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Research Article

Effect of Microenvironment under Different Colour Shade Nets on Biophysical Parameters and Radiation Use Efficiency in Spinach (*Spinacia oleracea* L.)

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ABSTRACT

A study was conducted at research farm of ICAR-Indian Agricultural Research Institute, New Delhi, to investigate the effects of microenvironment under different colour shade nets on the growth and development of vegetable spinach (*Spinacia oleracea* L.) during summer and rainy seasons, 2012. Spinach crop was sown under four different colour shade nets namely white, black, red and green with 40% mesh size and a control (without shade nets). Different crop growth parameters such as biomass, total leaf area, root and shoot length, number of leaves, leaf water potential, relative water content, chlorophyll content, water and radiation use efficiency and yield were measured at different growth stages after sowing. Results showed that plant grown under different colour shade nets had better crop growth, water and radiation use efficiency and yields compared to control. Green shade net had the best performance followed by red, black and white. Colour shade nets can be effectively used for growing spinach during adverse weather conditions.

Key words: Leaf water potential, Relative water content, Water use efficiency, Radiation use efficiency, Spinach

Introduction

It is well known that plants response to changes in the spectrum of electromagnetic radiation by modifying its morphology and physiological functions to be adapted to diverse environmental conditions (Kasperbahuer and Hamilton,1984). Such changes are governed by phytochromes, which have maximum absorption in red and blue or ultraviolet regions of the spectrum (Li *et al*., 2000). Phytochromes have the ability to identify changes in light composition and bring photomorphogenetic responses (Kim *et al*., 2004) and affect growth and development morphology (Stuefer and Huber, 1998), leaf and stem anatomy (Schuerger *et al*., 1997) distribution of photosynthetic products, photosynthetic efficiency and chemical composition.

Incident radiation spectrum in the visible region is modified by cromatinet coloured net, which increase the amount of diffuse light like transmission of photoactive radiation in the 400-540 nm wavelength region with the help of blue shade net, and by red shade net in the 590-760 nm region. Coloured shade nets exhibit special optical properties for control of light and modify the microclimate and provide physical protection against excessive radiation, insect pests and environmental changes (Shahak *et al*., 2004). Keeping these in background, a study was undertaken to test the effect of different coloured shade nets on growth, yield, radiation and water use efficiency in vegetable spinach.

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Materials and Methods

This study was conducted at the research farm, Centre for Protected Cultivation Technology, ICAR-Indian Agricultural Research Institute, New Delhi. Four colour shade nets *viz*., green, red, black, white with shading intensity of 40% were selected for testing. Color shade nets were obtained under the trade mark ChromatiNet from Polysack Plastics Industries (Nir-Yitzhak, Israel). Spinach (var. Pusa Bharati) was sown on 28th April, 2012 for summer (April to June 2012) and 6th July, 2012 for rainy (July to September 2012) season crop. The crop were line-sown with three replications in each net (black, white, red, green), and control (without shade). Fertilizer was applied by drip irrigation. Weeding was done manually as and when needed.

Three randomly selected plants were collected and their fresh and dry weights (oven-dried at 65°C for 48 h) were obtained. Leaf area was measured by using LI 3100 area meter (LI-COR). A pressure bomb (PMS Instruments Co, USA) was used to record the leaf water potential following Scholander *et al* (1964). Relative water content (RWC) was calculated using the following formula:

$$\text{RWC (Relative water content)} = \frac{\text{Turgid wt of sample- Fresh wt of sample}}{\text{Turgid wt of sample - Dry wt of sample}} \quad \ldots(1)$$

Chlorophyll content in fresh leaf was calculated using DMSO method:

$$\text{Total Chlorophyll content (mg/g of fresh weight)} = \frac{(20.2 \times A_{645} + 8.02\ A_{663}) \times V}{1000\ W} \quad \ldots(2)$$

where, A_{645} = Absorbance at 645 nm, A_{663} = Absorbance at 663nm, V = Final volume of chlorophyll extract in DMSO, and W= Weight of the plant sample

