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Response of Common Bean (*Phaseolus vulgaris* L.) to Different Levels of Shade

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Abstract: As a dominant component crop in intercropping systems, common bean was exposed to radiation deficit during whole plant growth period. Two determinate cultivars (Akhtar and COS16) were examined under four shading levels (0, 20, 40 and 55% reduction of full sun light) in a randomized block split plot design with three replications in 2004 and 2005. Shade levels and cultivars were allocated to main and sub plots, respectively. Increasing shade levels increased Leaf Area Index (LAI), Specific Leaf Area (SLA), Leaf Area Ratio (LAR), days to flowering, days to physiological maturity, grain filling period, mean grain weight and shoot dry weight. But the effects of shading on Leaf Weight Ratio (LWR) and grain yield per unit area were not significant. In comparison, grains per pod, grains per plant and HI decreased, as percentage of shade increased. It was, therefore, concluded that common bean could compensate the reduction in radiation and thus photosynthesis by increasing leaf area and then could prevent seed yield loss under shade stress via increasing grain filling duration and grain weight.

Key words: *Phaseolus vulgaris*, shade stress, yield, yield components

INTRODUCTION

Shade, regardless of its source, reduces the irradiance predominantly in the photosynthetically active region of the spectrum (400 to 700 nm). The level of irradiance is a major ecological factor that influences plant growth. Plants respond to different levels of irradiance through both genetic adaptation and phenotypic acclimation (Lambers *et al.*, 1998; Bell *et al.*, 2000). When plants are shaded by neighbors, two types of reactions can occur; shade-acclimation responses maximize light harvesting in shade condition through increase in specific leaf area and reduced chlorophyll a/b ratio (Evans and Poorter, 2001), whereas shade-avoiding responses maximize light capture by positioning the leaves out of the shade (Vandenbussche *et al.*, 2005). Mature leaves show very little adaptation to shade or sun, but whole plants of some species adapt very well to either condition during development, especially to shade. Of course, there are genetic limits to the extent of adaptation (Salisbury and Ross, 1992) or to the ability of a plant to dynamically acclimate to different light environments (Lin and Hsu, 2004).

Some plants seem to be obligate shade plants (for example *Alocasia macrorrhiza*); others are obligate sun plants (for example sunflower *Helianthus annus*). But most are facultative shade or sun plants. Facultative C-3 and C-4 sun plants adapt somewhat to shade by producing morphological and photosynthetic characteristics similar to those of shade plants (Bjorkman, 1981). Measurements of acclimation following transfer of plants between different light conditions revealed that leaves of some species exhibit substantial capacity for acclimation (Murchie and Horton, 1997; Greer, 1998; Wilson and Wild, 1990), whereas those of others show no or only a modest acclimation response (Chow *et al.*, 1991).

Both light quantity and quality are important in the reaction of shaded plants. Evidence has shown that the morphogenetic reactions occur in response to reductions in the total fluence rate (Fitter and Ashmore, 1974; Warrington *et al.*, 1976): increase in stem extension, changes in leaf size and structure, distribution and number of chloroplasts and photosynthetic and respiratory metabolism (Zhang *et al.*, 2003; Ballare, 2004; Weller, 2004). Photosynthesis under shade light requires maximizing the amount of light absorbed and the quantum yield for CO_2 uptake, while minimizing respiratory carbon losses. Shade plants have extremely low light-compensations, primarily due to their very low dark respiration (Fredeen and Field, 1991; Sims and Pearcy, 1991; Zhang *et al.*, 2003).

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In some regions of Iran legumes such as common bean are grown in apple gardens or in intercropping with maize, where shading or light deficit is a limiting factor. Common bean (*Phaseolus vulgaris* L.) is the centerpiece of the daily diet for more than 300 million of the world's people. This staple is the world's most important food legume, far outdistancing chickpeas, faba beans, lentils and cowpeas. Nutritionists characterize the common bean as a nearly perfect food because of its high protein content and generous amount of fiber, complex carbohydrates and other dietary necessities (Anonymous, 2001). Therefore, this research was aimed to evaluate the response of common bean to different levels of shading.

