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ISSN: 2096-3246
Volume 54, Issue 02, December, 2022

Special Issue

Phosphate solubilizing bacteria optimize wheat yield in mineral phosphorus applied alkaline soil

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Abstract

Limited availability of phosphorus (P) in agricultural soils is a major cause of poor growth and yield of crops throughout the world. Optimization of crops productivity can be achieved by increasing the bioavailability of P via phosphate solubilizing bacteria (PSB), however, their effectiveness may vary with changing agro-climatic conditions That's why current experiment was conducted to evaluate the poten- tial of phosphate solubilizing bacteria (with PSB and without PSB) in improving growth and yield of wheat under different P levels (0, 25, 50, and 100 % of recommended P). The PSB with 100% recommended P significantly enhanced wheat tillers m^{-2}, grains spike^{-1}, grains and biological yield compared to the rest of the treatment's combination. A significant improvement in 100 grains weight and rate of photosynthe- sis also validated the efficacious functioning of PSB and full recommended P. Furthermore, PSB were effective in optimizing wheat yield attributes at respective P level compared to Without PSB. Our findings imply that, PSB application along with 100% recommended P as inorganic phosphorus has potential to enhance wheat growth and yield over sole application of P fertilizers or PSB.

Key words: Phosphorus solubilizing bacteria, Alkaline, Soil, Wheat, Fertilizers.

1. Introduction

Wheat belongs to family Poaceae and used as an important source of food worldwide (Kaushik et al., 2013). It is also used in may industrial products such as breads, rolls, cakes, cookies and pastry products (Pena, 2002). In Pakistan, wheat was grown underarea about 9224 thousand ha with an annual production of 25.750 million tons (GOP, 2017). It contributes 1.9% in agriculture sectors GDP and 9.6% of valve added in agriculture in agriculture sector (GOP, 2017). However, in Khyber Pakhtunkhwa (KP), wheat crop was cultivated under 0.40 million hectares with its annual produc- tion of 0.90 million tons (GOP, 2018). In Pakistan, average yield of wheat is far behind than advance countries. Major reasons of of low wheat yield are low soil fertility, low organic matter, unbal- anced fertilizer uses, lack of improved varieties and improper agro-nomic practices (Azeem and Ullah, 2016).

Phosphorus is most important nutrient for growth and develop- ment, which is mainly responsible for the roots, shoots, flowers and seed developments, crop maturity and yield, fixation of nitro- gen in legumes, produce quality of resistance against plant dis- eases (Rogers and Wolfram, 1993). In most of the soil, phosphorus is already present but not available to plant becauseit is extremely responsive to the presence of Ca^{+2} and Mg^{+2} in alka- line soils and to aluminum (Al^{+3}) and iron (Fe^{+3}) in acidic soil (Hao et al., 2002). Furthermore, 70% of total applied P quickly convert into nonavailable phosphorus by these precipitation reactions (Alam and Ladha, 2004; Rafiullah et al., 2020). The efficiency of mineral phosphorus fertilizer is 10–25% throughout the world and the available phosphorus to plant is as low as 1.0 mg kg^{-1} (Rodrıguez and Fraga, 1999a,b).

In 1950 s, phosphorus solubilizing bacteria were being used as bio-fertilizer. They play vital role in elevating P availability in soil to plant (Chen et al., 2006; Kudashev, 1956) through mineralizing organic P, and solubilizing precipitated P (Mehrvarz et al., 2008). In the soil, PSB secrete phenolic compounds, protons (Adnan et al., 2020) and organic and mineral acids (Adnan et al., 2019) resulting in soil acidification (Adnan et al., 2017) and successive P availability in calcareous soils from $Ca_3(PO_4)_2$. The organic chelating cations, i.e., Al^{3+}, Ca^{2+} and Fe^{3+} and may increase the bioavailable P (Wahid et al., 2019). Phosphate solubilizing bacteria also increase P uptake and growth via biologic N fixation (Adnan et al., 2018; Wahid et al., 2020), by releasing growth promoters such as indoleacetic acid (IAA) (Pathan et al., 2018), gibberellins and cytokinins (Kucey, 1999), alkaline phosphatases and H^+ protonation (Chaiharn and Lumyong, 2011). Keeping in mind the problem of lower availability of P in alkaline soil, the current study was planned to explore the effects of different application rates of inorganic P fertilizer with and without PSB on growth and yield of wheat crop. It is hypothesized that combined use of PSB with inorganic P fertilizer is a better approach to improve wheat growth and yield.

2. Materials and methods

A field experiment was conducted to study the role of PSB in enhancing bio-availability of P at Agriculture Research Farm, Department of Agronomy, The University of J.S. University Shikohabad, Firozabad during2017–18.

2.1. Treatments detail

Two levels of PSB (0 and 1.5 kg ha^{-1}) and four levels of phosphorus in form of DAP. Phosphorus was applied at 0, 25, 50 and 100% of the recommended phosphorus levels (100 kg P ha^{-1}). Plot size of 9 m^2 was used in order to avoid dispersal of PSB in the plots. However, row to row and plant to plant distances was kept according to each plot requirements. Treatments includes: 0 % P (P0) + 1.5 kg ha^{-1} PSB, 25 % P (P25) + PSB, 50 % P (P50) + PSB, 100 % P (P100) + PSB, Control (0 %P + No PSB), T6 = P25, P50 and P100.

2.2. Irrigation

Total of four irrigations were provided through the cultivation period.

