Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; SP1: 2804-2807

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Physiological bases of shade tolerance in wheat varieties

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Abstract
Light is the main environmental factor which regulates growth and development of crop plants. Decrease in light intensity due to shading adversely affects plant growth and development. The present study was conducted to analyze the effect of varying degree of shades on physiological characteristics and yield of wheat crop. Two shading treatments were applied i. e. 33% shading (L1) and 66% shading (L2) with full sunlight as control (L0). The experiment was conducted for 2 years during the winter seasons of 2010-2011 and 2011-2012 in a split-plot design with three replications with shading treatments in the main plot and five varieties of wheat in the sub plots. The findings of the study showed that photosynthetic rate, stomatal conductance and transpiration rate at 10 days after anthesis (DAA) were significantly reduced while the intracellular CO2 concentration (Ci) increased with increase in shading during both the years. Grain yield of all the wheat varieties decreased with increase in shading during both the years. Varietal differences in grain yield under shading are discussed in relation to Pn rates and stomatal conductance.

Keywords: Light, Photosynthetic rate, Stomatal conductance, Transpiration rate

Introduction
India harvested 81.0 million tonnes of wheat from 29 million hectare with the average yield of 2.8 tonnes per hectare (Economic Survey, 2010-11). Besides due to ever increasing population, the land resources are not capable of fulfilling the associated demands for food, fodder, timber, fuel etc and hence, increased pressure on the world's resources and natural ecosystems were inevitable, predictable and will become more severe in future. These increased pressures on a fixed land base form the context within which forestry with agriculture (Agroforestry land-use) seems to be a logical solution to meet the requirements of fast growing population in sustainable manner and also ensure environmental stability and provide socio-economic security (Yadav, 1990).

Light is the main environment factor which determines the rate of crop development possibly because all plants and their process of development are sensitive to it. Light plays an important role in many plant processes like chlorophyll synthesis, enzyme activation, photosynthesis governing growth and development of plants. As a consequence of increase in aerosols, air pollutants and population density, dimming or shading (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).

Shading of plants generally decreases crop yields by reducing photosynthetic photon flux density and correspondingly, the crop photosynthesis. Changes in radiation influence both photosynthetic light and carbon use efficiency, and will ultimately affect total grain yield (Jiang *et al*. 2002). Shading during any developmental stage significantly impaired net photosynthesis in wheat leaves probably via changes in the functioning of chloroplasts and inhibition of the activity of photosystem II (PSII) (Mu *et al*. 2010). The decrease of photosynthetic rate due to shading at the canopy level is less than at the single leaf level. This has been ascribed to efficient acclimatization and adaptation capacities of plants to different light regimes (Li *et al*. 2010).

gro forestry is stated to be a sustainable land management system (King and Chandler 1978). In any agroforestry system, tree-crop interaction for solar radiation, moisture and mineral nutrients results in changed microclimates, which in turn affect the productivity of component crops. While moisture and nutrient availability could be agronomically managed, varietal selection is more important for shade tolerance in such a system. Yield reductions in various grain crops have been reported due to such interactions. The objective of this study was to work out the physiological bases of shade tolerance in wheat varieties.

Materials and Methods

The field experiments were conducted at the Norman Borlaug Crop Research Centre, G. B Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, Uttarakhand during the winter seasons of 2010-2011 and2011-2012. Pantnagar is located at 29o N latitude, 79.3o Elongitude and an altitude of 243.8 m above mean sea level in the Tarai belt of Shiwalik range of the Himalayan foothills. It falls under the sub-humid and sub-tropical climatic zone. The experiment was laid out in a split plot design with three replications. The main plot treatments comprised of three different levels of sunlight viz. full sunlight as control, and 66 and 33% of full sunlight as shade treatments while the sub-plot treatments consisted of five varieties of wheat. The gross plot size was 1.61 9 5.0 m while the net plot size was 1.15 9 4.0 m. A row spacing of 0.23 m, was maintained and the seed rate was 100 kg ha-1.

Data on photosynthetic rate, stomatal conductance and transpiration rate were recorded at 10 days after anthesis between 12:00-14:00 h with the help of an Infra-Red Gas Analyzer (Model: CI 310, CID Inc, USA). Data was recorded in the topmost fully expanded leaf (flag leaf). The temperature at the time of measurement was 28^0C at CO2concentration between 320–370 ppm and at PAR levels between 1,200-1,350 micro mol m-2 s-1. The observations were separately recorded on three leaves from each plot and mean value is presented. All these observations were made on intact leaves with a flow rate of 300 ml per minute.

Produce of net plot was threshed by using Pullman thresher. After winnowing, the grain yield was recorded.

Result and Discussion

Yield reductions in various grain crops due to shading have been reported in agroforestry systems. Therefore, varietal differences in shade tolerance can be evaluated to find out suitable crop varieties for such systems. This requires understanding of photosynthetic behaviours of crop plants under shading that determines final grain yield. The objective of the present study was to work out the physiological bases of yield reduction in wheat crop under varying degree of shades.

