Journal of Agrometeorology 17 (2) : 165-171 (December 2015)

Response of wheat and chickpea cultivars to reduced levels of solar irradiance

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ABSTRACT

The study was carried out at the Indian Agricultural Research Institute, experimental fields (28° N, 77° E) during 2008-2009 and 2009-2010 *rabi* season to observe response of wheat and chickpea cultivars to reduced levels of solar irradiance. In the present study two wheat (*Triticum aestivum;* HD 2643 and PBW 343) and two chickpea (*Cicer arienitum* L. ; BG 1105 and BGD 72) cultivars were subjected to 20 per cent and 35 per cent less levels of solar irradiance than the control that received 100 per cent natural sunlight during entire crop growth period. The results show that the height and leaf area index (LAI) of both the crops cultivars under reduced solar irradiance were more than natural light. Under reduced solar irradiance, height of wheat cultivar HD 2643 was more than PBW 343 and that of chickpea cultivar BG 1105 was more than BGD 72. Reduction in solar irradiance affected the photosynthesis and stomatal conductance process in both the crops. About 4-29 per cent reduction in rate of photosynthesis in wheat and chickpea varieties was observed under reduced levels of solar irradiance. Reduction in stomatal conductance under reduced levels of solar irradiance in wheat varieties was 6-28 per cent and in chickpea varieties it was 1-14 per cent. Biological yield of wheat and chickpea varieties was decreased by about 37-45 per cent and 13-53 per cent respectively, under reduced levels of solar irradiance. Observations show that among wheat cultivars PBW 343 was less affected by reduced levels of solar irradiance than HD 2643. Among chickpea cultivars BGD 72 was less affected by reduced levels of solar irradiance than BG 1105. The PBW 343 and BGD 72 cultivars of wheat and chickpea may be used by breeders to develop new varieties to increase agricultural production in climatic condition subjected to low irradiance.

Key words: Wheat, chickpea, irradiance, photosynthesis rate, stomatal conductance, yield

As a consequence of increase in aerosols, air pollutants and population density, dimming (decrease in global radiation i.e., the sum of the direct solar radiation and the diffuse radiation scattered by the atmosphere) have become major challenges to crop production in many areas of the world (Mu et al., 2010). Studies have shown that between 25°N and 45°N, global irradiance or incoming light has been reduced by as much as 1.4–2.7 per cent per decade (Stanhill and Cohen, 2001; Ramanathan and Feng, 2009). In India (8°4' and 37°6' N, 68°7' and 97°25' E) also like other parts of world, increasing load of aerosols and other air pollutants in atmosphere because of growth of infrastructure sector, population density, vehicular pollution, biomass burning causing significant solar dimming (Ohmura, 2006; Rao and Rao, 2010; Kambezidis *et al.,* 2012; Kaskaoutis *et al.,* 2011). During 1984-2004 at 12 urban Indian stations of Indo Gangetic Plains (IGP, 27° N, 80° E) region an average reduction of ~0.86 $Wm^{-2} yr^{-1}$ in ground-reaching solar radiation has been reported (Padma Kumari and Goswamy, 2010). Reduction in incoming solar irradiance levels during crop growth period significantly impairs its growth, physiological processes and yield (Acreche *et al.,* 2009; Mu *et al.,* 2010). Reports on the extent upto which reduction in incoming solar irradiance will be detrimental for Indian crops are very limited. Wheat and chickpea are important *rabi* crops of north India. Reported reduction in levels of incoming solar radiation for north India may act as constraint for the optimum yield of wheat and chickpea crops. Henceforth, field experiments were conducted with two varieties of chickpea and wheat crops grown under different irradiance (i.e., levels of reduction in incoming solar radiation) to observe: (1) effect of different irradiance on growth, physiological processes and yield of wheat and chickpea varieties.

