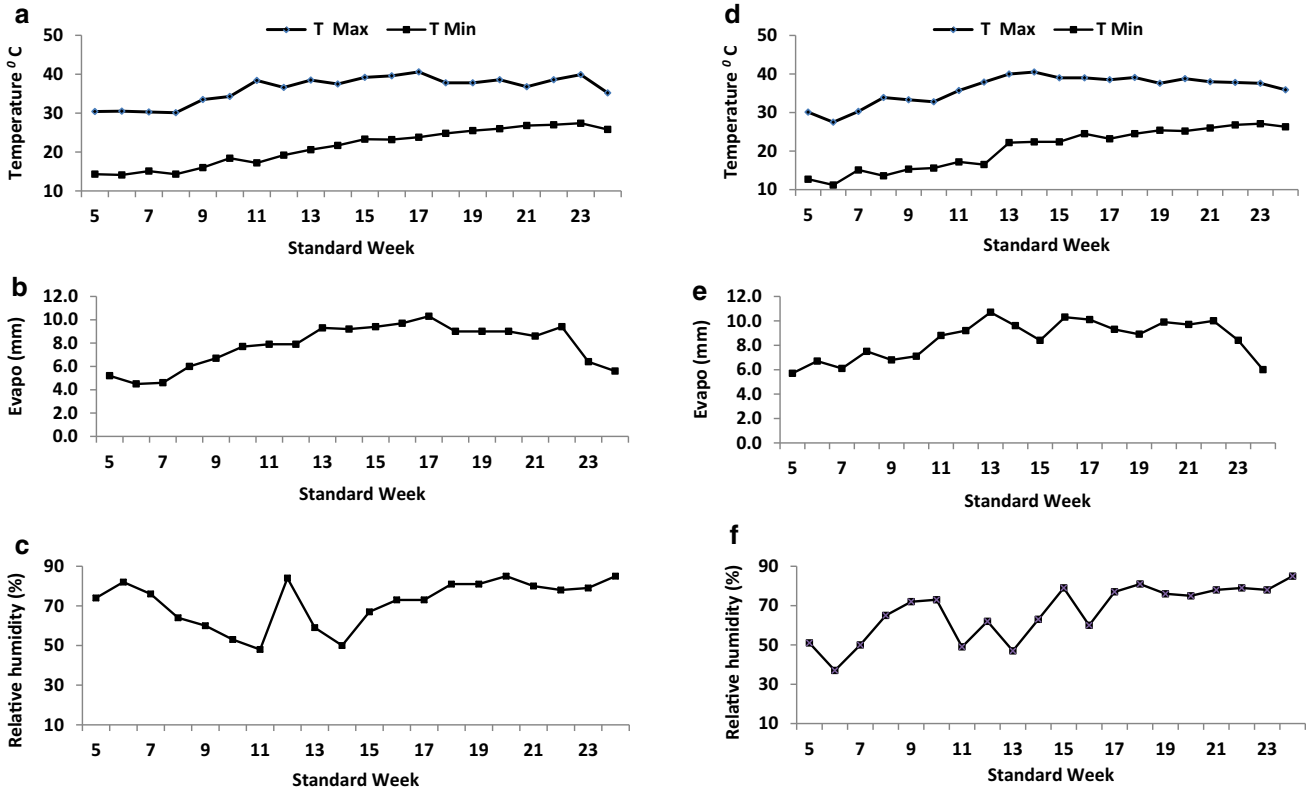

Fig. 1 Weather parameters during the crop growth period at Junagadh, Gujarat: Maximum and minimum temperature (°C), evaporation rate (mm) and relative humidity (RH %) during year 2011 (**a**, **b**, **c** respectively) and during year 2012 (**d**, **e**, **f** respectively)

Table 1 Mean soil moisture content at different soil depth from 30 DAS to 85 DAS in the experimental field during summer 2011 and 2012

Treatment plot	DAS	Soil depth 0–15 cm	Soil depth 15–30 cm
T_1	30	17.5	19.0
	45	15.0	16.3
	60	16.0	17.1
	75	15.0	16.5
	85	14.0	15.0
T_2	30	13.5	15.0
	45	11.6	12.3
	60	9.4	10.1
	75	16.2	17.2
	85	14.5	15.5
T_3	30	17.0	18.0
	45	15.0	16.0
	60	12.5	13.5
	75	9.2	11.6
	85	6.2	9.4

T_1 normal irrigation, T_2 transient water deficit stress during 30–60 DAS and T_3 transient water deficit stress during 60–85 DAS

terms of SLA varied at both growth stages. It was 129–156 cm^2g^{-1} at 60 DAS and 131–152 cm^2g^{-1} at 85 DAS.