The intercellular CO2 concentration (Ci), photosynthetic rate (Pn), stomatal conductance (Gs) and transpiration rate (E) of wheat varieties were significantly influenced by the degree of shading (Table 1). Diffusion of CO2 into the leaves is mainly driven through the stomatal aperture and linearly correlates with photosynthetic capacity. It plays an important role in the physiological process of plant modulated by environmental regime (Korner *et al*. 1979). The intercellular CO2 concentration (Ci) was significantly influenced by degree of shades at 10 days after anthesis (DAA) during both the years (Table 1). The CO2 concentration was higher under severe shade (L2, 66% shading) as compared to mild shade (L1) and full sunlight (L0, control) during both the years. Maximum Ci was recorded under 66% shading (L2) viz. 363.4 ppm during the first year and 370.8 ppm during the second year. The percent increase as compared to full sunlight was 10.9 and 12.5% respectively, during 2010-2011 and 2011-2012. However, there were no significant differences among the wheat varieties. Even the interaction between wheat varieties and degree of shades were non-significant in terms of Ci.

During both the years, the net photosynthetic rate was significantly higher (19.8 and 22.5 micro mol CO2 m-2 s-1during first and second year, respectively) under full sunlight (L1, control) which was reduced significantly with increase in the degree of shading. Among the varieties, PBW 233 exhibited significantly higher photosynthetic rate (16.7 micro mol CO2 m-2 s-1) than other varieties during the first year while during 2011–2012, the varieties PBW 233, UP 2684 and UP 2526 recorded similar Pn rates that was highest among the varieties. Significantly lower photosynthetic rate was recorded in the variety UP 2113 during the second year. Mu *et al.* (2010) reported that small reduction in radiation showed marked reduction in Pn of wheat flag leaf. The response of net photosynthetic rate (Pn) to shading differed amongst the cultivars (Li *et al*. 2010). The decrease in Pn rate is usually explained by reduction in stomatal conductance, which reduces CO2diffusion into the leaves (Condon *et al.* 2002).

In the present study, reductions in Pn rates under shading despite higher intercellular CO2 concentrations indicate that Pn rates was limited by the availability of light. Stomatal conductance (Gs) is a measure of the maximum rate of passage of carbon dioxide into the leaf. In the present study, it was maximum and significantly higher under full sunlight. The values were 257.4 and 222.7 mmolCO2 m-2 s-1 during 2010-2011 and 2011-2012, respectively. It was reduced significantly with increase in the magnitude of shade (Table 1) during both the years. Among the varieties, PBW 233 recorded higher stomata conductance (218.6 and 181.9 mmol CO2 m-2 s-1, respectively, during 2010-2011 and 2011-2012). While the varieties UP 2684 and UP 2113 recorded significantly lower stomatal conductance during 2010-2011, the variety UP 2113 only recorded the lowest value of Gs during second year of study.

In the present study, as compared to full sunlight, reductions in Gs was 55.2 and 48.4% during first and second year, respectively. These reductions in Gs explains the concomitant reductions in net photosynthetic rates under shade. Condon *et al.* (2002) reported that the decrease in Pn could be explained by reduction in stomata conductance under shading. Camilo *et al*. (2002) reported that the stomatal conductance and assimilation rates were higher in control plants, which indicated PAR limitation for photosynthesis in shaded plants.

The relationship between Gs and Pn rate was also observed in the varieties. The transpiration rate (m mol H2O m-2 s-1) was also significantly higher under full sunlight during both the years. It was 1.94 in 2010-2011 and 1.72 in 2011-2012, respectively. There was a reduction of 65-67% under severe shade as compared to full sunlight during both the years. This decrease in transpiration rates under shade could be due to the lower leaf and air temperatures that brought about a lower leaf-to-air vapour pressure gradient, and hence lower evaporative demand. Varietal differences in transpiration rates were non-significant during both the years. The interaction between degree of shading and varieties were non-significant for these three parameters during both the years (Table 1).

The maximum total grain yield, 42.9 q ha-1 during 2010-2011 and 43.6 q ha-1 during 2011-2012, was obtained under full sunlight which decreased significantly under mild and severe shades during both the years (Table 2 & 3). The reduction in grain yield under sever shading (66% shade) was about 52% during both the years as compared to that in full sunlight. A number of studies have shown reduced grain yield under shade or under trees (Verma *et al*. 2002; Kaushik *et al*. 2002). The interaction effect between shade levels and varieties show that all the five wheat varieties produced maximum grain under full sunlight which decreased with increased degree of shades during both the years.

In the first year, the magnitude of reduction in grain yield under 33 % shading was lowest (15.3%) in the variety UP

2113 while it ranged from 32-33.7% in the rest four varieties. Under 66% shading, all the varieties recorded about 50-53.4% reduction in grain yield. In the second year, under 33% shading, the variety PBW 233 recorded lowest reduction (29.7%) in grain yield while the variety UP 2113 recorded the maximum reduction (41.1%). Under severe shade, the reduction in grain yield was lowest in UP 2684 (44.5%) while in the rest four varieties, it ranged between 52.6-57.2% as compared to that under full sunlight.