MATERIALS AND METHODS

Experiments were conducted at the research field of Indian Agriculture Research Institute, New Delhi during *rabi* season of 2008-2009 and 2009-2010. The study site was located at 28°35' N, 77°12' E and with an altitude of 228.16 m

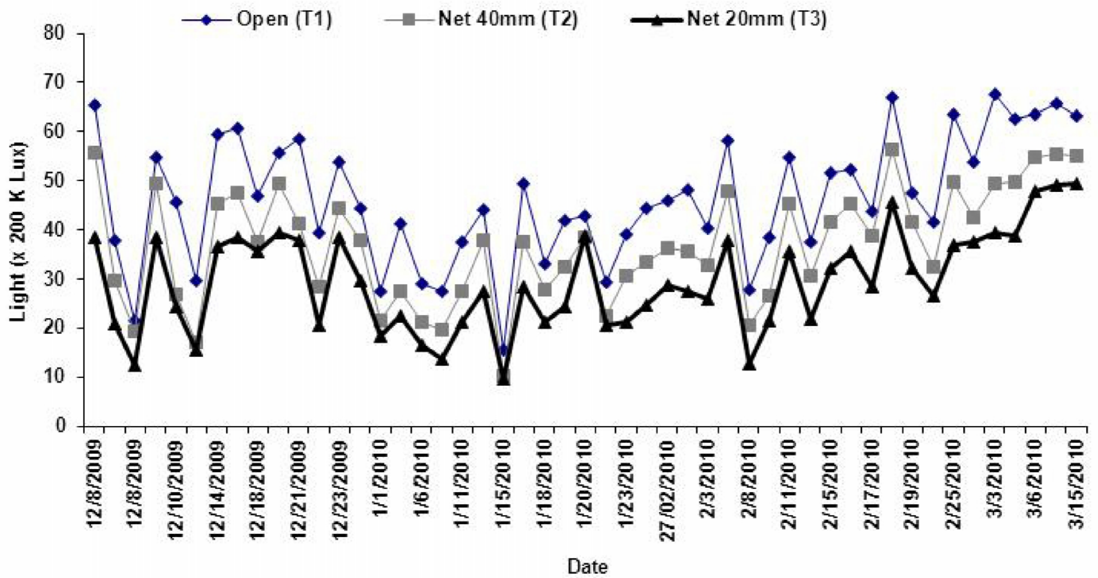

Fig.1: Solar irradiance under different treatment during the experiment

Table 1: Maximum and minimum temperature and relative humidity under different irradiance during crop growth period

Treatment	Tmax (^{0}C)	Tmin(^{0}C)	Relative humidity (max) (%)	Relative humidity (min) (%)
Open (T1)	29.4 ± 5.8	11.9 ± 3.6	56.3 ± 18.2	22.1 ± 5.3
Net 40mm (T2)	28.6 ± 4.2	13.2 ± 6.6	76.1 ± 8.9	35.1 ± 1.2
Net 20mm (T3)	27.5 ± 2.1	13.8 ± 4.1	75.0 ± 11.3	34.4 ± 4.6

above the mean sea level. The soil of experimental site was sandy loam having pH of 8.1, organic carbon 0.37 per cent, available phosphorus 8.30 kg ha^{-1}, available potash 176.0 kg $ha^{-1}$and available sulphur 12.0 kg ha^{-1}.

Two varieties of wheat (HD 2643 and PBW 343) were sown on 29th November and two varieties of chickpea (BGD 72 and BG 1105) were sown on 19th November in both the years. Seeds sown at 10cm distance in a row and distance maintained between rows were 20cm for wheat and 40cm for chickpea. A dose of 120:50:40 kg ha^{-1} of N:P:K was applied (half of N as basal and half after first irrigation) for wheat and 20:50:20:25 kg ha^{-1} of N:P:S:Zn as basal dose was applied for chickpea crop.

White nylon net screens of 40mm and 20mm mesh size were covered on the top of chickpea and wheat canopy from sowing to maturity to provide two low solar irradiance treatments. One set was kept without any nylon screen covering and maintained under natural sunlight and considered as open (T1). The screens were more than 180cm above the ground to ensure good ventilation and were large enough to fully cover the corresponding plots. The amount of incident sunlight under the 40mm (T2) and 20mm (T3) net treatments and open treatment (T1) was recorded using LUX meter (between 10:30 and 11:00 am) (Fig.1). The maximum and minimum temperatures and relative humidity under open treatment during the crop growth period were taken from field observatory for weather parameters under division of Agriculture Physics, IARI and under net treatments was recorded above canopy height using thermosensors (maxtech TM-1, India). The experiment was a split-plot design with sunlight levels as the main plot and crop cultivars as subplot and three replicates for each. The size of each plot was 3m×3m. The plot were kept weed free by weeding frequently and irrigated whenever needed to maintain sufficient soil moisture.