1st = 25 days after sowing (Crown root initiation)
2nd = 55 days after sowing (Tillering stage)
3rd = 80 days after sowing (Heading stage)
4th = 110 days after sowing (Milky stage/soft dough)

Days to emergence

Days were counted from sowing to harvesting when 90 % emergence of seedling completed in plot (Kumar, 2017).

$$\text{Emergence } m^{-2} = \frac{\text{Total number of seedling emerged}}{\text{Row to row distance} \times \text{Number of rows} \times \text{Row length}}$$

2.3. Number of tiller (m^{-2})

Number of tillers row^{-1} was noted by counting number of tillers in the central four rows and then converted into m^{-2}.

$$\text{Tillers } m^{-2} = \frac{\text{Total number of tillers counted in central four rows}}{\text{Row to row distance} \times \text{Number of rows} \times \text{Row length}}$$

2.4. Number of grains spike^{-1}

Number of grain $spike^{-1}$ was examined by random selection of 10 spikes from each treatment. After threshing each spike and counting its grains and then averaged.

2.5. Thousand grain weight (g)

The data regarding 1000 grain weight was recorded by counting a thousand grains from each treatment after harvesting and weighed using an electrical balance.

2.6. Biological yield (kg ha $^{-1}$)

After harvesting of each plot, the whole bundle was sun dried for five days. Bundle was weighed using spring balance and converted into kg ha^{-1} by formula:

$$\text{BIological Yeild } (\text{kg ha}^{-1}) = \frac{\text{Weight of sample } (\text{kg ha}^{-1}) \times 10000 \ (m^2)}{\text{Area Harvested } (\text{Sq: m})}$$

2.7. Grain yield (kg ha^{-1})

Grain yield obtained after threshing was weighed using an electrical balance and then yield obtained from each plot was converted into kg ha^{-1} by the formula:

$$\text{Grain yield } (\text{kg ha}^{-1}) = \frac{\text{Grain yield } (\text{kg ha}^{-1}) \text{ in central four row} \times 10000 \ m^2}{\text{row to row distance} \times \text{number of row} \times \text{row length}}$$

2.9. Statistical analysis

The replicated data was compiled and analysed for analysis of variance (ANOVA) according to two factorial complete randomized block (RCB) design and least significant difference (LSD) through computer software statistix-8.1, as prescribed by Steel et al. (1997).

3. Results and discussion

3.1. Tiller m^{-2}

Different application rates of P with and without PSB differed significantly for tillers m^{-2}. Tillers m^{-2} were significantly improved in PSB as compared to No PSB treatments. Application of P100 was significantly the best for improvement in tillers m^{-2} over P50, P25 and P0 with and without PSB (Fig. 1A). Similarly,