Water use efficiency of the crop was calculated as:

$$\text{Water use efficiency (WUE)} = \frac{\text{Biomass or yield of the crop (g m}^{-2})}{\text{Amount of water used in mm (ET}_c)} \quad \ldots(3)$$

Radiation use efficiency (RUE) of the crop was estimated as:

$$\text{Radiation use efficiency (RUE)} = \frac{\text{Amount of dry matter produced (g m}^{-2})}{\text{Amount of intercepted photoactive radiation (MJ m}^{-2})} \quad \ldots(4)$$

Intercepted photoactive radiation (IPAR) values were measured with the help of line quantum sensor. Radiation use efficiency (RUE) was calculated at weekly interval during the seasons.

Statistical analysis *viz*., computation of correlation coefficients, critical difference and Student t-test were carried out using MS Excel and SPSS (Ver. 10.0) packages. The required graphs were drawn using MS Excel software packages.

Results and Discussion

Crop biomass under colour shade nets

Total dry biomass of plants under control was significantly lower compared to shade nets, possibly due to better microclimatic condition in colour shade nets. The harvested biomass of the summer crop was 20-22, 29-33, 48-59 and 63-67% higher in white, black, red and green shade nets. However in rainy season, the biomass was lower in black and white as compared to control. The increase in biomass was 20-48% in red and 28-57% in green shade net (Fig. 1).

Leaf area under different colour shade nets

Results showed that in summer season, the leaf area had lowest value in control, followed by white, black, red and green shade net. The percentage increase in leaf area was 26.8-35.5 % under white shade net, 41.0-57.2% under black shade net and 71.3-86.4% under red shade net as compared to control and nearly double under green shade net. In rainy season, leaf area was found to be highest in green followed by red, control, white and black shade nets. The percentage reduction in leaf area under black colour shade net was 13-27%, under white shade

Fig. 1. Crop biomass under colour shade nets measured on 20, 40 and 58 days after sowing (DAS) during summer and rainy seasons

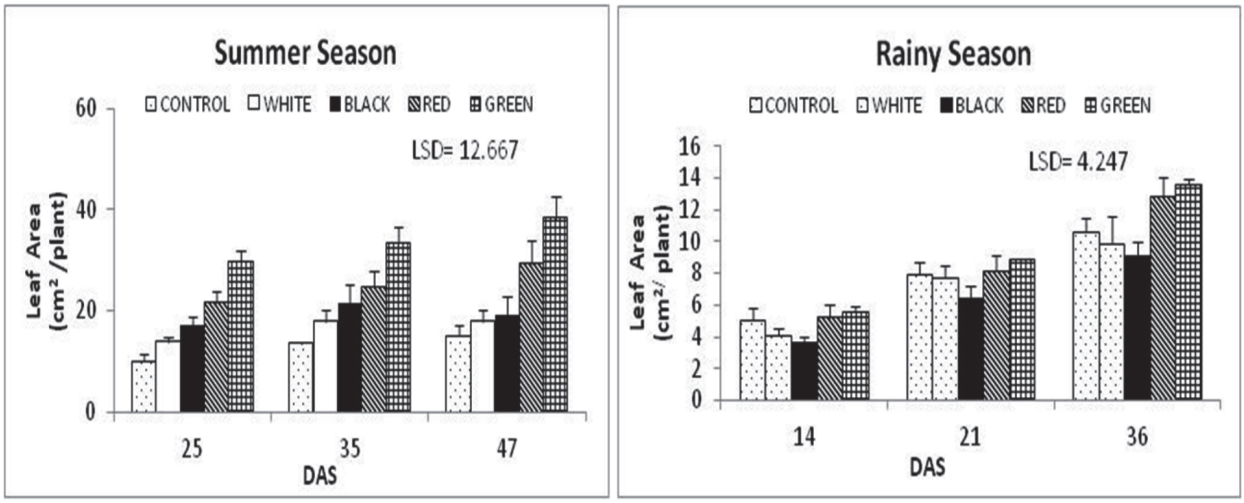

Fig. 2. Leaf area under colour shade nets on 14, 21 and 36 days after sowing (DAS) during summer and rainy seasons

net was 6-19% as compared to control. The percentage increase in leaf area compared to control was 20-22% under red shade net and up to 28% under green shade net (Fig. 2).

