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Physiological efficiencies in 186 peanut cultivars of various botanical groups

Amrit Lal Singh*, Rupesh Nakar, Vidya Chaudhari, Koushik Chakraborty, Nisha Goswami, Kuldeepsingh Kalariya, Chandrashekhar B Ajay, Pratap Virabhai Zala & Chhabil Bhai Patel

ICAR-Directorate of Groundnut Research, PB 5, Junagadh-362 001, Gujarat, India

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Peanut is a major oilseeds crop of India with its largest area in the world, but its productivity is less than the world average. Though India has released a number of peanut cultivars, studies on the physiological efficiencies of such varieties are scarce. In this study, we tried to elucidate the physiological basis, net photosynthesis (P_N), transpiration (E), stomatal conductance (g_s), chlorophyll fluorescence (F_v/F_m), SPAD chlorophyll meter reading (SCMR), chlorophyll (chl) contents in leaf at 60-65 days of crop and pod and haulm yields at harvest in 186 peanut cultivars during *Kharif* season. The average and range of P_N were 19.8 and 11.4-31.4 μ mol $m^{-2}s^{-1}$, g_s 0.25 and 0.11-0.45 m s^{-1}, E 6.84 and 3.96-11.61 m mol $m^{-2}s^{-1}$, SCMR 34.0 and 20.3-44.1, total chl 7.79 and 3.07-15 mg g^{-1} leaves, F_v/F_m 0.846 and 0.802-0.887, pod yield 179 and 68-309 g m^{-2} and haulm yield 464 and 144-884 g m^{-2} and a number of superior cultivars identified. The pod yield was strongly correlated with SCMR, chl and carotenoid contents, haulm yield and pods $plant^{-1}$, but weakly associated with P_N, g_s, and F_v/F_m. The P_N correlated with g_s and E, however, SCMR was the single best parameter. The Spanish and Virginia bunch groups showed most desirable physiological traits. The cultivars TPG 41, Chintamani, M 37, GG 8, GG 13, Kadiri 7 and M 522 showed superior physiological traits for their cultivation.

Keywords: *Arachis hypogaea*, Chlorophyll fluorescence, Photosynthesis, Pod and haulm yields, SCMR, Stomatal conductance, Transpiration, Water use efficiencies

The Peanut (*Arachis hypogaea* L) is a major oilseed and food legume of tropical and subtropical world. About 42 million tonne pods of peanut are produced from about 25 million hectare (m ha) distributed in about 110 countries mainly in semiarid region[1]. On large scale, the peanut is cultivated mostly in Asian (11.8 m ha), African (12.1 m ha) and American (1.1 m ha) countries and India, China, Nigeria, USA, Myanmar, Senegal, Sudan, Indonesia, Argentina and Tanzania are the major peanut producing countries[1]. Though it requires warm growing season with only 500-800 mm of well distributed rainfall, it is grown across wide range of environments mostly as rain-fed[2,3] with the world average yield of around 1700 kg ha^{-1} pods[1]. However, the productivity is less than 1000 kg ha^{-1} in more than 30% of the peanut growing countries and about 70% of the world peanut production occurs in the semi-arid to arid tropics[1]. India has the largest peanut area (5.5 m ha) in the world, but its average productivity is only 1500 kg ha^{-1}.

In India, initiatives on improvement of peanut production particularly, selection of genotypes received due attention only after 1960 and by the year 2011 about 190 peanut cultivars were released for cultivation[4]. The genetic improvement efforts at the Directorate of Groundnut Research and its coordinated centres in India, Bhabha Atomic Research Centre and International Crop Research Institute for Semi Arid Tropics, have succeeded in identifying trait specific peanut cultivars with variation in yield[4,5]. Though, peanut breeding programme introduces many new cultivars every year, most of the Indian peanut cultivars have a very narrow genetic base[6], often lacks in physiological evaluation in field[4]. The photosynthetic characteristics of a few peanut cultivars have been studied under excess as well as deficit irrigation[7-9]. However, the physiological efficiencies of the Indian peanut cultivars together have not been evaluated yet to find out efficient high yielding cultivars.

*Correspondence:
E-mail: alsingh16@gmail.com

Abbreviations: Chl, Chlorophyll; C_i, Internal CO_2 concentration; CT_{leaf}, Leaf cuvette temperature; DAE, Days after emergence; DAS, Days after sowing; E, Transpiration rate; FST, Valencia group; Fv/Fm, Chlorophyll fluorescence; g_s, Stomatal conductance; HY, Haulm yield; HI, Harvest Index; HIR, Virginia runner; HYP, Virginia bunch; PAR, Photosynthetically active radiation; PCA, Principal component analysis; P_N, Net photosynthetic rate; PY, Pod yield; RUE, **R**adiation use efficiency; SLA, Specified leaf area; SCMR, SPAD chlorophyll meter reading; SPAD, Soil plant analytical development; VCR, Visual chlorotic rating; VUL, Spanish bunch; WUE, Water use efficiency

In peanuts, production is influenced by the amount of chlorophyll and the rate of physiological processes[3] and it is useful to see improvement in growth and yield per resource use. The high yield has been the major criteria for selection of peanut cultivar. However, for broader environmental conditions, physiological traits, such as net photosynthetic rate (P_N), transpiration rate (E), better water use efficiency (WUE), radiation use efficiency (RUE) as well as chlorophyll fluorescence, may be more useful in the selection process[5]. The strong association of various physiological traits with yields is of immense importance in the existing cultivars for their better utilization in various environments[4]. The high association of P_N with stomatal conductance (g_s) shows its importance in regulation of P_N and E in peanut[10] as photosynthesis performs well even at rising temperature and atmospheric CO_2[11]. The high P_N in peanut during pod filling stage guide its time of observation[12]. Chlorophyll content can be measured simply and rapidly by hand held portable SPAD (soil plant analytical development) chlorophyll meter[13]. The WUE contribute directly to productivity under limited resources[14], and there is a close relationship between the SPAD chlorophyll meter reading (SCMR) and WUE in peanut[5,15]. Under water deficit stress, the SCMR has been identified as more pertinent trait than specific leaf area (SLA)[16].

Physiological studies in mini-core peanut accessions showed a large variability[5] and will be useful for further development of new cultivars. The principal component analysis (PCA) is a multivariate modeling technique useful in studying the similarity and dissimilarity, as it compresses data forming number of 'principal components' (PCs) describing independent variation in the data set visualized by various plotting systems[17]. The present work emphasizes characterization of all the available Indian peanut cultivars of various botanical and habit groups for important physiological traits *viz.* P_N, g_s, E, WUE, chlorophyll content and chlorophyll fluorescence, SCMR, yield attributes and their relation to yield with an objective to identify the most suitable cultivars with high physiological efficiencies and physiological traits in the field.

Materials and Methods

Field experiment, planting material and growing conditions

A field experiment was conducted during *Kharif* season 2012 at the research farm of ICAR-Directorate of Groundnut Research, Junagadh, Gujarat, India (70.36º E and 21.31º N and 83 m above msl) during rainy season, in a medium black calcareous (12% $CaCO_3$) clayey, Vertic Ustochrept soil, having 8.2 ppm P, 7.5 pH, 1.33% organic C, 800 ppm N, 11 ppm available S, and 3.5, 15.0 and 1.2 ppm DTPA extractable Fe, Mn and Zn, respectively. The field was ploughed, levelled and 10 cm deep furrows were opened at 45 cm spacing. A total of 186 peanut cultivars released for their cultivation in India belonging to four botanical groups i.e. VUL (var. *Vulgaris*)= Spanish bunch, FST (var. *Fastigiata*)= Valencia, HYP (var. *Hypogaea*) = Virginia bunch (VB), HIR (var. *Hirsute*)= Virginia runner (VR), were collected and shelled. The seeds of these 186 cultivars, each in one row plots of 5 m length, were sown at 10 cm spacing, with three replications. A common dose of 40 kg N, 50 kg P, 50 kg K_2O and 20 kg S ha^{-1} was applied 50% as basal and 50% at 40 days after sowing (DAS) and mixed in the soil using ammonium sulphate, diammonium phosphate, muriate of potash and elemental S and 500 kg ha^{-1} gypsum at flowering (40 DAS). The crop was grown under recommended package of practices with proper plant protection during the cropping season. The crop was harvested at maturity, dried in sun for a week, weighed and pod and haulm yields were recorded. Harvest Index was calculated by pod yield divided by total biomass.

Estimation of leaf-Level Gas Exchange, CO_2 fixation, WUE, RUE and chlorophyll fluorescence

All the gas exchange parameters *viz.* net photosynthetic rate (P_N), stomatal conductance (g_s), internal CO_2 concentration (C_i), transpiration rate (E) were recorded using portable photosynthetic system (Model LI-6400, LI-COR, USA) between 60-65 days after emergence (DAE) following the method described in our earlier studies[5]. The P_N, g_s, C_i, E were recorded between 08:00-11:30 h IST in the third fully opened leaf from the main axis from similar looking plants. Temperature was set at ambient giving a stable T_{leaf} reading. Photosynthetically active radiation (PAR) was set at 1650 µmol (photon) m^{-2} s^{-1} inside the cuvette, and [CO_2] left at ambient (390 µmol m^{-2} s^{-1}).