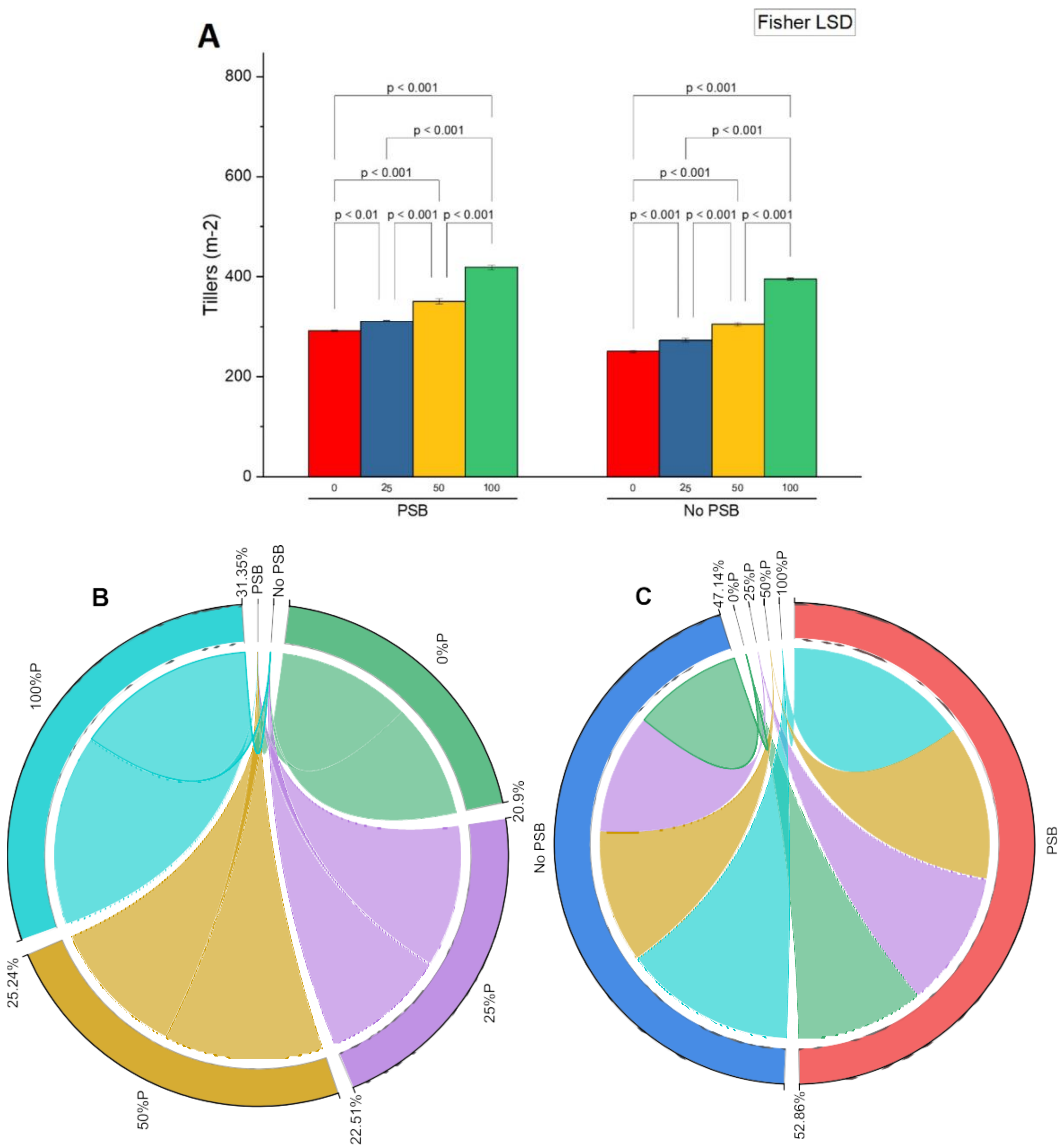

Fig. 1. Effect of different application rates of phosphorus with and without PSB on tillers m^{-2}. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for tillers m^{-2}. n.s. = non-significant.

P25 and P50 also caused significant increase in tillers m^{-2} over control (P0) with and without PSB. Chord diagram showed that percentage share of PSB was higher than No PSB treated wheat seeds for tillers m^{-2} (Fig. 1B). In the presence and absence of PSB, P100 gave highest percentage share for tillers m^{-2} in wheat and the PSB collectively recorded the highest share (52.86%) (Fig. 1C). (Cook and Vaseth, 1991) reported that phosphorus plays a vital role in developing seminal root and radical more in the plant and hence improvement in number of tillers occurs. According to Rahim et al. (2010) the amount of available phosphorus enhanced the number of tillers. It may be due to phosphorus essentiality in the development of roots leading to more nutrient's uptake by plants. Afzal and Bano, 2008 reported that combine application of PSB and phosphorus significantly enhanced the number of tillers.

3.2. Leaf area tiller^{-1} (cm)

Effect of P different rates with and without PSB was significant for leaf area tiller^{-1}. It was observed that PSB remained signifi- cantly better as compared to No PSB treatments for improvement in leaf area tiller^{-1}. Application of P100 differed significantly best for the increase in leaf area tiller^{-1} over P0 with and without PSB (Fig. 2A). Similarly P25 and P50 also caused significant improve- ment in leaf area tiller^{-1} over control (P0) with and without PSB. Chord diagram showed that percentage share of PSB was

