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RESEARCH PAPER

Effect of biofertilizer and boron application on growth and yield of Sorghum (*Sorghum bicolor*) under rainfed conditions

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Key Message: The combined application of Biofertilizer A (Biozote-M) at 5 kg ha^{-1} and boron at 2 kg ha^{-1}, along with the recommended dose of fertilizers, improved the growth, grain yield, and selected quality attributes of sorghum under rainfed conditions. These findings highlight the potential of integrated biofertilizer and boron application as a nutrient management strategy for improving sorghum productivity in rainfed areas.

Abstract

Sorghum (*Sorghum bicolor* L.) is an important cereal crop cultivated in rainfed areas due to its adaptability to water-limited conditions. However, nutrient deficiencies can restrict its growth and productivity. Therefore, this study was performed to evaluate the effect of biofertilizers and boron on morphological characteristics, growth and yield of Sorghum (C4). The Sorghum variety Chakwal Sorghum was used for the study purpose. Urea as a source of nitrogen (N) and DAP as a source of phosphorus (P), while sulphate of potash was added as a source of potassium (K) at the rate of 100, 75 and 60 kg ha^{-1} of NPK respectively. Borax was applied as a source of boron at two rates: Boron 1 (1 kg ha^{-1} borax) and Boron 2 (2 kg ha^{-1} borax). Biofertilizer A (Biozote-M, NARC) was applied at 5 kg ha^{-1}, while Biofertilizer B (CC7), prepared by the Department of Environmental Sciences, PMAS-Arid Agriculture University, Rawalpindi, was also applied at 5 kg ha^{-1}. Both biofertilizers were applied at a rate equivalent to 6 g plot^{-1}. The results of the study show that T5 treatment level comprising biofertilizer A (Biozote-M at the rate of 5 kg ha^{-1}) and boron 2 (borax 2 kg ha^{-1}) along with standard fertilizer dose (NPK 100, 75, 60 kg ha^{-1}) gave maximum plants per meter square, number of seeds per panicle, 1000 grain weight, biomass, seed yield and harvest index as compared to other treatments under study. The findings suggest that the combined application of boron at 2 kg ha^{-1} and Biofertilizer A (Biozote-M) at 5 kg ha^{-1}, along with the recommended dose of fertilizers, can improve sorghum productivity under rainfed conditions. This integrated nutrient management approach has potential for enhancing sorghum yield in rainfed areas. © 2026 The Author(s)

Keywords: Bio-fertilizers, Boron, Growth attributes, Nutrient management, Rainfed conditions, Sorghum yield

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench], commonly known as great millet, durra, or jowar, is cultivated for grain and fodder. Its grain is used for human consumption and animal feed, while its biomass and grain can also serve as feedstocks for biofuel production (Andronoiu & Nistor, 2025). Developing more than 4 meter in height, the Sorghum grain for the most part achieves 2 to 4 mm width (Kazungu et al., 2023). For syrup and ethanol production, sweet Sorghum cultivars are utilized which are relatively more in height than the grain Sorghum cultivars (Mathur et al., 2017; Nazli et al., 2024). Sorghum is an important crop due to its ability to grow under dry and stressful environmental conditions, particularly in marginal, semi-arid, and arid regions where many other crops fail to produce satisfactory yields (Prasad et al., 2021). Sorghum commonly called Jowar in Pakistan, grown for both fodder and grain is a significant kharif season crop. Sorghum is an important forage crop that supports livestock health and provides an essential source of feed for domestic animals (Iqbal & Iqbal, 2015). Sorghum feed includes 50% digestible nutrients with 8% protein, 2.5% fat and 45% nitrogen free extract (Chaudhary et al., 2024). In addition to grain, sorghum stover is an important source of feed for livestock, particularly cattle and dairy animals, during dry seasons when other feed resources are scarce (Tonisi et al., 2026). Forage sorghum is cultivated for its high green biomass yield and is well suited to summer production because of its ability to tolerate high temperatures and dry conditions (Dolapčev Rakić et al., 2025; Nahed et al., 2026). The average sorghum yield in Punjab region of Pakistan is approximately 13 t ha^{-1}, which is considerably lower than its potential yield of 50–70 t ha^{-1} (Iqbal et al., 2015). The major constraints affecting forage sorghum production in Punjab include low-yielding and poor-quality seeds, drought stress, weed infestation, inadequate or imbalanced fertilizer application, insect pest attacks, and inefficient marketing systems (Iqbal et al., 2015).

Biofertilizers are microbial formulations containing beneficial microorganisms that enhance plant nutrient availability, particularly by fixing atmospheric nitrogen either through free-living activity in the soil or through beneficial associations with plants (Figiel et al., 2025). They are important sources of beneficial microorganisms that convert nutrients from unavailable forms into plant-available forms through natural biological processes (Nosheen et al., 2021; Chaudhary et al., 2022). Biological nitrogen fixation is completed by both symbiotic and free-living organisms as well as certain cyanobacteria (formerly known as blue-green algae) (Soumare et al., 2020). Symbiotic nitrogen fixation produces 80% of the naturally fixed nitrogen (Liang et al., 2022). Nitrogen-fixing microorganisms exhibit host specificity, recognizing and colonizing the roots of compatible plant species to establish symbiotic associations and form root nodules (Li et al., 2023). An innovative formulation combining conventional fertilizers, micronutrients, and beneficial microorganisms, with sugarcane press mud as the base material, has been reported to improve nutrient availability and support plant growth (Septyani et al., 2019). Despite their potential benefits, the widespread adoption of biofertilizers has been limited by variability and inconsistency in their performance under field conditions (Mahendranathan & Mathushika, 2026). Biofertilizers offer an environmentally friendly alternative or supplement to synthetic fertilizers by reducing environmental pollution and supporting sustainable crop production. They are relatively inexpensive and can be produced locally using suitable methods. Depending on the microbial strains, crop species, soil conditions, and application methods, biofertilizers can improve crop yields and contribute to biological nitrogen fixation, potentially reducing the need for synthetic nitrogen fertilizers (Fallah Nosratabad & Khoshru, 2024). Moreover, continuous application of biofertilizers over 3–4 years may establish persistent microbial populations in the soil, potentially reducing the need for subsequent inoculation. However, the long-term persistence and effectiveness of these microorganisms depend on soil conditions, crop species, microbial strains, and agricultural management practices (Daniel et al., 2022; Maheshwari et al., 2022). Biofertilizers acting as organic fertilizer help in improving soil surface, structure and different properties of soil by adding nutrients to soil profile. They yield plant growth promoting substances like nutrients, carbohydrates, IAA and vitamins (Mahmud et al., 2021; Sreethu et al., 2023).