Observations for crop growth and physiological processes were recorded at three growth stages i.e., vegetative, flowering and maturity. The growth parameters - plant height, number of tillers in wheat, number of branches in chickpea and Leaf Area Index (LAI) using canopy analyser were recorded non-destructively at each growth stage for each variety and each treatment. Observations for photosynthesis and stomatal conductance were conducted on intact top mature leaves for wheat and chickpea plants at different growth stages with the help of IRGA system (LICOR 6200, Licor Inc., U.S.A) following standard refereed techniques between 9:30–11:00 am on clear sky days.

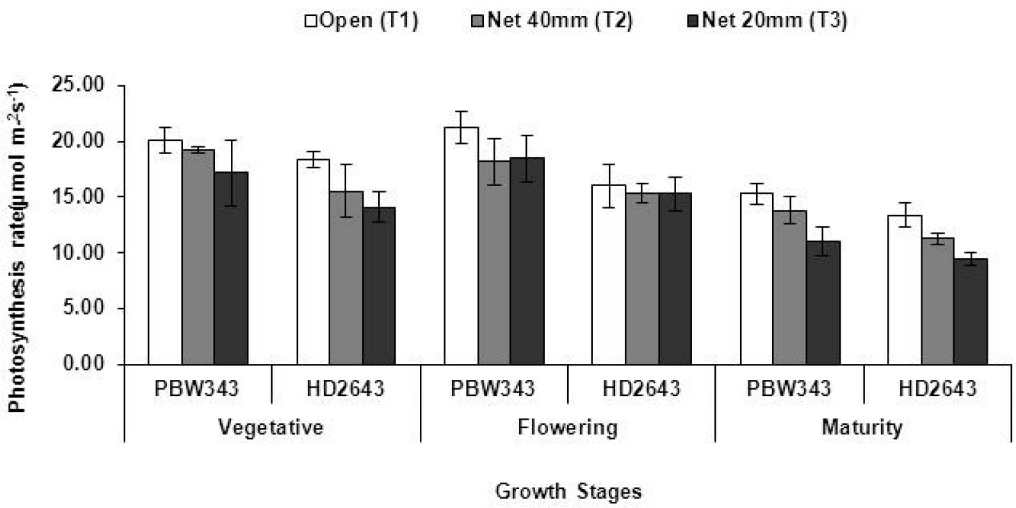

Fig.2: Effect of variation in irradiance on rate of photosynthesis in wheat varieties.