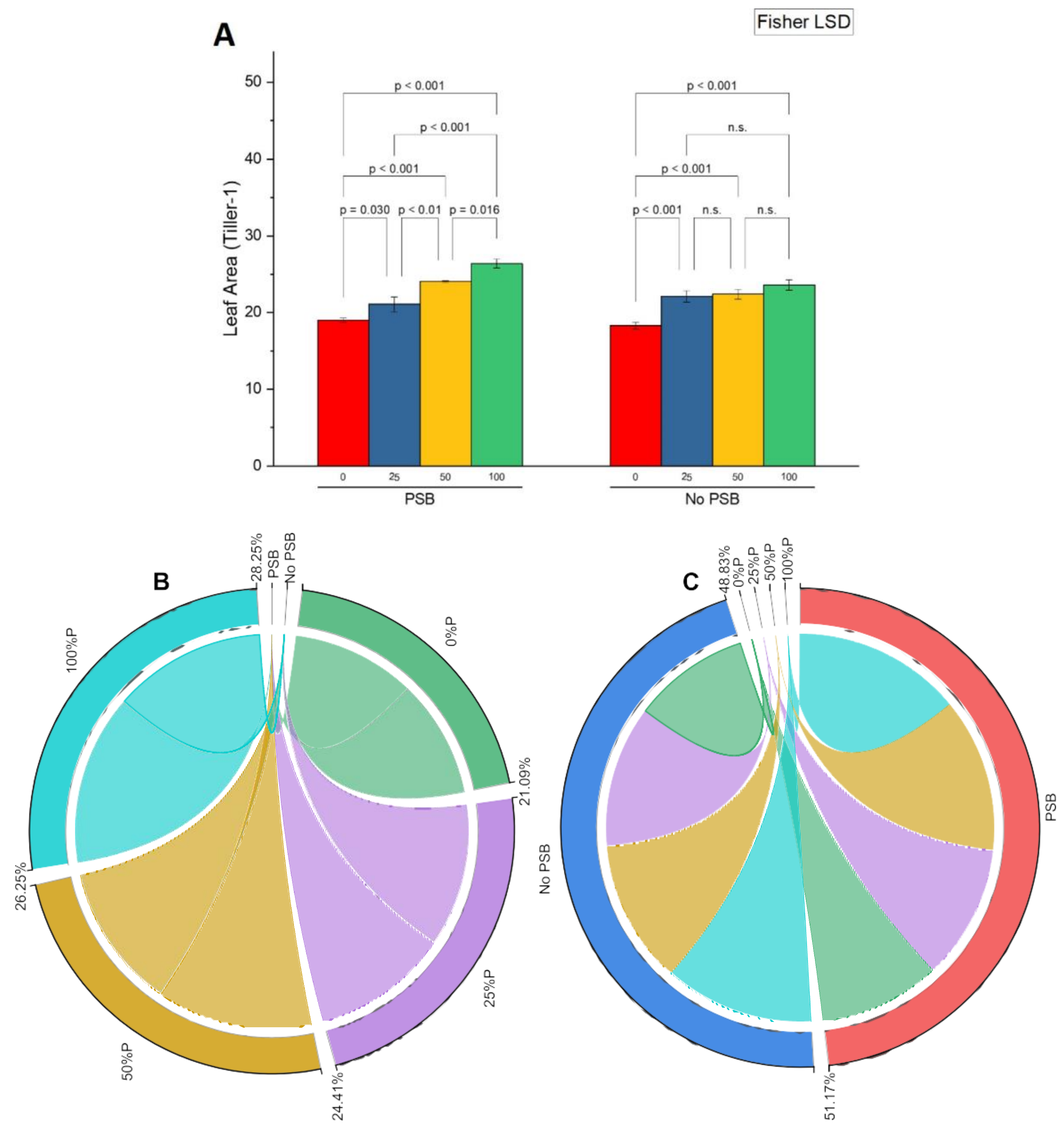

Fig. 2. Effect of different application rates of phosphorus with and without PSB on leaf area tiller-1. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for leaf area tiller-1. n.s. = non-significant.

higher than No PSB treated wheat seeds for leaf area tiller-1 (Fig. 2B). With and without PSB, P100 gave highest percentage share for leaf area tiller-1 in wheat (Fig. 2C). According to Hossain et al. (2011), the large leaf area plays important role in different physiochemical process of plant like chlorophyll formation, electron transport chain and enzyme activation. Similar results were also reported by Asad and Rafique (2000). Rodrıguez and Fraga (1999a,b) studied and revealed that phosphorus plays a vital role in increasing leaf area of the plant and adjustment availability for the growth of leaf. Fargeria et al. (1997) studied that proper phosphorus management increased leaf mass and number of tillers plant—1.

3.3. 1000-Grain weight (g)

Influence of P at different application rates in the presence and absence of PSB, was significant for 100 grains weight. Results confirmed that PSB was significantly better as compared to No PSB treatments for improvement in 100 grains weight. Application of P100 remained significantly best for enhancement in 1000 grains weight over P0 with and without PSB (Fig. 3A) Similarly, P50 also induced significant improvement on the 1000 grains weight with and without PSB over P0. In case of P25, a significant increase of 1000 grains was observed with PSB but no significant change was noted over P0 without PSB. Chord diagram showed that per-