The water use efficiency (WUE) was calculated by dividing P_N with E, while the radiation use efficiency (RUE) was calculated by dividing P_N with PAR value[18] (1650 in this study). The chlorophyll fluorescence traits F_m (Maximum fluorescence), F_v (Variable fluorescence), were recorded using a Handy plant efficiency analyzer (PEA) (Hansatech, USA) following Havaux[19] and F_v/F_m (Maximum efficiency of PS II) was calculated. Before taking observation, the selected leaves were dark adapted for a period of 30 min using leaf clips. A saturating flash light of 3000 µmol m^{-2} s^{-1} was applied to achieve the maximum fluorescence.

Measurement of SCMR, VCR and chlorophyll and carotenoid contents

The SPAD chlorophyll meter readings (SCMR) were recorded using SPAD-502 Plus (Konica Minolta, Japan) in the third fully opened leaf from the main axis uniformly in all the cultivars at 60 DAE following Samdur *et al.*[13]. The chlorophyll and carotenoid contents in leaves at 60 DAE were estimated by extracting these from 200 mg fresh leaf tissues in 10 mL of 80% acetone for 16 h at 20°C and the absorbance of the extract recorded at 440.5, 645 and 663 nm and calculating chlorophyll and carotenoid content[20,21]. The visual chlorotic rating (VCR) (1-5 scale) was recorded at 30, 50 and 70 DAE[22].

All the data were analysed statistically and tested for their significance and relationships among various parameters associated with physiological efficiencies were worked out using statistical software DSAASTAT ver 1.1[23]. The peanut cultivars were sorted for various parameters and categorized into high and low groups based on the deviation from the average. As a standard practice, the cultivars with their values higher than mean plus standard deviation (SD) were categorized as ‘high’ group and the one with values less than mean minus SD were categorized into the ‘low’ group for that parameter. The genotypes with values in between these were categorized into ‘medium’ group. Also, the data was subjected to PCA and cluster analysis for identifying cultivars with high physiological efficiencies. Classification and discrimination of 186 peanut cultivars were carried out by PCA and cluster analysis using PAST software[24]. The genotype-by-trait (GT-biplot) drawn using PC1 and PC2 and negatively correlated traits were arranged at cosine of 180° as its value is minus one, while those traits with cosine angle 90° have no correlation as its value is zero[25]. In case of positive correlation, cosine angle is zero and its value is one.

Results

Leaf VCR and SCMR, chlorophyll and carotenoid contents

The SCMR showed a large variation in 186 peanut cultivars ranging from 20.3-44.1 with an average of 34.0 (Table 1). Here 26 cultivars with SCMR >39 were

Table 1—Average, range and standard deviation of various physiological traits among 186 peanut cultivars of various botanical groups

Traits	105 VUL (Spanish bunch)		5 FST (Valencia)		41 HYP (Virginia bunch)		35 HIR (Virginia runner)	
	Range	Av±Sd	Range	Av±Sd	Range	Av±Sd	Range	Av±Sd
VCR	1-3	2.3 ±0.6	2-3	2.6±0.5	1-3	1.8±0.7	1-3	1.9±0.5
SCMR	20.3-41.5	32.1 ±4.9	22.4-37.7	30.2±5.8	31.3-44.1	37.5±3.2	26.8-42.2	36.3±3.8
Chl a	2.36-7.4	4.52±1.28	4.73-6.4	5.32±0.7	4.56-10.12	7.12±1.5	3.09-10.5	7.12 ±1.67
Chl b	0.71-3.8	1.64 ±0.67	1.72-3.2	2.52 ±0.6	1.19-4.40	2.77±0.6	1.10-4.12	2.61±0.63
Carotenoids	0.27-1.5	0.79 ±0.28	0.51-1.5	0.85±0.41	0.6-1.6	1.1±0.3	0.52-1.65	1.13 ±0.29
Pl ht (cm)	25.3-62	44.8 ±6.6	9.5-50	31.1±19.3	30.5-53.4	42.0±6.0	26.5-54.2	39.7 ±6.5
Pods/3pl	17.5-46.5	30.9 ± 5.7	10.0-40.5	19.6±13.2	9-53	28.3 ±7.8	18-50.5	28.2 ±7.4
PY (g/m^2)	79-260	169±40	68-208	116±54	128-309	196±50.5	104-284	199 ±41
HY (g/m^2)	179-884	422±130	144-439	303±141	328-848	536±151	362-730	529 ±108
P_N	13.1-31.4	19.6±4.3	12.6-25.6	19.8±5.5	15.4-28.3	20.6±3.3	11.4-30.3	19.5 ±4.2
g_s	0.13-0.45	0.25±0.08	0.20-0.40	0.30±0.8	0.16-0.42	0.27±0.08	0.11-0.38	0.22 ±0.07
E	4.06-11.6	7.28±2.33	5.23-10.7	7.64±2.3	4.15-9.12	6.07±1.4	4.30-9.41	6.34 ±1.3
CT_{leaf}	32.4-45.0	37.1±3.8	34.2-37.4	35.7±1.3	32.4-38.8	34.5±1.5	32.0-43.8	36.2±2.2
RUE	0.008-0.019	0.012±0.003	0.008-0.016	0.012±0.003	0.009-0.017	0.012±0.002	0.007-0.018	0.012±0.003
WUE	1.43-4.90	2.89±o.84	2.13-3.10	2.6 1± 0.4	2.07-4.1	3.48 ±0.53	2.01-3.92	3.10 ±0.46
F_v/F_m	0.806-0.870	0.844 ±0.014	0.822-0.841	0.834±0.009	0.815-0.871	0.847±0.015	0.802-0.887	0.851±0.03
HI	0.17-0.44	0.29±0.06	0.18-0.43	0.29±0.10	0.18-0.40	0.27±0.05	0.19-0.38	0.28 ±0.05

[Where botanical groups were SB= Spanish bunch (VUL), VL= Valencia (FST), VB= Virginia bunch (HYP), VR= Virginia runner (HIR); VCR= visual chlorotic rating score at 60 days after emergence (DAE); SCMR= SPAD chlorophyll meter reading at 60 DAE; Chl a = chlorophyll a (mg g^{-1} dry wt. of leaves) at 60 DAE; Chl b = chlorophyll b (mg g^{-1} dry wt. of leaves) at 60 DAE; Total Chl= Total Chlorophyll (mg g^{-1} d. wt. of leaves) at 60DAE; Carot = Carotenoids (mg g^{-1} d.wt. of leaves) at 60 DAE; Chl a/b=Ratio of chlorophyll a/b; PY =Pod yield; HY= Haulm yield; HI= Harvest Index; Pl.ht= plant height(cm); Pods/3 pl = number of pods/ 3 plants; P_N= Net photosynthetic rate (µ mol $m^{-2}s^{-1}$); g_s = stomatal conductance (m sec^{-1}); *E* = Transpiration rate (m mol $m^{-2}s^{-1}$); WUE= Water use efficiency; Fv/Fm= Maximum photochemical efficiency of PSII (Chlorophyll fluorescence).The CT_{leaf} is leaf cuvette temp and RUE is radiation use efficiencies] categorized as high SCMR cultivars and 34 cultivars with <29 SCMR were categorized as low SCMR cultivars (Table 2). Also, there was a large variation in SCMR among various botanical groups with mean SCMR high in Virginia (37.5 in HYP and 36.3 in HIR), and low in Spanish and Valencia (32.1 in VUL and 30.2 in FST) group of cultivars (Table 1). The chlorosis was scored as VCR, the

