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ORIGINAL ARTICLE

Photosynthetic efficiency among Indian peanut cultivars and influence of seasonal variation and zinc

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Abstract Sixty high yielding Indian peanut cultivars were studied for net photosynthesis (P_N), transpiration (E), stomatal conductance (g_s), water use efficiency (WUE), radiation use efficiency (RUE), SPAD chlorophyll meter reading (SCMR) and chlorophyll fluorescence (F_v/F_m) at 70–75 days and pod and fodder yields at harvest in field during both the *Kharif* (Wet) and *Rabi-summer* (Dry) seasons to find out the efficient cultivars and seasons. The dry season crop showed higher values of these parameters except E and F_v/F_m than that of wet season crop and application of Zn increased all these but reduced g_s and SCMR. On an average, the peanut cultivars showed 29.9 and 19.4 µmol (CO_2) m^2 s^{-1} P_N, 0.57 and 0.26 m s^{-1} g_s, 11.4 and 13.2 m mol m^{-2} s^{-1} E, 2.67 and 1.49 WUE, 0.018 and 0.012 RUE, 38.2 and 36.3 SCMR and 0.843 and 0.850 F_v/F_m during dry and wet seasons, respectively. The foliar application of zinc as 0.2% zinc-sulphate, during dry season, influenced all these parameters, with an average of 30.6 and 29.3 µmol (CO_2) m^{-2} s^{-1} P_N, 0.54 and 0.60 m s^{-1} g_s, 11.7 and 11.2 m mol m^{-2} s^{-1} E, 2.69 and 2.65 WUE, 0.019 and 0.018 RUE, 37.8 and 38.7 SCMR and 0.844 and 0.842 F_v/F_m with and without Zn, respectively. The study identified several photosynthetically efficient cultivars. There were 18 cultivars with high P_N and g_s, 18 cultivars with high P_N and E and 17 cultivars with high P_N and pod yield. Based on the overall performance the peanut cultivars being recommended are Tirupati 3, TG 37A, CSMG 884, RS 1, S 230, LGN 2, TPG 41 and SG 99 for dry season and GG 20, Tirupati 4, M 197, ALR 2, JL 501 and RG 141 for wet season.

Keywords Chlorophyll fluorescence · Net photosynthesis · Pod yield · Stomatal conductance · Transpiration

Introduction

The Peanut (*Arachis hypogaea* L.), is a major food legume and oilseeds crop of the tropical and subtropical world and about 41 million tonne pods are harvested from about 25 million hectare (m ha) of land distributed in about 120 countries mainly in semi-arid region (FAO 2015). Though, consumed worldwide, on large scale, the peanut is grown mostly in Asian (11.96 m ha) and African (11.85 m ha) continents and India, China, Nigeria, USA, Myanmar, Senegal, Sudan, Indonesia, Argentina and Tanzania are its major producing countries where it is grown across wide range of environments mostly as rain-fed crop(Singh 2003; Singh et al. 2013a). It requires warm climate with well distributed rainfall of 500–800 mm (Singh 2003). The peanut productivity is less than 1000 kg ha^{-1} pod in more than 30% of the peanut growing countries and only about 25% of the countries had above 2000 kg ha^{-1} pod yield (Singh et al. 2014b) with a global average pod yield of around 1800 kg ha^{-1} (FAO 2015). India has the largest peanut area (4.8–5.8 m ha) in the world, but its average productivity is fluctuating between 1300 and 1750 kg ha^{-1} during the last 5 years mainly due to its rain-fed (84% area) cultivation during *Kharif* as wet season crop. Only in about 16% of its area, in India, the peanut is grown during *Rabi-Summer* as a dry season crop under irrigation, where the productivity is above 1900 kg ha^{-1}.

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Presently, there are about 200 peanut cultivars released in India, but as of now, only 50–60 cultivars are under cultivation. The genetic improvement in peanut during past three decades resulted in increased production worldwide and efforts at DGR and its coordinated centres in India, BARC, ICRISAT and elsewhere have succeeded in identifying trait specific cultivars (Singh 2011; Singh et al. 2014a). However, most of the Indian peanut cultivars have a very narrow genetic base (Nigam et al. 2005). The dry matter production is influenced by the rate of physiological processes such as photosynthesis, transpiration and fluorescence (Singh et al. 2013a) governed by fertilizers (Singh et al. 2013b). The high net photosynthesis in peanut during pod filling stage (Nautiyal et al. 1999) specify its time of observation (Singh et al. 2014a). The WUE contribute directly to productivity under limited resources (Wright et al. 1994), and in peanut there is a close relationship between SCMR and WUE (Singh et al. 2013a, 2014a) and SCMR and pod yield (Kalariya et al. 2017). The high association of P_N with g_s (Nautiyal et al. 2002) indicates that transpiration also regulates P_N in peanut (Singh et al. 2014a). The recent physiological studies of mini-core peanut accessions showed a large variability (Singh et al. 2014a) useful for developing new cultivars.

The yield has been the major criteria for selection of peanut cultivar, however physiological traits such as WUE, P_N, E, RUE and chlorophyll fluorescence are more useful for the improvement in growth and yield per resource use and hence in selection for broader environment (Singh et al. 2014a, b). Though, the peanut breeding programme in India introduces a few new cultivars every year, most of them lack in physiological evaluation resulting in poor adaptability of these under changing environment. Nevertheless, there is a regular screening for abiotic stresses (Singh 2004; Singh and Basu 2005; Singh et al. 2013a). In chickpea, the genotype by environment interactions for yield accounted for more variation than that of genotypes alone (Berger et al. 2006). The photosynthetic characteristics of a few peanut cultivars have been studied under excess as well as deficit irrigation (Kalariya et al. 2013, 2015). However, the photosynthetic efficiency of the Indian peanut cultivars together has not been evaluated yet and there is a strong need to characterize existing cultivars for various physiological traits and their association with yields for their better utilization in various environments. The present work emphasizes a study of physiological traits viz. P_N, g_s, E, WUE, SCMR and chlorophyll fluorescence and yield and influence of seasonal variations (wet and dry) and zinc application in 60 high yielding peanut cultivars to identify photosynthetically efficient cultivars.

Materials and methods

Field experimentations

In a field experiment 60 high yielding peanut cultivars were grown during *Summer* (Dry) and *Kharif* (Wet) seasons of 2012 at the Directorate of Groundnut Research, Junagadh, Gujarat, India (70.36°E and 21.31°N and 83 m above msl), in a medium black calcareous (14% $CaCO_3$) clayey, Vertic Ustochrept soil having 8.4 ppm P, 7.5 pH, 1.2% organic C, 800 ppm N, 12 ppm available S, and 3.6, 16.0 and 1.3 ppm DTPA extractable Fe, Mn and Zn, respectively. The crop was grown under two distinct seasons, during *Rabi-Summer* as dry season crop by sowing it during first week of Feb and harvesting the same during May–June, as well as during *Kharif* as a wet season crop by sowing it during last week of June and harvesting during October. The crop was grown under proper soil moisture without any water stress. The dry season crop was totally irrigated while the wet season crop was rainfed with two protective irrigations during dry spells.

A total of 60 high yielding peanut cultivars (listed in Table 1), released for their cultivation in India, were assembled and shelled. The field was ploughed, levelled and 10 cm deep furrows were opened at 30 cm spacing and divided into strips across the row so as to get 6 strips each of 5 m row length. The seeds of 60 cultivars, each in one row plots of 5 m length, were sown at 10 cm spacing, in three replications in two sets one for control and other for foliar application of zinc in a factorial randomized block design. 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 planting using ammonium sulphate, DAP (diammonium phosphate), muriate of potash and elemental S (Singh and Basu 2005). These were mixed in the soil before sowing and 500 kg ha^{-1} gypsum mixed in the soil at flowering. The crop was grown under recommended package of practices with proper plant protection during the cropping season. For foliar Zn treatment, the aqueous solution of 0.2% zinc sulphate was applied on the groundnut foliage, thrice at 40, 55 and 70 DAE (days after emergence) at 500, 1000 and 1000 L ha^{-1}, respectively. The crop was harvested at maturity, dried in sun for a week and pod and haulm yields were recorded. Harvest Index was calculated by the formula, pod yield divided by total biomass.

Estimation of leaf-level gas exchange, CO_2 fixation, WUE, SCMR and chlorophyll fluorescence

At 70–75 DAE (days after emergence) of crop which is pod filling stage, the P_N, g_s, E were recorded using

Table 1 Net photosynthetic rate (P_N, μmol m^{-2} s^{-1}), stomatal conductance (g_s, m s^{-1}), transpiration rate (E, m mol m^{-2} s^{-1}) and water use efficiencies (WUE) and radiation use efficiencies (RUE) in 60 groundnut cultivars grown during dry season (values are mean of three replications) of 2012

