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Effect of Nano Fertilizers on Growth, Yield and Quality of Wheat

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Authors' contributions

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

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Abstract

A major factor affecting wheat crop production is the management of nutrients. The widespread application and limited success of present fertilizer management practices impact the economic and ecological expenses of agricultural production. Due to their unique features of reduced size, enhanced surface area, and reactivity, nano fertilizers can prove to be a viable alternative to the existing fertilizer management system. Furthermore, the nano fertilizers work effectively to increase protein content of wheat and chlorophyll contents while also reducing a variety of abiotic stresses. A field experiment was conducted during *rabi*, 2024-25 to evaluate the "Effect of nano fertilizers on growth, yield and quality of wheat". The trial comprised with different thirteen treatments (T_1: Control (No fertilizer treatment), T_2: 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering), T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI), T_4: 50% RDN through chemical fertilizer as basal, T_5: 100% RDN through nano (50% RDN basal + 25% at CRI and 25% at tillering), T_6: 75% RDN through nano (50% RDN basal + 25% at CRI), T_7: 50% RDN through nano as basal, T_8: 100% RDN through nano C (50% RDN basal + 25% at CRI and 25% at tillering), T_9: 75% RDN through nano C (50% RDN basal + 25% at CRI), T_{10}: 50% RDN

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through nano C as basal, T_{11}: 50% RDN through chemical fertilizer + two spray of nano urea @ 4 ml/L at CRI and tillering, T_{12}: 50% RDN through nano + two spray of nano urea @ 4 ml/L at CRI and tillering and T_{13}: 50% RDN through nano C + two spray of nano urea @ 4 ml/L at CRI and tillering) with three replications in Randomized Block Design. The results revealed that different treatment affect significantly yield and yield attributes of wheat except grain per spike and 1000 grain weight. Significantly higher grain yield (5613 kg/ha) and straw yield (6695 kg/ha) was recorded by treatment 100% Recommended dose of nitrogen through chemical fertilizer (50% RDN basal + 25% at crown root initiation and 25% at tillering) (T_2). Significantly higher plant height (96.33 cm), effective tillers per sq. meter (393), spike length (9.93 cm) and chlorophyll content (40.97) at 50 DAS by the treatment of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2), while, the effect of different treatment on quality parameter was found significant. Protein content (11.44%), gluten content (27.43%) and hectoliter weight (83.30 kg/hl) of wheat was observed significantly higher with application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2).

Keywords: Abiotic; biotic; nano fertilizer; grain yield; productivity; tillers and drought.

1. Introduction

"Wheat (*Triticum* spp.) belongs to poaceae family and is the second important food grain crop of India being next to rice. Among the different wheat species, common bread wheat [*Triticum aestivum* L. (6n=42)], occupying more than 85 per cent of the total area under wheat cultivation. Wheat has its own outstanding importance as a human food, rich in carbohydrates and protein. About 35 per cent of the World's population directly or indirectly depends upon wheat for food and providing 20 per cent of human dietary and energy supply and serving as the main source of protein in developing nations. It is very difficult to meet the food demand in future because land is shrinking and pressure on productivity enhancement is also increasing, productivity of wheat can only be enhanced by application of scientific tools and techniques in agriculture. Modern science basically deals with three technologies viz., information technology, biotechnology and nanotechnology. These three sciences proved their worth in every sector of society, but agriculture is still lagging behind". (Braun et al., 2010).

"In India wheat is an important cereal crop covering an area of 31.23 million hectares and produced annually 112.92 million tonnes with the productivity of 3615 kg/ha during 2023-24" (Anon., 2024a). "Wheat is cultivated almost in all the states of India but extensive cultivation is confined to Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan and Gujarat" (Braun et al., 2010).