TDM and PY

TDM decreased significantly due to irrigation treatments. It was 37.7 g $plant^{-1}$ in T_1, 36.2 g $plant^{-1}$ in T_2 and 30.2 g $plant^{-1}$ in T_3 (Table 4). Genotypic variations in TDM showed that the highest TDM was in ICGV 86031 (38.4 g $plant^{-1}$) and the lowest in TAG 24 (26.9 g $plant^{-1}$). The PY increased by 5 % in T_2 but, 26 % PY loss is reported in T_3 as compared to the T_1. Similarly as TDM, the PY was also varied due to genotypic differences, the highest PY being in ICGS 44 (11.4 g $plant^{-1}$) and the lowest in ICGV 86031 (7.8 g $plant^{-1}$). Varied response in PY due to irrigation was observed among the genotypes and the highest PY (12.7 g $plant^{-1}$) was in genotype SG 99 in T_1 and in genotype ICGS 44 in T_2 and it was lowest in genotype TAG 24 (5.5 g $plant^{-1}$) in T_3.

Harvest Index, Shelling (%) and 100 Seed Mass

The harvest index (HI) was almost the same in T_1 (0.26) and T_3 (0.25) but has increased in T_2 (0.29) (Table 4). Due to genotypic differences the lowest mean HI was observed in ICGV 86031 (0.20) and the highest mean HI in TAG 24 (0.32). Across the treatments, genotype TAG 24 topped for the highest HI (0.37) in T_2 and ICGV 86031 (0.19) stood at

Table 2 RWC(%), SCMR and SLA (cm^2/g) in peanut leaves at 60 and 85 DAS during summer 2011 and 2012 respectively, values are means of three replicates ± standard deviation