Table 2—Peanut cultivars with high and low values of physiological parameters

Physiological Parameters	High	Low
P_N	ICGS 11, GPBD 5, MH 1, TMV 3, GG 8, DRG 17, ICGS 5, TG 51, GG 13, HNG 69, BAU 13, GG 21, VG 9816, BG 1, JGN 3, DH 4-3, Chico, Gangapuri , TG 1, SG 84, ALR 3, GJGHPS 1, TNAU 256, GG 12, CSMG 9510, R 2001-3, ICGS 44 (>23.9 µmol $m^{-2}s^{-1}$)	TKG 19 A, Kadiri 8, AK 159, Tirupati 4, Pratap Mungphali 2, Kadiri 5, ICGV 00351, JL 286, TMV 12, OG 52-1, RS 138, CO 3, Jawan, Kadiri 71-1, RG 141, ICGS 1, TMV 9, Kadiri 6, TMV 13, ICGS 37, Dh 3-30, AK 12-24, Kadiri Harithandra, Kadiri Gold, VRI 4, ICGV 00350, GAUG 1, MH 2, S 230,RS 1 (<15.7 µmol $m^{-2}s^{-1}$)
Transpiration (E)	Tirupati 2, MH 1, KRG 1, Kadiri 4, ICGS 44, DH 4-3, Tirupati 3, CO 2, TNAU 256, Tirupati 4, TMV 11, ICGV 86590, TG 22, Girnar 1, S 206, ICG (FDRS) 4, ICGV 86031, GPBD 5, DRG 12, VRI 2, TMV 2, GG 8, RG 141, OG 52-1, R 8808, TG 26, TMV 3, AK 159, ICGS 37, Kisan, GJG 31, Chico, GJG 22, CO 1, HNG 69 (>8.9 mmol $m^{-2}s^{-1}$)	TMV 13, Kadiri 9, Pratap Mungphali 2, TMV 10,TMV 9, Girnar 3, AK 303, Somnath, Tirupati 1, GG 3, B 95, M 197, M 548, VG 9521, VRI 4, RS 1, DH 86, Kadiri 8, Kaushal, BSR 1, R 2001-2, TMV 12, GAUG 1, ICGS 1 (<4.7 mmol $m^{-2}s^{-1}$)
Pod yield (g m^{-2})	Kadiri 7, GJG 22, GG 13,TGLPS 3, ICGS 5, ALR 1, ICGV 000348, Mallika, GG7, ICGS 76, RG 141, GG 21, BAU 13, GG 20, M 548, ICGV 87846, ICGV 00350, R 2001-3, M 37, GJG 31, AK 159, M 522, ICGS 44, Chintamani, M 13, GG 11, GAUG 10, TPG 41, M 335, DH 86, TLG 45, JCG 88, LGN 2 (>225 gm^{-2})	GAUG 1, GPBD 4, T 64, Chico, AK 12-24, ICGV 86325, TMV 10, DRG 12, SB XI, TG 3, Kadiri 5, S 206, TG 26, LGN 1, DRG 101, UF 70-103, Tirupati 1, MH 2, TMV 9, Punjab 1, Kopargaon 3, TMV 11, ICG (FDRS)10, DH 40, TMV 12, MH 4 (<133 gm^{-2})
Conductance (g_s)	GPBD 5, GJGHPS 1, JGN 23, TMV 3, ICGS 11, HNG 69, DRG 17, BAU 19, GG 21, BAU 13, DH 8, Chico , TG 3, Gangapuri, ICGS 5, TG 1, GG 4, JL 220, GG 8, ALR 1, GG 12, GG 2, CSMG 884, TG 37 A, K 134, GPBD 4, TPG 41, VRI 16, JGN 3, Kopargaon 3, ALR 2, ICGV 86031, TG 32, TG 42, LGN 2 (>0.33 mmol $m^{-2}s^{-1}$)	Tirupati 4, VRI 5, Tirupati 1,TMV 12, SG 99, ICG (FDRS) 4, Kadiri 8, TMV 10, Kadiri 71-1, RS 138, CO 3, Chitra, VG 9521, Jawan, R 8808, CO 2, ICGS 1, CSMG 84-1, AK 159, OG 52-1, DH 4-3, BSR 1, Kokan Tapora , VRI 4, Champavat, S 230, RS 1, M 37 (<0.17 mmol $m^{-2}s^{-1}$)
WUE	JGN 3, TG 51, Kadiri 9, R 2001-3, GG 6, DH 86, ALR 2, GG 3, LGN 1, BG 2, Girnar 3, SG 99, TG 32, TMV 10, GG 7, Kadiri 7, AK 265, ALR 1, Kadiri 2, Kaushal, R 2001-2, MA 16, M 197, B 95, Chintamani, AK 303, UF 70-103, M 37, M 145, BG 3, ICGS 11, VG 9521 (>3.81)	DH 4-3, ICG(FDRS) 10, TNAU 256, Jawan, GJG 22, AK 12-24, RS 138, DH 2001-1, CSMG 2003-19, TG 26, TAG 24, ICGV 86031, TMV 11, Girnar 1, ICGS 44, TKG 19 A, S 206, JL 24, S 230, TG 22, Tirupati 2, ICG (FDRS) 4, DRG 12, KRG 1, Kadiri 4, VRI 2, CO 2, R 8808, ICGV 86590, TMV 2, AK 159, Tirupati 3, OG 52-1, ICGS 37, Tirupati 4, RG 141 (<2.31)
SCMR	TMV 10, M 145, Kadiri 7, AK 303, Chandra, JSP 19, ICGV 88448, Kadiri Gold, LGN 2, BAU 19, CSMG 84-1, Karad 4-11, M 37, MA 16, Chintamani, Girnar 2, Tirupati 3, BG 1, GAUG 10, RS 138, Punjab 1, ICGS 76, ICG (FDRS) 10, VRI 5, TPG 41, TG 1, (>39.0)	RG 141, DH 8, Tirupati1, DH 2001-1, TMV 9, TMV 11, CO 2, COGN 4, Tirupati 2, JL 220, TMV 12, TMV 3, JGN 3, TMV 4, OG 52-1, S 206, DH 40, Pratap Mungphali 1, MH 1, Jawan, Kadiri 4, CO 3, Tirupati 4, KRG 1, JGN 23, DH 86, JL 286, TMV 13, K 134, AK 12-24, GJG 31, VRI 3, Gangapuri, TG 3 (<29.0)
Total chlorophyll	M 37, CSMG 884, JSP 19, TMV 10, RG 510, Mallika, RSB 87, Chintamani, GPBD 5, AK 303, GG 15, DH 4-3, Kadiri 8, CSMG 84-1, BG 1, ICGV 000348, AK 265, Champavat, HNG 10, TG 1, GG 16, ICGV 00351, UF 70-103, B 95, BG 2, ICGV 88448, M 145, GG 11, GG 13, BG 3, GG 14, Chandra, Kadiri 3, Kadiri 71-1, Kadiri 7, LGN 1 (>10.6 mg g^{-1} dwt.)	VRI 2, Tirupati 4, GAUG 1, R 9251, KRG 1, R 8808, GPBD 4, ICGV 86590, Tirupati 1, CO 2, TMV 7, Pratap mungphali 2, DH 8, S 230, JCG 88, MH 1, Chico, RG 141, GJG 31, Kadiri 4, ICG (FDRS) 10, ICGV 91114, S 206, JL 286, COGN 4, VRI 3, Tirupati 2, AK 12-24, JL 220, TMV 12, DH 40, TG 3, (<5.0 mg g^{-1} dwt.)
Fv/Fm	Kadiri 71-1, DSG 1, AK 303, AK 12-24, Kaushal, ALR 3, TG 22, GG 5, GG 6, CSMG 84-1, M 522, JL 220, BG 1, Kadiri 8, JL 24, TKG 19 A, VG 9521, HNG 69, ICGV 86590, VRI 3, GAUG 10, TMV 7, DH 86, Karad 4-11, Chandra, SG 84, Girnar 1, Chintamani, GG 20, GG 12 (>0.860)	GG 8, ICGS 37, Girnar 2, TMV 13, MH 4, Girnar 3, BAU 19, Kadiri 6, MH 2, R 2001-3, JL 286, ALR 1, TG 32, Punjab 1, GJG 22, LGN 2, SB XI, GG 4, TG 17, TG 26, CO 1, GG 15 (<0.830)
HI	TPG 41, R 2001-3, GG 7, MH 2, GG 8, TLG 45, TGLPS 3, TG 26, ICGV 00350, TAG 24, JL 286, GJGHPS 1, TG 37 A, ICGV 00351, GG 2, JGN 3, ICGS 44, M 13, AK 159, SG 84, GG 6, Girnar 1, TMV 13, M 522, ICGV 000348, M 548 (>0.34)	Tirupati 3, ICGV 88448,DH 2001-1, GPBD 4, BG 1, Pratap mungphali 2, Kadiri 8, TMV 11, DRG 101, GG 12, Tirupati 1, TMV 3, ICGV 86325, CO 3, ICG (FDRS)10, TMV 4, COGN 4, Kopargaon 3, BG 2, RSB 87, TMV 12, VRI 6, DH 40 (<0.22)

average and range of which were 2.1 and 1.0-3.0, respectively. The mean and range of VCR varied with botanical groups and were 2.3 and 1-3 in VUL, 2.6 and 2-3.0 in FST, 1.8 and 1.0-3.0 in HYP and 1.9 and 1-3 for HIR (Table 1).

The average chlorophyll (chl) ‘a’, chl ‘b’, total chl and carotenoid contents of 186 cultivars were 5.66, 2.10, 7.79 and 0.91 mg g^{-1} dry wt. of leaves, respectively with a range of 2.36-10.8, 0.7-4.4, 3.07-15.01 and 0.27-1.65 mg g^{-1} dry wt. of leaves, respectively. The chl being the main deciding factor for photosynthesis, was examined critically and 36 cultivars with total chl >10.6 mg g^{-1} dry wt. of leaves were categorized as high chl cultivars and 32 cultivars with <5.0 mg g^{-1} dry wt. total chl were categorized as low chlorophyll cultivars. Interestingly 45 cultivars showed >10 mg total chl g^{-1} dry wt. of leaves. The mean and range of total chl contents, when compared among the botanical groups, were 6.12 and 3.07-10.95 mg g^{-1} dry wt. for VUL, 7.86 and 6.46-8.58 mg g^{-1} dry wt. for FST, 9.89 and 5.84-13.93 mg g^{-1} dry wt. for HYP and 9.73 and 4.19-14.0 mg g^{-1} dry wt. in HIR. The carotenoid content among cultivars ranged from 0.27-1.65 with a mean value of 0.91 mg g^{-1} dry wt. of leaves. However, the mean and range of carotenoid contents were 0.79 and 0.27-1.54 mg g^{-1} dry wt. for VUL, 0.85 and 0.51-1.53 mg g^{-1} dry wt. for FST and 1.08 and 0.63-1.62 mg g^{-1} dry wt. for HYP and 1.13 and 0.52-1.65 mg g^{-1} dry wt. in HIR (Table 1).