"In Gujarat, wheat is an important *rabi* crop and grown in Ahmedabad, Junagadh, Sabarkantha, Rajkot, Banaskantha, Kheda and Mehsana districts of the state and produced 4.01 million tonnes from 1.25 million hectares area with productivity of 3205 kg/ha" (Anon., 2024b). "But actual yield potential of wheat in Gujarat is 6617 kg/ha. As compared to 2012-13, the area, production and productivity of wheat in Gujarat increased to the tune of 2.22, 7.12 and 4.64 per cent, respectively" (Braun et al., 2010).

"Nanotechnology has made a real revolution in the agriculture. The use of nano-fertilizers has led to the increased productivity, reduced production costs in the last decade and also led to the increased production stability due to reduction of biotic and abiotic stresses. More solubility than the other similar non-nano-fertilizers is the important property of these fertilizers. Numerous reports have suggested that the application of nano particles increases the plant resistance against the drought stress by activating the antioxidant enzymes, facilitating the uptake process in the plants and enhancing their growth" (Ahmadian et al., 2021).

"Nano fertilizer, the most important field of agriculture has drawn the attention of the soil scientists as well as the environmentalists due to its capability to increase yield, improve soil fertility, reduce pollution and make a favourable environment for microorganisms. Nano fertilizers play role in boosting nutrients uptake and nutrients use efficiency, reducing losses through leaching and gaseous emissions along with reducing the risk of nutrient toxicity for ensuring food security achieved through higher productivity and economic turn outs by practicing the sustainable farming practices" (Ahmadian et al., 2021). "Nano urea (Liquid) is a source of

nitrogen. It emerged as a novel fertilizer for targeted and precise application of nitrogen. It can be transported. It is environment friendly and its production also doesn't pollute or harm environment in any way. It imparts dark-green colour in plants, promotes leaves, stem and other vegetative growth and development, Moreover, it also stimulates root growth. Nitrogen produces rapid early growth, improves quality of the grain, enhances the growth of leafy vegetables, and increases protein content of fodder crops" (Ahmadian et al*.,* 2021).

Hence, keeping the above facts in view, a field experiment was formulated on, "Effect of nano fertilizer on growth, yield and quality of wheat".

2. Materials and Methods

The field trials conducted in Gujarat (India) at the Wheat Research Station, Vijapur, Gujarat (Latitude 23°35'N, Longitude 72°58'E). To characterize experimental site, composite surface (0-15 cm) soil samples were collected initially. Then samples were air dried, ground and passed through 2 mm sieve and analyzed for their physical-chemical characteristics by adopting standard methodology. An experiment was conducted during the *Rabi,* 2024-25. The experimental soil was sandy loam with pH-7.39, electrical conductivity (EC) 0.21 ds/m, organic carbon 0.24 % with available N (184.25 kg/ha), P_2O_5 (65.42 Kg/ha) and K_2O (309.31 kg/ha). The experiment was laid out in Randomized Block Design with 13 treatments in 3 replications. The treatment consists different levels of urea and nano urea, *i.e*. T_1: Control (No fertilizer treatment), T_2: 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering), T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI), T_4: 50% RDN through chemical fertilizer as basal, T_5: 100% RDN through nano (50% RDN basal + 25% at CRI and 25% at tillering), T_6: 75% RDN through nano (50% RDN basal + 25% at CRI), T_7: 50% RDN through nano as basal, T_8: 100% RDN through nano C (50% RDN basal + 25% at CRI and 25% at tillering), T_9: 75% RDN through nano C (50% RDN basal + 25% at CRI), T_{10}: 50% RDN through nano C as basal, T_{11}: 50% RDN through chemical fertilizer + two spray of nano urea @ 4 ml/L at CRI and tillering, T_{12}: 50% RDN through nano + two spray of nano urea @ 4 ml/L at CRI and tillering and T_{13}: 50% RDN through nano C + two spray of nano urea @ 4 ml/L at CRI and tillering. Quantity of nano urea will be 4 ml/litre of water. Quantity of spray solution will be 400 litre of water/ha. All other cultivation practices were adopted as per recommendations. There was no rainfall during the crop season. Wheat variety GW 513 sown at 20.0 cm spacing between two row @ 120 kg/ha seed rate and crop fertilized according to treatment, however recommended dose of fertilizer was 90-60-40 kg/ha N-P_2O_5-K_2O, respectively. Sowing was done on 25th November, 2024 and crop harvested on 27th March, 2025. The values off "F" was worked out and compared with the values of table F at 5 per cent level of significance. The value of S.Em.±, C.D. and C.V. per cent were also calculated (Cochran and cox, 1967).