Boron is an essential micronutrient required for the normal growth and development of crop plants (Srivastava et al., 2025). It is an essential non-metallic micronutrient among the seven micronutrients required for plant growth and development. It plays a vital role in various physiological and biochemical processes that contribute to healthy plant growth and productivity (Camacho-Cristóbal et al., 2018; Shireen et al., 2018). Since its recognition as an essential trace element, boron has gained increasing importance in agriculture due to its critical role in plant growth, development, and crop productivity (Ganie et al., 2013). Across many regions worldwide, boron deficiency is frequently observed in light-textured sandy soils, particularly where intensive cropping and leaching have depleted available soil boron. It is also prevalent in soils characterized by limited acidity (Ahmad et al., 2012). Boron deficiency is widespread among numerous plant species worldwide and can adversely affect plant growth, development, and crop productivity. A considerable amount of boron is required to promote the health and yield of various crop plants (Wang et al., 2015). Crops grown in boron deficient conditions cannot attain their full potential for crop yield, quality and crop stand (Brdar-Jokanović et al., 2020). Crops absorb boron from the soil to support normal growth and development; therefore, boron fertilizers should be applied when necessary to maintain adequate nutrient availability and achieve optimal crop quality and yield (Shireen et al., 2018; Al-Amery & Khrbeet, 2025).

Despite the recognized importance of boron in plant growth and development, its availability in soil can be limited under certain soil and environmental conditions, potentially restricting crop growth and productivity. In rainfed agriculture, nutrient management is particularly important because water availability can limit nutrient uptake and crop responses to fertilizer application. The combined application of boron and biofertilizers may offer an approach to improving nutrient management; however, the effectiveness of this combination depends on the biofertilizer product, boron application rate, soil properties, and prevailing growing conditions. Therefore, the comparative performance of different biofertilizer products in combination with different boron rates requires evaluation under specific rainfed cropping conditions. The present study was designed to evaluate two biofertilizer products, Biozote-M (5 kg ha^{-1}) and CC7 (5 kg ha^{-1}), in combination with two boron application rates (1 and 2 kg ha^{-1} borax) for their effects on the growth, morphological characteristics, and yield of sorghum under rainfed conditions. The two boron rates were used to compare sorghum responses to different levels of boron application. Specifically, the study aimed to (i) compare the effects of the two biofertilizer products on sorghum growth and yield, (ii) assess the responses of sorghum to the two boron application rates, and (iii) evaluate the effects of combining biofertilizers and boron to identify a suitable nutrient-management strategy for sorghum production under water-limited rainfed conditions.

Materials and Methods

A field experiment was conducted to study the effect of biofertilizers and boron on morphological characteristics, growth and yield of C4 Sorghum crop at University Research Farm Koont, Dhudyal, District Chakwal (latitude 33.3°, longitude 73.3°, and 460 m above sea level with annual rainfall of 650-850 mm) during Kharif season 2018-2019 under rainfed conditions. The Sorghum seed was collected from PBG

department of PMAS-Arid Agriculture University. The size of plot was 3 m × 4 m. The seeds were sown by drill at a row space of 25 cm. Replications were separated from each other by 2 m distance, to have clear working space for plant sampling. Urea as a source of nitrogen (N) and DAP as a source of phosphorus (P), while sulphate of potash was added as a source of potassium (K) at rate of 100, 75 and 60 kg per hectare of NPK, respectively. Borax was applied as a source of boron at two rates: Boron 1 (1 kg ha^{-1} borax) and Boron 2 (2 kg ha^{-1} borax). Biofertilizer A (Biozote-M, NARC) was applied at 5 kg ha^{-1}, while Biofertilizer B (CC7), prepared by the Department of Environmental Sciences, PMAS-Arid Agriculture University, Rawalpindi, was also applied at 5 kg ha^{-1}. Both biofertilizers (Biozote-M and CC7) were applied through seed coating (seed inoculation) before sowing at a rate equivalent to 6 g $plot^{-1}$. The crop was arranged in a randomized complete block design with three replications of seven treatments: T1 = Control; T2 = B1; T3 = B2; T4 = Biofertilizer A + B1; T5 = Biofertilizer A + B2; T6 = Biofertilizer B + B1; T7 = Biofertilizer B + B2. Other agronomic practices were uniformly applied in all treatments.

