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RESEARCH ARTICLE

Enhancing yield and quality of wheat (*Triticum aestivum* L.) using sprayer and drone-assisted nano-NPK application with improved crop establishment techniques

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Abstract

This study evaluated different crop establishment methods (CEM) and nutrient management (NM) strategies involving foliar application of nano-NPK through drone and knapsack sprayer in wheat (*Triticum aestivum* L.). The experiment was conducted at Lovely Professional University, Punjab, in collaboration with D2F Services Private Limited. The experiment was laid out in a factorial randomized block design (FRBD) using two factors, CEM and NM during the *Rabi* seasons of 2023 and 2024. Crop establishment methods included furrow irrigated raised bed (FIRB) and the drilling method, while nutrient management comprised eight possible combinations of recommended dose of fertilizer (RDF; ranging from 50 %-100 %), farmyard manure (FYM) and foliar application of nano nitrogen, phosphorus and potassium (NPK). The result indicated that among the crop establishment methods, FIRB had a statistically significant (p <0.05) impact on yield attributes, yield and quality parameters as compared to the drilling method. On the other hand, among the nutrient management, treatment $N_{6,}$ which comprises 75 % RDF + one spray of drone-based nano NPK, was observed as the most effective and statistically significant at (p <0.05) compared to the rest of the treatments for plant height (cm), total number of tillers m^{-2}, productive tillers m^{-2}, spike length (cm), number of spikes $plant^{-1}$, number of spikelet $spikes^{-1}$, number of grains $spike^{-1}$, test weight (g) and grain yield (q ha^{-1}), protein content and gluten content (%). The correlation analysis of grain yield (q ha^{-1}) *vs.* effective tillers m^{-2} (r^2 = 0.981), number of spikes $plant^{-1}$, test weight (g) and gluten content (%) shows a positive relationship among them. These findings suggest that drone-assisted nano-NPK application and improved crop establishment techniques can effectively enhance the yield and quality of wheat.

Keywords: crop establishment methods; drone-assisted foliar application; knapsack sprayer; nano-NPK; protein; gluten

Introduction

Wheat (*Triticum aestivum* L.) is one of the world's most important staple food crops in the world, grown in temperate and subtropical climates (1). It is grown preferably as a *Rabi* season crop in India because of its temperature requirements. It requires 20-22 °C for seed germination, while 16-22 °C is ideal for the grain filling stage (2). India ranks as the second-largest wheat producer globally, after China, accounting for approximately 17 % of global production. Haryana and Punjab, both states, are significant contributors to the wheat production in India due to adequate irrigation facilities and the highest mechanization in agriculture (3, 4).

Considering the scenario, where most Indian farmers depend on broadcasting methods of sowing and knapsack sprayers for foliar application of nutrients. Our main goal of research is to suggest an alternative method of crop establishment and foliar application to avoid the wastage of seed, nutrients, labour cost and improve the crop yield. FIRB, an effective technique for producing wheat, conserves moisture and enhances crop growth, using small furrows between the beds to apply irrigation water, enabling water to reach the roots directly (5). Another popular technique for sowing is the drilling method, using a seed drill for sowing at the proper depth and spacing that minimizes seed waste, saves time and effort (6).

Wheat is a significant source of carbohydrate in the form of starch, accounting for around 60 %-75 % of the grain (7). It contains around 10 %-14 % of protein, including gluten, which is a kind of protein responsible for the good quality of bread. Additionally, it is also rich in vitamins, minerals and dietary fibre, enhancing the quality of the wheat crop (8).

Nano-NPK offers significant benefits in agriculture by improving nutrient absorption and translocation, thereby enhancing yield (9). It not only allows the precise delivery of nutrients but also readily passes through the tiny leaf openings to enter the plant and reduces the environmental impact as compared to the conventional form of fertilizer application (10, 11). Nowadays, a drone-based foliar application of nutrients is in use, which is popular for quickly, uniformly covering big areas, saving time and lowering the need for labour as compared to the conventional knapsack sprayer (12).