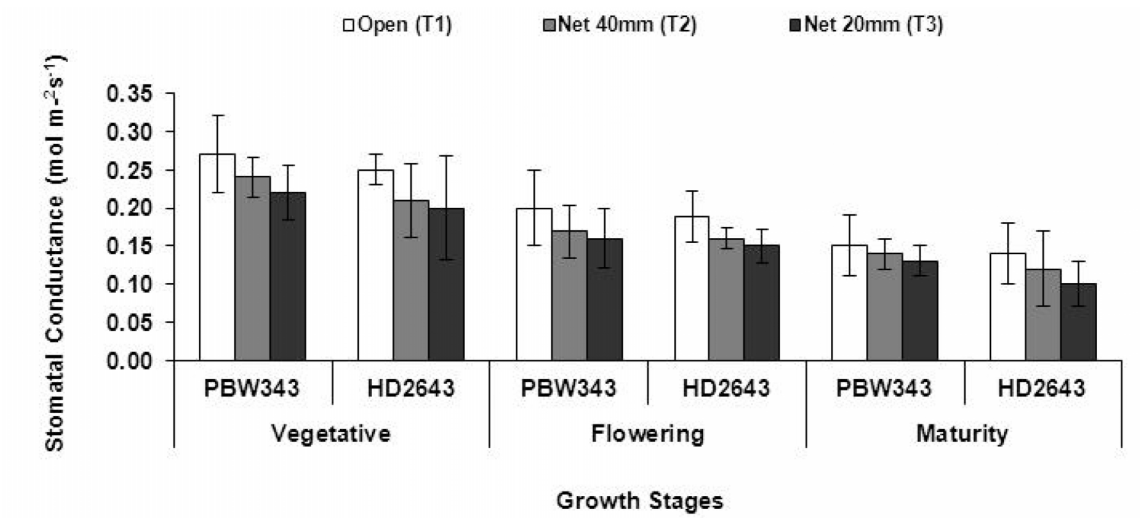

Fig.3: Effect of variation in irradiance on stomatal conductance in wheat varieties.

Biomass, grain weight and yield components i.e., number of spike m^{-2}, number of grains $spike^{-1}$ and 1000 grain weight were recorded in both crops varieties at maturity. The remaining plants were also used for calculating total biomass and grain weight m^{-2} land area. Data obtained from the experiments were subjected to one-way analysis of variance (ANOVA) for mean and LSD values through MS excel programmer of windows.

RESULTS AND DISCUSSION

Microclimate

The 40mm (T2) and 20mm (T3) net coverings in the two treatments blocked about 20±5 per cent and 35±5 per cent of the natural irradiance above the canopy respectively as compared to open (TI) treatment (Fig.1). Mean sunlight received at canopy level during crop growth period were 46.3, 36.8, and 29.5 Klux under open, 40mm and 20mm net treatments respectively. Mean maximum and mean minimum temperatures were less and relative humidity was more under 40mm and 20mm net treatments as compared to open treatment during the crop growth period in both the years (Table 1).

Wheat

Morphological growth : The height of wheat varieties grown under 40mm and 20mm net treatments was more as compared to open treatment. Maximum (34 per cent) and minimum (2 per cent) increase in height was observed in vegetative stage plants of HD 2643 and maturity stage plants of PBW 343 under 20mm net treatment (Table 2).

The reduction in number of tillers was observed in PBW 343 and HD 2643 under 40mm and 20mm net treatments as compared to open treatment. Reduction in number of tillers due to reduced level of solar irradiance in wheat

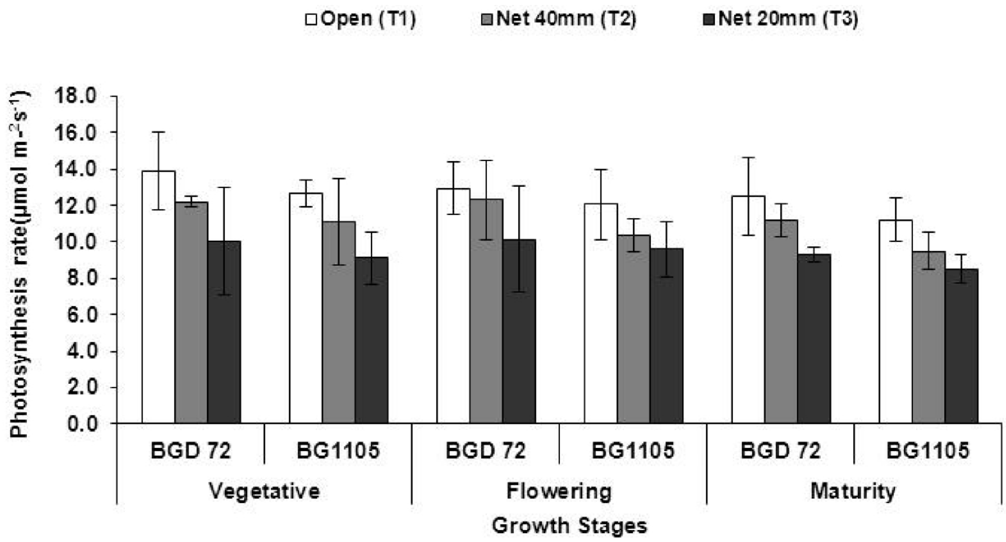

Fig.4: Effect of variation in irradiance on rate of photosynthesis in chickpea varieties.