Seed germination test

A laboratory germination test was conducted separately before the field experiment to assess the viability and germination capacity of sorghum seeds. Five Petri dishes were used as five replicates, with 10 seeds placed in each Petri dish, giving a total of 50 seeds. Germinated seeds were counted after five days under laboratory conditions. Germination percentage was calculated using the following formula:

$$\text{Germination percentage (\%)} = \frac{\text{Germinated seeds}}{\text{Total seeds sown}} \times 100$$

Phenological stages

Emergence stage initiates with emergence of first leaf and ultimately ends at the establishment of first tiller.10 plants from each plot were taken randomly and number of days was counted from sowing till seedling stage. Then the average was calculated. For stem elongation ten plants were randomly selected at stem elongation stage and number of days from sowing to stem elongation stage was counted and average was calculated. Flag leaf was measured by randomly picking ten plants and counting days from sowing to elongation and jointing stage. Then the average was taken out. Ten plants were chosen randomly and number of days from sowing till boot stage was counted and average was taken for these plants. Again, at this stage number of days for ten randomly selected plants was counted from sowing till flowering stage and average was computed. From each plot ten plants were selected at random and days were counted from sowing till heading stage of plants and average was calculated. At milking stage ten plants were selected at random and number of days were counted from sowing till milk stage gained by these plants. The average was calculated for this stage. Ten plants were selected at random from each plot, and the number of days from sowing up to dough development stage (milking stage) was taken and average was formulated. Number of days from sowing until ripening was counted for ten randomly selected plants from each plot, and when seeds and spikes become dry then average was computed.

Agro morphological parameters

Number of plants at three weeks of emergence was counted with the help of 1m quadrate as plant population. The data for plant height was taken by randomly selecting ten plants from each plot at the time of maturity. Height is measured from the soil level to the tip of the plant with the help of measuring tape and average was calculated. Number of leaves per plant was taken by counting leaves of 4-5 plants from each plot and then average was taken. Three lots of thousand seeds were taken from bulk seed sample of each treatment after threshing and weighed by electronic balance and average 1000 grain weight was calculated. 4-5 healthy panicle of Sorghum were cut out from each plot, threshed individually and number of seeds obtained was counted and average was computed as number of seeds per panicle. Sorghum plants from each plot were harvested and dried in the sun for few days to determine total biomass per hectare. Dried samples were then weighed, and recorded readings were converted into kg ha^{-1}. From each plot harvested plants were threshed manually after sun drying. Obtained seed were weighed and were converted into kg ha^{-1} as seed yield. Harvest index for Sorghum was calculated using formula (Reddy & Reddi, (2005):

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Grain quality traits

Grain protein content was determined using the Kjeldahl method. Briefly, grain samples were digested, followed by distillation and determination of nitrogen content through titration. The nitrogen percentage was multiplied by the conventional conversion factor of 6.25 to estimate crude protein content. Crude fiber content was determined using the gravimetric method. Briefly, grain samples were subjected to sequential digestion with dilute acid and alkali. The resulting residues were dried in an oven, weighed, and subsequently incinerated. Crude fiber content was calculated from the difference between the dried residue weight and the ash weight and expressed as a percentage of the original sample weight. Ash content was determined using the dry ashing method. A

known weight of grain sample was placed in a pre-weighed crucible and incinerated in a muffle furnace at 550 °C for 24 hours. After incineration, the crucible was cooled in a desiccator and weighed. Ash content was calculated as a percentage of the initial sample weight.

Soil analysis

Moisture contents

Moisture contents were calculated by taking samples from each plot randomly and weighing them on electronic balance. After taking wet weight, dry samples in an oven and after drying them, the difference in weight gave the moisture content of soil.

Available boron

Soil samples were collected from each experimental plot using a soil auger at a depth of 0–15 cm before and during the cropping period. Available boron was determined using the hot-water extraction method followed by the Azomethine-H colorimetric method. Briefly, soil samples were extracted with hot water, and the resulting extracts were treated with Azomethine-H reagent to develop a colored complex. Boron concentration was determined colorimetrically by measuring the absorbance of the developed color using a spectrophotometer (Olsen & Sommers, 1982).

Electrical conductivity (EC)

Electrical conductivity (EC) was determined using a 1:5 soil-water extract. Briefly, soil samples were mixed with distilled water at a soil-to-water ratio of 1:5 (w/v) and thoroughly shaken to obtain a uniform suspension. The electrical conductivity of the resulting extract was measured using a calibrated EC meter and expressed as dS m^{-1}.

Total organic carbon (TOC)

Soil samples were collected from each experimental plot before sowing and after crop harvesting. Total organic carbon was determined using the Walkley–Black wet oxidation method. Briefly, soil samples were treated with potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4) to oxidize the organic carbon. The excess potassium dichromate was determined by titration, and total organic carbon was calculated based on the amount of dichromate consumed during oxidation. The results were expressed as a percentage of soil dry weight.

Soil pH

Suspension of soil and water was made by taking 50 g of air-dried soil and 50ml water in an 100 ml beaker, stir it with glass rod and allow to stand for 30 min.

Statistical analysis

The collected data was statistically analyzed by using Statistix 8.1 for Analysis of Variance (ANOVA) and treatment means were compared by using LSD at 5% level of probability (Montgomery, 2001).

Results

Germination percentage

A separate laboratory germination test was conducted to assess the germination capacity of sorghum seeds before sowing in the field. The mean germination percentage was reported as 94.25% under laboratory conditions. This assessment provided background information on seed quality and was not included as a response variable in the field experiment.

Emergence

At emergence Coleoptile is visible at soil surface. Timely emergence of seed depends on soil conditions and moisture availability in soil, vigor of seed and depth of planting. Timely emergence contributes to good seed yield. Analysis of variance showed significant results of all treatments except control. Table 1 shows the emergence stage at different treatment levels. According to the results, the number of days to emergence was more in control T1 (9 days) in contrast to lowest days count to emergence in T4 (4 days). All other treatments statistically differ as compared to control in regard of plant emergence.