Materials and Methods

An experiment on enhancing the yield and quality of wheat using crop establishment methods and drone assisted foliar spray of nano-NPK. The research was carried out at the Research Farm of Lovely Professional University, which was located in the Kapurthala district of Punjab, India, during the *Rabi* season of 2023 and 2024. Before the experiment, a physicochemical test of the soil was conducted to analyze the soil health. The texture of the soil was sandy loam, had a pH of 7.52 and an electrical conductivity (EC) of 0.463 dS m^{-1}. The available nutrient in the soil was nitrogen 0.46 %, phosphorus 4.39 % and potassium 0.34 % respectively while the average annual rainfall was recorded as 1152.5 mm.

Experimental details

An experiment was conducted using the HD 2851 variety of wheat, procured from Punjab Agricultural University, by adopting a FRBD with two main factors (A and B) and three replications. The first factor was the CEMs, comprising two improved methods i.e. the FIRB [C_1] and drilling method [C_2]. The second factor was nutrient management (N), consisting eight possible combinations: control (N_1), 100 % RDF (N_2), 75 % RDF + one spray of nano-NPK (knapsack sprayer) (N_3), 50 % RDF + two sprays of nano-NPK (knapsack sprayer) (N_4), 50 % RDF + one spray of nano-NPK (knapsack sprayer) + 25 % FYM (N_5), 75 % RDF + one spray of nano-NPK (drone) (N_6), 50 % RDF + two sprays of nano-NPK (drone) (N_7), 50 % RDF + one spray of nano-NPK (drone) + 25 % FYM (N_8). Standard agronomic practices were followed to ensure uniformity of the research work. The individual plot size was 5 × 5 m, with row spacing of 22.5 cm and plant spacing of 10 cm.

Foliar application of nano NPK

The foliar application of nano-NPK was carried out at the tillering and jointing stage using both a drone and a knapsack sprayer. The drone-based foliar application of nutrients was conducted under the supervision of an expert from the Mohali-based D2F Service Private Limited (Fig. 1). The drone specification were; a spray rate of 1.5 L per min, a 10 L tank capacity and the ability to cover one acre in seven min (Model: Agribot A5; UIN: UA002DDS0TC).

Yield and yield contributing traits

Observations on the number of tillers m^{-2} and spikes m^{-2} were recorded by counting the number of plants per square meter, with only the tillers bearing grains considered as effective tillers. Spike length was measured from the base to the top of the spike, while the number of spikelets per spike was determined from five healthy tagged plants and expressed as their average value per spike. Grains were threshed from an area of 1 m^2 and their weight was recorded using a digital weighing balance and expressed as yield in q ha^{-1}. For test weight, a random sample of 1000 healthy grains was used and the value was expressed in grams (g).

SPAD index

Five randomly pre-tagged plants of flag leaf from each plot were selected to record the chlorophyll index, which was measured at two consecutive intervals of 60 and 90 days after sowing (DAS) by using the SPAD (Soil Plant Analysis Development) meter. The SPAD meter is a compact instrument with an accuracy of ± 1.0 (Model 502, Konica Minolta Sensing, Singapore Pte. Ltd.). Its working principles is based on non-destructive sampling; therefore, prior to recording values, the instrument was calibrated to ensure high accuracy.

Quality parameters

Protein content

The protein content was computed from the nitrogen content as per the method described elsewhere (13). A total of 1 g of dried, ground wheat flour was taken into a Kjeldahl digestion flask. To accelerate the digestion, 10 mL of H_2SO_4 and K_2SO_4 were added to the flask. The contents were heated until the mixture became transparent, indicating complete digestion. The cooled digest was transferred to a distillation unit, where NaOH was added to render the solution alkaline. The released ammonia was trapped in a conical flask containing boric acid and subsequently titrated with 0.1 N HCl. The percentage of nitrogen present in the sample was calculated from the following equation:

$$\text{Nitrogen (\%)} = \frac{(V_1\text{-}V_2) \times N \times 14.007 \times 100}{W \times 1000} \quad \text{(Eqn. 1)}$$

Fig. 1. Drone-based application of nutrients over the experimental field by an expert of D2F Services Private Limited.

Whereas,

V_1 and V_2 represent the volume of HCl used for the titration of the sample and blank.

N and W represent the normality of the solution and the weight of the sample, while 14.007 is the atomic weight of nitrogen.

