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Impact of Leaf Area Index on the Absorption of Photosynthetically Active Radiation in Barley (*Hordeum vulgare* L.) Crop under Diverse Sowing Dates and Cultivars

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Photosynthetically Active Radiation (PAR) is crucial for the physiological development of crops as it plays a key role in photosynthesis. A study was conducted at the CCS HAU Research Farm in Hisar, Haryana, during the rabi season of 2022-23 using a Split-plot design to explore the effect of Leaf Area Index (LAI) on absorbed PAR under different sowing dates and most commonly grown varieties of the region. Four barley cultivars (V1-BH 393, V2-BH 902, V3-BH 946, and V4-BH 885) were selected and grown under different sowing dates (D1 - 9th November 2022, D2 - 24th November 2022, D3 - 9th December 2022, D4 - 24th December 2022). The LAI and absorbed PAR were measured based on field observations. The findings indicated that the timely sown crop (D1) absorbed the highest PAR (86 to 95 %) and decreased absorption as sowing was delayed with the last date of sowing only absorbing 83 to 93 % of incoming PAR. D1 had more PAR absorption and LAI leading to more photosynthate accumulation and enhanced dry matter accumulation and an enlarged grain-filling period. The cultivar **BH 885** absorbed more PAR followed by BH 946, BH 902 and BH 393. The results showed a clear and strong positive correlation between LAI and absorbed PAR in all the treatments. Thus, early sowing dates and BH 885 variety is recommended for semi-arid climate of Hisar region in western Haryana.

Keywords: Barley crop; leaf area index; absorbed PAR; sowing dates and cultivars.

1. INTRODUCTION

Barley (*Hordeum vulgare L*.) is a significant rabi season crop, classified into three species: *H. vulgare L*. (six-rowed barley), *H. distichon L*. (two-rowed barley), and *H. irregular L*. (two-rowed barley). Barley can grow in a wide range of soils, from saline to poor-textured and is more drought-tolerant compared to other cereal crops. During the 2023-24 season, barley occupied 628 thousand hectares in India, yielding a total production of 1913 thousand tonnes, with an average yield of 3.0 t/ha (USDA, 2024). In Haryana (2023-24), barley covered 15.3 thousand hectares, yielding 53.54 thousand tonnes at an estimated 3486 kg/ha [1]. Major barley producing states include Rajasthan, Uttar Pradesh, Madhya Pradesh, Jammu and Kashmir, Himachal Pradesh, Haryana, and Punjab.

Photosynthesis is very crucial for physiological growth of Barley crop like any other crop, determining the plant's productivity. The spectral composition of incoming solar radiation is also essential in determining plant growth and yield. Solar radiation in the range of 400 to 700 nm, known as photosynthetically active radiation (PAR), is thus essential for photosynthesis and is the direct determining factor in plant growth [2]. In crop management, a careful understanding of the relationship between LAI and PAR is vital for maximizing crop productivity. A higher LAI can improve light interception and photosynthesis. The interception of PAR is influenced by the Leaf Area Index (LAI) and canopy structure [3,4]. Under projected climate variability scenarios, understanding of the relationship between LAI and PAR is essential for accurate yield predictions. This study focuses on understanding the relationship between PAR absorption and LAI in barley cultivars grown under diverse environmental conditions during the rabi season of 2022-23. The findings will provide valuable insights for the scientific community, extension agents and other stakeholders in agriculture and related fields.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted at the CCS HAU (Agricultural Meteorology Research Farm) in Hisar, Haryana (29°10'N latitude, 75°46'E longitude, 215.2 m altitude).

2.2 Climate

Hisar has a semi-arid, subtropical climate with extreme temperature variations. Due to south-westerly winds, the monsoon season begins in the first week of July and lasts until the second week of September. The Western Disturbance causes rainfall during the winter months. The weather is primarily dry from October to June, with scorching summers (maximum temperatures exceeding 45°C) and freezing winters (can go below 0 °C). The average annual rainfall is 450 mm, mainly due to the southwest

monsoon, and the region experiences light showers due to western disturbances in winter. The yearly rainfall coefficient of variation might vary from 45 to 50 percent. Monsoon season fluctuations for rainfall can reach about 80%, while winter season seasonal variation can reach up to 65%.