Stem elongation stage

Stem elongation stage is also termed as, growing point differentiation. At this stage the Sorghum plants transition from vegetative to reproductive. The total number of leaves and head size is determined at this stage. Mean number of days to stem elongation are shown in Table 1. Data regarding the days to stem elongation was significant with a larger number of days taken at control T1 (32 days) and minimum number of days to elongation of stem in T7 (23 days). T3, T4 & T6 being statistically similar remain at par with T5 and T2. The onset of stem elongation in T7 (Biofertilizer B + B2) can be explained by nitrogen, and boron application (2 kg ha^{-1}).

Flag leaf stage

At this stage, the flag leaf can be found in the whorl. Head keeps on creating and about 80% of the absolute leaf zone has

formed. Supplement and water take-up necessities increase. Formation of node in plant can be checked despite dissecting the stem by pressing the stem base with fingers. After the formation of flag leaf, the stem elongation stage comes to end. Table 1 shows mean number of days to flag leaf stages at different treatment levels of Sorghum plant. The larger number of days to flag leaf stage was taken by control T1 plants (43 days), whereas T3 (B2) plants took minimum number of days (32 days). Treatments i.e. T2, T5, T6 statistically remains at par with each other. In T3 plants, early flag leaf formation is attributed high boron levels (2 kg ha^{-1}).

Table 1 Effect of biofertilizer and boron on days to emergence, stem elongation and flag leaf stages of sorghum

Treatments	Emergence	Stem elongation stage	Flag leaf stage
T1	9^{a}	32^{a}	43^{a}
T2	5^{b}	28^{b}	34^{cd}
T3	5^{b}	26^{bc}	32^{d}
T4	4^{b}	25^{bc}	36^{b}
T5	5^{b}	24^{c}	34^{cd}
T6	7^{b}	25^{bc}	35^{bc}
T7	5^{b}	23^{c}	33^{d}

Each data is the average of three replicates.

Booting stage

At boot stage peduncle elongation has started resulting in the outcome of head from flag leaf sheath. Potential head size was determined. Data regarding mean number of days to booting stage is shown in Table 2. The data showed that there was significant effect of treatments to number of days taken to boot stage. At control T1 the number of days to boot were more (51 days) whereas, booting occurred earlier in T5 plants (42 days). All other treatments took a smaller number of days to boot stage as compared to control. In T5 (Biofertilizer A + B 2) the number of days is less due to action of biofertilizers and boron.

Heading stage

Inflorescence emergence is referred to as the heading stage. During this stage, the leaves are fully expanded and contribute to maximum light interception. The head reaches its full size and remains enclosed within the flag leaf sheath until emergence. Heading was considered to have occurred when the head completely emerged from the stem. Subsequently, the flowering or anthesis stage began, during which pollen grains were released from the anthers for pollination. Table 2 presents the mean number of days required by sorghum plants to reach the heading stage under different treatments. The results revealed significant differences among treatment levels. The maximum number of days was recorded in the control treatment T1 (60 days), whereas treatment T4 (Biofertilizer A + B1) reached the heading stage earliest (50 days). Thus, plants in T4 reached the heading stage 10 days earlier than those in the control treatment. Treatments T2, T3, and T7 were statistically similar and remained at par with T5 and T6, according to the LSD test. The earlier attainment of the heading stage in T4 may be attributed to the application of biofertilizer (Biozote-M), which potentially promoted early crop development.

Flowering stage

One half of the total dry matter of plant forms at half bloom. Grain filling starts, rendering the crop vulnerable to seed set losses through hot and dry weather. According to mean number of days from sowing to flowering shown in Table 2, the flowering stage comes in timely fashion with treatments of increasing Boron and Phosphorus levels as compared to control. Number of days to flowering was maximum in control (64 days) while minimum being observed in T7 (54). Time spent to reach flowering in T7 (Biofertilizer B + B 2) is 18 % less than that in control, which accounts for early seed forming and development and avoiding harsh environmental conditions. This stimulated performance in T7 level is attributed to higher boron levels in T7 (2 kg ha^{-1}). In T7 flowering occurred 1.8% earlier than T2, 5.5% earlier than T3, 7.4% earlier than T4, 3.7% earlier than T5 and 1.8% earlier than T6.

Table 2 Effect of biofertilizer and boron on number of days to booting, heading and flowering stages of sorghum

Treatments	Booting stage	Heading stage	Flowering stage
T1	51^{a}	60^{a}	64^{a}
T2	43^{b}	53^{bc}	55^{cd}
T3	44^{b}	54^{bc}	57^{bc}
T4	44^{b}	50^{c}	58^{b}
T5	42^{b}	55^{b}	56^{bc}
T6	45^{b}	51^{c}	55^{cd}
T7	43^{b}	53^{bc}	54^{d}

Each data is the average of three replicates.

Milking stage

The grain is at milking stage when seed is soft and whitish milk like liquid comes from seed on squeezing the seed. This was referred to milking stage. The weight of culm increases, and dry matter starts accumulating. Seed ripening process starts after this. Availability of moisture at this stage determined timely ripening of seed. Table 3 showed the mean of number of days to Milking stage, with maximum number of days taken in control T1 (76), and minimum days taken in T5(66). At T5 (Biofertilizer A + B2) the onset of milk stage was accounted to biofertilizers and boron accumulation. T3, T4 & T7 being statistically similar remain at par with T2&T6 which spent a smaller number of days as compared to control treatment to attain milking stage.