SN	Variety	P_N			g_s			E			WUE			RUE			SCMR			F_v/F_m		
		C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	Control	Zn	Mean
1	SB XI	25.1	25.5	25.3	0.53	0.71	0.62	9.9	12.6	11.3	2.54	2.02	2.28	0.015	0.015	0.015	37.8	43.2	40.5	0.835	0.852	0.843
2	SG 99	28.4	33.2	30.8	0.5	0.68	0.59	9.1	12.9	11	3.14	2.58	2.86	0.017	0.02	0.019	42.6	42.3	42.5	0.846	0.846	0.846
3	SG 84	22	28.8	25.4	0.36	0.69	0.52	6.5	13.4	10	3.38	2.14	2.76	0.013	0.017	0.015	31.7	40.6	36.2	0.835	0.864	0.85
4	JL 24	31.4	29.7	30.5	0.6	0.46	0.53	10.6	11	10.8	2.95	2.71	2.83	0.019	0.018	0.018	34.4	37.6	36.0	0.844	0.848	0.846
5	CO 1	24.6	24.6	24.6	0.51	0.64	0.57	9.6	11.9	10.8	2.55	2.06	2.3	0.015	0.015	0.015	32.9	37.4	35.2	0.847	0.846	0.846
6	VRI 2	29.6	25.7	27.7	0.47	0.54	0.51	9.6	11.5	10.5	3.1	2.23	2.66	0.018	0.016	0.017	34.4	41.1	37.8	0.838	0.848	0.843
7	CO2	31.2	29.5	30.4	0.65	0.66	0.66	11.3	12.1	11.7	2.76	2.43	2.6	0.019	0.018	0.018	33.6	40.0	36.8	0.851	0.849	0.85
8	GG2	35.4	36.1	35.8	0.67	0.7	0.69	11.4	12.8	12.1	3.12	2.81	2.97	0.021	0.022	0.022	35.8	44.6	40.2	0.836	0.853	0.844
9	GG 7	28.5	27	27.7	0.48	0.63	0.56	10.2	12.4	11.3	2.79	2.18	2.49	0.017	0.016	0.017	33.6	37.3	35.5	0.839	0.846	0.842
10	GG 12	37.1	26.9	32	0.76	0.54	0.65	12.7	12.8	12.7	2.93	2.11	2.52	0.022	0.016	0.019	35.7	35.0	35.4	0.859	0.85	0.854
11	GG 20	33.8	34	33.9	0.8	0.78	0.79	12.6	13.5	13	2.7	2.51	2.6	0.021	0.021	0.021	42.9	40.1	41.5	0.847	0.851	0.849
12	LGN 2	28.6	32.7	30.7	0.63	0.72	0.67	10.6	14	12.3	2.69	2.34	2.51	0.017	0.02	0.019	40.1	39.0	39.6	0.849	0.85	0.85
13	MH 1	25.9	21.6	23.8	0.44	0.43	0.43	9.4	12	10.7	2.77	1.8	2.28	0.016	0.013	0.014	34.9	40.6	37.8	0.837	0.846	0.841
14	RS 1	32.1	30.8	31.4	0.66	0.6	0.63	11.5	12.4	11.9	2.8	2.48	2.64	0.019	0.019	0.019	37.8	42.6	40.2	0.839	0.845	0.842
15	JL 501	26.1	31.8	29	0.62	0.69	0.66	10	13.6	11.8	2.62	2.33	2.47	0.016	0.019	0.018	39.0	41.0	40.0	0.853	0.852	0.852
16	ICG (FDRS) 4	25.8	27.6	26.7	0.7	0.59	0.64	11.8	9.7	10.7	2.2	2.85	2.52	0.016	0.017	0.016	38.8	35.8	37.3	0.852	0.847	0.849
17	S 230	31.6	34	32.8	0.68	0.58	0.63	11.1	10.7	10.9	2.83	3.18	3.01	0.019	0.021	0.02	41.2	38.7	40.0	0.85	0.862	0.856
18	R 8808	29.7	28	28.8	0.5	0.68	0.59	9.5	11.3	10.4	3.13	2.48	2.8	0.018	0.017	0.017	37.7	40.6	39.2	0.83	0.844	0.837
19	S 206	28.8	26.9	27.8	0.45	0.4	0.42	9.7	10.4	10.1	2.96	2.59	2.77	0.017	0.016	0.017	36.3	39.0	37.7	0.842	0.848	0.845
20	UF 70-103	31.4	37.4	34.4	0.62	0.59	0.6	11.7	8.8	10.2	2.7	4.27	3.48	0.019	0.023	0.021	35.9	35.0	35.5	0.83	0.84	0.835
21	RG 141	36.3	38.6	37.5	0.69	0.55	0.62	12.1	8.1	10.1	2.99	4.74	3.87	0.022	0.023	0.023	38.1	39.6	38.9	0.841	0.849	0.845
22	Tirupati 3	32.9	40.1	36.5	0.73	0.64	0.68	12.8	8.9	10.9	2.58	4.5	3.54	0.02	0.024	0.022	41.9	41.7	41.8	0.862	0.851	0.857
23	Tirupati 4	22.4	24.9	23.6	0.43	0.48	0.46	9.4	9	9.2	2.38	2.75	2.57	0.014	0.015	0.014	42.6	36.8	39.7	0.851	0.851	0.851
24	Kadiri 3	35	35.7	35.4	0.68	0.67	0.68	11.8	9.9	10.9	2.96	3.59	3.28	0.021	0.022	0.021	36.0	39.8	37.9	0.842	0.857	0.849
25	ICGS 5	33.9	32.9	33.4	0.58	0.53	0.55	11.8	9.1	10.4	2.88	3.62	3.25	0.021	0.02	0.02	41.1	37.4	39.3	0.842	0.852	0.847
26	ICGS 76	26.1	29.1	27.6	0.5	0.42	0.46	10.8	9.4	10.1	2.42	3.11	2.77	0.016	0.018	0.017	45.3	49.2	47.3	0.843	0.854	0.848
27	TPG 41	30.9	31.3	31.1	0.71	0.6	0.66	12.3	10.2	11.3	2.51	3.06	2.79	0.019	0.019	0.019	37.1	41.9	39.5	0.847	0.85	0.848
28	Tirupati 2	23.4	30.2	26.8	0.53	0.68	0.6	10.5	10.8	10.7	2.23	2.79	2.51	0.014	0.018	0.016	40.8	41.2	41.0	0.843	0.843	0.843
29	CSMG 884	29.6	33.4	31.5	0.51	0.44	0.48	11.1	8.9	10	2.67	3.75	3.21	0.018	0.02	0.019	41.4	42.4	41.9	0.837	0.847	0.842
30	TG 17	30.9	29.9	30.4	0.61	0.52	0.56	11.7	10.5	11.1	2.64	2.84	2.74	0.019	0.018	0.018	39.4	40.4	39.9	0.836	0.863	0.849
31	B 95	28.7	28.1	28.4	0.5	0.57	0.53	9	11.1	10	3.19	2.54	2.87	0.017	0.017	0.017	41.5	41.5	41.5	0.853	0.842	0.847
32	DRG 17	27.6	32.1	29.9	0.59	0.66	0.62	11.7	13.2	12.4	2.36	2.44	2.4	0.017	0.019	0.018	40.2	38.5	39.4	0.849	0.845	0.847
33	R 9251	29.5	27.3	28.4	0.63	0.47	0.55	12.1	10.5	11.3	2.44	2.6	2.52	0.018	0.017	0.017	41.3	33.8	37.6	0.861	0.836	0.848
34	RS 138	26.8	25.6	26.2	0.53	0.49	0.51	11.3	10.5	10.9	2.37	2.44	2.41	0.016	0.016	0.016	44.7	33.4	39.1	0.848	0.831	0.839

Table 1 continued

SN	Variety	P_N			g_s			*E*			WUE			RUE			SCMR			F_v/F_m		
		C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	Control	Zn	Mean
35	TG 26	28.8	31.9	30.3	0.75	0.72	0.73	12.8	13	12.9	2.25	2.46	2.35	0.017	0.019	0.018	44.0	34.4	39.2	0.861	0.829	0.845
36	TKG 19 A	30.4	28.7	29.6	0.57	0.55	0.56	11.6	13	12.3	2.63	2.2	2.42	0.018	0.017	0.018	42.5	34.4	38.5	0.849	0.851	0.85
37	DH 8	32.5	28.2	30.4	0.61	0.46	0.53	11.8	11.6	11.7	2.76	2.44	2.6	0.02	0.017	0.018	35.2	34.4	34.8	0.85	0.84	0.845
38	JL 220	30.3	31.1	30.7	0.78	0.7	0.74	14.7	13.7	14.2	2.07	2.27	2.17	0.018	0.019	0.019	38.4	37.6	38.0	0.847	0.84	0.843
39	TAG 24	27.8	31.3	29.5	0.71	0.63	0.67	13.3	13.5	13.4	2.09	2.32	2.2	0.017	0.019	0.018	35.5	30.3	32.9	0.856	0.829	0.842
40	ALR 3	28.1	32.3	30.2	0.44	0.43	0.44	11.2	13.1	12.2	2.5	2.47	2.49	0.017	0.02	0.018	39.6	36.1	37.9	0.863	0.847	0.855
41	ALR 2	30.9	33.7	32.3	0.66	0.51	0.59	13.9	15	14.4	2.23	2.25	2.24	0.019	0.02	0.02	37.0	38.2	37.6	0.836	0.84	0.838
42	HNG 10	27.8	29.5	28.7	0.75	0.46	0.6	14.1	12.5	13.3	1.97	2.35	2.16	0.017	0.018	0.017	35.2	36.0	35.6	0.838	0.84	0.839
43	DSG 1	26.9	29.5	28.2	0.64	0.44	0.54	13.1	13.9	13.5	2.05	2.12	2.08	0.016	0.018	0.017	35.7	37.8	36.8	0.84	0.841	0.841
44	Gangapuri	35	36.5	35.8	0.74	0.52	0.63	14.6	15.8	15.2	2.4	2.31	2.36	0.021	0.022	0.022	39.5	36.5	38.0	0.833	0.844	0.838
45	Chitra	30.7	32	31.3	0.62	0.53	0.57	12.8	14.5	13.7	2.4	2.2	2.3	0.019	0.019	0.019	37.9	34.0	36.0	0.824	0.849	0.837
46	Girnar 2	26.3	32.1	29.2	0.6	0.5	0.55	9.2	14.8	12	2.85	2.17	2.51	0.016	0.019	0.018	40.5	38.5	39.5	0.838	0.843	0.84
47	TG 37 A	31.2	32.2	31.7	0.59	0.46	0.52	10.5	12.2	11.3	2.98	2.64	2.81	0.019	0.02	0.019	31.3	33.1	32.2	0.824	0.834	0.829
48	DRG 12	27.8	29.6	28.7	0.48	0.35	0.41	7.9	11.6	9.8	3.51	2.56	3.03	0.017	0.018	0.017	37.9	36.6	37.3	0.828	0.828	0.828
49	JSP 19	31.9	28.8	30.4	0.63	0.46	0.54	9.2	12	10.6	3.48	2.4	2.94	0.019	0.017	0.018	45.6	39.0	42.3	0.841	0.85	0.845
50	K 134	34.5	32.9	33.7	0.67	0.44	0.56	11.8	13.5	12.7	2.93	2.43	2.68	0.021	0.02	0.02	44.5	38.3	41.4	0.823	0.842	0.832
51	BAU 13	25.4	26.5	25.9	0.51	0.36	0.44	11.1	7.7	9.4	2.29	3.46	2.88	0.015	0.016	0.016	32.9	34.9	33.9	0.837	0.821	0.829
52	M 13	24.6	25.1	24.8	0.61	0.43	0.52	12.2	9	10.6	2.01	2.8	2.41	0.015	0.015	0.015	38.1	36.5	37.3	0.841	0.825	0.833
53	M 145	28.5	30	29.3	0.61	0.47	0.54	11.3	11	11.1	2.52	2.73	2.63	0.017	0.018	0.018	37.9	31.6	34.8	0.834	0.84	0.837
54	M 197	28.1	30.8	29.5	0.55	0.4	0.48	10	8.8	9.4	2.82	3.49	3.16	0.017	0.019	0.018	37.0	33.2	35.1	0.835	0.829	0.832
55	M 522	25.6	28.7	27.1	0.45	0.42	0.44	9.4	11.3	10.4	2.72	2.53	2.62	0.016	0.017	0.016	39.9	34.6	37.3	0.838	0.841	0.84
56	CSMG 84-1	31.7	34.3	33	0.58	0.48	0.53	12.1	12.7	12.4	2.61	2.71	2.66	0.019	0.021	0.02	38.9	29.3	34.1	0.84	0.853	0.846
57	ICGV 86590	24.9	26.6	25.8	0.57	0.41	0.49	10.2	10.6	10.4	2.44	2.5	2.47	0.015	0.016	0.016	40.8	32.6	36.7	0.833	0.844	0.838
58	ICGV 86325	29.4	29.5	29.5	0.65	0.45	0.55	13.1	12.4	12.7	2.25	2.38	2.32	0.018	0.018	0.018	45.9	31.5	38.7	0.844	0.839	0.841
59	ICGV 86031	24.7	37	30.8	0.45	0.56	0.51	9.6	10.8	10.2	2.57	3.42	2.99	0.015	0.022	0.019	43.8	40.7	42.3	0.843	0.837	0.84
60	ICGV 88448	34.3	34.4	34.4	0.7	0.53	0.61	13	12.2	12.6	2.63	2.81	2.72	0.021	0.021	0.021	42.0	35.4	38.7	0.824	0.824	0.824
	Average	29.3	30.6	29.9	0.6	0.54	0.57	11.2	11.7	11.4	2.65	2.69	2.67	0.018	0.019	0.018	38.7	37.8	38.2	0.842	0.844	0.843
	Minimum	22	21.6	23.6	0.36	0.35	0.41	6.5	7.7	9.2	1.97	1.8	2.08	0.013	0.013	0.014	31.3	29.3	32.2	0.823	0.821	0.824
	Maximum	37.1	40.1	37.5	0.8	0.78	0.79	14.7	15.8	15.2	3.51	4.74	3.87	0.022	0.024	0.023	45.9	49.2	47.3	0.863	0.864	0.857
	Sd	3.5	3.8	3.2	0.1	0.11	0.08	1.6	1.8	1.3	0.36	0.6	0.36	0.002	0.002	0.002	2.6	3.1	1.7	0.01	0.009	0.007