Bright sunshine hours (BSSH) (Fig. 1) was found to be higher than normal at many SMWs (Standard Meteorological weeks) during the crop-growing season (2022-23). During the vegetative phase at first SMW (1.4 hours), BSSH was at its lowest. From there, it continued to rise until reaching its maximum during the 14th SMW (8.7 hours) at the physiological maturity stage.

2.3 Experimental Setup

Barley Crop (*Hordeum vulgare L.*) was sown with four different cultivars (V1-BH 393, V2-BH 902, V3-BH 946, and V4-BH 885) under four sowing dates: **D1** (D1 - 9th November 2022), **D2** (24th November 2022), **D3** (- 9th December 2022) and **D4** (24th December 2022). LAI and absorbed PAR were measured during the crop's growth stages from tillering to physiological maturity. The experiment was conducted using Split-Plot design. The crop was grown using Practises followed by farmers in Haryana state and as recommended by Package and Practises of CCS HAU, Hisar.

2.4 Agronomic Practices

2.4.1 Seed rate and sowing

The crop was sown at a depth of 5 cm using the *pora* method, maintaining a row spacing of 22.5 cm, with the help of a hand-pulled plough. A seed rate of 100 kg per acre was used for both timely and late sowing conditions.

2.4.2 Irrigation application

First irrigation during 2023 was applied on 15th December (D1); 5 January (D2); 31 January (D3 and D4) in different sowing dates. Similarly, the second Irrigation were applied for D1 and D2 sowing dates on 8th February and D3 and D4 sowing dates on 18th February 2023. The depth of irrigation (water level) provided was 60 cm and the method adopted for irrigation was flood irrigation.

2.4.3 Weed management

Following the initial irrigation to attain field capacity in the soil, weeding and hoeing were performed utilizing the traditional long-term hand hoe technique.

2.4.4 Leaf Area Index (LAI)

Plant leaf samples were taken from individual plots and were used for the measurement of leaf area (cm^2). Leaf area was measured using an LAI meter (LI-3000 Area Meter, LI-COR Biosciences, Nebraska, USA) to calculate the LAI. The leaf area was recorded at different growth stages from tillering to physiological maturity. using the formula given below LAI was calculated:

$$LAI = \frac{Leaf\ Area\ (cm^2)}{Total\ Land\ Area\ Covered\ by\ plant\ (cm^2)}$$