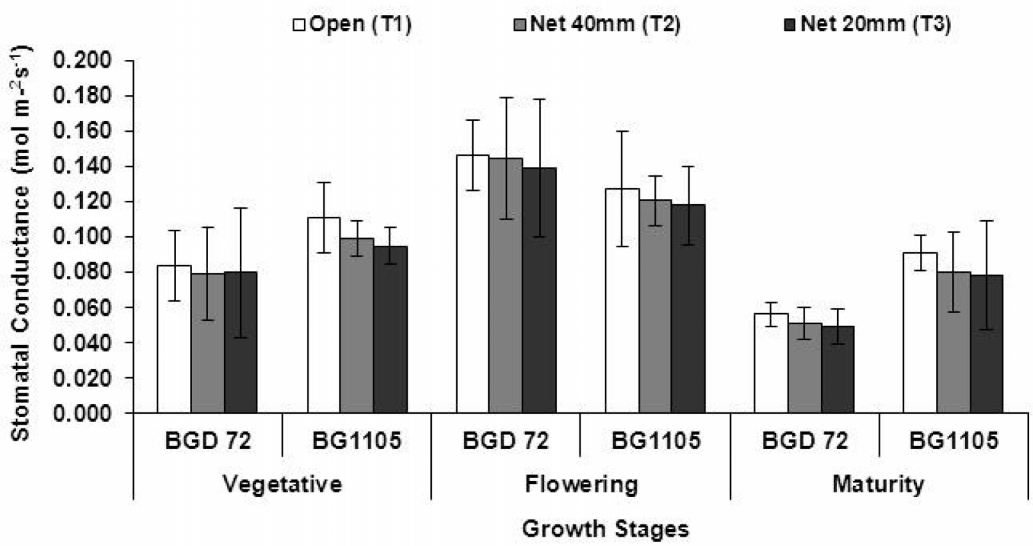

Fig.5: Effect of variation in irradiance on stomatal conductance in chickpea varieties.

varieties was in the range of 16-36 per cent, and it was more in HD 2643. Maximum reduction in number of tillers was observed at vegetative stage in HD 2643 wheat variety under 20mm net treatment (Table 2). Similar to our observation Bos and Neuteboom, (1998) also reported less tillers in wheat under low irradiance. Reduction in tillering attributed to a lower availability of local assimilates for tiller appearance (Bos and Neuteboom, 1998). LAI was more in wheat varieties under 40mm and 20mm net treatments as compared to open treatment and it was maximum at flowering stage. Among the varieties it was more in PBW 343 than HD 2643 under all the treatments.

Physiological response : The rate of photosynthesis was maximum at vegetative stage in wheat varieties under open treatment. Photosynthesis rate of HD 2643 was less as compared to PBW 343 at all growth stage under all treatments (Fig.2). Minimum photosynthesis was recorded at maturity in PBW 343 and HD 2643 under 20mm net treatment. Maximum (29.5 per cent) and minimum (4.3 per cent) reduction in photosynthesis was observed in HD 2643 at maturity and flowering stage respectively under 20mm net treatment.

The reduction in solar irradiance affected the stomatal conductance process in wheat varieties. Stomatal conductance of HD 2643 was less as compared to PBW 343 at all growth stages under 40mm and 20mm net treatments (Fig.3). Stomatal conductance in PBW 343 and HD 2643 was 20mm net treatment respectively. The key to plant productivity is photosynthesis, the process by which solar energy is fixed in carbohydrates and their secondary products. It has been reported that limitation for

Table 2: Effect of irradiance on growth attributes of wheat varieties (mean of 2 seasons)

Treatments	Plant height (cm)		Vegetative stage: No of Tillersplant-1		LAI		Flowering stage: Plant height (cm)		No of tillers plant-1		LAI		Maturity stage: Plant height (cm)		No of tillers plant-1		LAI	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
Open (T1)	51.4	49.8	12.6	14.8	2.7	2.9	63.2	83.8	13.8	16	3.1	3.2	67	85.8	14.0	16.1	2.8	3.1
Net 40mm (T2)	75.6	62.4	9.0	10.4	2.8	3.3	78.4	91.6	9.8	13.4	3.3	3.6	82	95.0	9.9	13.5	3.0	3.2
Net 20mm (T3)	78.4	64.2	8.0	10.1	3.1	3.4	81.6	92.0	9.1	13.2	3.4	3.9	95.6	88.4	9.3	13.3	3.1	3.5
CD *(P=0.05)*	10.4	8.9	1.7	1.5	ns	0.5	12.4	7.5	3.2	2.8	0.1	0.2	13.2	9.4	2.9	2.6	0.2	0.3

