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Original Research Article

Disparities in the phenomenological stages of malt barley (*Hordeum vulgare* L.) caused by fluctuating fertility levels and liquid biofertilizers in the semi-arid region of Rajasthan, India

Gopal Saini
Department of Physical Sciences, Lords University, Chikani, Alwar – 301028, Rajasthan, India
Corresponding author, E-mail: gopal.lordsuniv@gmail.com

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ABSTRACT
At the Department of Physics, Lords University, Chikani, Alwar, Rajasthan, a field experiment was carried out during the rabi season of 2022-23 and 2023-24 on clay loam soil with low available nitrogen (278.36 to 279.42 kg ha^{-1}), medium available phosphorus (18.73 to 20.39 kg ha^{-1}), and high available potassium status (328.40 to 332.72 kg ha^{-1}) with a slightly alkaline in reaction. The goal of the experiment was to assess how malt barley responded to fertility levels and biofertilizers. With 15 treatment combinations consisting of three fertility levels—70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1}, 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1}, and 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}—and five liquid biofertilizers—control, Azotobacter, PSB, KMB, and Azotobacter + PSB + KMB—the experiment was set up in a randomized block design (Factorial). As compared to applications of 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} and 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}, the experimental results showed that the malt barley crop required the most days to reach heading, 50% anthesis, and physiological maturity when fertilized with the highest fertility levels, i.e., 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1}. Azotobacter + PSB + KMB seed inoculation outperformed single inoculations of Azotobacter, PSB, and KMB in terms of maximum days to heading, 50% anthesis, and physiological maturity among other liquid biofertilizers. According to the study's findings, applying 70 kg N, 40 kg P_2O_5, and 25 kg K_2O ha^{-1} together with liquid biofertilizers Azotobacter, PSB, and KMB helped to prolong the crop's growth period and boost malt barley crop output.

1. Introduction

After wheat, rice, and maize, barley (*Hordeum vulgare* L.) is the fourth most important cereal crop in the world. It accounts for 15% of the consumption of coarse grains and roughly 7% of global cereal production. Due to its greater flexibility, barley may be produced in a variety of unfavorable climatic circumstances, including drought, salt, and alkalinity, and is grown in temperate, tropical, and subtropical regions of the world [1]. Because its hull and glumes are securely glued to the kernel and stay attached to the grain after threshing, barley is the cereal of choice for malting. Due to rising beer and other malt-based product consumption in many nations, two-rowed barley has recently become more popular in the malting and brewing industries [2]. Malt consumption has also shifted, with whiskies using 8% of malt and breweries using the remaining 60%–62% [3, 4]. The availability of nitrogen (N) has a significant impact on malting barley output due to its impacts on yield, grain protein content, and malting quality. Too much nitrogen in the soil can increase the kernel's protein level, which is not what you want for malting. High protein barley grains are more challenging to malt, produce fewer extracts, and might make brewing more challenging.

One of the most crucial prerequisites in this regard is thought to be adequate mineral fertilization. The most crucial nutrient for the growth and development of plants is nitrogen. Photosynthesis depends on chlorophyll, of which it is a crucial component. Plant metabolism is significantly influenced by phosphorus feeding, participating in a range of biological reactions. By controlling the cell membrane and maintaining the protoplasm at the right level of hydration, potassium plays a crucial part in the upkeep of cellular organisms. It gives plants resistance to bacterial and fungal infections by activating the enzymes involved in the metabolism of proteins and carbohydrates as well as the translocation of carbohydrates.

By fixing atmospheric nitrogen both with and without plant roots, solubilizing insoluble soil phosphates, producing plant growth substances in the soil, and solubilizing inorganic potassium from insoluble compounds and making it available for plant uptake, biofertilizers significantly increase soil fertility. In actuality, they are being encouraged to utilize the biological system of nutrient mobilization that is inherently present.

Azotobacter are free-living, abiotic soil microorganisms that are crucial to the natural nitrogen cycle because they bind atmospheric nitrogen that plants cannot reach. Higher crop yields are achieved by the conversion of administered phosphorus and insoluble phosphate into usable form by phosphorus solubilizing bacteria (PSB) [1]. The biofertilizer known as potassium mobilizing biofertilizer (KMB) is derived from a particular strain of *Frateuria spp*. beneficial bacteria that mobilize potassium. A helpful bacterium called *Frateuria spp*. can mobilize accessible potash close to plant roots. In order to reduce reliance on inorganic fertilizer alone, it is now important to encourage the combined use of chemical fertilizer and biofertilizer. Thus, the current study has been conducted in light of the aforementioned facts.