Root and leaf lengths and plant height under different colour shade nets

Plant height in summer spinach was maximum under green shade net, followed by red, black, white nets and control. Under green shade net, leaf length was nearly double as compared to control. Leaf length was 62-93, 15-40 and 8-17% higher under red, black, and white shade nets compared to corresponding values in control. During summer, root length was higher in red, followed by green, black and white nets, and the control. The increase in root length as compared to control was 46-71, 37-59, 24-47 and 10-32% under red, green, black and white shade nets.

In the rainy season, however, the root and leaf length and total plant height were higher in control, followed by green, red, white and black

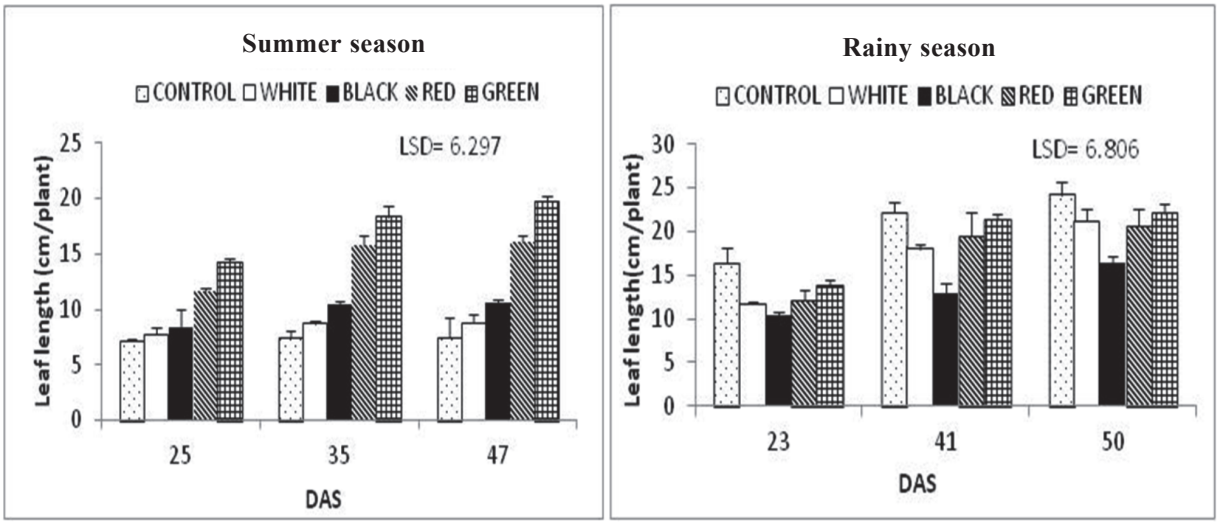

Fig. 3. Leaf length changes at three different days after sowing (DAS) under colour shade nets

shade nets. The leaf length was 8-15, 11-26, 12-19 and 32-41% lower in green, red, white and black shade nets, compared to control. Similarly, root length was 7.5-16.7% lower in green shade net, while it was 11-38, 16-40 and 36-48% lower under red, white and black nets compared to control (Fig. 3).

Leaf water potential and relative water content under different colour shade nets

Leaf water potential measured in summer was higher in green shade net followed by red, white, black nets and control. The increase was 5-8, 7-12, 8-13 and 10-14% under black, white, red and green nets compared to control (Fig. 4). Similarly, the RWC was higher in green (43-91%), followed by red (41-90%), white (36-85%) and black (40-67%) shade nets compared to control. However, in the rainy season, no significant difference in RWC was recorded (Fig. 5).