2.1 Nano Fertilizers

The Ray Nano Science & Research Centre has given experimental material nano nitrogen with different formulations. Provided nano urea utilized as a treatment in the trials.

2.2 Details of Observation and Spraying

All the recommended agronomical practices, except fertilizer application was followed for raising the healthy crop. Nano fertilizer treatments were imposed two sprays at 18-21 DAS and 35-40 DAS. The spraying was done with the help of knapsack sprayer having flat fan nozzle with a spray fluid of 400 L/ha. Common application of P (60 kg/ha) and K (40 kg/ha) applied in all treatment as per recommendation.

In each net plot area, five plants were selected at randomly to record observations of plant height, effective tillers, spike length, no. of grains per spike, 1000 grain weight, grain and straw yield.

2.3 Analytical Methods for Plant Samples

The plant samples of wheat leaves washed with distilled water. Samples were first air dried and then dried between 600–700^{o}C temperatures in a hot air oven. Dried samples were ground in a stainless-steel Wiley mill and digested in di-acid mixture (4 HNO3:1 HClO4). The volume was made up with glass double distilled water and then extract was filtered through Whatman filter paper No. 42. The acid extract was used for analysis of total N, P and K as per standard methods (Jackson, M. L., 1973).

3. Results and Discussion

The experiment was carried out at Wheat Research Station, S. D. Agricultural University,

Vijapur, Gujarat. The results on different parameters such as plant height, chlorophyll content, number of effective tillers, spike length, number of grains per spike, 1000 grain weight, grain and straw yield as well as quality parameter of wheat are described below.

3.1 Initial Plant Stand Per Metre Square

Data pertaining to initial plant stand per metre square revealed that application of different fertilizer treatments failed to reach the level of significance in result are presented in Table 1.

3.2 Plant Height (cm)

The periodical plant height of wheat recorded at 30, 60 DAS and at harvest are presented in the Table 1 showed that plant height was influenced significantly by nano fertilizer treatments at 60 DAS and at harvest, except at 30 DAS.

Application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher plant height (62.61 cm) and it remained at par with T_3, T_{11}, T_{12}, T_8 and T_5 at 60 DAS while at harvest, application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher plant height (96.33 cm) and it was remained at par with application of T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI) (94.76 cm). However, significantly lower value of plant height was recorded with treatment T_1: control (50.70 and 79.87 cm at 60 DAS and at harvest, respectively).

The growth of wheat crop was measured in terms of plant height. The plant height increased progressively with an age of the crop. The reason for better growth and development treatments might be due to increased availability of nitrogen to plant through inorganic fertilizer matching to the need of crop throughout the growing season. Being a cereal crop, wheat required nutrients throughout the growing season. Inadequate availability of nitrogen during initial growth period under treatment might be responsible for poor plant height. The results are in line with Rathwa et al. (2018), Rawate et al. (2022), Khadadiya et al. (2023), Ojha et al. (2023), Sarkar et al. (2023) and Yadav et al. (2023).

3.3 Number of Effective Tillers Per Metre Square

The mean data on number of effective tillers per meter square of wheat at harvest is presented in the Table 1 shows that effective tillers affected significantly by different nano fertilizer treatments.

Application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher effective tillers per meter square of wheat (393) and it was remained at par with treatment T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI) (372). Significantly lower number of effective tillers per meter row length of wheat was recorded with treatment T_1: control (281).