Genotype	RWC (%)								SCMR			
	2011				2012				2011			
	60 DAS		85 DAS		60 DAS		85 DAS		60 DAS		85 DAS	
	T_1	T_2	T_1	T_3	T_1	T_2	T_1	T_3	T_1	T_2	T_1	T_3
AK 159	93.3 ± 0.6	87.3 ± 1.0	91.4 ± 0.8	83.0 ± 1.6	95.3 ± 0.6	87.6 ± 0.6	95.1 ± 0.3	83.9 ± 1.1	32.6 ± 1.4	41.4 ± 0.5	36.1 ± 1.7	40.4 ± 0.5
DRG 1	93.8 ± 1.7	86.3 ± 0.6	94.0 ± 0.4	80.8 ± 2.6	96.6 ± 0.5	88.7 ± 0.9	94.4 ± 0.6	84.6 ± 0.9	30.7 ± 0.8	38.4 ± 0.4	32.9 ± 1.1	37.6 ± 0.8
ICGS 44	94.1 ± 2.0	89.7 ± 1.7	92.4 ± 0.7	82.6 ± 2.3	95.9 ± 0.3	89.7 ± 0.5	93.7 ± 1.2	84.9 ± 3.5	40.1 ± 0.2	46.9 ± 2.9	43.3 ± 0.6	43.5 ± 0.9
ICGV 86031	93.3 ± 1.3	84.0 ± 2.0	91.6 ± 0.9	83.7 ± 0.3	93.7 ± 0.6	87.8 ± 2.5	93.4 ± 0.3	84.9 ± 0.2	40.2 ± 0.4	45.1 ± 0.8	42.8 ± 1.0	44.0 ± 1.0
SG 99	94.4 ± 1.0	89.2 ± 0.5	92.7 ± 0.5	86.0 ± 0.8	96.9 ± 0.9	85.7 ± 4.4	94.6 ± ±0.5	82.8 ± 5.5	39.8 ± 0.3	48.3 ± 1.0	42.41 ± 1.2	48.9 ± 0.7
TAG 24	92.9 ± 1.9	87.6 ± 0.5	90.7 ± 1.1	82.7 ± 0.5	94.1 ± 0.1	89.5 ± 0.7	93.3 ± 0.7	84.2 ± 2.3	35.1 ± 0.9	40.2 ± 0.6	38.1 ± 1.5	40.0 ± 0.4
Mean	93.7	87.3	92.1	83.2	95.4	88.2	94.1	84.2	36.4	43.4	39.3	42.4
Genotype	SCMR				SLA (cm^2/g)							
	2012				2011				2012			
	60 DAS		85 DAS		60 DAS		85 DAS		60 DAS		85 DAS	
	T_1	T_2	T_1	T_3	T_1	T_2	T_1	T_3	T_1	T_2	T_1	T_3
AK 159	36.4 ± 0.7	43.9 ± 0.4	44.8 ± 1.8	48.0 ± 2.4	161 ± 5.6	138 ± 1.5	151 ± 6.5	124 ± 2.3	154 ± 2.4	148 ± 7.7	158 ± 5.9	131 ± 5.2
DRG 1	31.2 ± 0.6	39.6 ± 0.4	36.3 ± 1.9	38.6 ± 0.5	161 ± 2.9	143 ± 3.6	156 ± 1.7	146 ± 2.2	166 ± 7.9	152 ± 9.9	165 ± 5.2	141 ± 1.7
ICGS 44	42.1 ± 0.2	50.1 ± 0.4	43.9 ± 0.5	47.8 ± 1.2	149 ± 0.8	140 ± 8.6	156 ± 1.7	137 ± 8.4	151 ± 2.7	130 ± 15.6	157 ± 11.1	134 ± 11.3
ICGV 86031	39.8 ± 0.3	47.8 ± 0.8	44.0 ± 1.1	50.5 ± 1.5	133 ± 3.2	128 ± 1.3	146 ± 8.0	117 ± 4.2	138 ± 8.8	118 ± 6.9	143 ± 10.0	116 ± 10.7
SG 99	43.0 ± 0.2	50.2 ± 0.2	38.5 ± 1.1	41.3 ± 0.6	154 ± 5.2	139 ± 0.6	152 ± 10.4	119 ± 3.1	149 ± 8.0	137 ± 7.2	142 ± 3.5	118 ± 3.9
TAG 24	33.9 ± 0.9	41.8 ± 0.3	33.8 ± 0.9	41.1 ± 2.9	153 ± 4.0	137 ± 2.5	160 ± 6.4	130 ± 4.7	151 ± 3.8	145 ± 7.9	152 ± 9.3	128 ± 7.3
Mean	37.7	45.6	40.2	44.6	152	138	154	129	151	138	153	128

T_1 normal irrigation, T_2 transient water deficit stress during 30–60 DAS and T_3 transient water deficit stress during 60–85 DAS

Table 3 Repeated measure two-way ANOVA for RWC (%), SCMR and SLA (cm^2/g) at 60 DAS and 85 DAS in peanut genotypes during summer 2011 and 2012

	df	RWC		SCMR		SLA	
		60 DAS	85 DAS	60 DAS	85 DAS	60 DAS	85 DAS
Replication	2	1.69	0.85	4.27	0.98	14.53	3.30
Year	1	30.91	41.04	54.67	43.61	1.05	13.14
Replication × year	2	0.41	7.81	0.04	1.27	1.00	19.65
Treatment	1	831.31**	1601.40**	985.73**	251.25**	3268.73**	11,013.27**
Year × treatment	1	4.18	3.83	3.40	6.14*	4.85	0.05
Error treatment	4	0.79	4.27	2.82	0.32	39.58	10.72
Genotype	5	9.20**	1.90	217.60**	152.41**	957.35**	782.35**
Year × genotype	5	3.60	3.50	4.11**	67.72**	57.26	67.28
Treatment × genotype	5	5.37	4.00	1.84	2.69	9.21	62.54
Year × treatment × genotype	5	7.59*	6.54	2.68*	12.26**	108.59**	45.01
Residual	40	2.43	2.75	0.83	1.46	24.35	73.74
Total	71	15.49	26.34	31.38	21.70	142.25	265.51