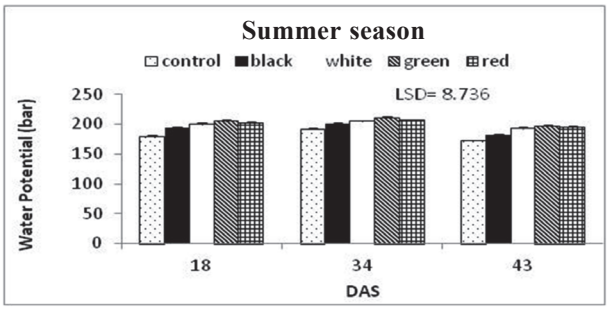

Fig. 4. Leaf water potential under colour shade nets on three DAS in summer season

Leaf chlorophyll content

Colour shade nets modified light concentration under different nets, which affected the chlorophyll concentration. Plants in summer had considerably higher chlorophyll content in red and green shade nets (54-67 and 52-62%), followed by white (19-35%) and black (12-31%), compared to control. In rainy season, however, the control exhibited higher chlorophyll content than the colour shade net. Chlorophyll concentration index measured by the SPAD chlorophyll meter showed that red, green, white and black shade nets had 10.7, 9.9, 6.8 and 4.4% higher values compared to control (Fig. 6). Guichard *et al*. (2001) observed that the shaded plants leaves had larger pigment-rich chloroplasts. Increasing irradiance suppressed the growth and leaf chlorophyll content of Dianthus and Rhododendron, in vitro (Marks and Simpson, 1999).

Water use efficiency, IPAR and radiation use efficiency under different colour shade nets

The water use efficiency was also higher under net than control. It was also higher in summer compared to the rainy season in all the colour shade nets and also in control (Table 1). Similarly, the Intercepted Photosynthetically

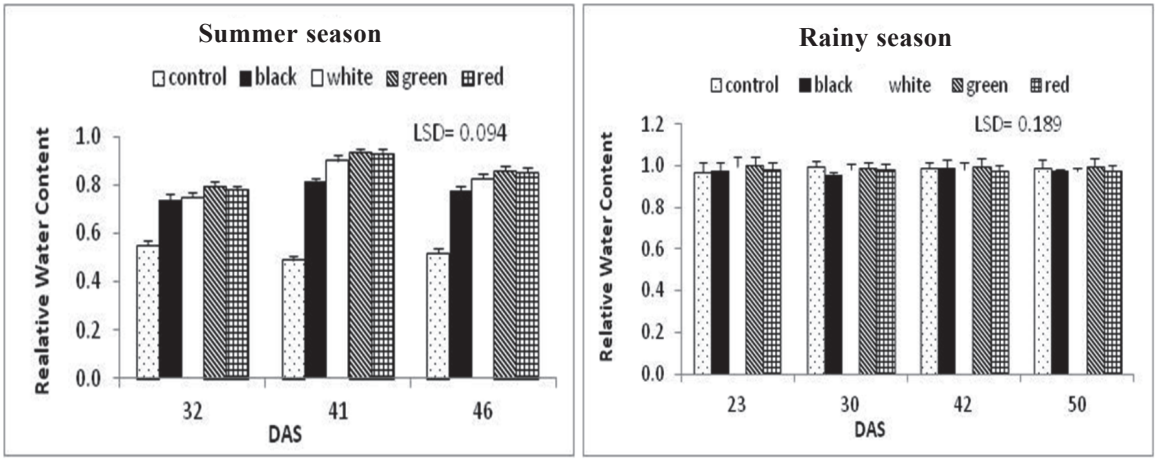

Fig. 5. Relative water content under different colour shade nets measured at three different DAS during summer and rainy seasons

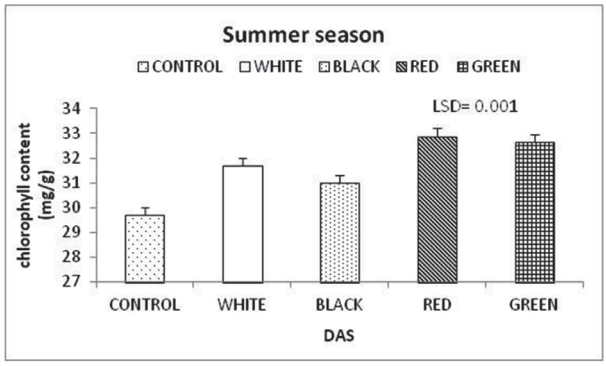

Fig. 6. Chlorophyll concentration index under colour shade nets and control (no net) at 38 DAS during summer season

in control; the nets had nearly double use efficiency than control (Table 3).