Gluten content

The gluten content of wheat flour was determined using the method described elsewhere (14). A 25 g sample of finely ground and sieved flour was used to ensure uniform particle size. Distilled water was then added while mixing until an elastic dough is formed, which was allowed to rest at room temperature for 20 min. The rested dough was transferred into a beaker filled with water to remove the soluble compounds and washing process was repeated until the water turned clear. The moist gluten was then transferred to a porcelain dish and dry in a hot air oven at 105 °C until a constant weight was obtained. Thereafter, it was placed in a desiccator to prevent moisture absorption until the gluten content was determined using the following formula:

Gluten content (%) = (Weight of gluten content / Weight of flour sample) × 100

Statistical analysis

The data were analysed using a FRBD, with a STAR software developed by IRRI, Philippines. The significance of the data was tested by using the ANOVA at $p < 0.05$ of the probability (15).

Results and Discussion

Yield and yield attributes

The response of drone and sprayer-based nano application of NPK and crop establishment methods on yield attributes, yield and quality of wheat (HD 2851) was evaluated. The data presented in Table 1 are marked as statistically significant for the first and second factors, i.e. CEM and NM, for all traits. The interaction between the CEM and NM was statistically significant ($p < 0.05$) for the total number of tillers, effective tillers m^{-2}, number of spikes $plant^{-1}$, number spikelets $spike^{-1}$ $plant^{-1}$, number of grains $spikes^{-1}$, test weight (g) and grain yield (q ha^{-1}), while remaining traits were observed as non-significant.

Table 1 further indicated that the FIRB method of sowing was comparatively better than the DM. The significantly highest value of plant height at 60 and 90 DAS (55.4 and 94.1 cm), total number of tillers (293 m^{-2}), effective tillers (283.2 m^{-2}), spike length (10.2 cm), number of spikes $plant^{-1}$ (8.9), number spikelet $spikes^{-1}$ $plant^{-1}$ (19.2), number of grains $spike^{-1}$ (46.4), test weight (44.7 g) and grain yield (41.6 q ha^{-1}). Across all combinations of the nutrient management, significantly highest value of plant height at 60 and 90 DAS (61.2 and 101.2 cm), total number of tillers (319.6 m^{-2}), effective tillers (314.4 m^{-2}), spike length in (11.9 cm), number of spikes $plant^{-1}$ (10.5), number spikelet $spikes^{-1}$ (21.7), number of grains $spike^{-1}$ (54.4), test weight (50.8 g) and grain yield (42.5 q ha^{-1}) were recorded in N_6 (75 % RDF + one spray of drone-based nano NPK), followed by N_2 (100 % RDF).

The significance of FRBD was recorded better method of sowing as compared to the DM. The FIRB method of sowing enhances yield and yield attributes by ensuring optimal soil aeration, managing water drainage, hence promoting strong root systems and facilitating nutrient absorption, resulting in taller and healthier wheat plants (16-18). Efficient water and nutrient use reduce soil compaction, leading to an increase in vegetative and reproductive parts of the wheat plant and ultimately enhanced yield (19-21). Additionally, the nano-NPK was used as one of the contents in the combination of N_6 treatment applied over the plant as a foliar application based on drone technology. This method of application enables the precise delivery of nutrients, ensuring the synchronized application of nano-NPK, which provides essential nutrients in nanoparticles (22, 23). These are more readily

Table 1. Response of sprayer and drone-assisted nano-NPK application and crop establishment techniques on yield attributes and yields in wheat