* Significant at $P < 0.05$

** Significant at $P < 0.01$

the last in T_1 and DRG 1 (0.20) in T_3. Water deficit condition during 60–85 DAS (T_3) reduced the shelling percentage. It was 68 % in T_1 and 61 % in T_3. Like TDM, PY and HI, due to genetic makeup of the genotypes, the shelling percentage also behaved differently with highest in SG 99 and the lowest in AK 159. The highest shelling percentage was observed in ICGS 44 (74) in T_2 and the lowest in TAG 24 (57) in T_3. Irrigation treatment affected 100 seed mass accounting 22 % reduction in T_3 as compared to the T_1. 100 seed mass was decreased from 41 g in T_1 to 39 g in T_2 and to 32 g in T_3. Genotype ICGS 44 (50.6) topped for 100 seed mass whereas genotype DRG 1 (28.4 g) had the lowest 100 seed mass. The interactions of treatment × genotype for 100 seed mass was significant and the same genotype ICGS 44 reported maximum of 100 seed mass (58 g) in T_1 and genotype DRG 1 the minimum (25 g) in T_3 (Table 5).

Stress Tolerance Index (STI)

Because the PY in T_2 was at par with that of the T_1 and there was a 26 % reduction in PY in T_3, the STI was calculated based on the reduction in PY in T_3 only (Fig. 2). On average, there was 4 % reduction in TDM in T_2 and 20 % reduction in T_3 as compared to the T_1 and 5 % increase in PY in T_2 is also observed. The percentage increase in PY in T_2 was highest in TAG 24 and interestingly, the highest reduction in PY in T_3 was also noted in the same genotype. The percentage reduction in PY in T_3 is in order of TAG 24 (37 %), SG 99 (36 %), DRG 1 (32 %), ICGS 44 (21 %), ICGV 86031 (12 %) and AK 159 (11 %). Similarly as TDM, PY, HI and 100 seed mass, the STI also varied among the genotypes due to genetic constitution and again, like other parameters, genotype ICGS 44 also topped for highest STI*100 value (116). It was interesting to note that genotype ICGV 86031 had lowest value of SLA and STI (54) (Fig. 2).

Association Between Various Traits

At 60 DAS there was a significant negative relationship between SLA and SCMR in T_1 ($r = -0.60^{**}$) and T_2 ($r = -0.61^{**}$) and thus, the relationship remained constant under different irrigation treatments at 60 DAS. At 85 DAS this relationship was significant in T_3 only with a weak correlation value ($r = -0.34^{*}$), showing non significance of the relationship at this particular crop growth stage in T_1 and also a lesser impact of water deficit on this relationship at the latter stage (Table 6). At 60 DAS the SCMR was positively correlated with TDM ($r = 0.43^{*}$) and PY($r = 0.51^{**}$) in T_1. In T_2 this relationship remained constant with a stronger correlation value for TDM ($r = 0.60^{**}$) but a weaker value for PY ($r = 0.42^{*}$). A similar trend was observed for the association of the SLA with the TDM as well as the PY but with a weak correlation values at the 85 DAS.

The leaf RWC was considered a more convenient integrator of plant water equilibrium than the leaf water potential [17, 18] and is more stable and sensitive than water potential in peanut under water deficit stress [19]. The significant reduction in RWC in this study was in close agreement with soil water availability which decreased due to water deficit stress.