Dough development stage

The dough stage begins following the completion of flowering and represents the early phase of kernel development. This developmental period is generally divided into soft-dough and hard-dough stages. During the dough phase, substantial accumulation of dry matter, proteins, and starch occurs within the developing grains. Thus, the initial process of grain development and dry-weight accumulation becomes evident during this stage. At hard dough the grain cannot be squeezed with fingers. The data regarding mean days to dough development stage is shown in Table 3, showing significant effect of different treatment levels. Minimum days to dough development (71 days) were taken by T5 (Biofertilizer A + B2) plants, whereas, maximum days were taken by control T1 plants (85 days). Treatments T4, T6 & T7 were statistically at par with T2&T3. In T5 boron (2 kg ha^{-1}) accounts for better growth whereas biofertilizers (Biozote-M) also stimulate grain formation.

Ripening stage

Sorghum plants having reached physiological maturity form dark spots opposite to embryo on the kernel. Plant is at maximum dry weight. Grain humidity fluctuates between 25 and 35% depending on Sorghum plants selection and growing conditions. Table 3 shows the mean number of days by each treatment to reach ripening stage. T1(control) plants spent a greater number of days (93 days) to ripening as compared to T4 (Biofertilizer A + B1) in which plants reached their ripening stage the earliest (85 days). This is attributed to addition of boron and nitrogenous fertilizers which help in plant ripening. T5, T6&T7 treatments were statistically similar remaining at par with T2&T3 spend significantly lower number of days to maturity as compared to control.

Table 3 Effect of biofertilizer and boron on number of days to milking, dough development and ripening stages of sorghum

Treatments	Milking stage	Dough development	Ripening stage
T1	76^{a}	85^{a}	93^{a}
T2	74^{a}	83^{a}	91^{a}
T3	71^{b}	80^{a}	90^{a}
T4	69^{b}	77^{b}	85^{b}
T5	66^{c}	71^{c}	87^{b}
T6	69^{b}	79^{b}	86^{b}
T7	69^{b}	78^{b}	88^{b}

Each data is the average of three replicates.

Agro morphological parameters

Plant population

Plant population (number of plants per m^2) is an important yield-related parameter that influences crop establishment, biomass production, and grain yield. The plant population of sorghum under seven different treatment levels is presented in Table 4. Analysis of variance revealed significant differences among treatments regarding plant population. The highest plant population (49 plants m^{-2}) was recorded in T5 (Biofertilizer A + B2), followed by T4 (48 plants m^{-2}). The lowest plant population (41 plants m^{-2}) was observed in the control treatment (T1). According to the LSD test, treatments T2, T3, T4, T5, T6, and T7 were statistically similar to each other but differed significantly from the control treatment. These results indicate that the application of biofertilizer and boron treatments improved sorghum plant population compared with the untreated control.

Plant height (ft)

Plant height is a key component of successful plant growth and yield. The data concerning plant height is shown in Table 4. Every treatment has significant effect on plant height except the control one. Significantly highest plant height (7.5 ft) was recorded in T5 (Biofertilizer A + B 2), whereas, smallest plant height (5.6 ft) was recorded in T1 (Control). However, T4 and T6 have showed non-significant increase in plant height but, have significant difference in plant height as compared to (T1) control. T2 and T7 were statistically similar with each other remaining at par with T3 and T1. The increase in plant height in T5 is attributed to the boron (2 kg ha^{-1}).

Number of leaves per plant

Another important parameter for successful growth and higher yield of a crop is the number of leaves per plant. The more the number of leaves, more the area for light interception which raises the photosynthesis process resulting in rapid plant growth. Number of leaves per plant also adds to the biomass of the crop. The data regarding number of leaves per plant is presented in Table 4. The analysis of variance showed significant effect of treatments on number of leaves per plant. The greater number of leaves (9) were recorded in T7 (Biofertilizer B + B 2), whereas, the lower value (5) was recorded in T1 (control). T2, T4 and T6 are statistically similar but have significantly a greater number of leaves per plant as compared to control while T3 and T5 were statistically similar with each other. The number of leaves per plant increases with increasing biofertilizers and nitrogen (100 kg ha^{-1}) levels at T7.

Table 4 Effect of biofertilizer and boron on plant population, plant height and number of leaves/plant of sorghum

Treatments	Plant population (m^{-2})	Plant height (ft)	No. of leaves per plant
T1	41^{b}	5.6^{c}	5.0^{b}
T2	47^{a}	6.5^{abc}	7.0^{ab}
T3	47^{a}	7.3^{a}	7.6^{a}
T4	48^{a}	6.2^{bc}	6.6^{ab}
T5	49^{a}	7.5^{a}	8.0^{a}
T6	47^{a}	6.7^{ab}	7.0^{ab}
T7	46^{a}	6.5^{abc}	9.0^{a}

Each data is the average of three replicates.

Number of seed per panicle

Seed number per panicle defines the increase in yield of a crop. The data regarding number of seeds per panicle of Sorghum crop is shown in Table 5. The effect of treatments on number of seeds per panicle was significant. Significantly highest grains per panicle (1434) were recorded in T5 (Biofertilizer A + B 2), while lowest grains per panicle (1276) were recorded in T1 (control). T2, T4 and T6 were statistically similar remained at par with T3 and T7, also increased significantly as compared to control. Increase in grains per spike in T5 is characterized by boron application (2 kg ha^{-1}), which influences grains per spike and in turn the seed yield of Sorghum.

1000 grain weight (g)

Thousand seed weight increases the overall seed produce of a crop. The data regarding 1000 grain weight of Sorghum is shown in Table 5. The analysis of variance showed significant effect of both organic matter and boron application on thousand seed weight. Significantly, highest thousand grain weight (25.3 g) was recorded in T5 (Biofertilizer A + B 2) where boron is applied at 2 kg ha^{-1}, while the lowest 1000 grain weight (17 g) was recorded in T1 (Control). All other treatments were statistically similar and showed significant increase in thousand grain weight as compared to control.