Where C is control, Zn is with 0.2% foliar application of Zn and M is mean values SD is standard deviations portable photosynthetic system (Model LI-6400, LI-COR, USA) following the method described in our earlier studies (Singh et al. 2014a; Nautiyal et al. 1999). The P_N, g_s, and E were recorded between 09:00 and 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/E, while the radiation use efficiency (RUE) was calculated by P_N/PAR value (Rosati et al. 2004) 1650 in this study. Carboxylation efficiency was calculated as per photosynthetic rate divided by internal CO_2. 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 70 DAE following Samdur et al. (2000). Also during this period, the Chlorophyll fluorescence traits F_m (Maximum fluorescence), F_v (Variable fluorescence), were recorded using a *Handy Plant Efficiency Analyzer (PEA)* (*Hansatech, USA*) as per the method described by Havaux (1993) and F_v/F_m (Maximum efficiency of PS II) was calculated. Before taking the 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.

All the data were analysed statistically and the peanut cultivars were sorted for their photosynthetic efficiency and the cultivars superior in several parameters identified. The principal component analysis of six parameters P_N, g_s, E, WUE, RUE and F_v/F_m was computed using SAS ver.9.4 and Clustering of cultivars into similar groups was performed using Ward's hierarchical algorithm based on squared Euclidean distances by software statistical package for the social sciences (SPSS) 16.0 package.

Results and discussion

The studies on the traits of photosynthetic efficiency viz. P_N, g_s, E, WUE, RUE and its fluorescence parameters, and SCMR in leaves at 70–75 DAE during mid pod filling stage of the crop and pod yields at harvest in 60 peanut cultivars showed a high degree of variability among cultivars (Fig. 1) as well as season (Tables 1 and 2) which are discussed in the following text. Accordingly this study identified a number of cultivars high and low in P_N, g_s, E, WUE, SCMR and yield traits and finally a few peanut cultivars with high photosynthetic efficiency.

Photosynthesis, SCMR and stomatal conductance

The P_N among 60 peanut cultivars ranged from 23.6 to 37.5 μmol (CO_2) m^{-2} s^{-1} with a mean value of 29.9 μ mol (CO_2) m^{-2} s^{-1} during dry season, but ranged from 14.5 to 26.3 μmol (CO_2) m^{-2} s^{-1} with a mean value of 19.4 μ mol (CO_2) m^{-2} s^{-1} during wet season (Tables 1 and 2). Of these 30 cultivars which showed $P_N > 30$ μmol (CO_2) m^{-2} s^{-1} during dry season and $P_N > 20$ μmol (CO_2) m^{-2} s^{-1} during wet season were categorized as high P_N (Table 4). Foliar application of Zn increased the P_N in leaves from the average value of 29.3 μmol (CO_2) m^{-2} s^{-1} in control plot to a value of 30.6 μmol (CO_2) m^{-2} s^{-1} in the Zn applied plot during dry season. The range of P_N was 22.0–37.1 μmol (CO_2) $m^{-2}s^{-1}$ in control plot which increased to 21.6–40.1 μmol (CO_2) m^{-2} s^{-1} with application of Zn. Interestingly under control condition only 25 cultivars showed $P_N > 30$ μmol (CO_2) m^{-2} s^{-1}, but 30 cultivars showed $P_N > 30$ μmol (CO_2) m^{-2} s^{-1} when Zn was applied.

Photosynthesis is the basis of plant growth and improving its efficiency has a greater role in increasing productivity of crops (Zhu et al. 2010; Evans 2013). In peanut, if there is no environmental stress, photosynthesis performs well at rising temperature and atmospheric CO_2 (Joseph 2005). Liu et al. (2012) suggested P_N and P_N/C_i as an effective selection indexes for the seed yield in soybean. In a study of 181 mini-core peanut germplasm during summer season, the P_N ranged 14.5–40.8 μmol m^{-2} s^{-1}, with a mean of 28.5 μmol m^{-2} s^{-1} and 34 photosynthetically efficient genotypes showed $P_N > 33$ μmol m^{-2} s^{-1} (Singh et al. 2014a). In Spanish peanut cultivars the crop yield is usually limited due to lower photosynthetic efficiency (Nautiyal et al. 2012). In this study several cultivars with high P_N also showed high pod yield.

The SCMR in leaf among 60 peanut cultivars ranged from 29.3 to 49.2 with a mean value of 38.2 during dry season, but ranged 28.3–46.5 with a mean value of 36.3 during wet season (Table 1 and 2). Of these 31 cultivars with SCMR value 38 and above during dry season and > 36 during wet season were categorized as high SCMR (Table 4). Foliar application of Zn decreased the SCMR in leaf of peanut cultivars from the average value of 38.7 in control to a value of 37.8 in the Zn applied leaves during dry season. The chloroplast pigments and their composition govern photosynthetic efficiency affecting plant growth, their adaptabilities to environments and finally yield potential (Singh 2011; Singh and Joshi 1993; Singh et al. 2013a, 2014b). With a positive relationship between SCMR and chlorophyll density, the SCMR values indicate the Chl status of the plant and is a handy instrument, easy to handle a large number of samples in peanut (Samdur et al. 2000) and cotton (Brito et al. 2011). The positive

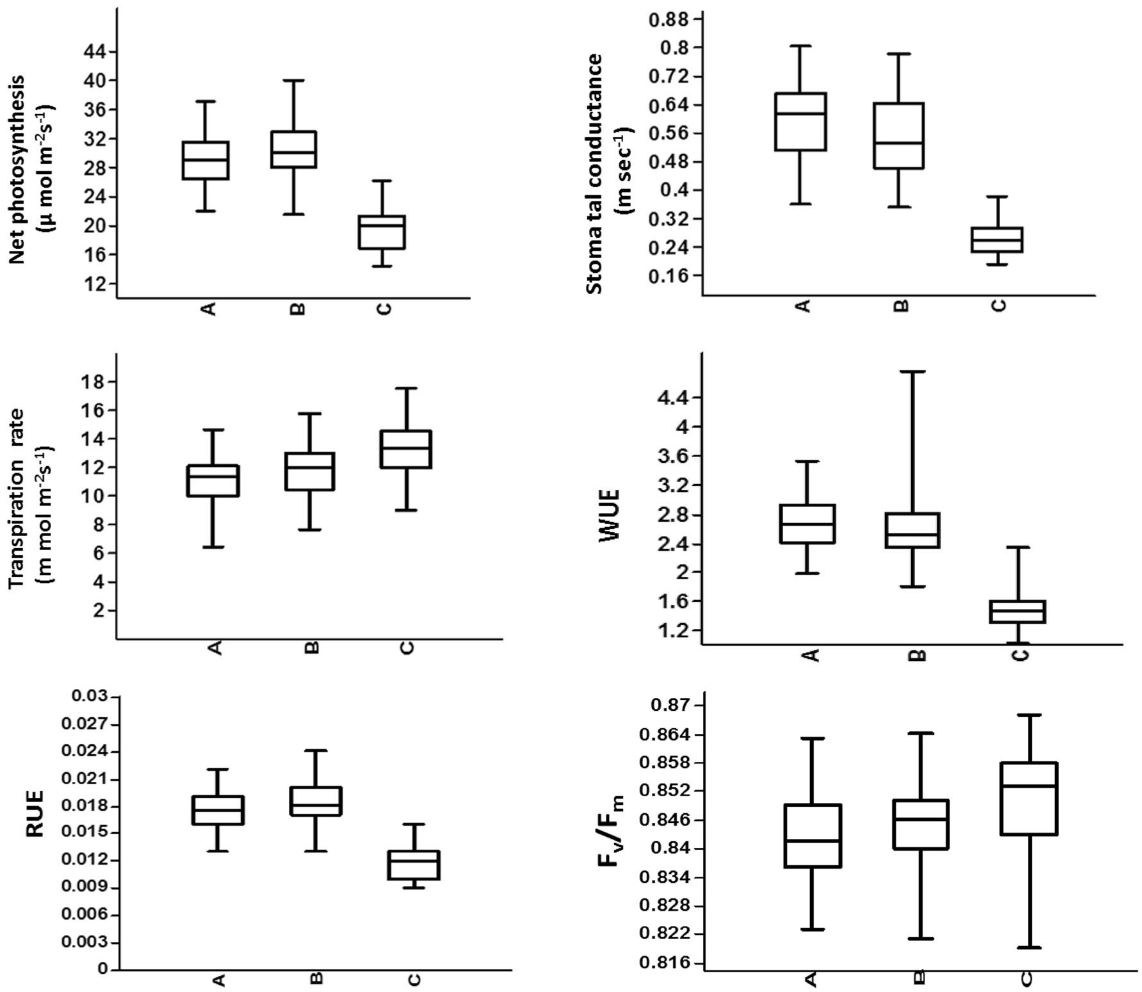

Fig. 1 Variations (Range and mean) in physiological traits among peanut cultivars and influence of cropping seasons and Zn application. The A and B represents data for dry season without and with Zn, respectively and C represents data for wet season without Zn

correlation of SCMR with total dry matter and pod yield both under well-watered and water deficit conditions suggest SCMR a rapid technique to screen large number of peanut genotypes for high yield (Kalariya et al. 2017).