2. Materials and methods

The field experiment was carried out at the Department of Physics, Lords University, Chikani, Alwar, Rajasthan, India, between Rabi 2021–22 and 2022–23. Mild winters and moderate summers, with high relative humidity from June to September, are characteristics of this region's typical sub-tropical climate. The South West monsoon, which occurs from June to September, is mostly responsible for the region's 637 mm of average annual rainfall. Clay loam soil with a slightly alkaline response, low available nitrogen (278.36 to 279.42 kg ha^{-1}), medium available phosphorus (18.73 to 20.39 kg ha^{-1}), and high available potassium status (328.40 to 332.72 kg ha^{-1}) were the characteristics of the experimental site. With 15 treatment combinations consisting of three fertility levels—applying 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1}, 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1}, and 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}—and five liquid biofertilizers—control, *Azotobacter*, PSB, KMB, and *Azotobacter* + PSB + KMB—the experiment was set up in a randomized block design (Factorial). Prior to seeding, furrows were drilled with half a dose of nitrogen and the complete amounts of potassium and phosphorus. At the time of the initial watering, the remaining half dose of nitrogen was applied topically. Using a normal process, the seeds were treated with liquid biofertilizers using 5 ml kg^{-1} seed two to three hours prior to sowing. The "DWRB-137" variety of malt barley was employed as the test crop. With a seed rate of 100 kg ha^{-1} and an interrow spacing of 20 cm, the seeds were planted in a furrow that had been opened to a depth of roughly 4-5 cm. To guarantee healthy crop growth, the crop was irrigated during both experimentation years during crucial growth stages, namely tillering (30 DAS) and blooming (80 DAS), in accordance with recommendations. When the plants were completely dry, the produce was taken from each separate plot. Each plot's first border plants were gathered and taken out. After that, the net area's plants were picked, packaged separately, and labeled. The labeled bundles were left to scatter on the threshing floor. The number of days needed for boot leaf stage, 50% heading, 50% anthesis, and physiological maturity—all calculated from the date of sowing—was counted in each plot to document observations.

3. Results and discussion

Days to boot leaf stage

Fertility levels: According to a review of the data, raising the fertility levels of the malt barley crop did not significantly affect the number of days until the boot leaf stage in either the experimentation years or the pooled analysis (Table 1).

Liquid biofertilizers: Malt barley seed injected with liquid biofertilizers did not significantly affect the number of days required to reach the boot leaf stage, regardless of the year or pooled basis.

Table 1: Impact of biofertilizers and fertility levels on malt barley's physiological maturity stage, 50% anthesis, heading stage, and days to boot leaf stage.

Treatments	Days to boot leaf stage			Days to heading stage			Days to 50 % anthesis			Days to physiological maturity		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Fertility levels												
50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}	53.00	54.45	53.73	67.00	68.01	67.51	74.15	75.22	74.69	114.36	115.57	114.97
60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1}	54.60	55.50	55.05	69.70	70.81	70.26	76.85	78.07	77.46	116.06	117.27	116.67
70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1}	55.70	56.85	56.28	71.70	72.81	72.26	78.85	80.07	79.46	120.06	121.27	120.67
S.Em.+	1.25	1.27	0.89	1.26	1.28	0.90	1.28	1.30	0.91	1.31	1.34	0.94
C.D. (P = 0.05)	NS	NS	NS	3.61	3.64	2.52	3.65	3.71	2.57	3.74	3.83	2.64
Liquid biofertilizers												
Control	51.75	53.42	52.58	65.58	66.53	66.06	72.53	73.50	73.02	112.54	113.75	113.15
Azotobacter	55.75	56.75	56.25	70.75	71.86	71.31	77.95	79.17	78.56	118.21	119.42	118.82
PSB	54.42	55.42	54.92	69.42	70.53	69.97	76.62	77.84	77.23	116.88	118.09	117.48
KMB	53.83	55.08	54.46	68.83	69.94	69.39	76.03	77.25	76.64	116.29	117.50	116.90
Azotobacter + PSB + KMB	56.42	57.33	56.88	72.75	73.86	73.31	79.95	81.17	80.56	120.21	121.42	120.82
S.Em.+	1.61	1.64	1.15	1.63	1.65	1.16	1.65	1.68	1.18	1.69	1.73	1.21
C.D. (P = 0.05)	NS	NS	NS	4.66	4.70	3.26	4.72	4.79	3.31	4.83	4.95	3.41

Days to heading

Fertility levels: Data shows that fertility levels significantly impacted the number of days to heading in the study year and in the pooled analysis (Table 1). Maximum days to heading were required for 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1}, which was comparable to 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} in both years but much later than 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}. After applying 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1} on a pooled basis, it took 67.51 days to reach heading, which was 2.8 and 4.7 days faster than applying 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} and 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1}, respectively.