(V1=HD2643 and V2=PBW343)

Table3: Effect of irradiance on yield attributes of wheat crop (mean of 2 seasons)

Treatments	No.of Spikesm-2		No.of Grainsspike-1		1000grain weight (g)		Biological Yield(gm-2)		Grain weight (gm-2)		Straw weight(gm-2)		Harvest Index (%)	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
Open (T1)	525	530	30	35	46	42	1455	1460	545	55	910	910	37	38
Net 40mm (T2)	278	315	29	33	42	40	865	908	316	350	55	558	36	38
Net 20mm (T3)	256	285	26	34	41	38	794	860	290	310	504	550	36	36
CD *(P=0.05)*	36.0	30.2	ns	ns	2.1	1.7	35.6	40.9	23.0	26.3	32.5	35.1	ns	ns

(V1=HD2643 and V2=PBW343)

photosynthesis is CO_2 concentration, but when it is replaced by availability of light, than it might be expected to decrease productivity (Taiz and Zeiger, 2010).

Yield : The reduction in level of incoming solar irradiance affected yield parameters of both wheat varieties. Number of grains spike^{-1} was less in wheat varieties under 40mm and 20mm net treatments than open treatment. Under 40mm and 20mm net treatments range of reduction of biological yield in HD 2643 was 40-45 per cent and PBW 343 was 37-41 per cent respectively(Table 3). Effect of reduced level of stomatal conductance and photosynthesis rate was reflected consequently through decrease in yield attributes of both crops varieties under reduced level of irradiance as compared to control plants. Similar to our results for yield of wheat varieties, Savin and Slafer (1991) also reported reduction in yield of Leones INTA wheat cultivar of Argentina. Jenner (1979) has shown that reductions in irradiance at, or soon after, anthesis reduce the number of developing grains and grain weight.

Chickpea

Morphological growth : The height of chickpea varieties grown under 40mm and 20mm net treatments was more as compared to open treatment, though difference in BG 1105 and BGD 72 plants height under open treatment was non significant. Height of BG 1105 plants under 20mm net treatment was 39.4, 38.9 and 35.4 per cent more than open treatment plants at vegetative, flowering and maturity stage respectively (Table 4). Reduction in number of branches in BG 1105 and BGD 72 was 30-43 per cent under 40mm net treatment as compared to open treatment (Table 3). LAI of BGD 72 chickpea variety was more as compared to BG 1105 and it was more under 40mm and 20mm net treatments. Variation in LAI of BGD 72 flowering stage plant grown under 40mm and 20mm net was non significant (Table 4).

Higher tolerance to low light conditions can be achieved by enhanced plasticity of light-harvesting variables (for example crown morphology) (Valladares and Ulo, 2008). This is supported by our observations in the current study where enhanced plant height and less number of branches were found with large leaves under 40mm and 20mm net treatments. Plants are able to increase light interception efficiency by increasing leaf area index (LAI) (Trapani *et al.,* 1992; Cohen *et al.,* 1997), this support our observations with respect to plant height and LAI. Thus, changed canopy architecture combined with the enlarged leaf area could partially compensate for the reduction in PAR at the cost of other growth parameters.