Table 4 Total dry matter (TDM g plant^{-1}), pod yield (PY g plant^{-1}), harvest index (HI), shelling (%) and 100 seed mass (g) in peanut genotypes during summer 2011 and 2012 values are means of three replicates ± standard deviation

Treatment	Genotype	TDM (g plant^{-1})			PY (g/plant^{-1})			HI			Shelling (%)			100 seed mass (g)		
		2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
T_1	AK 159	35.0 ± 3.4	38.9 ± 1.2	37.0	8.0 ± 1.5	9.4 ± 1.1	8.7	0.23 ± 0.022	0.24 ± 0.031	0.23	65 ± 1.0	63 ± 0.5	64	34 ± 1.5	30 ± 1.0	32
	DRG 1	37.4 ± 1.0	38.5 ± 1.6	37.9	8.2 ± 0.5	9.6 ± 1.4	8.9	0.22 ± 0.018	0.25 ± 0.025	0.23	67 ± 2.4	63 ± 0.9	65	33 ± 2.4	29 ± 1.9	31
	ICGS 44	40.6 ± 0.7	40.3 ± 1.7	40.4	11.9 ± 0.6	12.1 ± 0.8	12.0	0.29 ± 0.016	0.30 ± 0.022	0.30	74 ± 2.9	70 ± 1.3	72	56 ± 0.2	59 ± 2.2	58
	ICGV 86031	43.0 ± 1.9	37.8 ± 0.9	40.4	7.9 ± 0.9	7.6 ± 0.9	7.8	0.18 ± 0.018	0.20 ± 0.019	0.19	66 ± 4.4	68 ± 2.6	67	33 ± 1.2	30 ± 0.9	32
	SG 99	45.2 ± 1.7	37.5 ± 2.7	41.4	12.3 ± 0.9	13.1 ± 0.7	12.7	0.27 ± 0.011	0.35 ± 0.008	0.31	74 ± 0.4	71 ± 1.7	73	55 ± 0.5	52 ± 1.6	53
	TAG 24	27.8 ± 0.4	30.9 ± 2.6	29.4	9.1 ± 1.0	9.5 ± 2.6	9.3	0.33 ± 0.032	0.30 ± 0.074	0.32	69 ± 5.2	65 ± 4.6	67	38 ± 2.7	39 ± 1.9	38
Mean		38.2	37.3	37.7	9.6	10.2	9.9	0.25	0.27	0.26	69	67	68	42	40	41
T_2	AK 159	30.7 ± 1.2	31.4 ± 2.1	31.0	9.5 ± 0.4	8.4 ± 0.9	9.0	0.31 ± 0.020	0.27 ± 0.044	0.29	62 ± 0.9	60 ± 1.5	61	34 ± 1.4	32 ± 0.8	33
	DRG 1	36.4 ± 0.7	36.6 ± 2.0	36.5	8.5 ± 1.6	10.1 ± 0.3	9.3	0.24 ± 0.049	0.28 ± 0.010	0.26	63 ± 2.2	60 ± 0.4	62	29 ± 0.9	28 ± 1.0	29
	ICGS 44	39.1 ± 2.6	40.2 ± 1.5	39.6	12.0 ± 3.8	13.3 ± 1.2	12.7	0.31 ± 0.093	0.33 ± 0.034	0.32	74 ± 0.6	73 ± 1.6	74	53 ± 1.3	50 ± 1.7	52
	ICGV 86031	40.8 ± 4.8	40.8 ± 1.8	40.8	9.9 ± 2.6	7.4 ± 1.4	8.7	0.24 ± 0.037	0.18 ± 0.025	0.21	68 ± 5.6	64 ± 4.9	66	33 ± 2.3	32 ± 1.9	33
	SG 99	35.5 ± 4.9	43.8 ± 4.1	39.7	11.2 ± 3.6	13.1 ± 0.8	12.1	0.31 ± 0.069	0.30 ± 0.010	0.30	71 ± 0.6	70 ± 1.1	71	47 ± 0.8	52 ± 2.4	50
	TAG 24	29.7 ± 1.2	29.0 ± 0.4	29.3	10.7 ± 0.9	11.2 ± 0.8	10.9	0.36 ± 0.023	0.39 ± 0.025	0.37	68 ± 1.0	70 ± 2.2	69	43 ± 1.3	40 ± 1.8	41
Mean		35.4	37.0	36.2	10.3	10.6	10.4	0.29	0.29	0.29	68	66	67	40	39	39
T_3	AK 159	34.1 ± 1.4	28.0 ± 1.9	31.0	7.6 ± 0.9	7.9 ± 0.8	7.7	0.22 ± 0.020	0.28 ± 0.016	0.25	59 ± 2.3	57 ± 3.8	58	31 ± 0.9	32 ± 2.6	31
	DRG 1	30.2 ± 2.9	31.0 ± 1.8	30.6	5.6 ± 1.6	6.5 ± 0.9	6.0	0.18 ± 0.035	0.21 ± 0.025	0.20	64 ± 0.5	58 ± 2.1	61	26 ± 1.0	25 ± 3.2	25
	ICGS 44	30.9 ± 2.0	32.3 ± 3.9	31.6	9.6 ± 1.3	9.3 ± 0.9	9.4	0.31 ± 0.029	0.29 ± 0.016	0.30	63 ± 1.3	61 ± 1.5	62	42 ± 0.7	43 ± 1.2	42
	ICGV 86031	30.8 ± 4.1	36.9 ± 1.2	33.8	6.8 ± 1.3	6.9 ± 0.7	6.9	0.22 ± 0.059	0.19 ± 0.015	0.21	63 ± 3.2	61 ± 2.2	62	28 ± 0.5	24 ± 1.6	26
	SG 99	31.3 ± 3.0	33.1 ± 1.9	32.2	7.7 ± 1.5	8.5 ± 0.7	8.1	0.25 ± 0.046	0.26 ± 0.037	0.25	64 ± 0.8	64 ± 2.2	64	38 ± 0.7	36 ± 2.9	37
	TAG 24	22.6 ± 1.5	21.1 ± 4.3	21.9	6.3 ± 0.9	5.5 ± 1.6	5.9	0.28 ± 0.024	0.26 ± 0.030	0.27	58 ± 2.3	56 ± 2.2	57	28 ± 2.1	27 ± 1.9	28
Mean		30.0	30.4	30.2	7.3	7.4	7.3	0.24	0.25	0.25	62	59	61	32	31	32