The mean and range of stomatal conductance (g_s) in leaves of 60 cultivars was 0.57 and 0.41–0.79 m s^{-1} during dry season, but only 0.26 and 0.19–0.38 m s^{-1} during wet season indicating about two fold increase in g_s during dry season as compared to the wet season crop (Table 1 and 2). Of the 60 cultivars, 35 showed $g_s > 0.55$ m s^{-1} during dry season, however 30 cultivars showed $g_s > 0.25$ m s^{-1} during wet season (Table 4). Foliar application of Zn decreased the leaf g_s in peanut cultivars from the average value of 0.60 m s^{-1} in control plot to a value of 0.54 m s^{-1} in the leaves of Zn applied peanuts during dry season. The range of g_s was 0.36–0.80 m s^{-1} in control plot which decreased to 0.35–0.78 m s^{-1} with application of Zn. Interestingly under control condition 39 cultivars showed $g_s > 0.55$ m s^{-1}, but when Zn was applied this number was reduced to only 25 cultivars clearly indicating the role of Zn in decreasing g_s in peanut leaves.

Stomatal conductance measures the rate of passage of CO_2 entering, or water vapor exiting through the stomata on both side of leaf, the rate of which is directly related to the boundary layer resistance of the leaf and the absolute concentration gradient of water vapor from the leaf to the atmosphere. As the g_s 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. Variation in g_s, in the peanut cultivars in this study was mainly due to variation in their morphological characteristics and genetic makeup. In a study, the *E* among 181 mini-core germplasm accessions also showed a wide variation with 33 genotypes showing high *E*, and 32 showing low *E* (Singh et al. 2014a). The peanut productivity could be increased by enhancing g_s in the cultivars with high P_N, and by lowering the canopy-air temperature difference (Nautiyal et al. 2012). The peanut shows

Table 2 Net photosynthetic rate (P_N, µmol $m^{-2}s^{-1}$), stomatal conductance (g_s, m s^{-1}), transpiration rate (E, m mol m^{-2} s^{-1}) and water use efficiencies (WUE) and radiation use efficiencies (RUE) in 60 groundnut cultivars grown during wet season (values are mean of three replications) of 2012

S. nos	Cultivars	PN	g_s	E	WUE	RUE	SCMR	(Fv/Fm)
1	SB XI	21.9	0.33	9.4	2.33	0.013	36.0	0.865
2	SG 99	20.9	0.19	9	2.33	0.013	39.9	0.854
3	SG 84	18.7	0.38	12	1.56	0.011	32.7	0.844
4	JL 24	18.3	0.27	9.5	1.92	0.011	40.7	0.863
5	CO 1	17.1	0.25	9	1.91	0.01	35.2	0.854
6	VRI 2	21	0.35	12.8	1.64	0.013	36.3	0.841
7	CO2	20.5	0.3	11.5	1.79	0.012	33.5	0.855
8	GG2	16.2	0.31	12.4	1.31	0.01	36.1	0.858
9	GG 7	21.4	0.29	11.8	1.82	0.013	39.0	0.859
10	GG 12	19.9	0.31	12.7	1.56	0.012	39.9	0.856
11	GG 20	20.1	0.21	9.6	2.11	0.012	33.5	0.858
12	LGN 2	15.7	0.31	12.4	1.26	0.01	43.9	0.854
13	MH 1	14.5	0.25	10.8	1.34	0.009	32.8	0.845
14	RS 1	18.3	0.23	10.3	1.79	0.011	41.3	0.857
15	JL 501	20.6	0.31	13.9	1.48	0.012	37.3	0.859
16	ICG (FDRS) 4	17.7	0.3	13.6	1.3	0.011	30.9	0.841
17	S 230	16.7	0.26	12.2	1.37	0.01	33.4	0.855
18	R 8808	20.7	0.28	13.7	1.51	0.013	40.9	0.858
19	S 206	23.1	0.26	12.4	1.86	0.014	33.2	0.837
20	UF 70-103	22.1	0.35	17.1	1.3	0.013	37.9	0.863
21	RG 141	20.7	0.31	15.8	1.31	0.013	38.9	0.819
22	Tirupati 3	16.9	0.27	14.8	1.14	0.01	41.7	0.858
23	Tirupati 4	21.2	0.31	16.2	1.31	0.013	32.6	0.849
24	Kadiri 3	15	0.19	9.9	1.51	0.009	32.0	0.865
25	ICGS 5	15.1	0.24	13.7	1.11	0.009	36.9	0.842
26	ICGS 76	16.4	0.19	9.9	1.66	0.01	38.9	0.858
27	TPG 41	18	0.22	12.4	1.45	0.011	38.8	0.851
28	Tirupati 2	16.8	0.23	13.5	1.25	0.01	28.3	0.831
29	CSMG 884	20.5	0.24	14.3	1.43	0.012	31.5	0.863
30	TG 17	15.3	0.2	12.4	1.24	0.009	32.0	0.845
31	B 95	15.9	0.2	12.2	1.3	0.01	38.3	0.858
32	DRG 17	21.9	0.33	17.5	1.25	0.013	41.6	0.841
33	R 9251	16.3	0.29	15.5	1.05	0.01	32.8	0.853
34	RS 138	20.1	0.24	13.4	1.5	0.012	35.9	0.829
35	TG 26	19.1	0.23	12.8	1.49	0.012	32.9	0.839
36	TKG 19 A	15.4	0.28	15	1.03	0.009	38.9	0.851
37	DH 8	23.4	0.31	16.7	1.4	0.014	32.9	0.853
38	JL 220	21	0.29	16	1.31	0.013	31.3	0.829
39	TAG 24	16.6	0.28	15.1	1.1	0.01	35.9	0.868
40	ALR 3	19	0.22	12.3	1.54	0.012	33.2	0.85
41	ALR 2	22.2	0.27	14.6	1.52	0.013	39.2	0.836
42	HNG 10	17.5	0.26	13.9	1.26	0.011	38.2	0.852
43	DSG 1	23.1	0.28	16	1.44	0.014	36.2	0.819
44	Gangapuri	17	0.2	11.7	1.45	0.01	34.8	0.857
45	Chitra	21.3	0.27	14.5	1.47	0.013	35.6	0.859
46	Girnar 2	19	0.25	14.5	1.31	0.012	36.5	0.853
47	TG 37 A	26.3	0.29	16.9	1.55	0.016	38.4	0.852
48	DRG 12	15.6	0.21	12.7	1.22	0.009	37.4	0.857
49	JSP 19	18.5	0.23	13.5	1.37	0.011	41.5	0.858
50	K 134	22.2	0.23	14.4	1.54	0.013	46.5	0.844
51	BAU 13	20.7	0.19	11.6	1.78	0.013	37.8	0.853
52	M 13	21.4	0.23	14.1	1.51	0.013	33.9	0.853
53	M 145	23.2	0.23	14.3	1.62	0.014	35.2	0.847
54	M 197	23.3	0.28	16.5	1.41	0.014	35.0	0.825
55	M 522	20.3	0.21	13.3	1.52	0.012	35.3	0.863
56	CSMG 84-1	22.8	0.23	14	1.63	0.014	33.3	0.841
57	ICGV 86590	20.8	0.21	13.2	1.58	0.013	36.4	0.862
58	ICGV 86325	17.3	0.19	10.7	1.62	0.011	35.8	0.85
59	ICGV 86031	17.2	0.19	12.1	1.42	0.01	37.4	0.831
60	ICGV 88448	22.2	0.24	15.4	1.44	0.013	34.6	0.848
	Average	19.4	0.26	13.2	1.49	0.012	36.3	0.85
	Minimum	14.5	0.19	9	1.03	0.009	28.3	0.819
	Maximum	26.3	0.38	17.5	2.33	0.016	46.5	0.868
	Sd	2.7	0.05	2.1	0.27	0.002	2.5	0.011

maximum growth between 7 and 13 weeks after emergence (Singh and Joshi 1993) which is also the period for high, leaf-level gas exchange (Singh 2003, 2011; Singh et al. 2013a).

The zinc fertilizer plays an important role in the photosynthetic processes, increases chlorophyll content, net photosynthetic rate, and transpiration rate and also results in increases of leaf photo assimilates as well as grain yield in maize (Mao et al. 2014). The Zinc is involved in many enzyme systems and carbonic anhydrase is a very specific. More than 50% of the Indian soil show Zn deficiency in groundnut. The Zn deficient peanut plant show irregular mottling in upper leaves with yellow-ivory interveinal chlorosis causing reduction in yield (Singh 1994; Singh and Basu 2005). The calcareous soils, where this crop was grown, are characterized by high bicarbonate content with deficiency of Zn. In such soil the growth and photosynthesis increased due to Zn application in Brassicaceae species (Zhao and Wu 2017) and nutrients in peanuts (Singh et al. 2013b). The Zn deficiency causes the rapid inhibition of plant growth and development, which results in increased reactive oxygen species (ROS) due to photo-oxidative damage and consequently decreased net photosynthesis and photosynthetic electron transport (Bae et al. 2011). The application of Zn raised the plant dry weight, photosynthesis parameters, carbonic anhydrase activity, and chlorophyll contents in pistachio and also acted as a scavenger of ROS for mitigating the injury on biomembranes (Vahid 2017).

Transpiration and WUE

The transpiration rate (*E*) in leaves of 60 peanut cultivars during pod filling stage ranged from 9.2 to 15.2 m mol m^{-2} s^{-1} with a mean value of 11.4 m mol m^{-2} s^{-1} during dry season, however during wet season it ranged from 9.0 to 17.5 m mol m^{-2} s^{-1} with a mean value of 13.2 m mol m^{-2} s^{-1} (Tables 1 and 2). This clearly indicated that the transpiration rate was more during wet season than that during dry season. When the 60 cultivars were sorted base on *E* values, 31 cultivars showed $E > 11$ m mol m^{-2} s^{-1} during dry season and 30 cultivars showed $E > 13$ m mol m^{-2} s^{-1} during wet season (Table 4). The foliar application of Zn slightly increased the leaf *E* in peanut cultivars from the average value of 11.2 m mol m^{-2} s^{-1} in control plot to a value of 11.7 m mol m^{-2} s^{-1} in the Zn applied leaves during dry season. The range of *E* was 6.5–14.7 m mol m^{-2} s^{-1} in control plot which increased to 7.7–15.8 m mol m^{-2} s^{-1} with application of Zn. Accordingly under control and Zn applied condition 36 and 37 cultivars, respectively showed $E > 11$ m mol m^{-2} s^{-1} (Table 1).