Treatments	Plant height (cm)		Total number of tillers m^{-2}	Productive tillers m^{-2}	Spike length (cm)	Number of spikes $plant^{-1}$	Number Spikelet $spikes^{-1}$	Number of grain $spikes^{-1}$	Test weight (g)	Grain yield (q ha^{-1})
	60 DAS	90 DAS								
Crop establishment methods										
C_1	55.4	94.1	293.03	283.2	10.4	8.9	19.2	46.4	44.7	41.6
C_2	54.3	92.9	283.66	276.7	10.2	8.4	18.4	43.6	43.1	41.2
SE(m±)	0.10	0.10	0.51	0.50	0.04	0.03	0.05	0.12	0.10	0.02
CD (p<0.05)	0.30	0.32	1.56	1.51	0.11	0.08	0.15	0.35	0.31	0.06
Nutrient management treatments										
N_1	44.3	83.6	245.75	239.8	8.7	6.9	16.0	34.2	36.7	40.1
N_2	60.8	100.7	318.00	313.1	11.6	10.2	21.3	53.5	50.0	42.2
N_3	59.2	98.4	310.50	294.1	11.0	9.2	19.7	49.1	47.4	41.8
N_4	55.0	93.3	280.88	273.8	9.8	8.5	18.5	43.4	43.2	41.3
N_5	48.6	86.1	257.75	252.9	9.2	7.5	16.6	38.4	38.0	40.6
N_6	61.2	101.2	319.63	314.4	11.9	10.5	21.7	54.4	50.8	42.5
N_7	52.1	89.0	272.38	265.0	9.5	8.0	17.6	40.6	40.8	41.0
N_8	57.7	95.5	301.88	286.5	10.6	8.8	19.1	46.4	44.4	41.5
SE(m±)	0.19	0.21	1.02	0.99	0.07	0.05	0.10	0.23	0.21	0.04
CD (p<0.05)	0.59	0.63	3.11	3.02	0.22	0.15	0.30	0.71	0.63	0.12
CD (p<0.05) CXN	NS	NS	4.40	4.27	NS	0.21	0.42	1.00	0.89	0.17

Notes: C = Crop establishment methods (CEM), whereas C_1 FIRB, C_2 drilling method. N = Nutrient management treatments (NM) whereas, N_1 = control, N_2 = 100 % RDF, N_3 = 75 % RDF + 1 spray nano-NPK (knapsack sprayer), N_4 = 50 % RDF + 2 spray NPK (knapsack sprayer), N_5 = 50 % RDF + 1 spray NPK (knapsack sprayer) + 25 % FYM, N_6 =75 % RDF + 1 spray nano NPK (drone), N_7 = 50 % RDF + 2 spray NPK (drone) and N_8 = 50 % RDF + 1 spray NPK (drone) + 25 % FYM.

absorbed by plants, resulting in improved nutrient absorption efficiency, accelerating cell division and elongation, enhancing photosynthesis and promoting root formation (24-27). The results are consistent with the findings of earlier studies, which reported that the use of RDF with nano-NPK not only fulfilled the initial requirements but also facilitated nitrogen for chlorophyll synthesis, phosphorus for root growth and potassium for enzyme activation and other metabolic process (28-31).

SPAD index

Fig. 2 showing the response of the treatments in wheat leaves at 60 and 90 DAS. Among crop establishment methods, the value of the SPAD index was recorded comparatively better in FIRB method of sowing than DM (42.1 and 43.5), which was observed statistically significant ($p < 0.05$). Among the nutrient management, the significantly highest value of the SPAD index was observed in N_6 (47.4 and 48.3), followed by N_2 (46.9 and 47.3). However, the interaction between the CEM and NM for the SPAD index was recorded as non-significant.

Precise delivery of nano-NPK triggers multiple enzymes, influences meristematic activity in the plant and synthesis of chlorophyll (32). Fig. 2 shows the SPAD index was maximum in FIRB and N_6. Hence, the increased amount of chlorophyll accelerated the rate of photosynthesis as well as vegetative and reproductive growth (33, 34). Moreover, nitrogen stimulates the synthesis of cytokinin, responsible for triggering axillary buds for lateral shoot growth, such as tillers and yield attributes (35, 36). Thus, combined efforts lead to improved productivity of the wheat crop by improving yield attributes.

Protein and gluten content (%)

The protein and gluten content were estimated from the grains of wheat to assess the quality of wheat grains. Fig. 3, showing the response of the treatments in wheat. Among crop establishment methods, the value of the protein and gluten (%) was recorded higher in FIRB than DM (10.2 % and 11.6 %), which was observed statistically significant at $p < 0.05$. Among the nutrient management, the significantly highest value of the protein and