The higher number of effective tillers per metre row length may be due to sufficient availability of nitrogen to the root of the crop when crop was fertilized with inorganic fertilizer alone or in combinations with urea and nano urea spray, which may increase the nutrition to active growing part of plant, which have the ability to multi shooting with sufficient availability of nutrients and that's why ultimately leads to higher shooting of the tillers to the base of the plant. Similar results were reported by Pagar et al. (2016), Navrang and Tomar, (2016), Shekhar et al. (2021), Sarkar et al. (2023), Guriya et al. (2024) and Mandal et al. (2024).

3.4 Spike Length (cm)

The data presented in Table 1 shows that spike length of wheat affected significantly by different nano fertilizer treatments.

Spike length of wheat recorded significantly higher with application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) (9.93 cm) which was statistically at par with treatment T_2, T_4, T_5, T_6, T_8, T_9 and T_{11}. Significantly lower spike length recorded with control treatment (8.68 cm).

3.5 Number of Grains Per Spike

Data presented in Table 1 revealed that application of different nano fertilizer treatments failed to reach the level of significance on number of grains per spike of wheat.

Table 1. Effect of different nano fertilizer treatments on growth and yield attributes of wheat

Treatments	Plant stand /m²	Plant height (cm)			Effective tillers / m²	Spike length (cm)	No. grains/ spike	1000 grain weight (g)
		30 DAS	60 DAS	At harvest				
T_1: Control (No fertilizer treatment)	273	29.12	50.70	79.87	281	8.68	42.80	46.63
T_2: 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering)	258	32.14	62.61	96.33	393	9.93	52.07	49.87
T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI)	273	31.94	61.88	94.76	372	9.71	49.67	48.81
T_4: 50 % RDN through chemical fertilizer as basal	235	29.74	54.57	90.13	332	9.66	45.53	48.64
T_5: 100% RDN through nano (50% RDN basal + 25% at CRI and 25% at Tillering)	257	31.38	59.16	89.53	298	9.48	47.73	49.68
T_6: 75% RDN through nano (50% RDN basal + 25% at CRI)	264	30.28	56.54	89.07	293	9.20	41.93	49.26
T_7: 50% RDN through nano as basal	261	30.24	56.29	87.40	288	8.91	44.80	45.98
T_8: 100% RDN through nano C (50% RDN basal + 25% at CRI and 25% at tillering)	277	29.93	59.54	91.07	331	9.60	49.40	48.29
T_9: 75% RDN through nano C (50% RDN basal + 25% at CRI)	256	30.54	54.68	87.33	300	9.27	43.73	48.97
T_{10}: 50% RDN through nano C as basal	277	31.04	55.10	89.73	290	9.17	49.73	48.94
T_{11}: 50% RDN through chemical fertilizer + two spray of nano urea @ 4 ml/L at CRI and tillering	268	30.45	60.94	93.80	334	9.79	44.67	49.20
T_{12}: 50% RDN through nano + two spray of nano urea @ 4 ml/L at CRI and tillering	261	31.24	59.69	91.27	305	8.84	45.07	48.02
T_{13}: 50% RDN through nano C + two spray of nano urea @ 4 ml/L at CRI and tillering	271	30.91	56.87	86.47	317	9.07	43.60	50.40
S.Em+	9.02	0.72	1.82	1.44	13.10	0.26	2.74	1.68
CD @ 5%	NS	NS	5.3	4.2	38.30	0.80	NS	NS
CV%	5.93	4.06	5.46	2.78	7.14	4.82	10.27	5.98