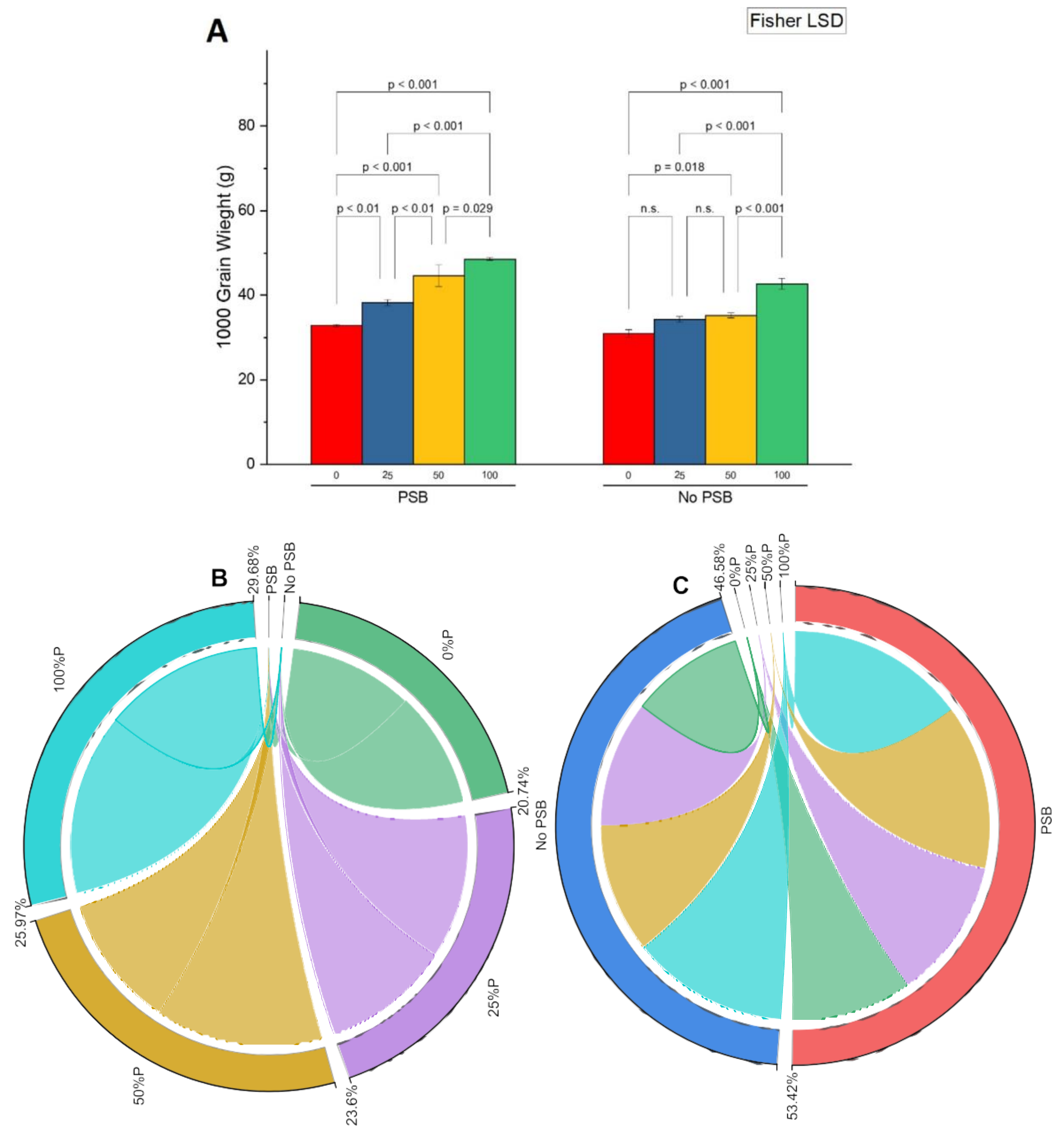

Fig. 3. Effect of different application rates of phosphorus with and without PSB on 100 grains weight. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for 100 grains weight. n.s. = non-significant.

centage share of PSB was higher than No PSB treated wheat seeds for 1000 grains weight (Fig. 3B). With and without PSB, P100 gave highest percentage share for 1000 grains weight in wheat (Fig. 3C). Rock minerals of phosphate are much soluble to provide sufficient amount of available phosphorus crop uptake (Hossain and Sattar, 2014). The results are in conformity with findings of Hossain and Sattar (2014). Verma (1993) stated that phosphate solubilizing microorganisms (PSMs) application can increase crop yield up to 70 percent. Grain yield was increased by combined application of PSB and P (Sial, 2015).

3.4. Grain spike^{-1}

Effect of P at different application rates in the presence and absence of PSB, was also significant for grains spike^{-1}. Statistical analysis showed that PSB remained significantly best over No PSB treatments for increase in grains spike^{-1}. Treatment P100 differed significantly better for improvement on the grains spike^{-1} over P0 with and without PSB (Fig. 4A). Similarly, P25 and P50 also induced significant increase in grains spike^{-1} over P0 with and without PSB. Chord diagram showed that percentage share of PSB

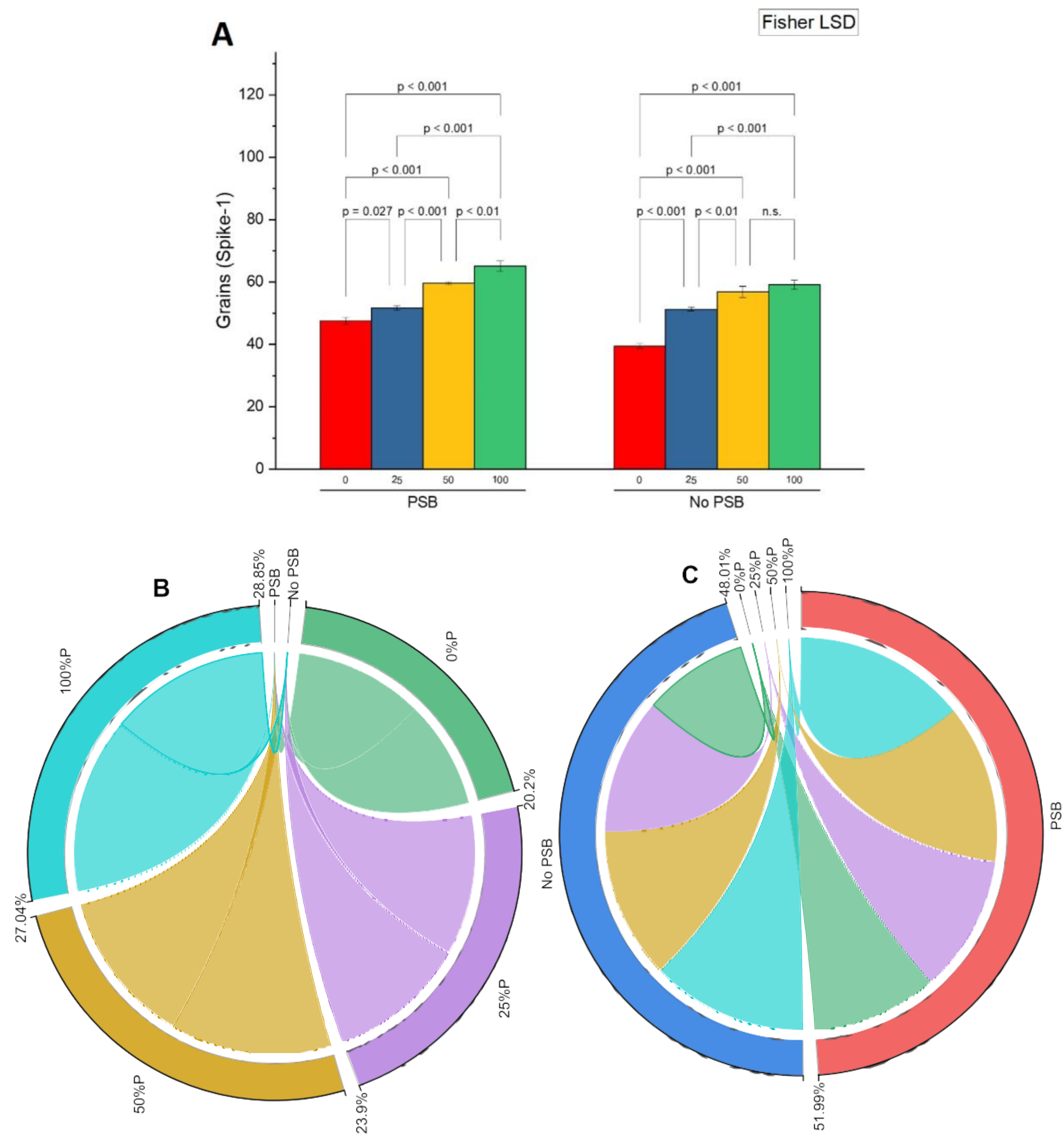

Fig. 4. Effect of different application rates of phosphorus with and without PSB on grains spike^{-1}. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for grains spikes^{-1}. n.s. = non-significant.