Photosynthesis, stomatal conductance, transpiration, WUE and chlorophyll fluorescence

The P_N in 186 peanut cultivars ranged from 11.4-31.4 µmol (CO_2) $m^{-2}s^{-1}$ with a mean of 19.8 µmol (CO_2) $m^{-2}s^{-1}$, of these 27 cultivars with P_N >23.9 µmol (CO2) $m^{-2}s^{-1}$ were categorized as high P_N and 30 cultivars with P_N <15.7 µmol (CO2) $m^{-2}s^{-1}$ were categorized as low P_N cultivars (Table 2). The range and mean P_N values were 13.1-31.4 and 19.6 µ mol (CO2) $m^{-2}s^{-1}$, respectively among 105 VUL cultivars, 12.6-25.6 and 19.8 µ mol $m^{-2}s^{-1}$ among 5 Valencia cultivars, 15.4-28.3 and 20.6 µmol $m^{-2}s^{-1}$, among HYP and 11.4-30.3 and 19.5 µmol $m^{-2}s^{-1}$, among HIR cultivars (Table 1).

The mean and range of leaf stomatal conductance (g_s) in 186 cultivars was 0.26 and 0.11-0.45 m s^{-1} and transpiration rate (E) 6.84 and 3.96-11.61 mmol $m^{-2}s^{-1}$, respectively. Interestingly, 35 cultivars with g_s >0.33 m s^{-1} were categorized as high g_s cultivars and 28 cultivars with g_s <0.17 were categorized as low g_s cultivars (Table 2). The mean g_s among various botanical groups were 0.25, 0.30, 0.27 and 0.22 in VUL, FST, HYP and HIR, in the range of 0.13-0.45, 0.20-0.40, 0.16-0.42, and 0.11-0.38, respectively. The average E for VUL and FST groups were 7.28 and 7.6 mmol $m^{-2}s^{-1}$ while this was 6.1 and 6.3 mmol $m^{-2}s^{-1}$ for HYP and HIR groups, respectively in the range of 4.1-11.6, 5.2-10.7, 4.2-9.1 and 4.3-9.4 mmol $m^{-2}s^{-1}$, respectively, (Table 1). Here, 35 cultivars with E >8.9 mmol $m^{-2}s^{-1}$ were categorized as high E and 24 cultivars with E <4.7 mmol $m^{-2}s^{-1}$ were low E (Table 2).

The mean and range of WUE among 186 cultivars were 3.06 and 1.43-4.9 and 32 cultivars with >3.81 WUE were grouped as high WUE and 36 cultivars with WUE <2.31 were categorized as low WUE (Table 2). The average and range of WUE were 2.89 and 1.43-4.90 among VUL cultivars, 2.61 and 2.1-3.1 among FST, 3.48 and 2.07-4.1 in HYP and 3.10 and 2.01-3.92 among HIR group of cultivars, respectively (Table 1).

On an average, the leaf chlorophyll fluorescence (F_v/F_m) value of all cultivars was 0.846 with a range of 0.802-0.887. However, the average and range of F_v/F_m values for different botanical groups were 0.844 and 0.806-0.870 for VUL, 0.834 and 0.822-0.841 for FST, 0.843 and 0.815-0.871 for HYP and 0.851 and 0.802-0.887 for HIR, respectively (Table 1). Among these, 30 cultivars with F_v/F_m value >0.860 and were categorized under high F_v/F_m and 22 cultivars with <0.830 were categorized as low F_v/F_m cultivars (Table 2).

Pod and haulm yields and harvest index (HI)

The physiological parameters finally contributed to the yield in terms of dry matter production and yield with a mean of 179 g m^{-2} pod yield and 464 g m^{-2} haulm yield which ranged 68-309 g m^{-2} pod yields and 144-884 g m^{-2} haulm yields among 186 peanut cultivars. Average pod yield among the various botanical groups were 169, 116, 196 and 199 g m^{-2} in VUL, FST, HYP and HIR, respectively which ranged 79-260, 68-208, 128-309 and 104-284 g m^{-2}, respectively (Table 1). Out of 186 cultivars, 33 with >225 g m^{-2} pod yield were categorized as high yielder and 26 cultivars with <133 g m^{-2} pod yield were categorized as low yielding cultivars (Table 2). The average and range of haulm yields were 422 and 179-884 g m^{-2} in VUL, 303 and 144-439 g m^{-2} in FST, 536 and 328-848 g m^{-2} in HYP and 529 and 362-730 g m^{-2} in HIR group of cultivars, respectively. The mean and range of HI in peanut cultivars were

0.28 and 0.17-0.44 which varied with the production of biomass and botanical groups (Tables 1 & 2). The mean and range of HI were 0.29 and 0.17-0.44 for VUL, 0.29 and 0.18-0.43 in FST, 0.27 and 0.18-0.40 in HYP and 0.28 and 0.19-0.38 in HIR, respectively. Here, 26 cultivars with HI >0.34 were grouped as high HI cultivars and 23 with HI <0.22 were categorized as low HI cultivars (Table 2).

Comparison of various botanical groups

The four botanical groups cultivars when compared for various physiological traits the mean values and range showed different trends. The Spanish bunch (VUL) group showed highest range (minimum-maximum) of VCR, SCMR, carotenoids, chl a/b, haulm yield, HI, *E* and WUE, the Virginia bunch (HYP) group showed highest range of chl b, pod yield and pods per plant, Virginia runner (HIR) recorded higher range of chl a, chl a+b, P_N, g_s and F_v/F_m and Valencia group (FST) had higher range for plant height and pods $plant^{-1}$ (Table 1). However, the mean values of SCMR, chl b, Total chl (a+b), carotenoides, haulm yield, P_N, g_s and WUE were higher in Virginia bunch; Virginia runner recorded high average values of chl a, chl a/b, pod yield and F_v/F_m; Valencia had high average values for VCR, g_s and *E* whereas Spanish bunch (VUL) had higher average values for plant height and pods per plant.

Association of physiological traits, cultivars with multiple traits, PCA and cluster analysis

The various physiological parameters, observed in 186 peanut cultivars, when correlated with each other, very useful associations were observed (Table 3). There were positive correlations between SCMR and chlorophyll (for both chl a and chl b and total chl), SCMR and carotenoid, SCMR and pod yield, SCMR and haulm yield, SCMR and WUE, SCMR and F_v/F_m, chl and carotenoid contents, chl content and pod yield, chl content and haulm yield, chl content and WUE, chl b content and F_v/F_m, carotenoid content and pod yield, carotenoid content and haulm yield, carotenoid content and WUE, chl a/b ratio and plant height, pod and haulm yields, pod yield and harvest index, pod yield and pods/plant, haulm yield and plant height, haulm yield and pods/plant, harvest index and pods/plant, harvest index and g_s, plant height and pods/plant, pods/plant and P_N, P_N and g_s , P_N and *E* (Table 3). However, negative correlations were found between VCR and SCMR, VCR and chl content, VCR and carotenoid content, VCR and pod yield, VCR and haulm yield, VCR and F_v/F_m, SCMR and chl a/b ratio, SCMR and plant height, SCMR and *E*, chlorophyll content and plant height, chlorophyll content and *E*, carotenoid content and plant height, carotenoid content and *E*, chlorophyll a/b ratio and WUE, haulm yield and HI, HI and plant height and *E* with WUE.

The peanut cultivars when compared botanical group wise the Spanish and Virginia runner showed positive correlations between SCMR and chl, SCMR and carotenoids, chl and carotenoid. All these groups showed positive correlations between plant height and haulm yield and g_s and P_N. But there was very weak

Table 3—Correlation among various physiological and yield traits in 186 peanut cultivars

	VCR	SCMR	Chl a	Chl b	Total chl	carot	Chl a/b	PY	HY	HI	Pl. H	Pods/3pl	P_N	g_s	*E*	WUE
SCMR	-0.50**															
Chl a	-0.42**	0.66**														
Chl b	-0.29**	0.59**	0.89**													
Total chl	-0.38**	0.65**	0.98**	0.95**												
Carot	-0.36**	0.57**	0.79**	0.59**	0.73**											
Chl a/b	-0.02	-0.17*	-0.20**	-0.60**	-0.35**	0.06										
PY	-0.38**	0.29**	0.28**	0.21**	0.25**	0.25**	0.02									
HY	-0.20**	0.22**	0.29**	0.22**	0.27**	0.17*	0.08	0.47**								
HI	-0.14	0.03	-0.04	-0.04	-0.04	0.05	-0.03	0.38**	-0.61**							
Pl. H	0.21**	-0.25**	-0.30**	-0.33**	-0.32**	-0.21**	0.20**	0.05	0.34**	-0.35**						
Pods/3pl	-0.03	-0.02	-0.10	-0.11	-0.09	-0.14	0.06	0.49**	0.23**	0.18*	0.22**					
P_N	0.04	0.06	0.03	0.11	0.08	0.00	-0.17*	0.10	-0.03	0.12	-0.04	0.17*				
g_s	0.12	-0.03	-0.08	-0.03	-0.05	0.00	-0.08	0.03	-0.13	0.18*	-0.08	0.10	0.64**			
E	0.11	-0.23**	-0.37**	-0.33**	-0.35**	-0.30**	0.10	-0.05	-0.14	0.11	0.13	0.12	0.45**	0.19**		
WUE	-0.13	0.27**	0.39**	0.41**	0.41**	0.32**	-0.22**	0.12	0.10	-0.01	-0.14	0.02	0.23	0.19	-0.73**	
Fv/Fm	-0.16*	0.17*	0.14	0.15*	0.13	0.13	-0.10	0.10	0.08	-0.03	-0.01	-0.11	-0.02	-0.09	-0.03	0.04

[Details of the abbreviations are given in Table 1] correlation between P_N and pod yield in all the botanical groups. Further, the Spanish group showed positive correlations between chl and pod yield and negative correlations between HI and plant height, haulm yield and HI, E and WUE. The Virginia runner group, showed positive correlation between, carotenoid and F_v/F_m, plant height and pod yield, P_N and pods, pod yield and HI, haulm yield and RUE, E and P_N, g_s and E, while negative correlations between, SCMR and RUE, E and WUE. In case of Virginia bunch group the SCMR and carotenoid, pod yield and HI, E and P_N, g_s and E, showed positive correlations while E and chl a, E and carotenoid, P_N and WUE, g_s and WUE showed negative correlations.