Table 2. Effect of fertilizer treatments on chlorophyll content of wheat

Treatments	Chlorophyll content (SPAD value)	
	30 DAS	50 DAS
T_1: Control (No fertilizer treatment)	20.40	27.17
T_2: 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering)	31.90	40.97
T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI)	28.73	35.60
T_4: 50% RDN through chemical fertilizer as basal	26.07	31.23
T_5: 100% RDN through nano (50% RDN basal + 25% at CRI and 25% at tillering)	27.83	31.70
T_6: 75% RDN through nano (50% RDN basal + 25% at CRI)	26.23	29.77
T_7: 50% RDN through nano as basal	25.23	28.57
T_8: 100% RDN through nano C (50% RDN basal + 25% at CRI and 25% at tillering)	26.83	31.63
T_9: 75% RDN through nano C (50% RDN basal + 25% at CRI)	25.87	30.37
T_{10}: 50% RDN through nano C as basal	25.07	28.13
T_{11}: 50% RDN through chemical fertilizer + two spray of nano urea @ 4 ml/L at CRI and tillering	28.30	29.67
T_{12}: 50% RDN through nano + two spray of nano urea @ 4 ml/L at CRI and tillering	26.87	28.70
T_{13}: 50% RDN through nano C + two spray of nano urea @ 4 ml/L at CRI and tillering	27.40	29.60
S.Em+	0.28	0.52
CD @ 5%	0.83	1.5
CV%	1.84	2.91

Table 3. Effect of fertilizer treatments on yield characteristics of wheat

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
T_1: Control (No fertilizer treatment)	2047	3203	38.71
T_2: 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering)	5613	6695	45.65
T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI)	5098	6260	44.99
T_4: 50% RDN through chemical fertilizer as basal	4434	5666	43.93
T_5: 100% RDN through nano (50% RDN basal + 25% at CRI and 25% at tillering)	3923	4602	46.05
T_6: 75% RDN through nano (50% RDN basal + 25% at CRI)	3844	4531	45.94
T_7: 50 % RDN through nano as basal	3444	4223	44.93
T_8: 100% RDN through nano C (50% RDN basal + 25% at CRI and 25% at tillering)	4101	4958	45.19
T_9: 75% RDN through nano C (50% RDN basal + 25% at CRI)	3963	4563	46.32

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
T_{10}: 50% RDN through nano C as basal	3565	4490	44.13
T_{11}: 50% RDN through chemical fertilizer + two spray of nano urea @ 4 ml/L at CRI and tillering	4684	5616	45.44
T_{12}: 50% RDN through nano + two spray of nano urea @ 4 ml/L at CRI and tillering	3548	4119	47.16
T_{13}: 50% RDN through nano C + two spray of nano urea @ 4 ml/L at CRI and tillering	3852	4748	44.88
S.Em+	243.13	364.10	1.73
CD @ 5%	709.64	1062.7	NS
CV%	10.50	12.88	6.66