Biological yield/biomass (kg ha^{-1})

Total biomass value is the indicator of the total yield potential of any crop in a given period of time. The data regarding total biomass of Sorghum crop is shown in the Table 6. The analysis of variance showed that the biomass of Sorghum is significantly influenced by the application of biofertilizers and boron. Significantly highest biomass value (2417 kg ha^{-1}) was recorded in T5 (Biofertilizer A + B2) whereas lowest biomass value (2139.3 kg ha^{-1}) was recorded in T1 (control). T2, T3, T4 and T7 were statistically similar remaining at par with T6 and T1. The increase in biological yield at T5 is significantly influenced by increasing biofertilizers (Biozote-M) application.

Table 5 Effect of biofertilizer and boron on seeds/panicle and thousand grain weight of sorghum

Treatments	Number of seeds/panicle	Thousand grain weight(g)
T1	1276^{d}	17.0^{b}
T2	1380.7^{bc}	22.3^{a}
T3	1375.0^{c}	22.0^{a}
T4	1391.7^{bc}	24.3^{a}
T5	1434.7^{a}	25.3^{a}
T6	1386.7^{bc}	24.0^{a}
T7	1416.3^{ab}	24.3^{a}

Each data is the average of three replicates.

Seed yield (kg ha^{-1})

Seed yield is a quantitative trait and accounts for the weight of seeds from certain field or plot. Seed yield is calculated by harvesting and threshing the grain and then weighing on an electronic balance. The results demonstrated in Table 6 show that seed yield is significantly influenced by boron application up to certain level/treatments. Seed yield is maximum (1280 kg ha^{-1}) in T5 (Biofertilizer A + B 2). The lowest seed yield is recorded in control T1 (846 kg ha^{-1}). Other treatments being statistically similar showed a significant increase in yield as compared to control.

Harvest index (%)

The translocation or transportation of assimilates from source to sink is known as, Harvest Index. Harvest index is the ratio of total reaped grain to total shoot dry matter. The ability of the crop plant to change a dry matter into a financial yield is evaluated through harvest index. The more the harvest index value, the more is the ability to convert dry matter into economic plant parts. Table 6 shows the data regarding harvest index of Sorghum. Significantly highest harvest index (52.97%) of Sorghum crop was recorded in T5 (Biofertilizer A + B 2), while the lowest harvest index (39.55) was recorded in T1 (control). The increase in harvest index in T5 is attributed to biofertilizer (Biozote-M) and boron (2 kg ha^{-1}) levels which influenced seeds per panicle, leaves per plant, plant population ultimately increasing the biomass and seed yield of Sorghum crop.

Table 6 Effect of biofertilizer and boron on biomass, seed yield and harvest index of sorghum

Treatments	Biological yield/biomass (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
T1	2139.3^{c}	846.0^{b}	39.55
T2	2312.3^{ab}	1116.0^{a}	48.26
T3	2314.3^{ab}	1166.0^{a}	50.38
T4	2406.7^{ab}	1266.0^{a}	52.61
T5	2417.0^{a}	1280.3^{a}	52.97
T6	2264.0^{bc}	1116.0^{a}	49.29
T7	2346.7^{ab}	1160.0^{a}	49.44

Each data is the average of three replicates.

Grain quality traits

Grain protein content (%)

Grain protein content usually expressed as percentage of grain dry mass is the major determinant of the quality of a grain. Sorghum samples were analyzed for crude protein content using standard methods of Association of Official Agricultural Chemists [AOAC], (1960). Table 7 shows significant increase in protein content with nitrogen levels. According to the results T5 (Biof A + B 2) has 29.2% significantly more protein content (9.04%) as compared to control (6.40%). The increase in protein content in T5 was 19.13%, 9.18%, 18.47%, 14.49%, and 19.02%, as compared to T2, T3, T4, T6 and T7. The increase in crude protein content in T5 (Biof A + B 2) is accounted to boron (2 kg ha^{-1}).

Grain fiber content (%)

Crude fiber is a degree of the extent of indigestible cellulose, lignin and other components present in food. Grain fiber content for Sorghum samples were determined using Soxhlet apparatus. Table 7 shows significant effect of biofertilizers and boron application on grain fiber content of Sorghum. Total fiber content decreases significantly as compared to control. In Sorghum, fiber contents increase with decreasing nitrogen application. Significantly highest value was obtained at control. Lowest fiber percentage was recorded in T5 (Biof A + B2) which is due to increase in nitrogen and boron levels. In T5, fiber contents (62.27%) were 5.69% less than in control (66.03%). T4, T6 and T7, were statistically similar, decreased significantly as compared to control remaining at par with T3 and T2.

Total ash (%)

Ash content is the measure of total amount of minerals present within the grain sample. These minerals may include specific inorganic components present within grains such as Ca, K, Na and Cl. The type of minerals present in a grain determines the quality, taste, appearance, texture and stability. Table 7 shows significant increase in total ash percentage content in Sorghum seeds as result of boron application. Significantly highest ash content was recorded in T5 (7.75%) which is 31.8% more than that of control level ash content (5.88%). Similarly, in T5 ash content was 8.54% more than T2, 7.64% more than T3, 5.16% more than T4, 2.65% more than T6 and 4.31% more than T7. The increase in ash percentage in T5 (Biof A + B2) is accounted to higher boron (2 kg ha^{-1}) and nitrogen treatment levels.