The cultivars sorted out based on the physiological traits were further compared for their common occurrence and the cultivars high in 2-5 traits were identified (Table 4). There were 15 cultivars showing very high P_N and g_s, 9 with high P_N and E, 12 with high WUE and chl, 7 with high SCMR and pod yield, 6 with high P_N and pod yield, and several cultivars with high in two physiological traits. There were several cultivars with high in three physiological traits. Three cultivars (M 37, Chintamani, and Kadiri 7) showed high WUE, SCMR, PY and chlorophyll and two cultivars (Chintamani, and AK 303) showed high WUE, SCMR, chlorophyll and F_v/F_m, besides these the cultivar Chintamani also high PY also and hence was high in five physiological parameters. On the other hand, the cultivar TPG 41 had high PY, g_s, SCMR and HI. Some of the cultivars high in four physiological traits were HNG 69 (P_N, g_s, E, F_v/F_m), GPBD 5 (P_N, g_s, E, chl), ICGS 44 (P_N, E, PY, HI), GG 8 (P_N, g_s, E, PY), R 2001-3 (P_N, WUE, PY, HI), JGN 3 (P_N, g_s, WUE, HI), TG 1 (P_N, g_s, SCMR, chl), BG 1 (P_N, SCMR, chl, F_v/F_m), TPG 41 (PY, g_s, SCMR, HI).

The principal component analysis (PCA) identified six significant components which accounted for approximately 79% variance of which the PC1, PC2, PC3 and PC4 contributed 30, 13, 12 and 9%, respectively towards cumulative variance (Table 5). Discriminating power of principle components as inferred from PCA showed decreasing trend with the highest for PC1 (5.08) and the lowest for PC6 (1.1). The first component (PC1) significantly correlated with (>0.70) SCMR, chl a, chl b, chlorophyll a+b and carotenoides. The PC2 significantly correlated with P_N and g_s, PC3 correlated significantly with pod and haulm yields and number of pods and PC4 had high loadings for VCR, haulm yield, P_N and g_s. However, the PC5 and PC6 correlated significantly with E and chl a/b, respectively. The PCA scores of cultivars for components 1 and 2 when presented in Fig. 1, the PCA plot of 186 cultivars grouped these into two different clusters. Cluster 1 was comprised of cultivars mainly from Spanish bunch group, however, cluster 2 was dominated by Virginia group cultivars.

The genotype-by-trait (GT-biplot) drawn using PC1 and PC2 explained 43% of the total variation (Fig. 2). The relatively low proportion of variation reflects the complexity of the relationships among the traits in the GT-biplot, a vector is drawn from the origin to each of the traits to facilitate the visualization of the relationship among traits. Coefficient of correlation (r) between any two traits is approximated by the cosine of the angle between their vectors. The GT-biplot compare cultivars on the basis of multiple traits and identify the one possessing desirable traits as generally the traits with longer vectors explain the larger proportion of the observed variation whereas the traits with shorter vectors explain limited variation. Accordingly the physiological traits conductance (N), HI (J) and P_N (M) with their longer vector showed larger variations whereas traits number of pods (L), F_v/F_m (Q) and pod yield (H) with shorter vectors explained smaller variations among cultivars. Angle of vectors among the traits SCMR (B), Chl a (C), Chl b (D), total Chl (E), carotenoides (F), pod yield (H) and WUE (P) were less than 90º and hence were positively correlated. However, the angle between vectors of traits B, C, D, E, F, H and P showed more than 90° with traits E (O), VCR (A), chl a/b (G) and plant height (K) and hence were negatively correlated. Meanwhile angle between vectors of traits B, C, D, E, F, H and P were nearly at right angle with N, J and M and hence exhibited very low correlation.

The multiple parameters hierarchical cluster analysis using Ward's method grouped 186 peanut cultivars into 9 different clusters with varied number of cultivars in each clusters showing similarity in various physiological traits (Table 6), but without following any particular botanical class. Average cluster values for different traits when calculated clusters 1, 3 and 7 had high pod yields (Table 7). Cluster 1 and 3 contained 18 and 15 cultivars, respectively with high SCMR, chl a, chl b, carotenoids, pod and haulm yields, number of pods, P_N, and F_v/F_m and WUE. The cluster 7 contained 17 cultivars with higher pod yield, HI, number of pods,

Table 4—Highly efficient peanut cultivars with multiple physiological traits (*contd.*)

Traits with high values	Cultivars with high physiological efficiencies	Total cultivars
$P_{N,}$ g_s	ICGS 11, GPBD 5, TMV 3, GG 8, DRG 17, HNG 69, ICGS 5, BAU 13, GG 21, JGN 3, Chico, Gangapuri, TG 1, GJGHPS 1, GG 12,	15
$P_{N,}$ *E*	GPBD 5, MH 1, TMV 3, GG 8, HNG 69, DH 4-3, Chico, TNAU 256, ICGS 44,	9
$P_{N,}$ WUE	ICGS 11,TG 51, JGN 3, R 2001-3	4
$P_{N,}$ chl	GPBD 5, GG 13, BG 1, DH 4-3, TG 1	5
$P_{N,}$ F_v/F_m	HNG 69, BG 1, SG 84, ALR 3, GG 12	5
$P_{N,}$ PY	ICGS 5,GG 13, BAU 13, GG 21, ICGS 44, R 2001-3	6
$P_{N,}$ HI	GG 8, JGN 3, SG 84, GJGHPS 1, R 2001-3, ICGS 44	6
$g_{s,}$ *E*	GPBD 5, TMV 3, GG 8, HNG 69, Chico, ICGV 86031	6
$g_{s,}$ WUE	ICGS 11, JGN 3, ALR 1, ALR 2, TG 32	5
$g_{s,}$ SCMR	TG 1, TPG 41, BAU 19, LGN 2	4
$g_{s,,}$ chl	GPBD 5, TG 1, CSMG 884	3
$g_{s,,}$ F_v/F_m	HNG 69, GG 12, JL 220	3
$g_{s,}$PY	ICGS 5, BAU 13, GG 21, ALR 1, TPG 41, LGN 2	6
$g_{s,}$ HI	GG 8, JGN 3, GJGHPS 1, TPG 41, GG 2, TG 37 A	6
E, SCMR	Tirupati 3	1
E, chl	GPBD 5, DH 4-3	2
E, F_v/F_m	HNG 69, ICGV 86590, TG 22, Girnar 1	4
E,PY	ICGS 44, RG 141, AK 159, GJG 22, GJG 31	5
E, HI	GG 8, ICGS 44, Girnar 1,TG 26, AK 159	5
WUE, SCMR	M 37, Chintamani, Kadiri 7, TMV 10, MA 16, AK 303, M 145	7
WUE, chl	M 37,AK 265, Chintamani, Kadiri 7, TMV 10, BG 3, LGN 1, BG 2, B 95, AK 303, UF 70-103, M 145	12
WUE, F_v/F_m	Chintamani, GG 6, DH 86, Kaushal, AK 303, VG 9521	6
WUE, PY	R 2001-3, M 37, Chintamani, Kadiri 7, ALR 1, DH 86	6
WUE,HI	JGN 3, R 2001-3, GG 6, GG 7	4
SCMR, chl	BG 1, M 37, Chintamani, Kadiri 7, TMV 10, M 145, AK 303, Chandra, JSP 19, CSMG 84-1, ICGV 88448, TG 1	12
SCMR, F_v/F_m	BG 1, Chintamani, GAUG 10, AK 303, Chandra, CSMG 84-1, Karad 4-11	7
SCMR, PY	ICGS 76, M 37, Kadiri 7, Chintamani, GAUG 10, TPG 41, LGN 2	7
Chl, F_v/F_m	BG 1, Chintamani, AK 303, Chandra, CSMG 84-1, Kadiri 8, Kadiri 71-1	7
Chl, PY	GG 13, ICGV 000348, Mallika, M 37, Kadiri 7, Chintamani, GG 11	7
Chl, HI	ICGV 000348, ICGV 00351	2
PY, HI	R 2001-3, ICGS 44, AK 159, TGLPS 3, ICGV 000348, M 548, ICGV 00350, M 522, M 13, TPG 41, TLG 45	11
$F_v/F_{m,}$ PY	GG 20, M 522, Chintamani, GAUG 10, DH 86,	5
$F_v/F_{m,}$ HI	SG 84, Girnar 1, M 522, GG 6,	4
$P_{N,}$ $g_{s,}$ *E*	GPBD 5, TMV 3, GG 8, HNG 69, Chico	5
$P_{N,}$ $g_{s,}$ WUE	ICGS 11, JGN 3	2
$P_{N,}$ $g_{s,}$ chl	GPBD 5, TG 1	2
$P_{N,}$ $g_{s,}$ F_v/F_m	HNG 69, GG 12	2
$P_{N,}$ $g_{s,}$ PY	ICGS 5, BAU 13, GG 21	3
$P_{N,}$ $g_{s,}$HI	JGN 3, GJGHPS 1	2
$P_{N,}$ *E*, chl	GPBD 5, DH 4-3	2
$P_{N,}$ *E*, HI	GG 8, ICGS 44	2
$P_{N,}$ SCMR, chl	BG 1, TG 1	2
$P_{N,}$ chl, PY	GG 13	1
$P_{N,}$ $F_v/F_{m,}$ HI	SG 84	1