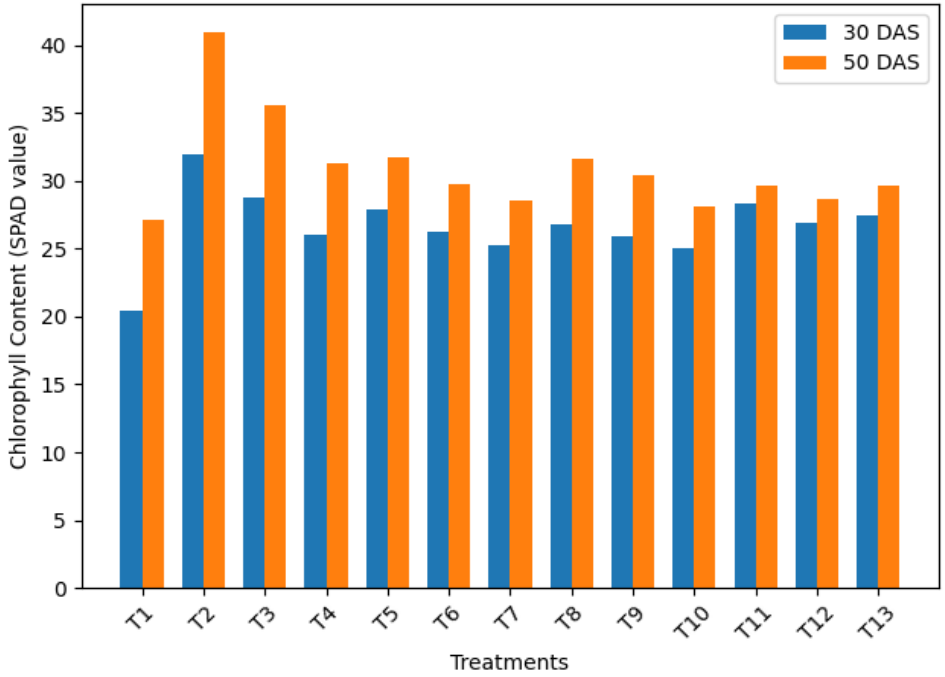

Fig. 1. Bar diagram showing comparative efficacy of chlorophyll content

Table 4. Effect of nano fertilizer on quality parameters of wheat

Treatments	Protein Content (%)	Moisture Content (%)	Starch content (%)	Gluten content (%)	Sedimentation Value (ml)	Hectolitre weight (kg/hl)
T_1: Control (No fertilizer treatment)	10.57	11.17	64.97	27.00	33.13	81.1
T_2: 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering)	11.44	11.53	65.33	27.43	33.77	83.0
T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI)	10.52	11.70	64.73	26.70	33.23	80.5
T_4: 50% RDN through chemical fertilizer as basal	9.76	11.10	64.63	26.67	32.60	80.7
T_5: 100% RDN through nano (50% RDN basal + 25% at CRI and 25% at tillering)	8.68	11.17	64.90	26.53	33.17	81.4
T_6: 75% RDN through nano (50% RDN basal + 25% at CRI)	11.38	11.63	65.83	27.20	34.37	80.6
T_7: 50 % RDN through nano as basal	9.01	11.67	64.93	26.87	33.90	81.0
T_8: 100% RDN through nano C (50% RDN basal + 25% at CRI and 25% at tillering)	9.60	11.27	64.83	26.70	33.93	80.8
T_9: 75% RDN through nano C (50% RDN basal + 25% at CRI)	8.58	11.47	64.80	26.27	32.47	80.8
T_{10}: 50% RDN through nano C as basal	9.17	11.57	64.83	26.33	32.87	81.3
T_{11}: 50% RDN through chemical fertilizer + two spray of nano urea @ 4 ml/L at CRI and tillering	8.63	11.43	64.80	26.03	32.83	80.8
T_{12}: 50% RDN through nano + two spray of nano urea @ 4 ml/L at CRI and tillering	9.49	11.53	64.90	26.60	33.00	80.0
T_{13}: 50% RDN through nano C + two spray of nano urea @ 4 ml/L at CRI and tillering	10.09	11.67	64.97	26.63	33.97	80.8
S.Em+	0.63	0.22	0.23	0.22	0.65	0.31
CD @ 5%	1.8	NS	NS	0.7	NS	0.9
CV%	11.15	3.39	0.61	1.46	3.39	0.67