This indicates that in both the years, the magnitude of reduction in grain yield was increased with increased shading and there were varietal differences in the magnitude of reduction. However, magnitude of reduction in grain yield was less as compared to the magnitude of reduction in solar radiation (44.5-57.2% reduction in grain yield as compared to 66% reduction in solar radiation). Similar findings have been reported by Mu *et al*. (2010) that the wheat grain yield losses under shading were proportionately less

Than the reduction in solar radiation. An assessment of varietal performances under shade

Reveals that among the varieties, significantly lower grain yield was recorded in UP 2113 under full sunlight as well as at various degrees of shades during both the years. The variety PBW 233 out yielded other varieties except UP2565 under any light condition in the first year. In second year also, PBW 233 recorded higher yields among the varieties under all light conditions. Closely following this variety was UP 2565 which recoded similar yields as that of PBW 233 under all light conditions in the first year and

Under full light only in the second year.

Table 1: Intercellular CO_2 concentration, Photosynthetic rate, Stomatal conductance and Transpiration rate at 10 days after anthesis in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	10 days after anthesis							
	CO_2 concentration (ppm)		Photosynthetic rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)		Stomatal conductance ($mmol\ CO_2\ m^{-2}\ s^{-1}$)		Transpiration rate ($mmol\ H_2O m^{-2}\ s^{-1}$)	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades								
L0-Full sun light	323.7	324.6	19.8	22.5	257.4	222.7	1.94	1.72
L1-Mild shade	347.3	341.3	13.9	14.8	165.6	155.0	1.04	0.97
L2-Severe shade	363.4	370.8	10.3	10.6	115.3	114.9	0.63	0.59
SEm ±	2.2	2.3	0.3	0.5	3.1	3.5	0.05	0.02
CD at 5%	8.7	9.1	1.3	1.9	12.1	13.8	0.20	0.06
B. Wheat varieties								
UP 2684	344.5	344.7	14.0	16.6	157.7	172.8	1.26	1.08
UP 2526	349.2	345.5	14.4	16.2	176.7	163.6	1.27	1.11
UP 2565	341.1	348.2	14.9	15.1	190.8	164.4	1.13	1.08
UP 2113	346.7	346.5	13.6	13.9	153.6	138.2	1.20	1.10
PDW 233	342.4	342.8	16.7	17.9	218.6	181.9	1.16	1.08
SEm ±	4.0	2.9	0.6	0.6	4.7	3.3	0.10	0.04
CD at 5%	NS	NS	1.6	1.7	13.8	9.7	NS	NS
CV (%)	3.5	2.5	11.4	11.0	7.9	6.1	26.4	10.4
Interaction (AxB)	NS	NS	NS	NS	S	S	NS	NS

* L0 (control) Full sun light, L1 Mild shade (33% shading), L2 Severe shade (66% shading)

** NS Non-significant

Table 2: Grain yield ($q\ ha^{-1}$) in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Grain yield	
	2010-11	2011-12
A. Degree of shades		
L0-Full sun light	42.9	43.6
L1-Mild shade	29.9	28.0
L2-Severe shade	20.6	20.8
SEm ±	0.1	0.2
CD at 5%	0.6	0.7
B. Wheat varieties		
UP 2684	29.4	30.5
UP 2526	32.5	31.2
UP 2565	33.6	31.5
UP 2113	25.7	26.8
PDW 233	34.3	33.8
SEm ±	0.4	0.5
CD at 5%	1.1	1.4
CV (%)	3.5	4.6
Interaction (AxB)	S	S

S-Significant NS-Non-significant

Table 3: Grain yield (q ha^{-1}) in different wheat varieties as influenced by varying degree of shades during 2010-11 and 2011-12

Wheat varieties (B)	Degree of shades (A)					
	Grain yield (q ha^{-1})					
	L0	L1	L2	L0	L1	L2
UP 2684	40.9	27.3	20.2	42.0	26.3	23.3
UP 2526	45.4	30.3	21.9	43.7	29.4	20.7
UP 2565	47.1	31.2	22.5	46.3	28.5	19.8
UP 2113	33.3	28.2	15.5	39.1	23.0	18.3
PDW 233	48.0	32.6	23.0	46.7	32.8	22.0
		SEm ±	CD at 5%	SEm ±		CD at 5%
To compare means of two B at the same 'A'		0.6	1.8	0.8		2.4
To compare means of two 'A' at the same or different 'B'		0.6	1.7	0.8		2.2

L0-Full sun light L1-Mild shade L2-Severe shade

Conclusion

Higher grain yields of the variety PBW 233 can be ascribed to its higher net photosynthetic rate and stomatal conductance among the varieties. Moreover, these characters were unaffected by different levels of shades in the same variety (interaction were non-significant, Table 1). It is evident that the high yielding varieties PBW 233 and UP 2565 are expected to perform better under shade conditions due to maintenance of photosynthetic rates and stomata conductance.

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