was higher than No PSB treated wheat seeds for grains spike^{-1} (Fig. 4B). With and without PSB, P100 gave highest percentage share for grains spike^{-1} (Fig. 4C). Hossain and Sattar (2014) showed that increment in phosphorus levels also increased the number of grains spike^{-1}. In photosynthesis, phosphorus plays important role which leads to enhanced number of grains spike^{-1}. The results are in conformity by research determination of Sarker et al. (2014), they stated that application of PSB (*Pseudomonas*) enhanced the availability of nutrient to plant which enhanced plant growth and yield.

3.5. Spike length (cm)

Results showed that influence of P at different application rates with and without of PSB, was significant for spike length. Inoculation of PSB remained significantly best over No PSB treatments for increase in spike length. Application of P100 was significantly different for improvement on the spike length over P0 with PSB (Fig. 5A). P50 caused a significant increase in spike length over P0 without PSB. Chord diagram showed that percentage share of PSB was higher than No PSB treated wheat seeds for spike length

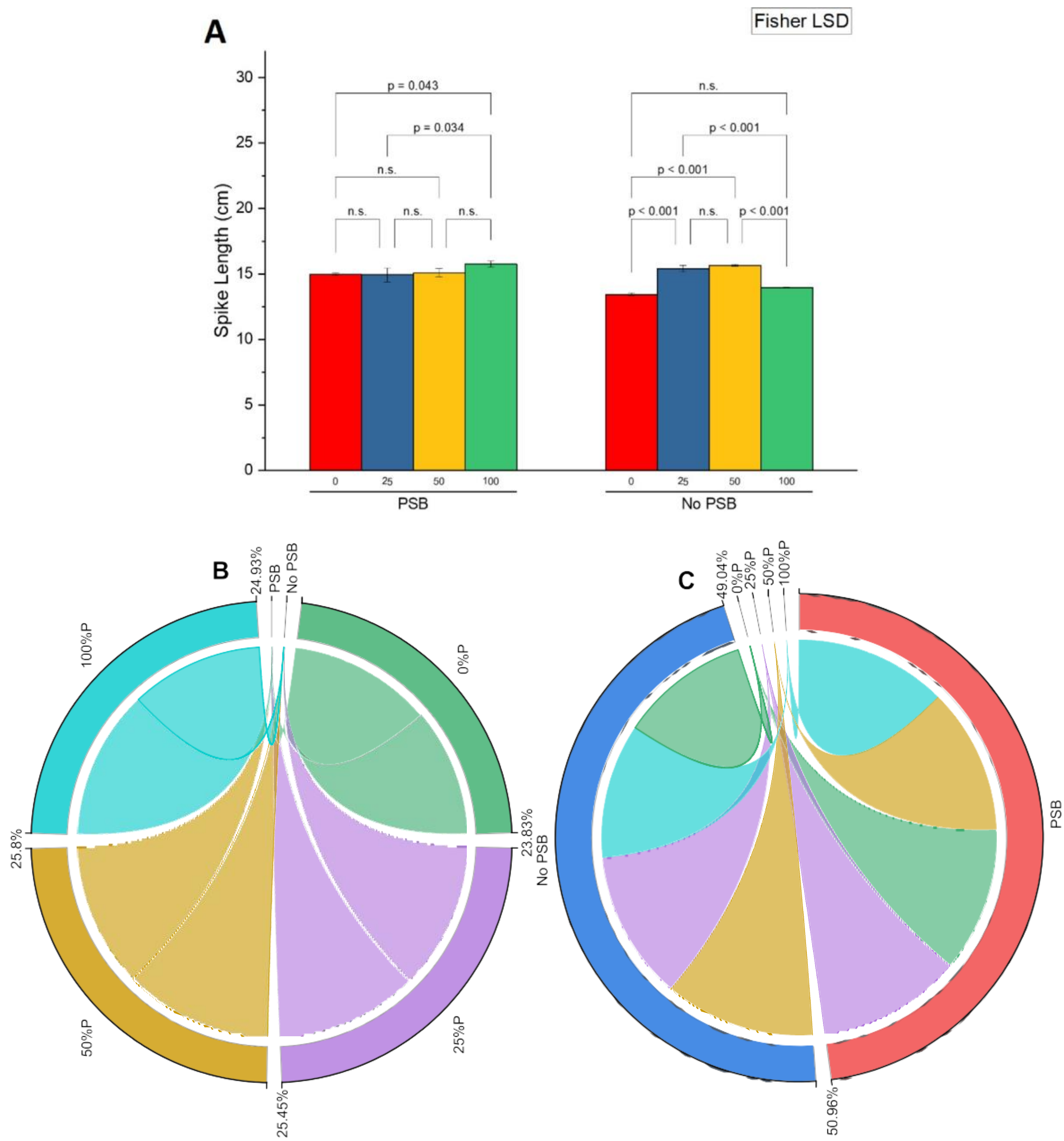

Fig. 5. Effect of different application rates of phosphorus with and without PSB on spike length. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for spike length. n.s. = non-significant.