Table 7 Effect of biofertilizer and boron on protein content, fiber content and ash content of sorghum

Treatments	Protein content (%)	Fiber content (%)	Ash content (%)
T1	6.4^{d}	66.03^{ab}	5.88^{c}
T2	7.31^{c}	65.14^{ab}	7.14^{b}
T3	8.21^{b}	64.55^{b}	7.20^{b}
T4	7.37^{c}	64.78^{b}	7.37^{ab}
T5	9.04^{a}	62.27^{c}	7.75^{a}
T6	7.73^{bc}	62.83^{c}	7.55^{ab}
T7	7.32^{c}	62.43^{c}	7.43^{ab}

Each data is the average of three replicates.

Soil analysis

Moisture content

The proportion of the water content to that of solids in a specified mass of soil is known as, Moisture content of given soil mass. This ratio is mostly expressed as percentage. Table 8 shows the data regarding moisture percentage of soil. The highest moisture content was recorded in T4 (37%), which indicates sufficient water available in soil for growth of crop and good crop stand.

Available boron

Soil Samples for available boron were taken and analyzed in laboratory. Table 8 shows available boron content of soil. Boron levels in soil were found to be satisfactory for crop growth. The maximum available boron was recorded in T5 (0.44 mg/kg).

Electrical conductivity (dsm^{-1})

The electrical conductivity of soil depends on applied nutrients and moisture seized by soil particles. Soil electrical conductivity is measured by EC meter which is the measure of soil salinity. Electrical conductivity is the simplest method to assess soil fertility, yield potential and soil salinity levels. Data regarding Electrical conductivity of soil is shown in Table 8. Maximum Electrical conductivity recorded in T2 (0.85) falls in non-saline range and is considered ideal for crop growth.

Total organic carbon

The degree of carbon confined within soil organic matter, is known as total organic matter. Total organic carbon impacts on many soil properties including color, nutrient holding capacity and structure, which therefore effects water relations, aeration and workability. Total organic matter content is shown in the Table 8. The results show that TOC content increases with increasing NPK treatments as compared to control with the highest level in T7(0.410%) and the lowest in T1 (0.302%).

Soil pH

Soil pH is an important soil chemical property that indicates its acidic or alkaline nature and influences nutrient availability and plant growth (Singh et al., 2025). Soil samples were collected from each treatment plot, and a soil suspension was prepared by mixing 50 g of soil with 50 mL of distilled water (1:1 soil-to-water ratio). Soil pH was measured using a calibrated pH meter. Table 8 presents the soil pH values recorded under different treatments. The experimental soil exhibited slightly acidic to near-neutral conditions, with pH values ranging from 6.20 to 6.74. The highest pH was recorded in T7 (6.74), whereas the lowest pH value was observed in T5 (6.20). These values fall within the commonly suitable pH range for sorghum growth. Although T7 recorded the highest soil pH, the highest grain yield was obtained in T5. This indicates that the highest yield did not correspond to the highest recorded soil pH, suggesting that crop performance was influenced by several factors rather than soil pH alone.

Table 8 Effect of biofertilizer and boron on moisture content, available boron, EC, total organic carbon and pH of soil samples

Treatments	Moisture content (%)	Available boron (mg kg^{-1})	EC (dsm^{-1})	Total organic carbon (%)	pH
T1	35	0.33	0.64	0.302	6.60
T2	36	0.42	0.85	0.344	6.40
T3	35	0.43	0.48	0.360	6.66
T4	37	0.33	0.54	0.396	6.57
T5	35	0.44	0.54	0.308	6.20
T6	35	0.40	0.76	0.360	6.62
T7	34	0.37	0.39	0.410	6.74

Each data is the average of three replicates; EC = Electrical conductivity (dsm^{-1})

Discussion

Boron is one of those micronutrients which are inadequate in soils. Boron lack delays grain setting in wheat, bringing about extended number of open spikelets and diminished number of grains per spike. The distinction in the quantity of open spikelets under typical and boron lacking soil conditions has been utilized to look at wheat genotypes for boron proficiency (Rerkasem et al., 1993). Visual side effects of Boron insufficiency for the most part become obvious in dicots, corn and wheat at tissue convergences of under 20-30, 10-20 and 10 mg/kg weight, individually. Dietary issues ascribed to boron insufficiency are additionally common among vegetables, foods grown from the ground trees. Marschner (1995) revealed that boron is essential for cell division and extension in meristematic tissues, herbal organs and for male bloom readiness, dust tube germination close by its extending and seed/regular item improvement. Furthermore, in boron insufficient soils seeds create strange seedlings. Dell et al. (1997) found that absence of Boron subdues root stretching through obliging cell development and cell division in the creating zone of root tips. Insufficiency of boron causes restriction of leaf improvement and decline in photosynthesis, anyway precise employment of boron in photosynthesis remain

to be explored. In the field, sexual duplication is as often as possible progressively affected by low boron and basic grain yield diminishes may occur without visual signs imparted during vegetative advancement. Seeds inoculated with biofertilizers increased emergence up to 18.5% as compared to non-treated ones, also reported by Nezarat & Gholami (2009). Similar results were obtained by Gebremariam & Assefa (2015) who reported increase in stem elongation of Sorghum with increasing nitrogen level up to a certain quantity (100 kg ha^{-1}). Bruns (2016) supported these results by finding out that flag leaves growth is stimulated by nitrogen treatments. Rehman et al. (2012) reasoned that foliar use of boron ought to be made at booting and anthesis stage to acquire better return. Nezarat and Gholami (2009) reported that higher head and shoot dry weight occurred as response to biofertilizer treatment at heading stage. Rehman et al. (2012) supported these results that foliar application of boron stimulates anthesis and booting, resulting in higher grain yield. Jahan et al. (2012) confirmed growth promoting effect of biofertilizers in sesame. These results were confirmed by Shinde et al. (2017) who found out that in Sorghum plant dough development is influenced by boron application. Comparatively lower Boron level B1 (1 kg ha^{-1}) accounts for early maturing and seed development along with nitrogen as reported by Alkhamisi et al. (2017).