The mean and range of WUE among 60 cultivars were 2.67 and 2.08–3.87 during dry season and 1.49 and 1.03–2.33 during wet season, respectively indicating 1.5–2.0 folds increase during dry season as compared to that of wet season crop (Table 1 and 2). The 60 peanut cultivars when sorted for WUE, 30 cultivars which showed WUE > 2.6 during dry season and only 26 cultivars which showed WUE > 1.5 during wet season were categorized as high WUE (Table 4). Here also when mean values were compared the foliar application of Zn slightly increased the WUE in peanut cultivars from the average value of 2.65 in control to a value of 2.69 in the Zn applied peanuts during dry season. The range of WUE was 1.97–3.51 in control plot which increased to 1.8–4.74 with application of Zn. Here under control condition 34 cultivars showed WUE > 2.6, but interestingly when Zn was applied only 23 cultivars showed WUE > 2.6 clearly indicating that all the cultivars did not response to Zn in increasing WUE and there was interaction of Zn with cultivars.

High transpiration efficiency, i.e., the ratio of mass accumulation to transpiration, is often suggested as a critical factor to be intervened for genetic improvement to increase crop yields in water-limited environments. However, component traits, i.e., P_N, g_s and biomass accumulation, contributing to transpiration efficiency, are more effective in using available water throughout the growing season to maximize ultimately growth and yield of the crop (Sinclair 2012). Better WUE or drought tolerance in peanut is globally one of the most challenging aspects of this crop, majority of which is grown under rain-fed condition (Singh et al. 2013a). But unfortunately, limited success had been achieved in this regard due to lack of precise trait specific selection and more consorted efforts on comparison with a number of genotypes (Singh et al. 2013a, 2014b).

The WUE in mini-core germplasm ranged from 1.43 to 4.9 with an average of 3.06 and 32 genotypes with WUE > 3.8 were identified as high WUE (Singh et al. 2014a). These high WUE genotypes are more fit for limited water supply conditions. Variation in WUE and chlorophyll density was closely correlated in such a way that chlorophyll density could be used as potential indicator of TE in peanut (Arunyanark et al. 2008).

Chlorophyll fluorescence and RUE

The chlorophyll fluorescence traits F_m (Maximum fluorescence), F_v (Variable fluorescence), in the peanut leaves also recorded during pod filling stage (70–75 DAE) showed remarkable variation among the cultivars and also due to Zn treatments (Tables 1 and 2). The average and range of F_v/F_m values were 0.843 and 0.824–0.857 during dry season and 0.850 and 0.819–0.868 during wet season. These values in peanut leaves were 0.842 and 0.823–0.863 when grown without Zn and 0.844 and 0.821–0.864 with Zn, respectively. The 60 cultivars when sorted, 30 cultivars showed F_v/F_m values more than 0.843 during both the season and hence were categorized as high F_v/F_m and 30 cultivars with less than 0.843 were categorized as low F_v/F_m cultivars (Table 4).

The mean and range of radiation use efficiencies (RUE) among peanut cultivars were 0.018 and 0.014–0.023 during dry season and 0.012 and 0.009–0.016 during wet season showing 1.5 folds more RUE during dry season as compared to the wet season crop. The 60 peanut cultivars sorted for RUE, showed 23 cultivars with RUE > 0.019 during dry season and 24 cultivars showing RUE > 0.012 during wet season were categorized as high RUE (Tables 1 and 4). Here also the foliar application of Zn slightly increased the RUE in peanut cultivars from the average value of 0.018 in control to a value of 0.019 in the Zn applied peanuts during dry season, with a range of 0.013–0.022 RUE in control and 0.013–0.024 in Zn applied plants. Here 23 and 29 cultivars showed RUE > 0.019 without and with Zn.

The Chlorophyll fluorescence, considered to be signature of photosynthesis (Schreiber 2004), is a non-invasive measurement of photosystem II activity, the sensitivity of which to abiotic and biotic factor make this a key technique and indicator of how plants respond to environmental changes (Murchie and Lawson 2013). It is a highly useful parameter and the F_v/F_m ratio is an important tool in determining damage to photosynthetic apparatus under drought stress (Kalariya et al. 2013, 2015; Nakar and Singh 2013; Rahbarian et al. 2011). Under water stress increase in leaf temperature decreases chl content and F_v/F_m, indicating the damage and down regulation of PSII in peanut (Shahenshah and Isoda 2010). Irrigation at 50% of the evapotranspiration demand severely affected the chlorophyll fluorescence, but a reduction of 25% was desirable from yield point of view (Kalariya et al. 2015). The F_v/F_m, in the mini-core peanut germplasm accessions ranged from 0.81 to 0.87 and the genotypes having F_v/F_m more than 0.86 were categorized as high, while having $F_v/F_m < 0.84$ were marked as low Chlorophyll fluorescence genotypes (Singh et al. 2014a). The P_N and F_v/F_m were high in the peanut genotypes with higher seed yields due to high radiation use efficiency later in the growing season (Cao and Isoda 2008). In this study several cultivars high in P_N and F_v/F_m were identified.

Principal component analysis

The photosynthetic efficiency among peanut cultivars was also assessed using principal component (PC) analysis of six parameters P_N, g_s, E, WUE, RUE and F_v/F_m (Table 3). There were altogether 6 PCs of which first four (PCs) together explained 99% of the variability in the peanut cultivars studied during both the seasons. The detail analysis showed that during wet season, the PC 1 accounted for 43.46% of the total variation in the cultivars where P_N (0.566), RUE (0.562), E (0.42) and g_s (0.32), contributed maximum variation whereas F_v/F_m (− 0.27) contributed negatively (Table 3). The PC 2 contributed 30.4% of the total variation where WUE (0.72), RUE (0.27), P_N (0.27) and F_v/F_m (0.235) contributed positively and E (− 0.48) and g_s (− 0.20)

Table 3 Principal component analysis of six traits (P_N, g_s, E, WUE, RUE and F_v/F_m) studied in 60 groundnut cultivars during two different seasons (dry and wet)

	Wet season						Dry season					
	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.60762	1.82533	0.90606	0.6268	0.0246	0.00947	3.059	1.820	0.881	0.217	0.017	0.006
Proportion	0.4346	0.3042	0.1510	0.1045	0.0041	0.0016	0.510	0.303	0.147	0.036	0.003	0.001
Cumulative (%)	43.46	73.88	88.98	99.43	99.84	100	50.99	81.33	96.01	99.62	99.9	100
Physiological traits												
P_N	0.566248	0.272144	− 0.008309	0.1868	0.2990	− .69347	0.4971	0.3481	0.0936	− 0.2364	0.0906	− 0.7475
g_s	0.323048	− .207979	0.643865	− .66025	− .03844	− .02003	0.5096	− 0.1691	− 0.0076	0.8406	− 0.0696	− 0.0150
E	0.428542	− .482056	0.053557	0.3719	0.4755	0.4653	0.4806	− 0.3535	− 0.2086	− 0.3056	0.6442	0.3036
WUE	0.038763	0.720202	− .010769	− .25888	0.4636	0.4445	− 0.0967	0.6955	0.2860	0.2502	0.5326	0.2808
RUE	0.562792	0.276098	− .034988	0.1842	− .68367	0.3231	0.4999	0.3389	0.0702	− 0.2695	− 0.5368	0.5192
Fv/Fm	− .270401	0.235336	0.762338	0.5383	− .02250	− .00221	0.0540	− 0.3560	0.9279	− 0.0946	0.0116	0.0177

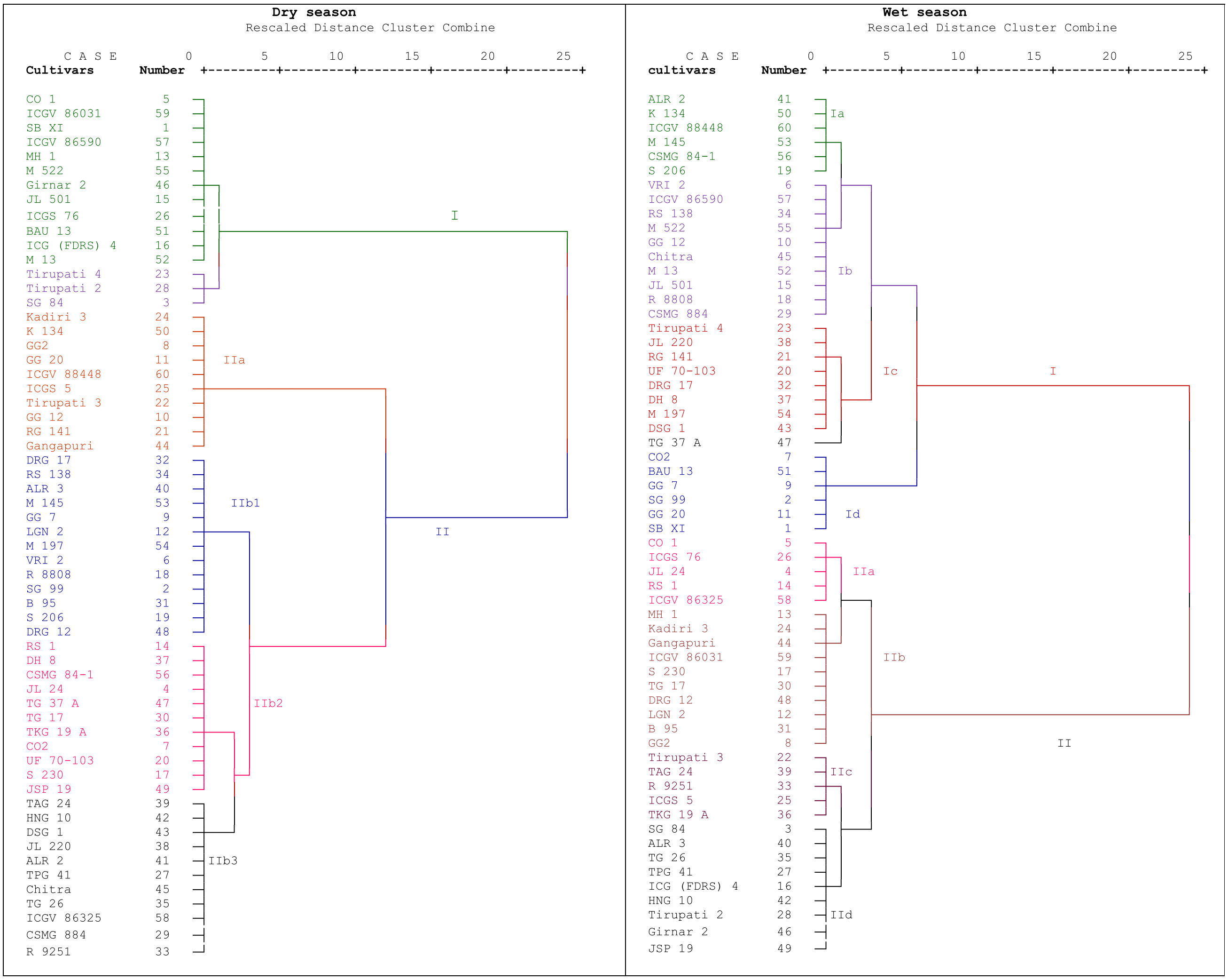

Fig. 2 Clustering (Ward's) dendrograms of 60 peanut cultivars based on six parameters (P_N, g_s, E, WUE, RUE and F_v/F_m) for dry and wet seasons