(Fig. 5B). With and without PSB, P50 gave highest percentage share for spike length (Fig. 5C). By interaction of PSB and P, spike length of wheat was particularly influenced, as it has important effect in critical processes as cell division, cell enlargement, photosynthesis (Krishnaraj and Dahale, 2014). Sharma et al. (2012) also reported that P application improved plant height and spike length by stimulating various processes in plant like cell division and cell enlargement.

3.6. Biological yield (kg ha^{-1})

Influence of P at different application rates with and without of PSB, was significant for biological yield. Inoculation of PSB performed significantly better over No PSB treatments for increase in biological yield. The application of P100, P50 and P25 significantly improved the biological yield over P0 with and without PSB (Fig. 6A). Chord diagram showed that percentage share of PSB was higher than No PSB treated wheat seeds for biological yield (Fig. 6B). With and without PSB, P100 gave highest percentage share for biological yield (Fig. 6C). The enhancement of biological yield may be the attributes of availability of more phosphorus to plant due to PSB and improved plant growth (Egamberdiyeva et al. 2004). The similar results were also reported by Hossain and Sattar (2014). Sharma et al. (2012) showed that the combination of PSB and phosphorus has massive role in cell division, root elongation and imperative constituent of ATP and ADP which are responsible for the yield and yield component improved.

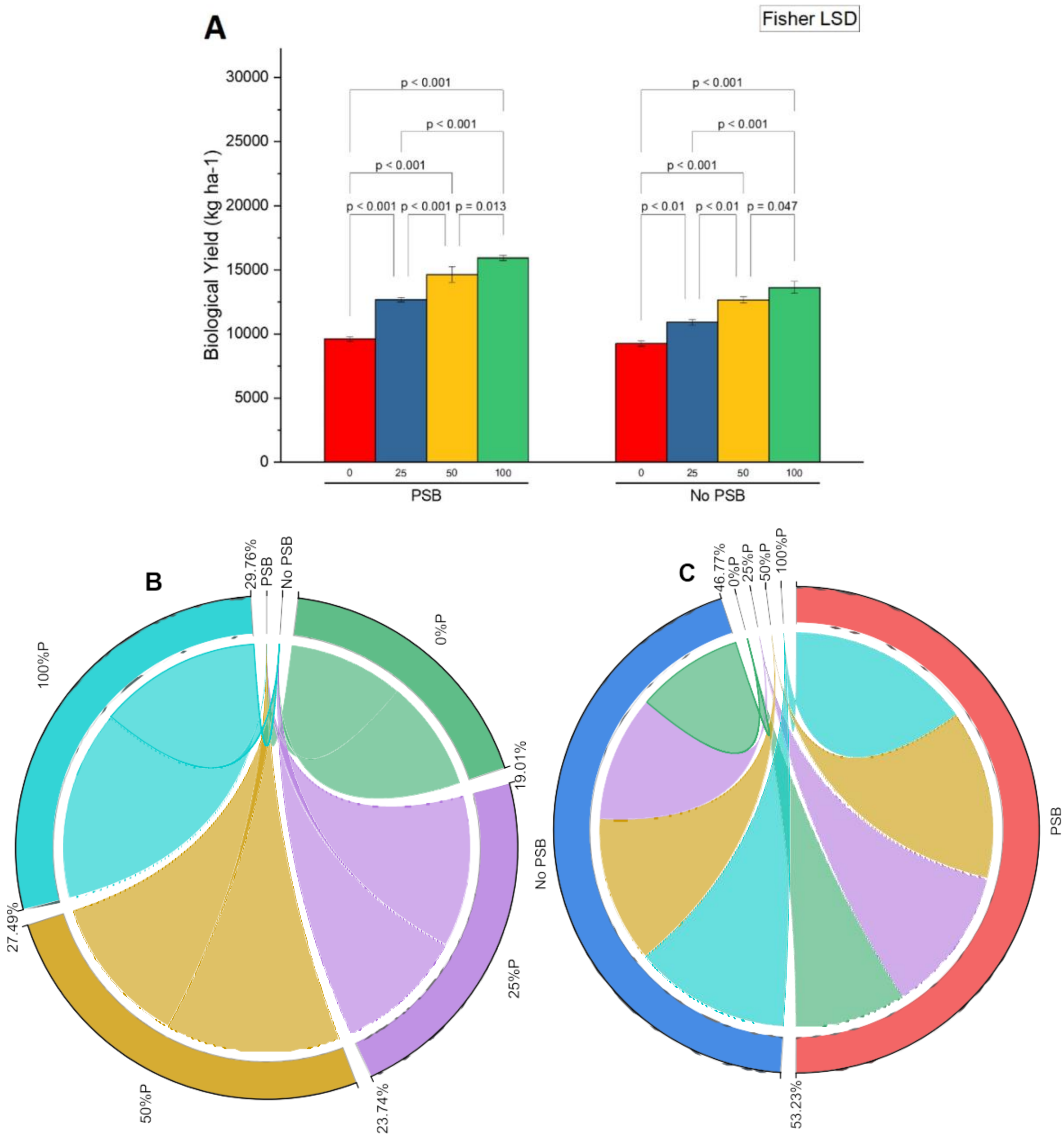

Fig. 6. Effect of different application rates of phosphorus with and without PSB on biological yield. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for biological yield. n.s. = non-significant.