Plant height expanded straightly and altogether with the expansion in the pace of nitrogen application from 0 through 138 kg N ha^{-1} was reported by Shamme et al. (2016). Alkhamisi et al. (2017) found plant height increments with boron levels in a specific way. Nezarat and Gholami (2009) revealed that seed inoculation with development advancing microbes expands plant height and leaf region. The use of boron with nitrogen expanded number of leaves per plant in Sorghum bringing about more biomass was additionally detailed by Shamme et al. (2016). The outcomes are comparable with the discoveries of Rehman et al. (2012) that higher number of grains per spike is the consequence of positive job of boron in capacities like germination, feasibility, improvement and development. More prominent the quantity of seeds per panicle, higher will be the seed yield of the harvest. The impact of term and timing of warmth and dry season weight on Sorghum yield, essentially on seeds per panicle, was accounted for by Crauford and Peacock (1993) who detailed an 87% decrease in yield brought about by worry during booting and blooming. Thousand seed weight increments with expanding Boron levels, as announced by Waseem et al. (2012). Shamme et al. (2016) also reported that highest 1000 grain weight being observed at 92 kg N/ha. Biomass increases with nitrogen rates up to a certain limit, as reported by Shamme et al. (2016). Zand & Shakiba (2013) also concluded in their study that nitrogen application causes increase in plant density which in return increase yield of Sorghum. Our results agree with findings of Rehman et al. (2012) that, harvest index increases with increased boron application rates.

Our findings were confirmed by Ayub et al. (2002) who reported increase of protein contents with increasing nitrogen levels. The trend of increasing fiber contents with decreasing nitrogen treatment levels were also reported by Ayub et al. (2002). Significant increase in grain ash content by boron and nitrogen application and suitable harvesting time, was also reported by Ayub et al. (2002). Chandrasekar et al. (2005) explored effect of nitrogen & biofertilizers level on the improvement and yield of *Echinochloa frumentacea* (Roxb.). The effects of biofertilizer inoculation with Azotobacter and Azospirillum, synthetic nitrogen fertilizer (Urea), and their different combinations were evaluated in *Echinochloa frumentacea* to assess their influence on morphological traits, biochemical characteristics, biomass production, and yield. Compared with the untreated control, application of either bacterial inoculant, particularly when combined with nitrogen fertilizer, enhanced plant growth, yield, and biochemical attributes. Overall, the findings demonstrated that integrating biofertilizers with synthetic nitrogen fertilizer produced greater improvements in morphological and yield-related parameters than the use of either biofertilizer or chemical fertilizer alone. The best return of Azospirillum with 100% urea treatment acquired 8525.55 kg ha^{-1}. Biofertilizers with 100% urea treatment created most significant returns contrasted and control. When looked at the Azospirillum and Azotobacter mixes, Azospirillum alongside 100% urea yielded preferable outcomes over control.

Our findings coincided with those of Singh (2005) who found that the biofertilizers or microbial inoculants are the arrangements of live microorganisms used to improve plant sustenance and soil fruitfulness accomplishing there by more and economical creation. Biofertilizers offer a modest, low capital concentrated, non-bulk and ecofriendly source to help efficiency. Bagyaraj et al. (2015) worked on the use of azotobacter that brought about useful impacts on low yields of rice, wheat, sorghum, maize, pearl millet and cotton. The examination in India demonstrated expanded yield of grains by 10% and 13-39% in vegetables and accessible information likewise showed that azotobacter was progressively successful on manured soil. Alkhamisi et al. (2017) evaluated the response of the multi-cut sorghum cultivar ‘Super Dan’ to six boron concentrations, including 0 (control), 1, 2.5, 5, 7.5, and 10 mg L^{-1}, under three irrigation-water salinity levels of 1, 5, and 10 dS m^{-1}. The experiment was conducted in pots containing sandy loam soil using a randomized complete design and was continued for five months during the summer season of 2007–2008, with four forage harvests. Boron application, salinity, and their interaction significantly ($0.01 < p < 0.05$) influenced plant height and green forage weight. The application of 5 mg L^{-1} boron resulted in significantly greater green and dry matter production ($p < 0.05$), particularly under the elevated salinity levels of 5 and 10 dS m^{-1}. At 5 dS m^{-1} salinity, green and dry matter weights reached 109.33 and 37.18 g, respectively, whereas corresponding values at 10 dS

m^{-1} were 86.03 and 29.95 g, respectively, during the first and subsequent harvests.

Conclusion

In rainfed areas of potohar nutrient deficiency is a major problem for crop growth and crops usually have poor stand and low yield. T5 treatment level comprising biofertilizer A (Biozote-M @ 5 kg ha^{-1}) and boron 2 (2 kg ha^{-1} borax) along with standard fertilizer dose (NPK100,75,60 kg ha^{-1}) gave maximum plants per meter square, number of seeds per panicle, 1000 grain weight, biomass, seed yield and collect file when contrasted with different medications under investigation. It is therefore concluded that, (T5 treatment) this combination can give best results under rainfed conditions however, more research is needed for better growth and high yield of Sorghum crop. For future research we can test different consortiums/combinations of biofertilizers and quantities of boron, for economically best combination with minimum dose of fertilizer to explore highest yield potential.

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ii. Competing interests: The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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