Yields under different colour shade nets

The crop yields were higher under nets than the control during summer season. Yields were 66, 59, 24 and 22% higher in green, red, black and white nets compared to control. However, in rainy season, black and white shade nets resulted in lower yields than the control (Table 4).

Further analyses indicates that the least significant difference (LSD) in summer for leaf area was 12.67, biomass 0.13, leaf length 6.30,

Table 1. Water use efficiency (kg ha^{-1} mm^{-1}) in control (no net) and in different colour shade nets during summer and rainy seasons

Season	Control	Black	White	Red	Green
Summer	4.12 ± 0.03	4.57±0.06	5.07±0.17	6.01±0.09	6.27±0.05
Rainy	2.7±0.13	2.92±0.09	3.4±0.11	5.8±0.23	6.3±0.29

Active Radiation (IPAR) was also higher in nets in summer, although no significant changes were recorded during rainy season (Table 2). Radiation use efficiency was also higher in nets compared to control. During summer, it was 9-14 and 27-57% higher in white and black nets compared to control. In red and green shade nets, the radiation use efficiency was nearly double compared to control. This could be attributed to a better crop growth under colour shade net in summer. During rainy season, radiation use efficiency was lowest

water potential 8.74, RWC 0.09 and chlorophyll content was 0.001. While during rainy season the LSD were 4.25, 0.12, 6.81, and 0.19 for leaf area, biomass, leaf length and RWC, respectively. These are in agreement with others e.g., Loughrin and Kasperbahuer (2001) reported that when soil covered with red plastic, *Ocimum basilicum* produced greater leaf area, biomass and yield. Similarly, Li *et al*. (2000) observed that, when leaf area reduced, photosynthetic area and dry biomass also decreased. Vegetative growth was

Table 2. Intercepted photosynthetically active radiation under colour shade nets during summer and rainy seasons

Days after sowing	Control	Black	White	Red	Green
		Summer season (April-June)			
11	178.8±1.3	186.8±1.4	182.2±1.5	181.2±1.3	180.5±2.2
23	368.0±1.2	372.8±1.4	375.1±1.7	372.8±1.4	371.8±1.7
31	533.2±2.0	557.2±1.3	543.5±2.0	540.2±1.5	538.8±1.1
		Rainy season (July-September)			
13	78.5±1.5	77.9± 0.9	75.9±0.8	75.9± 1.8	79.9±0.7
25	161.3±1.2	160.0±1.1	156.1±1.2	155.9± 0.6	160.5± 1.7
37	226.9 ± 0.5	225.1±0.5	219.5±1.1	219.3± 1.7	225.8± 1.2

Table 3. Radiation use efficiency (g/MJ) on different days after sowing under different colour shade nets during summer and rainy seasons

Days after sowing	Control	Black	White	Red	Green
		Summer season (April-June)			
11	0.07±0.003	0.11±0.0071	0.08±0.0023	0.25±0.0049	0.28±0.001
23	0.10±0.0021	0.12±0.0027	0.11±0.0020	0.19±0.0018	0.20±0.0027
31	0.11±0.0076	0.14±0.0021	0.12±0.0013	0.18±0.0011	0.19±0.003
		Rainy season (July-September)			
13	0.22±0.0077	0.40± 0.0015	0.59±0.002	0.6± 0.001	0.62±0.003
25	0.23±0.0062	0.25±0.0043	0.31±0.003	0.42± 0.002	0.44± 0.006
37	0.19 ± 0.008	0.21±0.002	0.28±0.006	0.31± 0.008	0.33± 0.004

Table 4. Yield (kg ha^{-1}) under different colour shade nets

Season	Control	White	Black	Red	Green
Summer	8950±256	10931±146	11078±183	14233±256	14893±330
Rainy	2525±64	1530±34	1465±30	2605±96	3580±94

higher under red and yellow nets compared to black, dwarfing was induced by blue net, while grey net increased branching and reduced leaf size and variegation in *Pittosporum* (Oren-Shamir *et al*., 2001; Shahak, 2008).