negatively. The PC 3 and PC 4 accounted for 15 and 10% of the variation, respectively with maximum variation by F_v/F_m and g_s in PC 3 and by F_v/F_m and E In PC 4. The principal component analysis during dry season, showed that the PC 1 accounted for 51% of the total variation in the cultivars and the traits g_s (0.5), RUE (0.49), P_N (0.49) and E (0.48) contributed maximum (Table 3). The PC 2 contributed 30% of the total variation and WUE (0.69), P_N (0.34) and RUE (0.33) contributed maximum. The PC 3 accounted for 14.7% of the variation to which F_v/F_m (0.92) and WUE (0.28) contributed maximum.

Cluster analysis

The Ward's cluster dendrogram of 60 peanut cultivars based on the P_N, g_s, E, WUE, RUE and F_v/F_m for photosynthetic efficiency broadly classified these into two major clusters (efficient and inefficient one) during both the seasons with slight variations (Fig. 2). During dry season, cluster I lists 15 photosynthetically in-efficient cultivars characterized by low P_N, g_s, E, and F_v/F_m, whereas, cluster II was divided into two clusters (IIa and IIb). The cluster IIa consists of 10 photosynthetically efficient cultivars (Kadiri 3, K134, GG 2 GG 20, ICGV 88448, ICGS 5, Tirupati 3, GG 12, RG 141 and Gangapuri) with high P_N, g_s, E, WUE and F_v/F_m and hence were most important one. The IIb was further divided into three sub-clusters (IIb1, IIb2 and IIb3). The cluster IIb1 also contained 13 photosynthetically in-efficient cultivars with low P_N, g_s, E. The cluster IIb2 contained 11 cultivars with high P_N, and F_v/F_m whereas cluster IIb3 contained 11 cultivars with low F_v/F_m.

During wet season, 60 cultivars were classified into two distinct clusters mainly based on photosynthetic efficiency. The cultivars falling in cluster I had high P_N, whereas the cultivars of cluster II had low P_N. The cluster I was subdivided into three different clusters (Ia, Ib, and Ic). The cluster

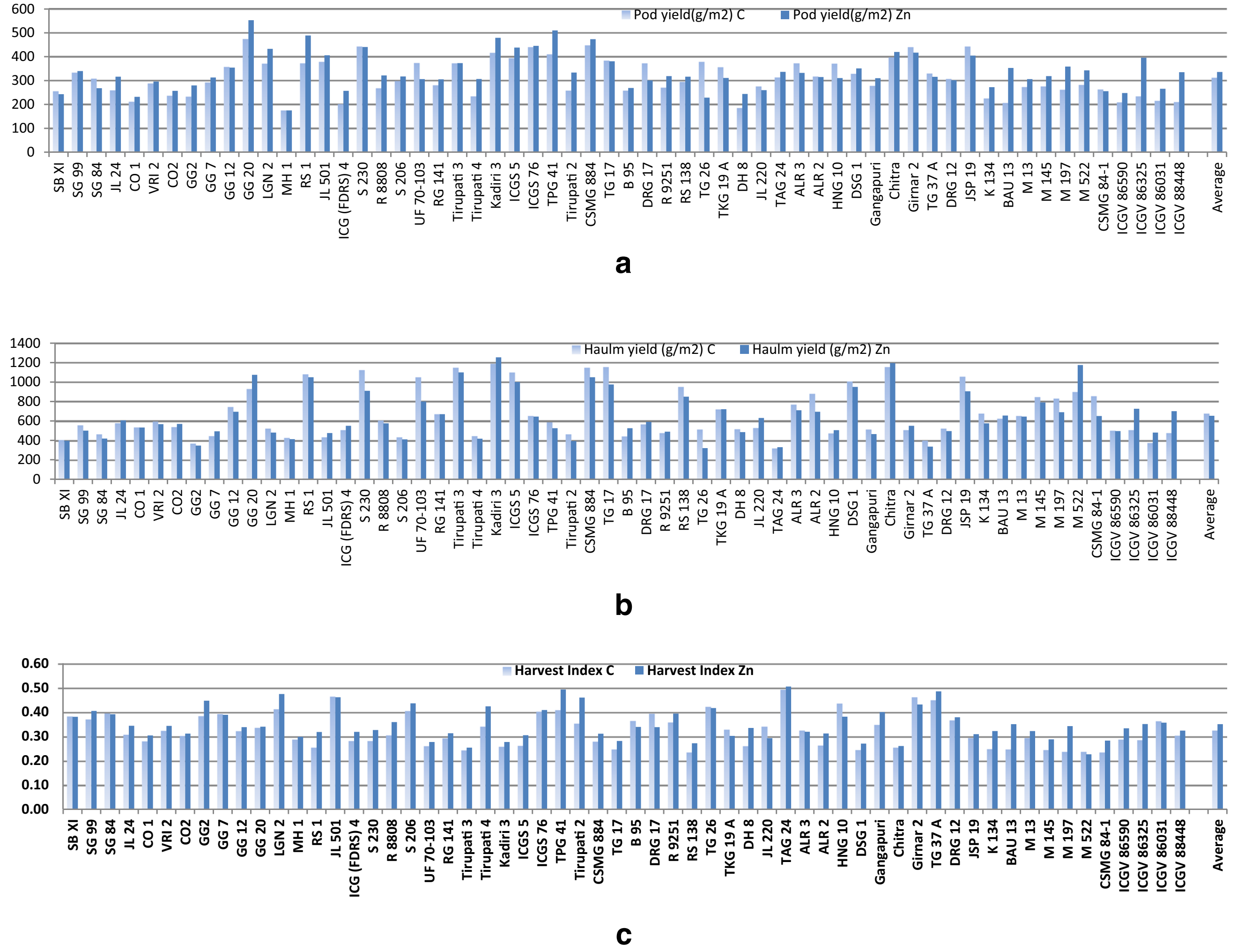

Fig. 3 Mean pod (**a**) and haulm yields (gm^{-2}) and Harvest index (**c**) of 60 groundnut cultivars grown without (C) and with Zn during dry season

Ia contained 6 cultivars with high P_N and low g_s; the cluster Ib contained 10 cultivars with high P_N, E, and F_v/F_m and cluster Ic contained 9 cultivars (Tirupati 4, JL 220, RG 141, UF 70-103, DRG 17, DH 8, M 197, DSG 1 and TG 37A) with high P_N, g_s, E, and RUE. The cluster II with low P_N, was divided into four sub-clusters (IIa, IIb, IIc, IId). Cluster IIa contained 5 cultivars with high WUE and F_v/F_m but low g_s, E, cluster IIb contained 10 cultivars with high F_v/F_m but low g_s, E, WUE. The Cluster IIc contained 5 cultivars with high g_s, E, and F_v/F_m, but with low WUE and Cluster IId contained 9 cultivars with high E, and low g_s, WUE.

Pod and haulm yields and harvest index (HI)

The photosynthetic parameters finally contribute to the dry matter production and their translocation towards pod. The mean and range were 324 and 175–514 g m^{-2} pod yield and 666 and 325–1223 g m^{-2} haulm yield, respectively during dry season and 201 and 132–309 g m^{-2} pod yield and 724 and 343–1007 g m^{-2} haulm yield, respectively during wet season among 60 peanut cultivars (Figs. 3 and 4). Of these 34 cultivars showed more than 300 g m^{-2} pod yield during dry season, but only 27 cultivars could yield more than 200 g m^{-2} pod during wet season. Application of Zn increased the pod yield, but reduced haulm yield, however did not affect total biomass. The Zn controlled excess growth and helped in mobilization of more photosynthates towards pod thus increased HI. The mean and range of HI, which varied with the production of biomass in peanut cultivars were 0.34 and 0.23–0.50 during dry season and 0.29 and 0.18–0.43, respectively during wet season (Figs. 3 and 4). There were 35 cultivars which showed HI more than 0.30 during dry season, but only 23 cultivars during wet season. The photosynthetic parameters finally contribute increased biomass and conversion to pod