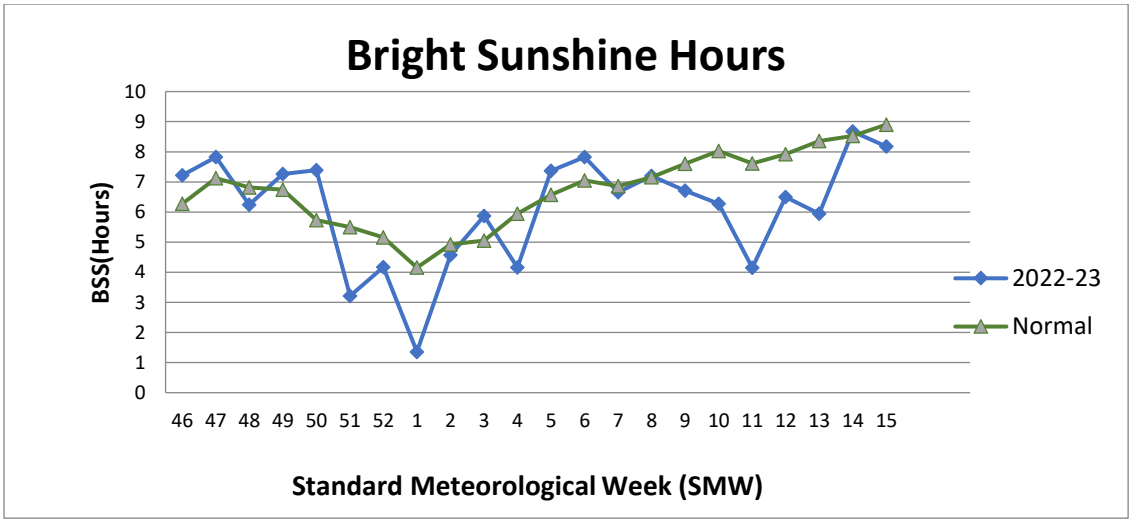

Fig. 1. Bright Sunshine Hours (Hours) along with normal during cropping season of 2022-23

2.5 Photosynthetically Active Radiation (PAR)

PAR was measured using a line quantum sensor (Model L1-191R-BNC-2) to assess solar radiation in the range of 400-700 nm. Unit of measurement of line quantum sensor is micro moles/m^2/sec which was computed to W/m2 by multiplying with the constant (0.219). The PAR observations were taken at two different altitudes of the crop canopy: one meter above the canopy and at the ground level below the canopy. The observations were made during all stages: tillering, jointing, booting, anthesis, hard dough, and physiological maturity between 12:00 and 13:00 hrs. The sensor was positioned above the canopy with its face toward the sky to obtain the incident PAR, inverted toward the ground to observe the reflected PAR, and diagonally on the ground at random sites to obtain the transmitted PAR. Absorbed PAR was calculated using the equation:

$$Absorbed\ PAR = 1 - Reflected\ PAR - Transmitted\ PAR$$

2.6 Statistical Analysis

Correlation coefficients were calculated to study the relationship between LAI and absorbed PAR. The experimental site data was statistically analyzed using ANOVA. The significance of the treatment effect at 5% probability was tested using the F-test. The critical difference (C.D.) was used to determine whether the mean of the two treatments diverged significantly.

3. RESULTS AND DISCUSSION

Leaf area index (LAI): Table 1 shows the LAI recorded at various phenophases of the barley crop during the 2022-2023 growing season. The LAI increased as the crop progressed through growth stages, peaking at the anthesis stage and then decreased until physiological maturity. This increase in LAI from the tillering phase onward is attributed to enhanced solar radiation absorption, which boosted photosynthesis rates in the Barley crop. Additionally, the rise in leaf number and plant height contributed to the increase in LAI in the Barley crop [5]. After anthesis, as the plant entered senescence, the LAI declined until maturity. The highest LAI was observed in the timely sown crop (D1) followed by D2, D3 with the lowest LAI recorded in the late-sown crop (D4), consistent with findings by Navreet et al. [6] and Renu et al. [7] for the same crop and under similar treatments. At the anthesis stage in 2022-2023, the LAI for D1 was 4.50, D2 was 4.26, D3 was 4.19 and D4 was 3.98. Navreet et al. [6], Karan Chabbra [8] and Saha et al. [9] also reported approx. LAI values of 4-5 at anthesis, in line with the findings of this experiment. Among varieties, BH 885 had the highest LAI, followed by BH 946, BH 902 and BH 393. BH 885 exhibited the highest LAI due to extensive tillering and a greater number of leaves. At the anthesis stage in 2022-2023, BH 885 recorded an LAI of (4.28), followed by BH 946 (4.25), BH 902 (4.22), and BH 393 (3.19). These results are in tune with the experiment performed by Navreet Bassi [10].