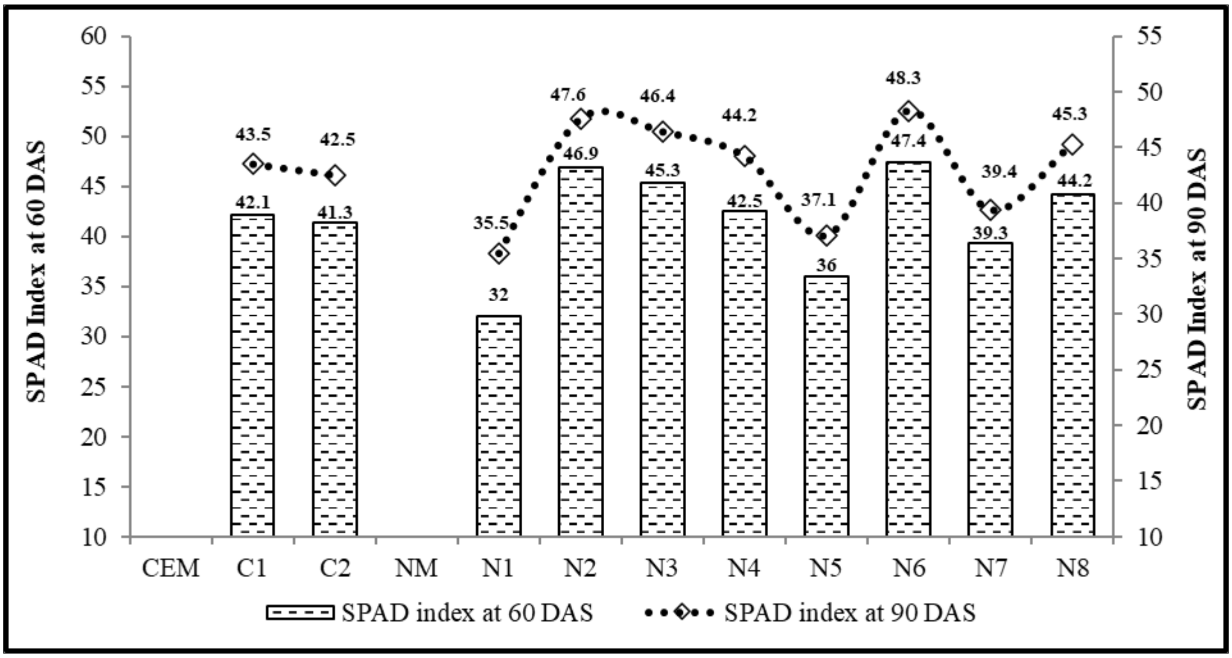

Fig. 2. Response of the treatments on SPAD Index at 60 and 90 DAS in wheat.