Accumulation of photosynthetic products was enhanced through shading. Normally, environmental variations alter the distribution of photosynthetic products within the plant and modify the root-shoot ratio. Red light induces the expression of a gene that codifies a key enzyme during synthesis of gibberelline (Toyomatsu *et al*., 1998). The higher value of leaf and root length in the present study observed in spinach could be attributed to the variation in light intensity and temperature.

Plant under shade nets had lower leaf vapour pressure deficit and higher leaf water potential than the control (Smith, 1995). Radiation use efficiency is enhanced by the diffuse component of the incident radiation under colour shade nets (Healey *et al*., 1998). Diffuse light cause help to increase radiation use efficiency, yields and affecting timing of plant flowering and its amounts (Gu *et al*., 2002; Sinclair *et al*., 1992; Gangopadhyay *et al*., 1970). Yield was also affected by a better environment under colour shade nets. Rylski and Spigelman (1986) reported that during summer season, with the help of shade nets, radiation reduction was 26%, which increased *C. annuum* production compared to those in full sunlight. Reduced total and

Table 5. Statistical analysis for summer and rainy season

			Sum of Squares	df	Mean Square	F	Sig.
Summer Season							
Leaf area * tr	Between Groups	(Combined)	2163.699	14	154.550	8.553	0.000
	Within Groups		542.108	30	18.070		
	Total		2705.807	44			
biomass * tr	Between Groups	(Combined)	13.966	14	0.998	506.679	0.000
	Within Groups		0.059	30	0.002		
	Total		14.025	44			
Leaf length * tr	Between Groups	(Combined)	773.199	14	55.229	12.408	0.000
	Within Groups		133.530	30	4.451		
	Total		906.729	44			
RWC * tr	Between Groups	(Combined)	0.826	14	0.059	45.754	0.000
	Within Groups		0.039	30	0.001		
	Total		0.864	44			
Chlorophyll * tr	Between Groups	(Combined)	1.065	14	0.076	152.846	0.000
	Within Groups		0.015	30	0.000		
	Total		1.080	44			
Water potential * tr	Between Groups	(Combined)	4899.244	14	349.946	40.482	0.000
	Within Groups		259.333	30	8.644		
	Total		5158.578	44			
Rainy Season							
Leaf area * tr	Between Groups	(Combined)	508.893	14	36.349	17.791	0.000
	Within Groups		61.295	30	2.043		
	Total		570.188	44			
biomass * tr	Between Groups	(Combined)	3.941	14	0.282	328.057	0.000
	Within Groups		0.026	30	0.001		
	Total		3.967	44			
Leaf length * tr	Between Groups	(Combined)	605.379	14	43.241	8.288	0.000
	Within Groups		156.520	30	5.217		
	Total		761.899	44			
RWC * tr	Between Groups	(Combined)	0.014	14	0.001	0.279	0.002
	Within Groups		0.109	30	0.004		
	Total		0.123	44			

marketable yield of non-shaded plants was probably due to high heat stress.

Conclusion

During summer season, biomass, leaf area and yield were higher in colour shade nets compared to the control. During rainy season, yield was reduced as compared to summer under all the colour shade nets and also in control excess humidity and rainfall in rainy season was harmful to the crop. Radiation use efficiency was also higher under colour shade nets as compared to the corresponding value under control. During summer, the yield was the highest in green shade net followed by red, black, white nets and the control, but during rainy season, control had higher yield than the white and black shade nets.

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