Table 4: Effect of irradiance on growth attributes of chickpea varieties (mean of 2 seasons)

Treatments	Vegetative stage						Flowering stage						Maturity stage					
	Plant height (cm)		No of Tillersplant^{-1}		LAI		Plant height (cm)		No of tillers plant^{-1}		LAI		Plant height (cm)		No of tillers plant^{-1}		LAI	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
Open (T1)	35.2	33.2	12.6	12.4	2.1	1.4	56.2	57.6	18.2	14.4	3.9	3.7	62.2	62	15	14.6	2.7	2.3
Net 40mm (T2)	49.4	46.4	8.2	7	2.4	1.7	74.4	83.2	10.4	8.6	4.3	4.2	75.6	87	10.4	9.2	3.1	2.7
Net 20mm (T3)	49.4	54.8	9.2	7.8	2.5	1.5	80	94.2	11	9.4	4.2	3.8	81	95.6	8.8	9.2	2.6	2.4
CD(P=0.05)	11.2	10.1	2.5	3.1	ns	ns	15.2	20.2	5.3	4.5	0.3	0.4	11.1	15.2	4.2	3.8	0.3	0.4

(V1=BGD72 and V2= BG 1105)

Table 5: Effect of irradiance on yield attributes of chickpea crop (mean of 2 seasons)

Treatments	No.of pods/plant		No.of seeds/pod		1000grain weight (g)		Biological Yield (gm^{-2})		Straw yield (gm^{-2})		Seed yield (gm^{-2})		Harvest Index (%)	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
Open (T1)	65	55	1	1	250	220	750	625	490	377	260	248	35	40
Net 40mm (T2)	27	25	1	1	240	212	652	475	506	332	146	143	30	30
Net 20mm (T3)	27	16	1	1	218	170	492	291	372	227	120	124	24	22
CD(P=0.05)	3.1	4.2	ns	ns	12.6	10.5	33.6	20.3	15.4	29.8	22.7	13.5	1.9	2.4

(V1=BGD72 and V2= BG 1105)

Physiological response : The photosynthesis rate was maximum at vegetative stage in both chickpea varieties under open treatment. Minimum rate of photosynthesis (9.3μmol $m^{-2}s^{-1}$) in BGD 72 and BG 1105 (8.5μmol $m^{-2}s^{-1}$) was recorded at maturity stage under 20mm net treatment (Fig.4). Reduction in photosynthesis rate was observed maximum (28.1 per cent) in BG 1105 at vegetative stage under 20mm net treatment and minimum (4.8 per cent) in BGD 72 at flowering stage under 40mm net treatment as compared to open treatment.

Among chickpea varieties stomatal conductance was less in BG 1105 as compared to BGD 72 at all the three growth stages under all treatments (Fig. 5). Maximum and minimum stomatal conductance in BGD 72 and BG 1105 was recorded at flowering stage under open treatment and at maturity stage under 20 mm net treatment respectively. In literature lots of evidences indicated that photosynthetic rate and stomatal conductance of leaves are linearly correlated across diverse environments (Field, 1987; Taiz and Zeiger, 2010). Any decrease in any one parameter will consequently decrease second one.

Yield attributes : The reduction in level of solar irradiance affected yield parameters of both chickpea varieties. The biological yield reduction range under 40mm and 20mm net treatments in BGD 72 was 13-34 per cent and in BG 1105 was 24-53.4 per cent (Table 5).

The reduction in seed yield under 40mm and 20mm net treatments than open treatment in BGD 72 and BG 1105 was in the range of 53-43 per cent and 50-42 per cent respectively (Table 5). The significantly lower harvest index of 40mm and 20mm net treatment plants was result of high dry matter production and limited supply of assimilate for seed growth. A combination of limited assimilate supply as a result of less PAR and the tendency for excessive vegetative growth would have diverted much needed assimilates from the already limited supply for seed development, to the maintenance of vegetative growth (Verghis *et al.,* 1999). Low yield in both chickpea varieties under 40mm and 20mm net treatments could be also explained by less light capture and its affected redistribution between vegetative organs to seeds.

CONCLUSION

In the light of the present study results, it is concluded that reduction in total incoming solar irradiance adversely affects the growth and yield of wheat and chickpea cultivars. However, important variability in terms of growth, physiological processes and crop yield was observed amongst cultivars of both wheat and chickpea. The impact of artificially induced reduced levels of solar irradiance was less in wheat cultivar PBW 343 as compared to HD 2643 and in chickpea cultivar BGD 72 as compared to BG 1105. The existence of genetic variability among wheat and chickpea cultivars, as shown in this work, might be useful in selecting optimal cultivars to increase agricultural production in climatic condition subjected to low solar intensity.

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Received : February 2015 ; Accepted : October 2015