(*contd.*)

Table 4—Highly efficient peanut cultivars with multiple physiological traits

Traits with high values	Cultivars with high physiological efficiencies	Total cultivars
g_s, E, HI	GG 8	1
g_s WUE, PY	ALR 1	1
E, HI, PY	ICGS 44, AK 159	2
E, HI, F_v/F_m	Girnar 1	1
WUE SCMR, chl	M 37, Chintamani, Kadiri 7, TMV 10, AK 303, M 145	6
WUE SCMR, F_v/F_m	Chintamani, AK 303	2
WUE, SCMR, PY	M 37, Chintamani, Kadiri 7	3
WUE, chl, F_v/F_m	BG 3, B 95, AK 303	3
WUE, F_v/F_m, HI	GG 6	1
WUE, chl, PY	M 37, Chintamani, Kadiri 7	3
WUE, PY, F_v/F_m	Chintamani, DH 86	2
SCMR, PY, g_s	TPG 41, LGN 2	2
SCMR, F_v/F_m, Chl	BG 1, Chintamani, AK 303, Chandra, CSMG 84-1	5
SCMR,PY, F_v/F_m	GAUG 10	1
SCMR, chl, PY	Chintamani, Kadiri 7	2
PY , F_v/F_m, HI	M 522	1
chl, PY, HI	ICGV 000348	1
P_N, g_s, E, F_v/F_m	HNG 69	1
P_N, g_s, E, chl	GPBD 5	1
P_N, E, PY, HI	ICGS 44	1
P_N, g_s, E, PY	GG 8	1
P_N, WUE, PY,HI	R 2001-3	1
P_N, g_s, WUE, HI	JGN 3	1
P_N, g_s, SCMR, chl	TG 1	1
P_N, SCMR, chl, F_v/F_m	BG 1	1
PY, g_s , SCMR, HI	TPG 41	1
WUE, SCMR, PY, chl	M 37, Chintamani, Kadiri 7	3
WUE, SCMR, chl, F_v/F_m	Chintamani, AK 303	2
PY,WUE, chl, SCMR, F_v/F_m	Chintamani	1

[Details of the abbreviations are given in Table 1]

Table 5—Principal component analysis for different physiological traits among 186 peanut cultivars

Traits	Principal components (PC)					
	1	2	3	4	5	6
Eigen value	5.08	2.19	2.02	1.62	1.35	1.10
% variance	29.86	12.91	11.89	9.51	7.92	6.45
cumulative variance	29.86	42.77	54.66	64.17	72.10	78.55
Loadings						
A. VCR	-0.52	0.01	-0.24	0.45	-0.10	-0.07
B. SCMR	0.76	0.03	0.09	-0.14	0.17	0.08
C. Chl *a*	0.94	-0.04	-0.01	0.00	0.12	0.11
D. Chl *b*	0.90	0.08	-0.13	0.19	0.14	-0.23
E. Total chl	0.95	0.02	-0.05	0.08	0.14	0.00
F. Caro	0.77	-0.03	0.00	-0.14	0.07	0.41
G. Chl *a*/*b*	-0.34	-0.28	0.26	-0.36	-0.08	0.71
H. Pod yield (PY)	0.37	0.13	0.74	-0.30	-0.18	-0.19
I. HY	0.31	-0.52	0.63	0.32	0.10	0.00
J. HI	0.00	0.67	-0.01	-0.62	-0.27	-0.13
K. Plant height	-0.35	-0.41	0.47	0.32	0.00	-0.01
L. Pods/3 pl	-0.07	0.17	0.73	-0.03	-0.30	-0.26
M. P_N	0.04	0.72	0.27	0.46	0.19	0.17
N. g_s	-0.05	0.69	0.14	0.40	-0.06	0.32
O. E	-0.49	0.38	0.28	-0.06	0.70	0.02
P. WUE	0.54	0.09	-0.09	0.37	-0.64	0.09
Q. Fv/Fm	0.21	-0.09	0.01	-0.08	0.30	-0.28

[Details of the abbreviations for serial number A to Q are given in Table 1]

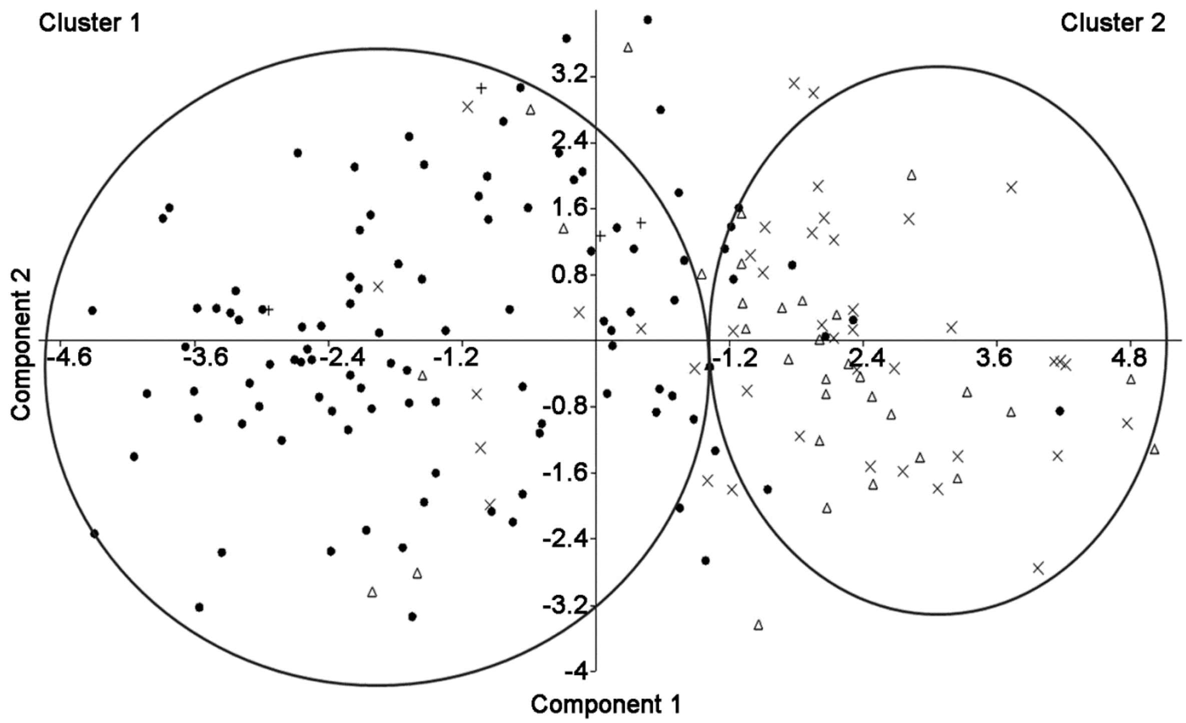

Fig. 1—Principal component analysis of 186 peanut cultivars for various physiological traits. The legend are • = Spanish bunch, + = Valencia, × = Virginia bunch, Δ= Virginia runner