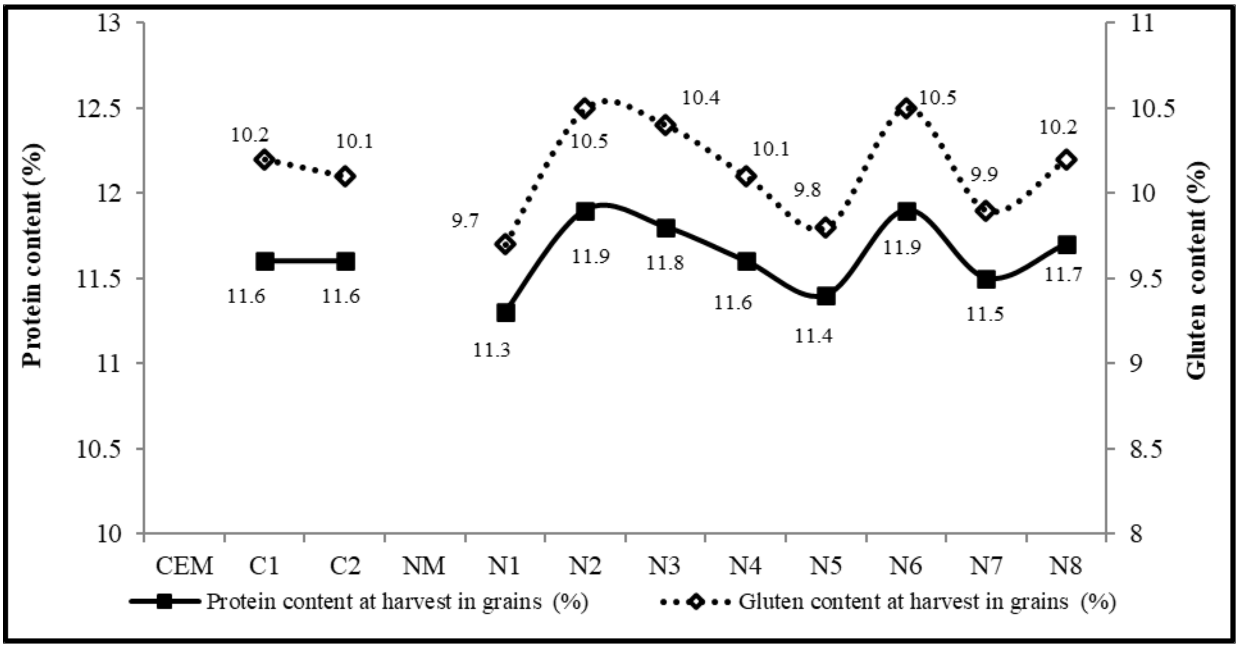

Fig. 3. Response of the treatments on the protein and gluten content (%) in wheat.

gluten (%) was recorded in N_6 and N_2 (10.5 % and 11.9 %), followed by N_3(10.4 % and 11.8 %). However, the interaction between CEM and NM for protein and gluten content was non-significant.

Quality parameters of wheat grains, including protein and gluten content, which were significantly influenced by the treatment and recorded the highest in FIRB and N_6 as compared to the control (Fig. 3). The nano-NPK was used as a foliar application, contributes to leading protein synthesis because nitrogen is a key component of amino acids, which are building blocks of protein synthesis (37). Additionally, the increased nitrogen use efficiency triggers the synthesis of gluten-forming protein in wheat grains plays a crucial role in improving the texture of bread (22).

Correlation studies among the yield attributes, yield and quality trait

Correlation studies demonstrated that the significance of the treatments in relation to the yield attributes, grain yield and quality parameters. A strong positive correlation exists between effective tillers and grain yield (r^2= 0.981), number of spikes plant^{-1}and grain yield (r^2= 0.982), test weight and grain yield (r^2=0.974), gluten content and grain yield (r^2= 0.970) respectively (Fig. 4 & 5). These results point out the effectiveness of treatment in improving the yield attributes, grain yield and quality of wheat grains. The results of the correlation studies align with the use of nano-NPK in wheat crop had a positive correlation with the grain production, total chlorophyll, nitrogen content and gluten content (31).

Conclusion

Based on the findings of the present piece study, it can be concluded that among the crop establishment methods, FIRB proved an effective than the conventional DM. The efficiency of the FIRB method is attributed to maintaining optimal moisture supply, better drainage and nutrient availability, which together improved yield and yield attributes in wheat. Additionally, under nutrient management, the treatment N_6 was identified as the most effective. The use of drone-assisted foliar spray of nutrients ensured uniform distribution across the research plot compared to the knapsack hand sprayer, thereby improving nutrient use efficiency. This approach positively influenced the overall yield attributes of wheat, leading to higher yields. Protein content, gluten content and SPAD index were also improved under FIRB method of crop establishment and the N_6 treatment, thereby enhancing wheat grain quality. Overall, the use of FIRB method combined with 75 % RDF and one drone-based spray of nano-NPK represents an effective strategy to improve both yield and quality of the wheat.