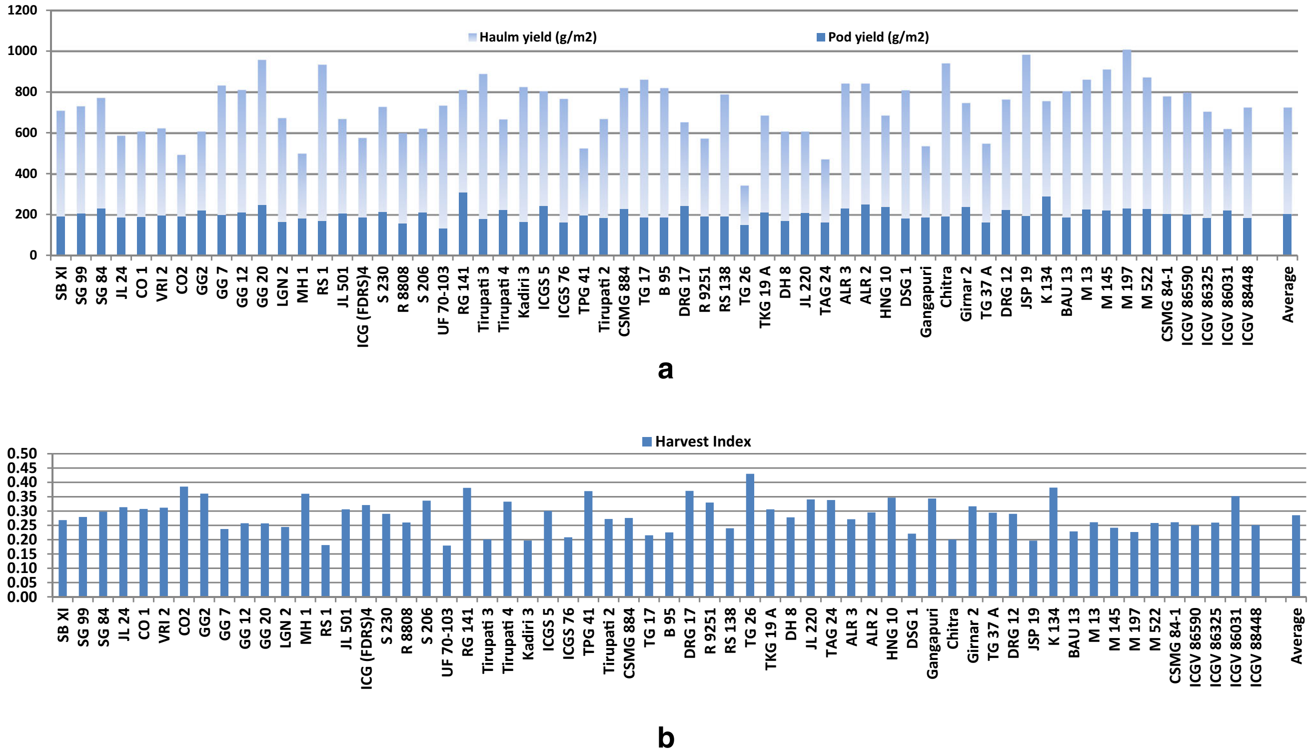

Fig. 4 Mean pod and haulm yields and their total biomass (gm^{-2}) (**a**) and harvest index (**b**) of 60 groundnut cultivars grown during wet season

and haulm yields which showed a wide range depending upon the season.

Identification of cultivars with multiple traits

The cultivars sorted out based on the physiological traits were further compared for their common occurrence and there were a number of cultivars showing high values for two to three traits (Table 4) and a few in four to eight traits (Table 5). There were 18 cultivars (GG 20, JL 220, TG 26, GG 2, Tirupati 3, Kadiri 3, LGN 2, CO 2, TPG 41, GG 12, Gangapuri, ICGV 88448, UF 70-103, SG 99, ALR 2, Chitra, TG 17, K 134) showing very high P_N (> 30 μmol m^{-2} s^{-1}) and g$_s$ (> 0.55 m s^{-1}) and also 18 cultivars (Gangapuri, ALR 2, JL 220, Chitra, GG 20, TG 26, GG 12, K 134, ICGV 88448, LGN 2, TKG 19 A, ALR 3, RS 1, CO 2, DH 8, TG 37 A, TPG 41 and TG 17) showing very high P_N (> 30 μmol m^{-2} s^{-1}) and E (> 11 mmol m^{-2} s^{-1}) during dry season. Interestingly 17 cultivars (GG 20, CSMG 884, TPG 41, Kadiri 3, S 230, RS 1, JSP 19, ICGS 5, Chitra, LGN 2, TG 17, Tirupati 3, GG 12, ALR 3, UF 70-103, SG 99, TG 37 A) with high P_N (> 30 μmol m^{-2} s^{-1}) also showed high pod yield (> 300 g m^{-2}) during dry season. On the other hand 8 cultivars (RG 141, Gangapuri, GG 2, K 134, CSMG 84-1, ICGV 88448, ICGV 86031, DH 8) which though had high P_N (> 30 μmol m^{-2} s^{-1}) showed less than 300 g m^{-2} pod yield. In contrast 6 cultivars (DRG 12, ICGV 86325, Girnar 2, ICGS 76, M 522, RS 138) which though had P_N in between 26 and 30 μmol m^{-2} s^{-1} also showed high pod yield (> 300 g m^{-2}). A total of 11 cultivars (Tirupati 3, ICGS 5, CSMG 884, RS 1, S 230, TG 17, TG 26, LGN 2, TPG 41, SG 99) during dry season and 7 cultivars (K 134, DRG 17, ALR 2, JL 501, SG 99, RG 141) during wet season showed high SCMR, P_N, and pod yield. A number of cultivars high in several photosynthetic parameters identified here will be useful.

The inter-relationship among physiological traits and yield are well worked for this crop (Singh 2003, 2004; Singh et al. 2013a, 2014b). The traits P_N and E help in empirical selection in peanut (Nigam et al. 2005). The transpiration efficiency under drought is directly correlated with SCMR (Krishnamurthy et al. 2007). The recent study of various physiological parameters in mini-core accessions showed a positive correlation between P_N and g_s, P_N and E, P_N and WUE, and P_N and F$_v$/F$_m$, SCMR and F$_v$/F$_m$, E and g_s, while E was negatively correlated with WUE (Singh et al. 2014a). Positive correlation between E, leaf area and yield has been reported for peanut under drought (Ravindra et al. 1990). The strong relationship between P_N and g$_s$ indicated that apart from carbon fixation it also regulates transpiration in peanut (Nautiyal et al. 1999) and high SCMR was positively correlated with chlorophyll content hence maintain higher rate of photosynthesis. The

Table 4 Peanut cultivars with high photosynthetic efficiency and yields during various seasons

SN	Parameters	Dry, 2012	Wet, 2012
1	P_N (μmol m^{-2} s^{-1})	RG 141, Tirupati 3, Gangapuri, GG2, Kadiri 3, UF 70-103, ICGV 88448, GG 20, K 134, ICGS 5, CSMG 84-1, S 230, ALR 2, GG 12, TG 37 A, CSMG 884, RS 1, Chitra, TPG 41, ICGV 86031, SG 99, JL 220, LGN 2, JL 24, TG 17, JSP 19, CO 2, DH 8, TG 26, ALR 3 ($>$ 30 μmol m^{-2} s^{-1})	TG 37 A, DH 8, M 197, M 145, DSG 1, S 206, CSMG 84-1, K 134, ICGV 88448, ALR 2, UF 70-103, SB XI, DRG 17, GG 7, M 13, Chitra, Tirupati 4, VRI 2, JL 220, SG 99, ICGV 86590, RG 141, BAU 13, R 8808, JL 501, CO 2, CSMG 884, M 522, GG 20, RS 138 ($>$ 20 μmol m^{-2} s^{-1})
2	Conductance (g_s, m s^{-1})	GG 20, JL 220, TG 26, GG 2, Tirupati 3, Kadiri 3, LGN 2, TAG 24, JL 501, CO 2, TPG 41, GG 12,, ICG (FDRS) 4, RS 1, S 230, Gangapuri, DRG 17, SB XI, RG 141, ICGV 88448, UF 70-103, Tirupati 2, HNG 10, R 8808, SG 99, ALR 2, Chitra, CO 1, TG 17, GG 7, K 134, TKG 19 A ($>$ 0.55 m s^{-1})	SG 84, VRI 2, UF 70-103, SB XI, DRG 17, GG 2, GG 12, Tirupati 4, RG 141, DH 8, JL 501, LGN 2, CO 2, ICG (FDRS) 4, JL 220, GG 7, R 9251, TG 37 A, DSG 1, R 8808, TAG 24, M 197, TKG 19 A, JL 24, ALR 2, Tirupati 3, Chitra, HNG 10, S 230, S 206 ($>$ 0.25 m s^{-1})
3	Transpiration (E) m mol m^{-2} s^{-1})	Gangapuri, ALR 2, JL 220, Chitra, DSG 1, TAG 24, HNG 10, GG 20, TG 26, GG 12, ICGV 86325, K 134, ICGV 88448, DRG 17, CSMG 84-1, LGN 2, TKG 19 A, ALR 3, GG 2, Girnar 2, RS 1, JL 501, CO 2, DH 8, TG 37 A, GG 7, R 9251, SB XI, TPG 41, M 145, TG 17 ($>$ 11 mmol m^{-2} s^{-1})	DRG 17, UF 70-103,TG 37 A, DH 8, M 197, Tirupati 4, JL 220, DSG 1, RG 141, R 9251, ICGV 88448, TAG 24, TKG 19 A, Tirupati 3, ALR 2, Chitra, Girnar 2, K 134, CSMG 884, M 145, M 13, CSMG 84-1, JL 501, HNG 10, ICGS 5, R 8808, ICG (FDRS) 4, JSP 19, Tirupati 2, RS 138, M 522, ICGV 86590 ($>$ 13.0 mmol m^{-2} s^{-1})
4	WUE	RG 141, Tirupati 3, UF70-103, Kadiri 3, ICGS 5, CSMG 884, M 197, DRG 12, S 230, ICGV 86031, GG 2, JSP 19, BAU 13, B 95, SG 99, JL 24, TG 37 A, R 8808, TPG 41, S 206, ICGS 76, SG 84, TG 17, ICGV 88448, K 134, VRI 2, CSMG 84-1, RS 1, M 145, M 522 ($>$ 2.6)	SG 99, SB XI, GG 20, JL 24, CO 1, S 206, GG 7, CO 2, RS 1, BAU 13, ICGS 76, VRI 2, CSMG 84-1, M 145, ICGV 86325, ICGV 86590, GG 12, SG 84, TG 37 A, K 134, ALR 3, M 522, ALR 2, R 8808, M 13, Kadiri 3 ($>$ 1.50)
5	RUE	RG 141, Tirupati 3, Gangapuri, GG 2, Kadiri 3, UF70-103, ICGV 88448, GG 20, K 134, ICGS 5, CSMG 84-1, S 230, ALR 2, GG 12, TG 37 A, CSMG 884, RS 1, Chitra, TPG 41, ICGV 86031, SG 99, JL 220, LGN 2, ($>$ 0.019)	TG 37 A, DH 8, M 197, M 145, DSG 1, S 206, CSMG 84-1, K 134,, ICGV 88448, ALR 2, UF 70-103,SB XI, DRG 17, GG 7, M 13, Chitra, Tirupati 4, VRI 2, JL 220, SG 99, ICGV 86590, RG 141, BAU 13, R 8808 ($>$ 0.012)
6	F_v/F_m	Tirupati 3, S 230, ALR 3, GG 12, JL 501, Tirupati 4, CO 2, TKG 19 A, SG 84, LGN 2, ICG (FDRS) 4, Kadiri 3, TG 17, GG 20, TPG 41, ICGS 76, R 9251, B 95, DRG 17, ICGS 5, SG 99, CO 1, CSMG 84-1, JL 24, JSP 19, TG 26, S 206, DH 8, RG 141, GG 2 ($>$ 0.843)	TAG 24, SB XI, Kadiri 3, JL 24, UF 70-103, CSMG 884, M522, ICGV 86590, GG7, JL 501, Chitra, GG 2, GG 20, R 8808, Tirupati 3, ICGS 76, B 95, JSP 19, RS 1, Gangapuri, DRG 12, GG 12, CO 2, S 230, SG 99, CO 1, LGN 2, R 9251, DH 8, Girnar 2, BAU 13, M 13, HNG 10, TG 37 A, TPG 41, TKG 19 A ($>$ 0.850)
7	Pod yield (g m^{-2})	GG 20, CSMG 884, TPG 41, Kadiri 3, ICGS 76, S 230, RS 1, Girnar 2, JSP 19, ICGS 5, Chitra, LGN 2, JL 501,TG 17, Tirupati 3, GG 12, ALR 3, HNG 10, UF 70-103, DSG 1, DRG 17, SG 99, TKG 19 A, TAG 24, TG 37 A, ALR 2, ICGV 86325, M 522, M 197, S 206, RS 138, DRG 12, TG 26, GG 7 ($>$ 300 g m^{-2})	RG 141, K 134, ALR 2, GG 20, ICGS 5, DRG 17, HNG 10, Girnar 2, SG 84, ALR 3, M 197, CSMG 884, M 522, M 13, Tirupati 4, DRG 12, M 145, GG 2, ICGV 86031, S 230, TKG 19 A, S 206, GG 12, JL 220, JL 501, SG 99, CSMG 84-1 ($>$ 200 g m^{-2})
8.	SCMR	ICGS 76, SG 99, JSP 19, ICGV 86301, CSMG 884, Tirupati 3, GG 20, B 95, K 134, Tirupati 2, SB XI, GG2, RS 1, JL 501, S 230, TG 17, Tirupati 4, LGN 2, TPG 41, Girnar 2, DRG 17, ICGS 5, TG 26, R 8808, RS 138, RG 141, ICGV 86325, ICGV 88448, TKG 19 A, JL 220, Gangapuri ($>$ 38 and above)	K 134, LGN 2, Tirupati 3, DRG 17, JSP 19, RS 1, R 8808, JL 24, SG 99, GG 12, ALR 2, GG 7, RG 141, ICGS 76, TKG 19A, TPG 41, TG 37 A, B 95, HNG 10, UF 70-103, BAU 13, DRG 12, ICGV 86301, JL 501, ICGS 5, Girnar 2, ICGV 86590, VRI 2, DSG 1, GG2 ($>$ 36)