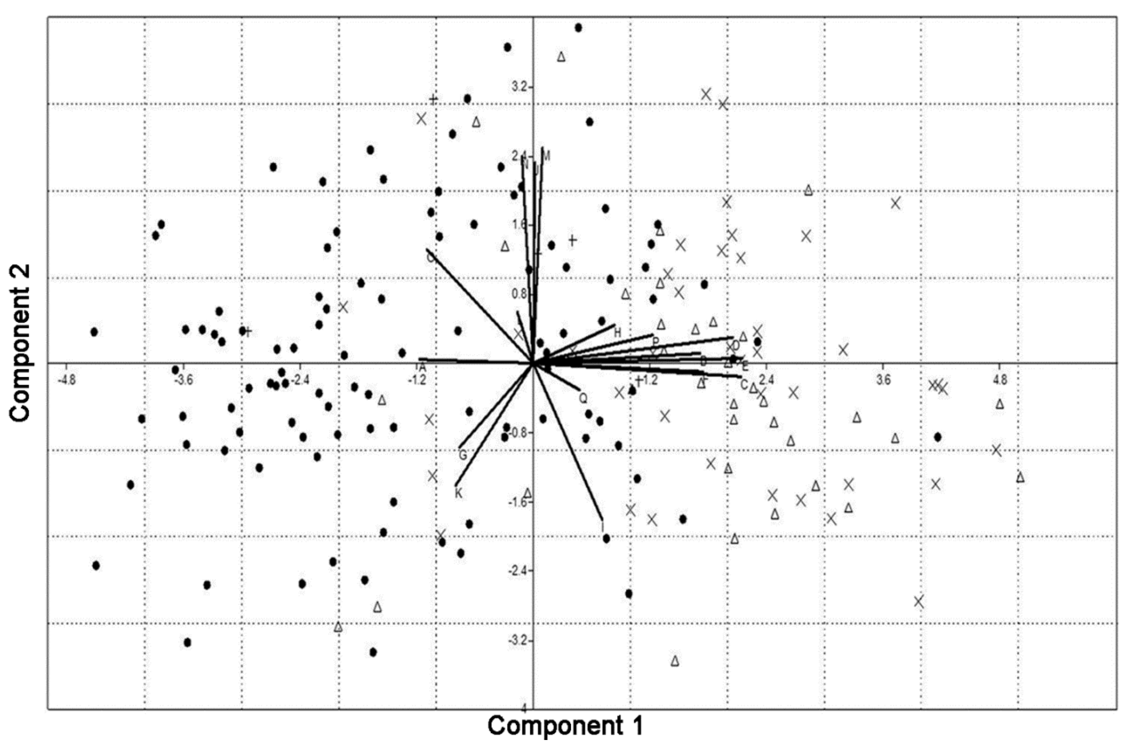

Fig. 2—Vector view of genotype- trait biplot summarising the interrelationship among the traits studied in 186 peanut cultivars. A = VCR; B = SCMR; C = chl a; D = chl b; E = Total Chl (a+b); F = Carotenoids; G = chl a/b ratio; H = pod yield; I = Haulm yield; J = Harvest Index; K = plant heignt; L = pods/plant; M = P_N; N = Cond; O = Transpiration; P = WUE; Q = Fv/Fm. • = Spanish bunch, + = Valencia, × = Virginia bunch, Δ= Virginia runner

Table 6—Grouping of peanut cultivars into various clusters using Ward's method

Clusters	Cultivars	Total
1	K 134, Kadiri 9, LGN 2, ICGV 86031, Karad 4-11, Somnath, Chandra, RS 138, Kadiri 7, GG 13, ICGS 5, GAUG 10, ALR 3, JSP 19, GG 21, ICGS 76, Mallika, M 37	18
2	BG 2, CO 3, TMV 4, MA 16, RS 1, ICGV 88448, Pratap Mungphali 2, Kokan Tapora, BAU 19, VRI 16, S 230,TKG 19 A, T 28, GG 12	14
3	TMV 3, RSB 87, GG 11, Tirupati 3, VRI 5, BG 1, AK 265, Kadiri 8, COGN 4, VRI 6, GJG 22, Chintamani, GJG 31, ALR 1, ICGV 87846	15
4	MH 4,TG 26, MH 2	03
5	LGN 1, TMV 9, Jyoti, SB XI, KRG 1, R 9251,TG 22, OG 52-1,VRI 3,TMV 13, Chico, DRG 12, DH 101, ICGS 11, GG 8, GG 2, JL 286, TAG 24, TG 37 A, JL 24, GG 6, JGN 3	22
6	Kaushal, AK 303, AK 12-24, TG 17,VG 9521, ICG (FDRS) 4, JGN 23, T 64, BSR 1, GG 3, VG 9816, DRG 17, Girnar 3, Girnar 2, Girnar1, Jawan, Chitra, HNG 69, GG5,TNAU 256, Tirupati 2, SG 84, Kadiri Harithandra, VRI 2, Kisan, TG 32, ICGV 00351, GJGHPS 1, GG 7, R 2001-3, TLG 45,TPG 41	32
7	M 335, AK 159, ICGV 86590, ICGS 44, M 13, ICGV 00350, TGLPS 3, DH 86, JCG 88, GG 15, Kadiri Gold, M 522, M 548, GG 20, RG 141, BAU 13, ICGV 000348	17
8	CSMG 9510, GPBD 5, SG 99, RG 510, ICGV 91114, Kadiri 71-1, JL 220, Kokan Gaurav, RG 425, GG 16, ICGS 1, TMV1, CSMG 2003-19, GG 14, Kadiri 6, B 95, VRI 4, M 197, DH 2001-1, ICGV 86325, GAUG 1, Dh 3-30, GPBD 4	23
9	Kadiri 5, UF 70-103, MH 1, S 206, TG 3, DH 4-3, TMV 10, Kopargaon 3, DRG 101, Tirupati 1, TMV 11, Punjab 1, DH 40, ICG (FDRS) 10, TMV 12, JL 501, DSG 1, CSMG 884, Pratap Mungphali 1, ALR 2, BG 3, Tirupati 4, Gangapuri, HNG 10, GG 4, R 2001-2, ICGS 37, TG 51, CSMG 84-1, Kadiri 4, Kadiri 2, Champavat, TG 1, R 8808, Kadiri 3, TG 42, M 145, CO 2, TMV 7, CO 1, DH 8, TMV 2	42

Table 7—Average cluster values of various physiological traits observed in peanut cultivars

Clusters	VCR	SCMR	Chl a	Chl b	Chl a+b	Carot	Chl a/b	PY g m^{-2}	HY g m^{-2}	HI	Plant ht. (cm)	Pods/ plant	P_N	g_s	*E*	WUE	Fv/Fm
1	1.59	37.74	6.70	2.42	9.12	1.10	2.79	231	601	0.28	42.7	11.1	21.2	0.25	6.53	3.33	0.85
2	1.93	34.94	6.07	2.17	8.24	0.98	2.87	175	642	0.21	46.9	9.2	17.7	0.23	5.82	3.09	0.84
3	1.93	35.17	6.79	2.45	9.24	0.94	2.97	219	779	0.22	47.3	11.3	20.6	0.24	7.11	3.05	0.85
4	2.00	33.03	5.53	2.31	7.84	0.75	2.58	98	160	0.38	15.4	5.7	16.4	0.22	6.95	2.39	0.82
5	2.27	31.55	4.43	1.60	6.13	0.75	2.89	147	301	0.33	41.4	9.6	20.7	0.27	7.64	2.87	0.85
6	2.19	33.68	5.38	1.98	7.36	0.96	2.83	176	351	0.33	41.8	9.9	20.1	0.27	6.75	3.18	0.85
7	1.82	34.37	5.94	2.15	8.08	0.93	2.83	244	467	0.34	42.5	10.8	18.7	0.23	6.85	2.94	0.85
8	2.30	34.13	5.82	2.12	8.12	0.89	2.84	164	490	0.25	42.7	9.3	18.6	0.23	5.99	3.17	0.85
9	2.29	33.02	5.36	2.09	7.45	0.86	2.71	150	413	0.26	43.8	9.3	20.2	0.25	7.34	2.96	0.84

[Details of the abbreviations are given in Table 1]

but with moderate value of SCMR, chl a, chl b, carotenoids, haulm yield and P_N. This clustering could be useful for identifying cultivars with potentially high values of various physiological parameters.

Discussion

The studies on physiological traits *viz*. P_N, g_s, *E*, WUE, VCR, SCMR, chlorophyll and its fluorescence parameters in leaves at 60-65DAE and pod and haulm yields at harvest in 186 peanut cultivars belonging to various botanical groups showed a high degree of variability among cultivars but slight variations among botanical groups. Characterization of physiological traits is indispensable to facilitate utilization of these peanut cultivars for further yield improvement.

The chloroplast pigments, their concentrations and composition govern photosynthetic efficiency, plant growth, their adaptabilities to environments and finally yield[3-5,26]. Five parameters, explaining intensity and composition of chloroplast pigments *viz*. VCR, chl a and chl b, carotenoids and SCMR, measured in 186 peanut cultivars between 60-65 DAE, in this study, showed a wide variations among cultivars, but all these traits showed a good association among themselves as well as with yield attributes. The VCR is the rating of leaf chlorosis based on its appearance and intensity and scored as 1 for complete green without chlorosis and 5 for severe chlorosis, and hence is negatively correlated with chl content and yield[22]. The VCR among 186 cultivars varied from 1-3 with a mean of 2.1, with obvious negative correlations with SCMR, chl and carotenoids. The total chl and carotenoid contents among 186 cultivars ranged 3-15 and 0.27-1.65 mg g^{-1} dry wt. of leaves, respectively. The range of SCMR among peanut cultivars was 20.3-44.1 and 26 cultivars showed >39 SCMR. The peanut genotypes with SCMR value >40 were highly tolerant to iron chlorosis[13]. Positive correlations of SCMR with chl and carotenoid, again justify SPAD chlorophyll meter a very useful to handle a large number of peanut genotypes. Its usefulness has also been reported in cotton[27].