Absorbed photosynthetically active radiation (PAR%): Fig. 2 shows the absorbed photosynthetically active radiation (Absorbed PAR %) in Barley crop for different dates of sowing and varieties at various phenophases for 2022-23 Rabi season. This increase in absorption was linked to a rise in available solar radiation for the crop [11], which further declined due to senescence and chloroplast protein degradation, ultimately reducing PAR absorption. The highest PAR absorption occurred in the timely sown crop (D1) followed by D2, D3, and the lowest in the late sown crop (D4) across all phenological stages. Early sown crop had robust plant growth and more leaf area index than the late sown crops. Similar trends were observed by Navreet et al*.* [6] and Chabbra et al. [8] in barley crop and Dutta et al*.* [12] reported similar findings in rice. At the anthesis stage in 2022-2023, PAR absorption was 94.88 % for D1, 93.90% for D2, 92.88% for D3 and 91.79% for D4. Among varieties, BH 885 absorbed the most PAR during Booting (93.77%) Anthesis (93.98%), hard dough (89.00 %) and physiological maturity (85.36%) in 2022-2023. BH 946 had the highest PAR absorption during jointing (89.22%). BH 393 exhibited the lowest PAR absorption across most phenophases, except during tillering stage, where it recorded the highest PAR absorption at 86.13%. The main reason behind this finding is that as the crop progressed, BH 885 had gained and retained more number of tillers and leaves contributing to more Leaf area index, which ultimately intercepted and Absorbed more PAR (photosynthetically active radiation).

Correlation between LAI and absorbed PAR (%): Table 2 presents a strong and significant positive correlation between LAI and absorbed PAR across all phenophases under consideration *i.e.* tillering, jointing, booting,

Table 1. Leaf Area Index (LAI) in different phenophases of the crop for different barley varieties for 2022-23 rabi season

	Leaf Area Index (LAI)						
Treatments	**Tillering**	**Jointing**	**Booting**	**Anthesis**	**Milking**	**Hard Dough**	**Physiological Maturity**
9th Nov 2022	2.79	3.66	4.43	4.50	2.48	1.83	1.07
24th Nov 2022	2.65	3.57	4.08	4.26	2.36	1.62	1.02
9th Dec 2022	2.47	3.50	3.96	4.19	2.25	1.55	0.95
24th Dec 2022	2.27	3.35	3.85	3.98	2.12	1.39	0.93
CD at 5%	0.03	0.03	0.06	0.04	0.03	0.11	0.04
SE(m)	0.01	0.01	0.01	0.01	0.01	0.03	0.01
BH 393	2.50	3.47	4.04	4.19	2.26	1.55	0.94
BH 902	2.53	3.50	4.06	4.22	2.28	1.58	0.97
BH 946	2.56	3.54	4.10	4.25	2.32	1.62	1.01
BH 885	2.59	3.57	4.12	4.28	2.35	1.65	1.04
CD at 5%	0.03	0.04	0.06	0.03	0.02	0.02	0.05
SE(m)	0.01	0.01	0.01	0.01	0.01	0.01	0.01