3.7. Grain yield (kg ha^{-1})

For grain yield, application of P at variable application rates with and without of PSB remained significant. PSB inoculation with application of P100, P50and P25 significantly enhanced grain yield over P0 (Fig. 7A). Whereas, only the applications of P50 and P100 caused significant increase in grain yield over P0 without PSB. Chord diagram showed that percentage share of PSB was higher than No PSB treated wheat seeds for grain yield (Fig. 7B). Without and with PSB, application of P100 gave highest percentage share for grain yield (Fig. 7C).

4. Conclusion and recommendations

It is conducted that the application of PSB along with different levels of inorganic phosphorus give the best results for yield and yield component. Hundred percent of inorganic phosphorus along with PSB application significantly increased yield (69%) and yield component of wheat crop. Hence, 100% of P from inorganic source along with PSB for maximum productivity. Therefore, it is concluded from this study, that more research is recommended in different pockets of the Hazara Division, prior to its commercial recommendation in the area.

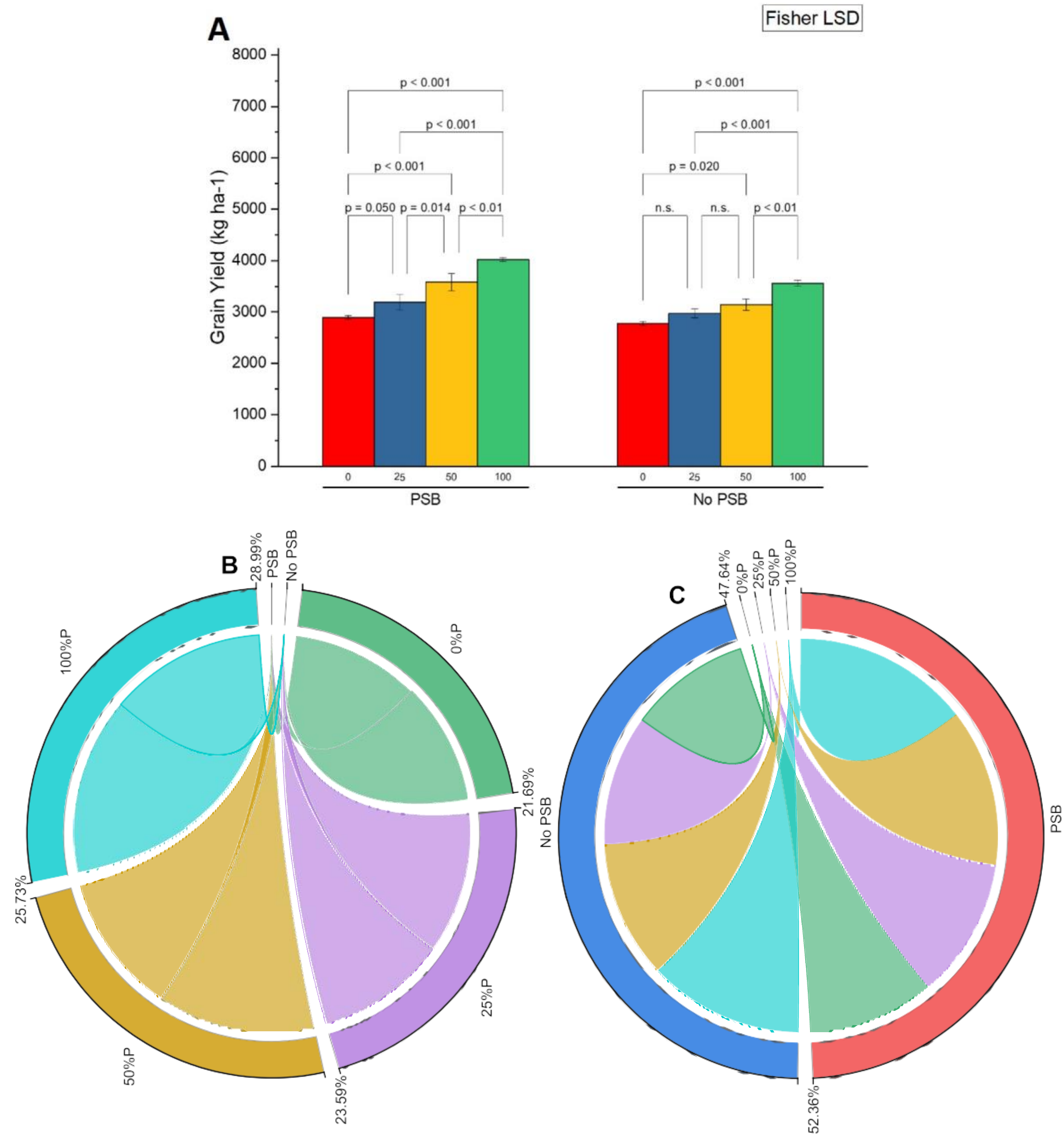

Fig. 7. Effect of different application rates of phosphorus with and without PSB on grain yield. Bars are means of three replicates ± standard error. Values on bars are p values computed by Fisher LSD (A). Chord diagram is showing percent share of different application rates of P (B) and PSB (C) for grain yield. n.s. = non-significant.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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