MATERIALS AND METHODS

An experiment was set up at the Research Farm of Tabriz University, Tabriz, Iran (Latitude 38°05′N, Longitude 14°17′E, Altitude 1360 m above sea level), in 2004 and it was repeated in 2005. The climate is characterized by mean annul precipitation of 271.3 mm per year, mean annul temperature of 10°C, mean annul maximum temperature of 16°C and mean annual minimum temperature of 2.2°C.

Two cultivars of common bean (*Phaseolus vulgaris* L. cv. COS16 and Akhtar; determinate growth habit) were planted by hand on 27 May 2004 and on 25 May 2005 in 5 cm depth of soil. Plots consisted of 10 rows 3 m in length; spaced 25 cm apart, oriented in an east-west direction and had thinned to 40 plants m^{-2} when the seedlings had two true leaves. A side-dressing of 138 kg ha^{-1} Ammonium Nitrate was given after thinning. Hand control of weeds and furrow irrigation were carried out every week during the plant growing period. Harvest dates were 13 and 14 September for 2004 and 2005 experiments, respectively.

Both experiments were randomized block split plot design in three replications, with the shading treatments in main plots and cultivars in subplots. Shading nets of woven plastic strips spread over a wooden framework (3×3 m) were placed in the field 1 m above the soil immediately after seedling emergence. Strips were arranged to reduce the level of PAR (photosynthetically active radiation) by 80, 60 and 45%. So four treatments were achieved: (1) no-shade control (S0), (2) 20% shade (S1), (3) 40% shade (S2) and (4) 55% shade (S3).

Five plants from each plot were used to measure leaf area and leaf and shoot dry weights at anthesis. Days to flowering was recorded as the number of days from planting to first anthesis. Days to physiological maturity was calculated as the number of days from planting to when 50% of the plants had pale yellow flexible pods. Fifteen plants of each plot were harvested to determine grain yield and yield components, including grains per pod, grains per plant and 100 grain weight.

Combined analysis of variance appropriate for a split-plot design was conducted, using General Linear Model (GLM) procedure of SAS statistical package (SAS Institute, 1992). Year was considered as random effect, while shading and cultivars were fixed in the model. The Least Significant Difference (LSD) method ($p \leq 0.05$) was used to evaluate differences between shadings and cultivars.

RESULTS

Combined analysis of variance of the data showed (Table 1) that Leaf Area Index (LAI), Specific Leaf Area (SLA), Leaf Area Ratio (LAR), days to flowering, days to physiological maturity, grain filling period, grains per pod, grains per plant, 100 grain weight, shoot dry weight and Harvest Index (HI) were significantly affected by shading. However, the effects of shading on Leaf Weight Ratio (LWR) and grain yield per unit area were not significant. Both cultivar and year had significant effects on LAR, grains per pod, grains per plant, 100 grain weight and HI. Cultivar effect on LAI and grain yield per unit area and year effect on shoot dry weight were also significant.

Increasing shade levels resulted in significant increase in LAI and days to physiological maturity. SLA, LAR, days to flowering, grain filling period, 100 grain weight and shoot dry weight, also, increased, with increasing shade percentage. However, differences in SLA between S1 and S2 and between S2 and S3, differences in LAR among S1, S2 and S3, differences in days to flowering between two consecutive levels of shading, differences in grain filling period and 100 grain weight between S0 and S1 and differences in shoot dry weight between S0 and S1 and between S2 and S3 were not significant (Table 2). In comparison, grains per pod, grains per plant and HI decreased, as percentage of shade increased. Grains per pod and HI under S3 were significantly lower than S0 and S1, but there was no significant difference between S3 and S2. The highest and the lowest number of grains per plant were obtained under S0 and S3, respectively, but difference between S1 and S2 was not statistically significant (Table 2).

Although, LAI and LAR for Akhtar were significantly lower than those for COS16, but Akhtar was comparatively superior in grains per pod, grains per plant, 100 grain weight, grain yield per unit area and HI.