T_1 normal irrigation, T_2 transient water deficit stress during 30-60 DAS and T_3 transient water deficit stress during 60 to 85 DAS

Table 5 Repeated measure two-way ANOVA for total dry matter (TDM g plant^{-1}), pod yield (PY g plant^{-1}), harvest index (HI), shelling (%) and 100 seed mass (g) in peanut genotypes during summer 2011 and 2012

Effect	DF	TDM	PY	HI	Shelling (%)	100 sw
Replication	2	17.44	16.82	88.70	0.50	0.18
Year	1	4.29	3.84	14.45	113.84	37.61
Replication × year	2	6.87	1.09	1.60	11.31	4.15
Treatment	2	570.21**	98.92**	201.76**	566.17**	870.03**
Year × treatment	2	13.33	0.55	12.63	1.96	1.89
Error treatment	8	7.74	3.75	20.54	4.13	5.76
Genotype	5	336.69**	42.93**	369.74**	202.69**	1521.10**
Year × genotype	5	1.02	2.99	21.26	4.86	6.51*
Treatment × genotype	10	15.72**	4.58**	29.74**	33.06**	71.68**
Year × treatment × genotype	10	36.31**	1.42	19.59*	6.32	11.66**
Residual	60	5.42	1.47	9.34	6.66	2.53
Total	107	35.67	6.04	35.49	29.33	97.75

* Significant at $P < 0.05$; ** significant at $P < 0.01$

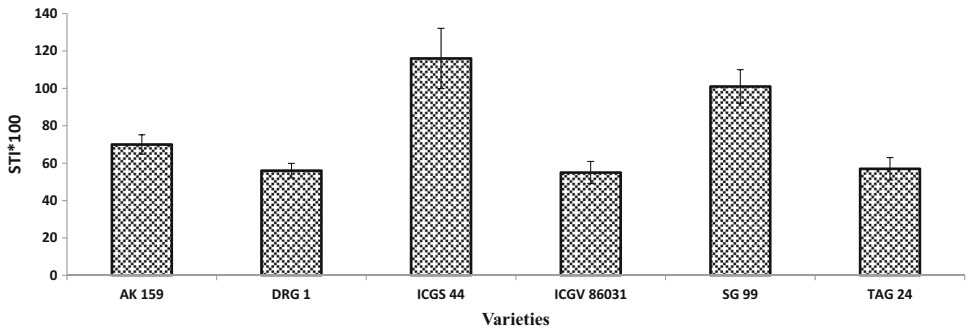

Fig. 2 Value of STI*100 in peanut genotypes under water deficit stress condition during 60–85 DAS. *Error bars* represent ± standard error of mean