In this study, the P_N among peanut cultivars showed a wide range 11.4-31.4 µmol $m^{-2}s^{-1}$ and as many as 28 cultivars were photosynthetically more efficient with P_N >23.9 µmol $m^{-2}s^{-1}$. In a study of 181 mini-core peanut, the P_N ranged 14.5-40.8 µmol $m^{-2}s^{-1}$ during summer season[5]. However, the stomatal behaviour and g_s can be changed through hormonal sprays[28]. In Spanish cultivars, the yield is limited due to lower P_N[29], however in this study, there was very weak association between P_N and pod yield. In soybean, P_N and P_N/C_i were effective selection indexes for seed yield[30]. The close association of chlorophyll density with WUE makes it a potential indicator of transpiration efficiency in peanut[31].

Stomatal conductance (g_s) is the measure of the rate of passage of CO_2 entering, or water vapor exiting through the stomata on both side of leaf. In this study, the range of leaf g_s in 186 cultivars was 0.11-0.45 m s^{-1} and 35 cultivars showed high g_s >0.33 m s^{-1}. However, the leaf E ranged 3.96-11.61 m mol $m^{-2}s^{-1}$ with again 35 cultivars showing high E >8.9 mmol $m^{-2}s^{-1}$. As the g_s estimates the rate of gas exchange (i.e., carbon dioxide uptake) and transpiration (i.e., water loss) through stomata, it is determined by the degree of stomatal aperture and the physical resistances to the movement of gases between the air and the interior of the leaf. As the g_s is a function of the density, size and degree of opening of the stomata and greater g_s can potentially increase productivity by higher photosynthesis and transpiration rates. Variation in g_s, and E in the peanut cultivars in this study was attributed mainly due to variation in the morphological characteristics of their leaves, as the soil and climates were almost similar for all the cultivars. Nautiyal *et al*.[29] hypothesizes that peanut productivity could be increased by enhancing g_s in the cultivars with high P_N, and by lowering the canopy-air temperature differences.

The peanut leaves show diurnal variations in P_N and g_s, however, maximum between 08:00–13:00 with least differences making it ideal time to measure these[2], though transient soil moisture deficit during early growth stages increases yield[4]. The peanut leaf showed maximum P_N after attending its full expansion, but become less efficient after two weeks of full expansion[16]. The peanut crop show maximum growth between 7–13 weeks after emergence[26] and this is the period for high, leaf-level gas exchange[2-4]. Thus, measurement of P_N in the third fully matured leaf from the top during the pod development stage ie. from 60-65 DAS, ideal for screening large number of genotypes[5] and was also followed here. High transpiration efficiency *i.e.*, the ratio of mass accumulation to transpiration, is a critical factor for genetic improvement to increase crop yields. The WUE among the 186 peanut cultivars, ranged from 1.43-4.9 with 32 cultivars showing high WUE >3.8. However, component traits, P_N, g_s, and biomass accumulation, are more effective in using available water throughout the growing season to maximize growth and yield of the crop[32]. The mini-core germplasm showed high variability in WUE and 30 genotypes with WUE >3.8 were identified[5].

The chlorophyll fluorescence, considered to be signature of photosynthesis[33], is a highly useful parameter and the Fv/Fm ratio is an important tool in determining damage to photosynthetic apparatus under drought[8,34]. There is damage and down regulation of PSII in peanut under water stress due to increase in leaf temperature and decreased Fv/Fm[8,35]. Fluorescence is the emission of electromagnetic radiation by a substance as a result of its exposure to electromagnetic radiation of a different wavelength. Chlorophyll fluorescence measurements are completely non-invasive and allows studying photosynthesis *in vivo*, particularly useful in situations of a various environmental factors. As there was no resource limitation in this study, very narrow range of F_v/F_m 0.802-0.887 among the peanut cultivars was observed, and the one with >0.860 were categorized as high while with <0.830 were low F_v/F_m cultivars. The Fv/Fm in the mini-core germplasm grown during summer also ranged from 0.81-0.87 and the one having Fv/Fm >0.86 were categorized as high and <0.84 were marked as low[5]. The peanut showed higher seed yields due to high P_N and Fv/Fm and high RUE later in the growing season[36]. Here five cultivars high in P_N and Fv/Fm identified.

These physiological parameters finally contributed to yield which ranged from 68-309 g m^{-2} pod yield and 144-884 g m^{-2} haulm yield with the HI in the range of 0.17-0.44. There were positive correlations between SCMR and pod and haulm yields, SCMR and WUE, SCMR and F_v/F_m, but negative correlations between, SCMR and plant height, SCMR and *E*. There is inter-relationship among physiological traits which play their important role in increasing yield in peanut[2,3,37]. Strong positive correlation between P_N and g_s indicate that apart from carbon fixation it also regulates transpiration. Peanut genotypes with high SCMR had positive correlation with chl content[38] hence high P_N[31]. The P_N and *E*, help in empirical selection[6], and under drought there was a positive correlation between *E*, leaf area and yield[3]. The mini-core germplasms also showed positive correlation between P_N and g_s, P_N and *E*, P_N and WUE, and P_N and Fv/Fm, SCMR and Fv/Fm, *E* and g_s traits[5]. The transpiration efficiency under drought correlate with SCMR[39]. In peanut the WUE correlated with SCMR and SLA[5,15,40], and hence both of these can be used as surrogate of WUE to evaluate large populations by recording it after 60 days of crop growth[41], but between 60-80 DAS only[3,5,37,42]. Also, there is a strong correlation between WUE and SCMR both under normal[43] and under drought[14]. However, there is an indication of salinity stress indices of morphological and physiological traits at the seedling stage in rice[44]. In this study, the SCMR with its strong correlation with chl and yields was highly useful parameter.

A comprehensive relationship for all the physiological parameters in peanut cultivars, worked out both within and between different habit groups, showed obvious positive correlations between pod and haulm yields, pod yield and harvest index (HI), pod yield and number of pods, haulm yield and plant height, haulm yield and number of pods, plant height and number of pods, number of pods and P_N, P_N and g_s, P_N and *E*. The chlorophyll was an important factor and the Spanish and Virginia runner showed positive correlations between SCMR and chl, SCMR and carotenoids, chl and carotenoid. Only the Spanish group showed obvious positive correlations between chl and pod yield. The Virginia runner on the other hand, showed positive correlation between plant height and pod yield, P_N and pods and both Virginia bunch and runner showed positive correlations between *E* and P_N, g_s and *E*.

The evaluation of physiological parameters responsible for growth and yield in all the peanut cultivars of India revealed considerable variations and subsequent identification of cultivars for high, medium, and low P_N, g_s, *E*, WUE, SCMR and Fv/Fm shall be of immense use in increasing the productivity. The cultivars with high P_N and pod yield, high P_N and WUE, high P_N and g_s, high P_N and Fv/Fm, high P_N and chl and high SCMR and pod yield identified in this study will help in increasing productivity. The cultivars with high SCMR or chl and pod yield are: ICGS 76, M 37**,** Kadiri 7, Chintamani, GAUG 10, TPG 41, LGN 2, GG 13, ICGV 000348, Mallika, GG 11, and high P_N and pod yields are: ICGS 5, GG 13, BAU 13, GG 21, ICGS 44, R 2001-3. The peanut cultivars TPG 41, Chintamani, M 37, GG 8, GG 13, Kadiri 7, GPBD 5, HNG 69, M 522 superior in 2-3 physiological traits along with pod yield are good for their cultivation and also useful for developing peanut varieties with a good yield potential. This information will be of immense use for improvement in various yield traits and finally increasing productivity of peanut worldwide.

The PCA is a robust tool for evaluation of cultivars to reduce the large number of correlated variables into smaller components. It helps to extract the independent variables that matter the most and gives direct measurement of total variance explained by few of the important components. In this study the PCA identified six components accounting for 79% variance of which PC 2 correlated with P_N and g_s, the PC 3 correlated with pod and haulm yields and number of pods. The PCA scores of 186 cultivars for components 1 and 2 when plotted, grouped these into two different clusters, comprising of cultivars mainly from Spanish and Virginia groups, respectively. The genotype-by-trait (GT-biplot) compare cultivars on the basis of multiple traits and also identify the one possessing desirable traits. The conductance, HI and P_N showed larger variations whereas number of pods, F_v/F_m, and pod yield explained smaller variations among cultivars. These associations among various physiological traits as revealed by PCA were in agreement with the worked-out correlations among these traits.

In this study, all the available Indian peanut cultivars, of various botanical groups, were characterized for physiological traits and the physiologically efficient cultivars for various traits were identified. The Spanish and Virginia bunch groups were having most of the desirable physiological traits. The information generated from this study would be helpful for future peanut crop production programme worldwide. Finally, this study identified a number of cultivars high in two-three physiological traits and a few cultivars high in four to five physiological traits.

Conclusion

Results of this study suggest that there are large variation in physiological parameters among the Indian peanut cultivars and relatively small variation among various botanical groups. The SCMR, chlorophyll, carotenoids, P_N and g_s, and pod and haulm yields are the major physiological traits and the cultivars identified with high and low in various physiological traits will act as a source of variation for future studies. Cluster analysis of 17 physiological traits, grouped 186 cultivars into nine clusters showing similarity in physiological traits. The peanut cultivars high in multiple physiological traits coupled with high pod yield are recommended. The peanut cultivars TPG 41, Chintamani, M 37, GG 8, GG 13, Kadiri 7, GPBD 5, HNG 69, M 522 superior in 2-3 physiological traits along with pod yield are good for cultivation. Among various botanical groups the Spanish and Virginia bunch were most desirable for various the physiological traits.

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