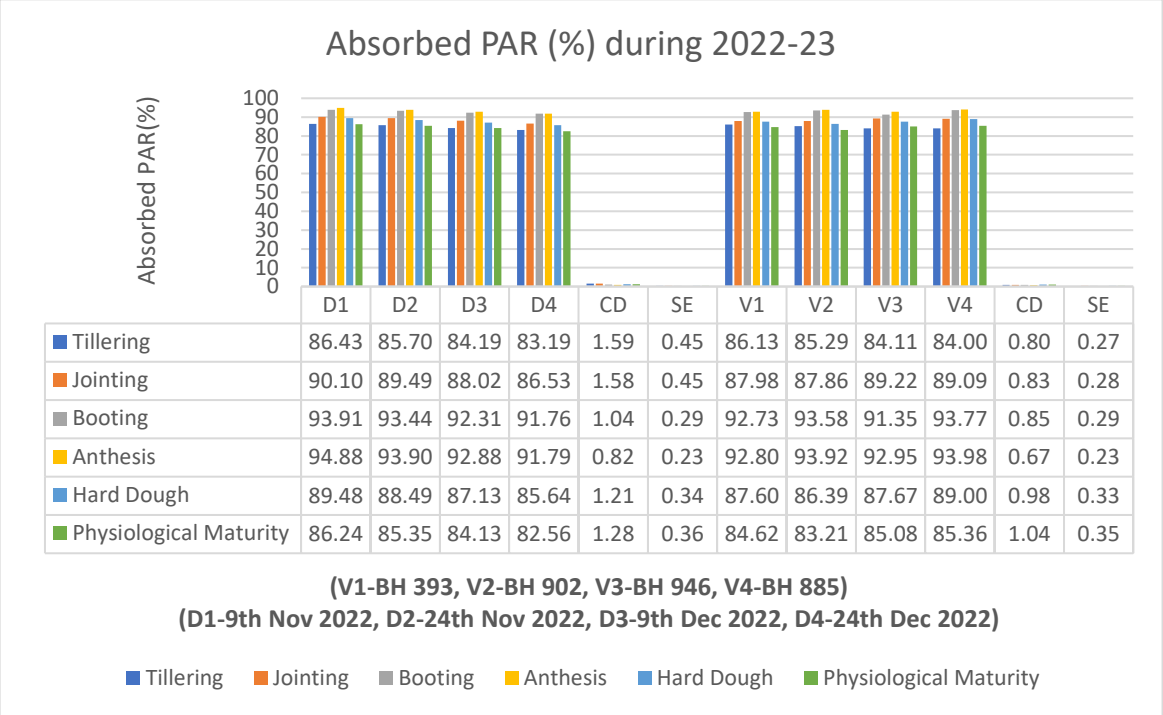

Fig. 2. Absorbed photosynthetically active radiation (Absorbed PAR %) for different barley phenophases and varieties for 2022-23 rabi season

anthesis, hard dough and physiological maturity. This correlation indicates that an increase in LAI leads to higher PAR absorption. As the barley crop grows, LAI increases until anthesis, after which it declines till physiological maturity, mirroring the same trend in PAR absorption, which peaks at anthesis then decreases till physiological maturity. Singh et al. [13] observed that solar radiation absorption declines as LAI decreases due to leaf senescence, reaching its peak during early anthesis. The strongest correlation was found at the tillering stage (0.99) and jointing (0.99) Phenophases with a 99% significance level, highlighting the effect of LAI on PAR absorption. The weakest correlation was observed at physiological maturity (0.92), with a 95% significance level, reflecting a reduced influence of LAI on PAR absorption. At anthesis, a strong positive correlation (0.98) was noted, with a 99% significance level. Similar results were also found by Navreet et al. [6], Chabbra et al. [8] and Renu et al. [7] where a strong positive correlation between PAR and LAI was revealed.

Table 2. Correlation coefficient for the 2022–2023 rabi season to analyze the relation between LAI and absorbed PAR (%)

	Tillering	Jointing	Booting	Anthesis	Hard Dough	hysiologicalMaturity
LAI	0.99**	0.99**	0.96**	0.98**	0.97**	0.92*

***1% level of significance *5 % level of significance*

4. CONCLUSIONS

This study aimed to find the effect of LAI owing to different dates of sowing and different varieties on absorbed PAR within the canopy of barley crop under conditions of Hisar region in western Haryana, India. The results concluded that delayed sowing leads to a reduction in both LAI and PAR absorption, as found in D1 with the highest values, while the lowest values for D4 treatment. A strong correlation between LAI and PAR absorption observed across all phenophases, indicated that the decrease in leaf area corresponds to a decrease in the ability of crop to absorb PAR (photosynthetically active radiation) for photosynthesis which could be determinantal to growth, stage and final yield of the Barely crop. Likewise, BH-885 possessed higher LAI and PAR absorption among different cultivars which might be due to varietal superiority and a greater number of tillers and leaves. The LAI could again result in variability of PAR and yield among different crop varieties. Thus, considering the results early sowing dates and BH 885 variety is recommended for Hisar region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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