Reduction in SLA is an adaptive mechanism to cope up with the adverse conditions created due to water deficit stress. Genotypic differences in this regard showed the differential capacity of individual genotype against stress. Deposition of cuticle on the leaf surface increased leaf weight and is one of the causes of reduced SLA resulting higher leaf thickness Significant relationships between TE, SLA, chlorophyll and the photosynthetic enzyme ribulose 1-5 bisphosphate carboxylase (Rubisco) content in peanut suggested that photosynthetic capacity is the main cause of variation for TE in peanut [20]. Studies on water deficit stress under rain-out shelter in Kharif season has documented such reduction in SLA [21]. According to several authors, the SLA is an economic surrogate tool to select for WUE [22, 23] and an important trait to increase water use efficiency or drought tolerance in peanut [24]. The SCMR is an indicator of photosynthetically active light transmittance characteristics which is dependent on unit quantity of chlorophyll/unit leaf area [25] and thus can be treated as index of the greenness of a leaf. Water deficit condition leads to reduced leaf water content and thus to a higher concentration of chlorophyll content on fresh weight basis. In addition, there are some reports in which chlorophyll content has increased due to water deficit stress in peanuts [26] and this has been treated as an adaptation mechanism against stress and thus, the increase in chlorophyll density in a leaf enhances SCMR value [27]. The water deficit stress imposed during 30 to 60 DAS had non-significant effect on PY, but the water deficit stress imposed during 60 to 85 DAS lead to 26 % yield loss. Peanut is an indeterminate plant type and hence, flowering continues along with the reproductive growth. Decrease in the rate of flower production after the third flowering peak under well irrigated condition is a typical characteristics in peanuts. Reduced rate of flower production due to drought stress during flowering is reported however, the total number of flowers per plant is not affected as the duration of flowering is typically extended due to stress [28, 29]. Moreover, a

Table 6 Correlation coefficients for the associations among the parameters in peanut genotypes

T_1	SCMR 60 DAS	SLA 60 DAS	SCMR 85 DAS	SLA 85 DAS	TDM g plant^{-1}
SLA 60 DAS	−0.60**				
SCMR 85 DAS	0.71**	−0.62**			
SLA 85 DAS	−0.37*	0.35*	−0.23		
TDM g plant^{-1}	0.43*	−0.20	0.53**	−0.09	
PY gm^{-2}	0.51*	0.08	0.20	−0.01	0.39*

T_2	SCMR 60 DAS	SLA 60 DAS	TDM g plant^{-1}	T_3	SCMR 85 DAS	SLA 85 DAS	TDM g plant^{-1}
SLA 60 DAS	−0.61**			SLA 85 DAS	−0.34*		
TDM g plant^{-1}	0.59**	−0.36*		TDM g plant^{-1}	0.45*	−0.29	
PY gm^{-2}	0.42*	−0.04	0.34*	PY gm^{-2}	0.35*	−0.13	0.48**

* Significant at $P < 0.05$; ** significant at $P < 0.01$

significant burst in flowering on relief of stress is an exclusive feature of flowering behaviour under moisture stress, particularly when drought is imposed just prior to reproductive development [30]. When stress is imposed during 30 to 45 DAS the first flush of flowers produced up to 45 days do not form pegs during that time, however, flowers produced after re-watering compensate for this loss [28]. Impaired pegging promoted by the combined effect of enhanced soil strength and declined plant water status (i.e., turgor) in peanut had resulted in decreased number of pegs that enter into the soil surface [31]. Reports are also there in which pegs initiated during drought stress have an ability to suspend development during the period of soil water deficit and to re-initiate pod development after the drought stress is relieved [32]. This adaptive trait of peanut to intermittent droughts indicates that pegs are reproductive organs with the capacity of enduring moderately long limitations to pegging related to the effects of water deficit, in contrast to the rapid loss in embryo viability observed in other grain-crop species like maize [33] or soybean [34]. After rehydration compensation of loss of flower production and resumed growth of suspended pegs would have resulted in no loss and rather a marginal increase of PY even under water deficit stress during 30–60 DAS. Several reports indicated that the pod development phase is the most sensitive period to moisture deficit [35–37] and the present results support the same. A significant yield loss due to water deficit stress during 60–85 DAS clearly indicated that sequence of growth stages from beginning seeding to beginning maturity is highly susceptible to water deficit condition in summer.