Table 1: Combined analysis of variance of the effects of different shade levels on various traits of two common bean cultivars

Source	df	Leaf area index	Specific leaf area ($m^2 kg^{-1}$)	Leaf weight ratio	Leaf area ratio ($m^2 kg^{-1}$)	Days to flowering	Days to physiological maturity	Grain filling period
Total	47	-	-	-	-	-	-	-
Year	1	0.148	20.5	0.001	4.5**	0.00	0.021	0.021
Replicate	4	0.154*	29.93*	0.005*	0.46	2.75	0.146	3.1
Shade	3	1.34**	75.05**	0.0005	1.97**	18.94**	164.6**	73.24**
Y*S	3	0.001	3.60	0.0009	0.12	0.83	1.41	1.02
Ea	12	0.059	7.69	0.001	0.30	2.64	0.95	1.53
Cultivar	1	0.45**	7.80	0.003	3.34**	2.08	0.52	4.69
S*C	3	0.004	3.2	0.0005	0.045	1.36	1.24	0.24
Y*C	1	0.006	6.65	0.0002	0.122	4.08	1.02	1.02
Y*S*C	3	0.02	4.06	0.0008	0.004	0.25	0.41	0.46
Eb	16	0.034	9.65	0.0012	0.21	3.0	2.4	5.67
R^2	-	0.92	.76	0.68	0.84	0.70	0.93	0.74
CV	-	7.53	13.87	17.21	10.28	3.55	1.71	5.74

Source	df	Grains per pod	Grains per plant	100 grain weight (g)	Yield ($g m^{-2}$)	Shoot dry weight ($g m^{-2}$)	Harvest index
Total	47	-	-	-	-	-	-
Year	1	1.53**	37.61**	209.8**	8.53	24506.5**	0.014**
Replicati	4	0.016	0.99	3.97	148.12	3423.3	0.002
Shade	3	0.68**	14.53**	75.6**	181.57	9750.3*	0.005**
Y*S	3	0.023	0.835	2.52	133.48	1947.7	0.0002
Ea	12	0.104	1.50	3.76	142.1	1351.7	0.001
Cultivar	1	1.997**	18.39**	44.6*	12045.7**	5349.3	0.017**
S*C	3	0.0165	0.304	1.17	87.4	790.0	0.0003
Y*C	1	0.0315	0.012	4.88	347.2	906.4	0.000002
Y*S*C	3	0.0023	0.064	0.95	95.3	726.3	0.0002
Eb	16	0.042	1.61	6.14	112.3	2083.3	0.001
R^2	-	0.91	0.83	0.85	0.90	0.75	0.84
CV	-	8.31	7.7	6.4	4.18	8.21	6.24

* Significant at $p \le 0.05$, ** Significant at $p \le 0.01$

Table 2: Comparison of means of the traits for two common bean cultivars under four shade levels

Treatment	Leaf area index	Specific leaf area ($m^2 kg^{-1}$)	Leaf weight ratio	Leaf area ratio ($m^2 kg^{-1}$)	Days of flowering	Days to physiological maturity	Grain filling period	Grain per pod	Grain per plant	100 grain weight (g)	Yield ($g m^{-2}$)	Shoot dry weight ($g m^{-2}$)	Harvest index
Shade													
0%(S0)	2.05d	19.2c	0.202a	3.9b	47.2c	86.1d	38.9c	2.7a	17.8a	35.9c	253.2a	526.6b	0.48a
20%(S1)	2.36c	21.9b	0.209a	4.4a	48.4bc	88.4c	40.0c	2.6ab	16.6b	37.6c	250.2a	536.9b	0.47ab
40%(S2)	2.59b	23.4ab	0.196a	4.6a	49.3ab	92.0b	42.7b	2.4bc	16.5b	39.4b	258.9a	575.8a	0.45bc
55%(S3)	2.83a	25.1a	0.197a	4.9a	50.1a	94.4a	44.3a	2.2c	15.1c	41.8a	251.2a	584.6a	0.43c
Cultivar													
COS16	2.55a	23.0a	0.209a	4.7a	49.0a	90.1a	41.2a	2.3b	15.9b	37.7b	237.6b	545.4a	0.44b
Akhtar	2.36b	22.0a	0.193a	4.2b	48.5a	90.3a	41.8a	2.7a	17.1a	39.7a	269.2a	566.5a	0.48a
Year													
2004	2.40a	21.7a	0.197a	4.2b	48.7a	90.21a	41.46a	2.3b	15.6b	40.8a	254.0a	578.6a	0.44b
2005	2.51a	23.0a	0.205a	4.7a	48.7a	90.25a	41.50a	2.7a	17.4a	36.6b	253.0a	533.4b	0.47a