high E and P_N cultivars could be used in yield maximization. In wheat, the SPAD value also correlated with photosynthetic efficiency and canopy radiation use efficiency (RUE) (Fotovat et al. 2007) and there was a positive association between total biomass and RUE (Singh et al. 2012).

In the present study, we worked out photosynthetic efficiency among 60 high yielding peanut cultivars of India and to find out the bottlenecks of low yield and suggest remedial measure for realizing high yields through traits improvements. The relationships in various photosynthetic parameters were worked out to know the efficiencies of

Table 5 Highly efficient peanut cultivars with multiple physiological traits for various seasons

SN	Traits with high value	Dry 2012	Traits with high value	Wet 2012
1	Py, Hy, P_N, g_s	Chitra, GG 12, UF 70-103, ALR 2,	Py, P_N g_s, E, RUE	DRG 17, M 197, M 13, Tirupati 4, S 206, JL 220
2	Py, HI, g_s, E, F_v/F_m	JL 501, TPG 41, LGN 2, GG 20, GG 12, DRG 17, TKG 19 A, TG 26	Py, HI, g_s, E, Fv/Fm	HNG 10, TKG 19 A, JL 501
3	Py, HI, P_N, g_s, E, F_v/F_m	LGN 2, GG 12, GG 20, TG 26	Py, HI, P_N, g_s, E, Fv/Fm	JL 501
4	Py, Hy, P_N, F_v/F_m, WUE, RUE	ICGS 5, Tirupati 3,	Py, Hy, P_N, Fv/Fm, WUE, RUE	SG 99, M 13
5	Py, HI, g_s, E,	JL 501, TPG 41, LGN 2, GG 20, GG 12, HNG 10, DRG 17, TKG 19 A, TAG 24, TG 26, GG 7	Py, P_N g_s, E	RG 141, ALR 2, DRG 17, M 197, M 13, Tirupati 4, S 206, JL 220, JL 501
6	Py, HI, F_v/F_m, WUE	ICGS 76, SG 99, TPG 41, S 206,	Py, HI, Fv/Fm, g_s	GG 2, HNG 10,S 230, TKG 19 A, JL 501,
7	Py, Hy, P_N, WUE, RUE	CSMG 884, Kadiri 3, S 230, RS 1, ICGS 5, Tirupati 3,	py, Hy, bio, HI, E	ICGS 5, Girnar 2
8	Py, Hy, P_N, F_v/F_m, WUE	JSP 19, Kadiri 3, S 230, ICGS 5, TG 17, Tirupati 3	py, Hy, bio, WUE	ALR 3, M 522, M 13, M 145, GG 12, SG 99, CSMG 84-1
	Py, HI, hy, F_v/F_m, WUE	ICGS 76	Py, Hy, Bio, HI, Fv/Fm, g_s	S 230
9	Py, HI, hy, g_s, E, Fv/Fm	TKG 19A	Py, Hy, Bio, HI, Fv/Fm, E	Girnar 2
10	Py, HI, hy, P_N, E, Fv/Fm	ALR 3,	Py, Hy, Bio, HI, Fv/Fm	DRG 12, S 230
11	Py, Hy, P_N, g_s, E, RUE	Chitra, GG 12, ALR 2	Py, Bio, HI, P_N E, WUE	K 134
12	Py, HI, P_N,E, WUE, RUE	TG 37 A	Py, HI, P_N g_s, E, RUE	Tirupati 4, S 206, JL 220
13	Py, Hy, P_N, g_s, Fv/Fm, WUE, RUE	Kadiri 3, S 230, Tirupati 3	Py, HI, P_N g_s, E, WUE, RUE	S 206
14	Py, Hy, P_N, g_s, E, F_v/F_m, WUE	TG 17	Py, Hy, Bio,P_N E, WUE	M 522, M 13, M 145, CSMG 84-1
15	Py, Hy, P_N, g_s, E, WUE, RUE	RS 1	Py, Hy, Bio, HI, g_s WUE	SG 84
16	Py, HI, P_N, g_s, F_v/F_m, WUE, RUE	SG 99	Py, Hy, Bio, P_N, Fv/Fm, WUE	GG 20, M 13, SG 99
17	Py, HI, P_N, g_s, E, Fv/Fm, RUE	LGN 2, GG 12	Py, Hy, Bio, Fv/Fm, g_s WUE	GG 12, M13
18	Py, HI, hy, P_N, g_s, E, Fv/Fm, RUE	GG 20, GG 12	Py, Hy, Bio, Fv/Fm, P_N, E,	CSMG 884, M 13
19	Py, HI, P_N, g_s, E, F_v/F_m, WUE, RUE	TPG 41	PY, Hy, Bio, HI, P_N g_s, E, RUE	RG 141, ALR 2
20			Py, Hy, Bio, P_N g_s, E, RUE	M 197, M 13
21			Py, Hy, Bio, P_N, E, WUE, RUE	M 145, CSMG 84-1, M13
22			Py, Hy, Bio, HI, P_N g_s, E, WUE, RUE	ALR 2
23			Py, Hy, Bio, Fv/fm,, P_N g_s, E, WUE, RUE	M 13

Where PY is pod yield, HY is haulm yield, Bio is total biomass peanut cultivars and yield traits. It would be more desirable for improvement in growth and yield per resource use rather than yield alone. The evaluation of photosynthetic parameters responsible for growth and biomass production and yield in high yielding peanut cultivars of India revealed considerable variations among the cultivars and subsequent identification of cultivars for high, P_N, g_s, E, WUE, SCMR and F_v/F_m shall be of immense use in selection of cultivars and increasing the productivity.

There was seasonal variation among the physiological parameters. The dry season crop showed 1.5–2.0 fold higher P_N, g_s, WUE, RUE, and slightly higher SCMR and these all resulted in higher pod yield than that of wet season crop, but the E and F_v/F_m values were slightly higher in wet season crop. The dry season crop is sown during first week of Feb and harvested during last week of May to first week of June, however the wet season crop is sown during last week of June and harvested during mid to last week of October. The dry season crop faced 8–10 h Sun shine and 55–70% RH during the crop season, but low temperature during February month delayed germination by 3–4 days, flowering by 5–7 days, crop growth and finally increased crop duration by 7–10 days than that of wet season crop. But once this crop has reached to flowering in 2nd week of March the temperature and bright sunshine were congenial for photosynthesis. The wet season crop, though face ambient temperature and > 70% RH ideal for growth during entire crop duration, it encounter cloudy days with only 2–6 h Sunshine during first 2 months which elongate plant size resulting in lesser HI. Our earlier study report that, though the cumulative per day dry matter production was similar during both the season, the crop growth rates during 7–13 week were more but with lesser leaf area duration (LAD) during wet season than that of dry season as a result maximum dry matter was attained at 11–12 week during the wet season and at 14–15 week during dry season (Singh and Joshi 1993). Thus, the major advantages of dry season crop were higher LAD, stomatal conductance and better partitioning which helped the plant to show higher physiological efficiencies than that during the wet season crop.

The cultivars with high P_N and pod yield, high P_N and WUE, high P_N and g_s, high P_N and F_v/F_m, $_{\text{high}}$ P_N and chl and high SCMR and pod yield have been identified in this study which will help in increasing productivity. The cultivars with high P_N and pod yields are of immense use and GG 20, CSMG 884, TPG 41, Kadiri 3, S 230, RS 1, JSP 19, ICGS 5, Chitra, LGN 2, TG 17, Tirupati 3, GG 12, ALR 3, UF 70-103, SG 99, TG 37 A which were superior in more than four traits along 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.

Conclusions

The physiological studies among 60 Indian peanut cultivars during mid of the pod filling stage (70–75 days) of the crop showed a large variation in P_N, g_s, E, WUE, RUE, SCMR and F_v/F_m in leaves and were the main deciding factors for pod yields at harvest. Further most of these parameters, except E, and F_v/F_m were high during dry season resulting in higher yield than that during wet season. Foliar application of Zn increased all these parameters except g_s and SCMR. Based on the overall performance the peanut cultivars Tirupati 3, TG 37A, CSMG 884, RS 1, S 230, LGN 2, TPG 41 and SG 99 are recommended for their cultivation during dry season and cultivars GG 20, Tirupati 4, M 197, ALR 2, JL 501and RG 141 during wet season.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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