The HI is the ratio of total dry matter to the economical yield (PY) and thus a high HI indicates a high partitioning ability. It has been identified as a drought resistance trait in peanut [38, 39] and the ability to partition dry matter into harvestable yield under limited water supply is an important trait for drought tolerant genotypes [40]. Increased HI due to water deficit stress during 30–60 DAS is the result of decrease in TDM along with a marginal increase in PY. Even though the TDM was almost similar in ICGS 44, ICGV 86031 and SG 99 the variation in HI seems to be because of different partitioning efficiency. A greater contribution of the foliage to the TDM is the reason of low HI in ICGV 86031 whereas the higher HI in TAG 24 is due to proportionately a lower contribution of foliage in the TDM showing the higher partitioning efficiency of this genotype. All six genotypes produced different TDM, PY HI and STI under the same water deficit condition suggest variation in intrinsic capacity to mine water from soil, their utilization in bio-mass production and final yield partitioning. The lack of relationship between SLA and TDM and PY shows that PY is decided by other than WUE but production of higher TDM per unit water transpired is critically and essentially required for a sustainable production of peanuts.

The water deficit during 30–60 DAS has decreased 100 seed mass against a marginal increase in the PY indicated that water deficit stress resulted in fruitful development of additional pegs, developed from flowering flush as a result of stress withdrawal, into pod however, with a limited seed filling may be because of the competition for development of pods in close vicinity. A similar enhancement in reproductive efficiency (flower to pod ratio) due to imposition of water deficit stress during 20–50 DAS has been previously reported [41]. On the other side, reduced PY and 100 seed mass due to water deficit stress imposed during 60–85 DAS seems to be because of impaired pod development followed by poor seed filling due to lack of moisture in pod zone.

The STI is an overall index of yield potential and stress tolerance and genotypes can be effectively distinguished based on their STI value in both stressed and non-stressed environment. As per the STI value lowest in ICGV 86031 even against the lowest SLA which is considered as a surrogate of TE failed to improve the stress tolerance efficiency

in this genotype and the reason is due to a greater PY deviation under water deficit stress as compared to the well watered condition. At the same time it is quite interesting to note that genotype ICGS 44, having highest STI value, higher SCMR but not the low SLA, topped for the STI. The second highest STI value is in genotype SG 99 which is also not having the lowest SLA value but has a higher SCMR indicating that higher SCMR has indirect and positive relations with STI which is evidenced from the correlation matrix. Under severe drought (1/3 available water), SLA showed a more important contribution to WUE than the other traits in peanuts in greenhouse condition [42].

Conclusion

In this field study, the negative relationship between the SLA and the TDM under well-watered and water deficit stress during 30–60 DAS showed that SLA can be potentially used as selection tool but, at 85 DAS, the non-significant relationship between SLA and TDM clarified that the SLA cannot be potentiality used as a selection trait for the stress period of 60–85 DAS which actually causes the reduction in PY. SCMR had positive association with TDM and PY at 60 and 85 DAS under well watered and water deficit conditions. Hence, SCMR could be used as selection criteria along with other yield parameters for identifying superior genotypes. Thus, it is suggested to record SCMR at 85 DAS as a rapid technique for screening a large number of stable peanut breeding materials for water deficit stress tolerance. This technique will help breeders to identify probable superior breeding materials based on SCMR before harvest which could be confirmed later based on pod yield under water stress condition. This helps breeder to minimise the labour and work load during varietal development programs.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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