Different letter(s) indicating significant difference at $p \le 0.05$

One hundred grain weight and shoot dry weight in 2004 were significantly greater than those in 2005. However, LAR, grains per pod, grains per plant and HI in 2004 were significantly lower than those in 2005.

DISCUSSION

Shade increase led to higher LAI. Plants that grow in a shady environment invest relatively more of the products of photosynthesis and other resources in leaf area to increase light harvesting and photosynthetic surface (Lambers *et al*., 1998). Johnston and Onwueme (1990) in tropical root crops, Arvarerenga *et al*. (2003) in *Croton urucurata* and Roussopoulos *et al*. (1998) in cotton also reported leaf area increment under low light intensities. Jones and McLeod (1940) reported that leaf area is a commonly used characteristic in evaluating tolerance of shaded species. Generally, the increase of leaf area with shading is one of the ways used to increase photosynthetic surface, ensuring a more efficient yield in low light intensities and consequently, compensating the low photosynthetic rates per leaf area, a characteristic of shaded leaves.

As a result of shade increase, Specific Leaf Area (SLA) was increased; whereas LWR was slightly, but not significantly, decreased, indicating that increasing shade percentage could decrease leaf thickness. Lambers *et al.* (1998) suggested that leaves of shade grown plants are relatively thin. They have a high SLA and low leaf mass density. This is associated with relatively few and small palisade mesophyll cells per unit area. Fukai *et al.* (1984) in Cassava and Rodriguez *et al.* (2000) in wheat also reported a higher SLA in shaded plants. SLA is a much more variable parameter than LWR; in other words, leaf area is more plastic than leaf weight (Fitter and Hay, 1987). Most probably LWR is a reflection of the plant ability to maintain its normal developmental pattern and it will be found to be constant over a range of flux densities to which a plant is adapted. Non-adapted plants in shade, however, exhibit etiolation and LWR is then reduced (Fitter and Hay, 1987).

LAR is the ratio of leaf area to plant dry mass and reflects the size of photosynthetic surface relative to the respiratory mass. Generally, it is factored into two terms, Leaf Weight Ratio (LWR) and Specific Leaf Area (SLA) (Pearcy *et al.*, 1989). So the increment of LAR with increasing shade percentages was mainly due to an increase in SLA, compared to LWR (Table 2). Worku *et al.* (2004) found that SLA and LAR both increased as an acclimation characteristics to reduced irradiance in common bean.

Increasing shade percentage delayed flowering and physiological maturity and increased grain filling period, which led to an increase in mean grain weight. However, grains per pod and per plant decreased with increasing shade levels. Consequently, grain yield per unit area did not differ significantly among shading treatments (Table 2). This is attributed to compensating growth of yield components, when distribution of some yield limiting resources is affected by genetic and environmental factors (Van schoonhoven and Voysest, 1991).

Increase in shoot dry weight with increasing shade levels, reduced HI. This could be due to an increase in vegetative growth duration (Table 2) and decreased root/shoot ratio under shade (Sidique *et al.*, 1990; Urbas and Zobel, 2000), which allocated more assimilates for shoot rather than root growth. Considering increases in LAI, SLA and LAR and no significant changes in LWR and grain yield per unit area with increasing shade levels, it can be concluded that common bean could compensate the reduction in radiation and thus photosynthesis by increasing leaf area and then could prevent seed yield loss under shade stress via increasing grain filling duration and grain weight.

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