Liquid biofertilizers: During the study years and in the pooled analysis, data showed that inoculating malt barley seed with liquid biofertilizers both separately and in combination had a substantial impact on days to heading (Table 1). In comparison to seed inoculation with Azotobacter alone and co-inoculation of *Azotobacter* + PSB + KMB, the crop needed the fewest days to head under control, which was comparable to single inoculation of PSB and KMB in both years. *Azotobacter*, PSB, and KMB inoculation alone, as well as *Azotobacter* + PSB + KMB inoculation, significantly increased days to heading by 5.25, 3.91, 3.33, and 7.25 days, respectively, when compared to control on a pooled basis.

Days until 50% of the anthesis

Fertility levels: The data clearly show that fertility levels significantly impacted the number of days to 50% anthesis in both the pooled analysis and the experimentation years (Table 1). The highest number of days needed to reach 50% anthesis for the application of 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1} was considerably longer than that of 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}, but it was comparable to 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} in both years.

When 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1} was applied, it took 74.69 days to reach 50% anthesis, which was 2.7 and 4.8 days faster than when 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} and 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1} were applied, respectively.

Liquid biofertilizers: Based on the data, it can be concluded that days to 50% anthesis were significantly impacted by inoculating malt barley seed with liquid biofertilizers both alone and in combination over the research years and in the pooled analysis (Table 1). In comparison to seed inoculation with *Azotobacter* alone and co-inoculation with *Azotobacter* + PSB + KMB, the crop took the fewest days to reach 50% anthesis under control, which was comparable to single inoculation of PSB and KMB in both years. *Azotobacter*, PSB, and KMB inoculation alone, as well as *Azotobacter* + PSB + KMB co-inoculation, significantly increased days to 50% anthesis by 5.54, 4.21, 3.62, and 7.54 days over control, respectively, on a pooled basis.

Days till physiological maturity

Fertility levels: In both the study years and the pooled analysis, fertility levels significantly impacted the number of days until physiological maturity (Table 1). In comparison to applications of 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} and 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1} in both years, the malt barley crop fertilized with 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1} took the longest to reach maturity, taking the most days.

Applying 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1} required 120.67 days to reach physiological maturity, which was 4.0 and 5.7 days longer than applying 60 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} and 50 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}, respectively, according to pooled analysis.

Liquid biofertilizers: During the study years and in the pooled analysis, the inoculation of malt barley seed with liquid biofertilizers, both separately and in combination, had a substantial impact on the number of days to physiological maturity (Table 1). The crop reached physiological maturity under control in the fewest number of days, which was comparable to single inoculation of PSB and KMB in both years but much sooner than seed inoculation with *Azotobacter* alone and co-inoculation with *Azotobacter* + PSB + KMB. *Azotobacter*, PSB, and KMB inoculations alone, as well as *Azotobacter* + PSB + KMB inoculation, significantly increased days to physiological maturity by 5.67, 4.33, 3.75, and 7.67 days above control, respectively, on a pooled basis.

Application of 70 kg N + 40 kg P_2O_5 + 25 kg K_2O ha^{-1} enhanced days to heading, 50% anthesis, and physiological maturity, according to the phenological research. Their crucial role in enhancing the nutrient status of the plant organs and providing an adequate supply of metabolites appears to be the reason for the longer duration of each phenological stage (heading, 50% anthesis, and physiological maturity) as well as the overall crop growth period with rising fertility levels. These could have postponed the senescence of each plant part and allowed for optimal growth. By increasing photosynthetic activity and extending the leaf's lifespan, nitrogen administration boosted vegetative growth, improved plant height, and accumulated dry matter, all of which postponed the barley ear heading. The findings [5–10] are also consistent with the findings above.

4. Conclusions

It has been demonstrated that applying 70 kg N, 40 kg P_2O_5, and 25 kg K_2O ha^{-1} in addition to inoculating seeds with *Azotobacter* + PSB + KMB helps to prolong crop growth and boost malt barley yield.

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