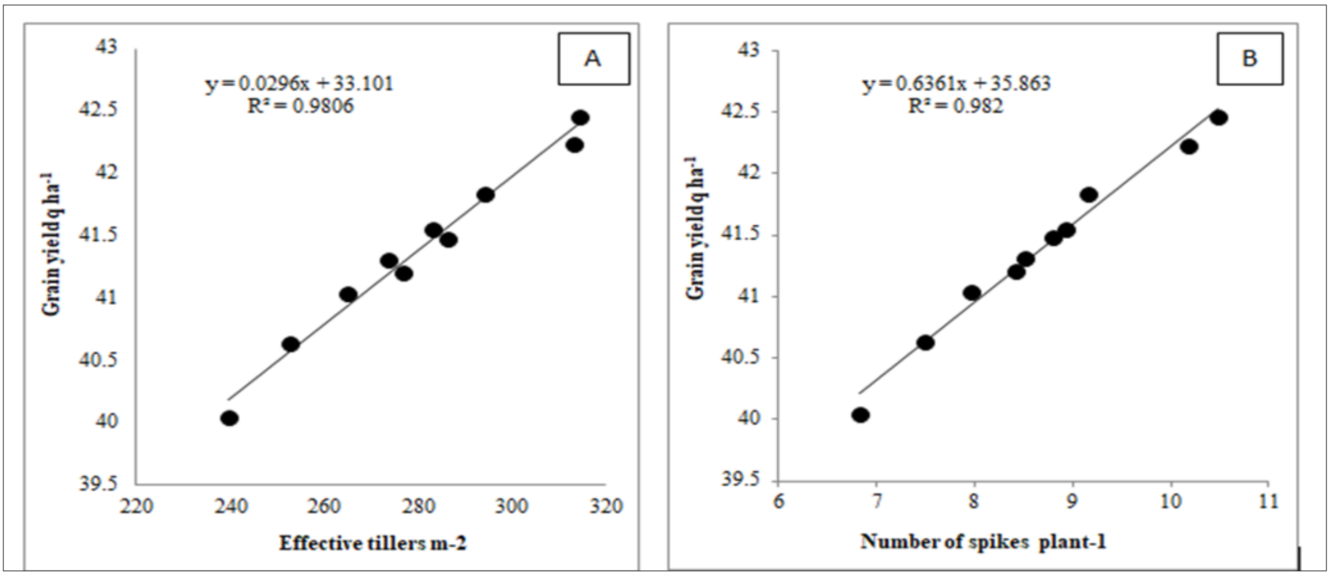

Fig. 4. Correlation between the grain yield and effective tillers [A] and between the grain yield and number of spikes plant^{-1} [B].

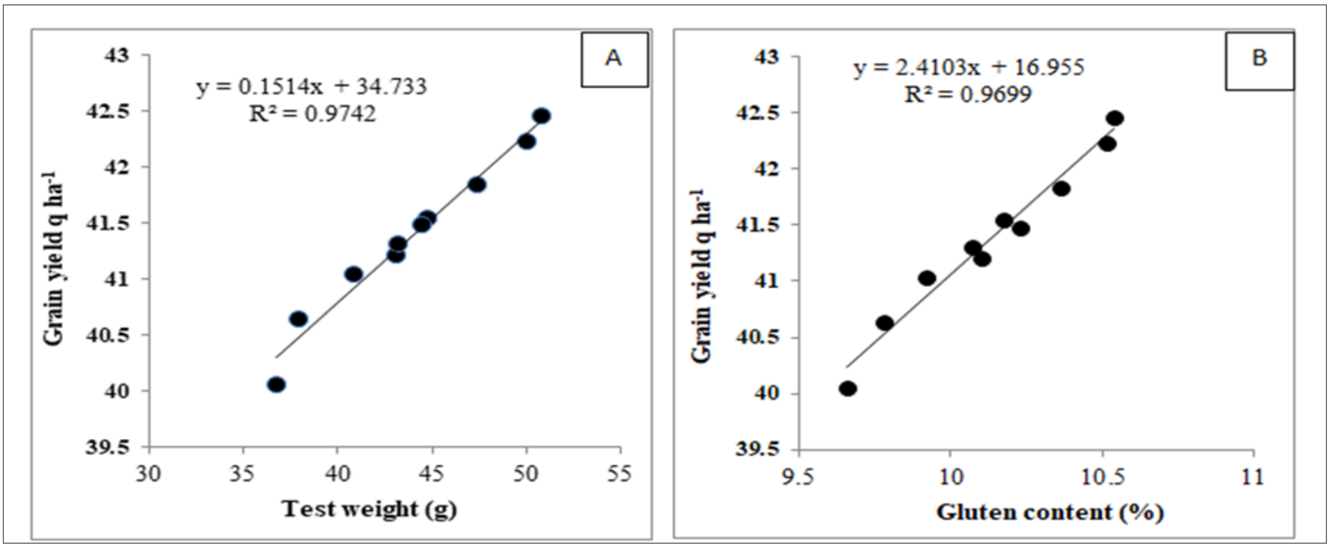

Fig. 5. Correlation between the grain yield and test weight [A] and between the grain yield and gluten content [B].

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Authors' contributions

All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: There is no conflict between the authors.

Ethical issues: None

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