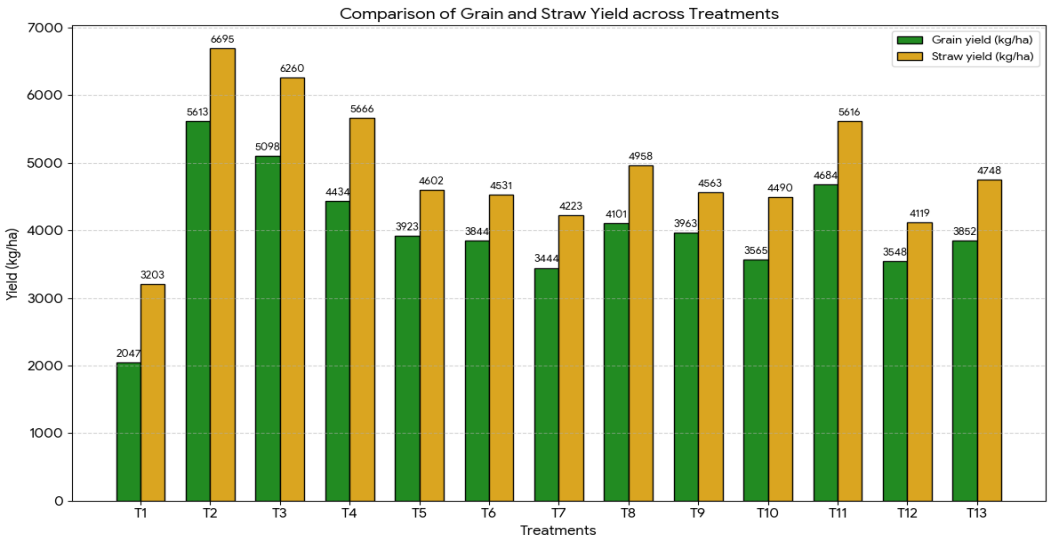

Fig. 2. Bar diagram showing Comparative efficacy of Grain and straw Yield

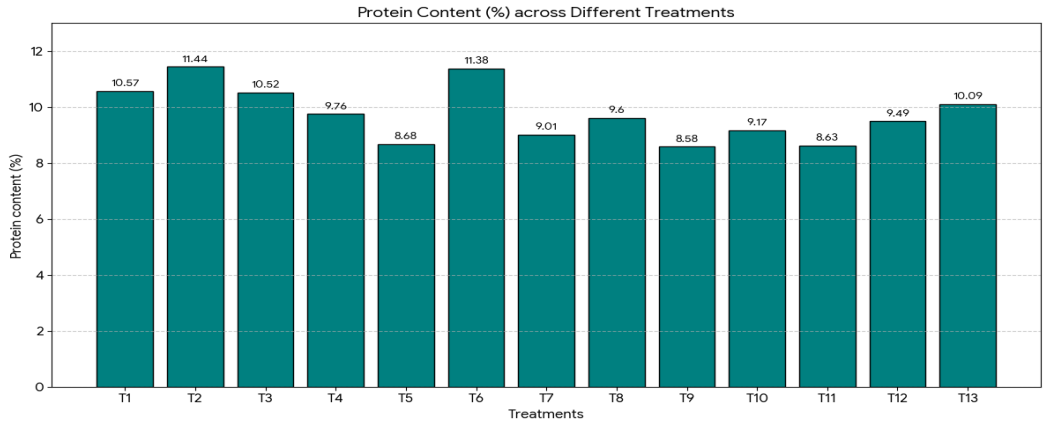

Fig. 3. Bar diagram showing comparative efficacy of protein content

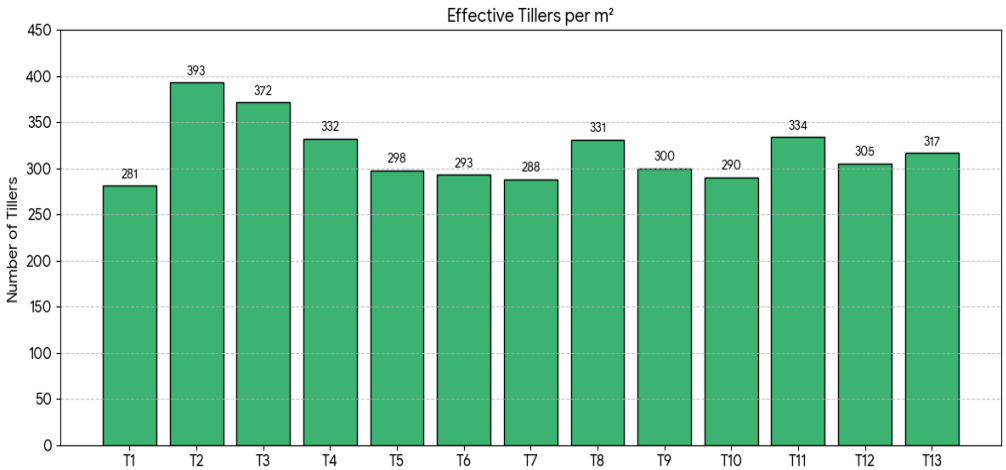

Fig. 4. Bar diagram showing comparative efficacy of effective tillers

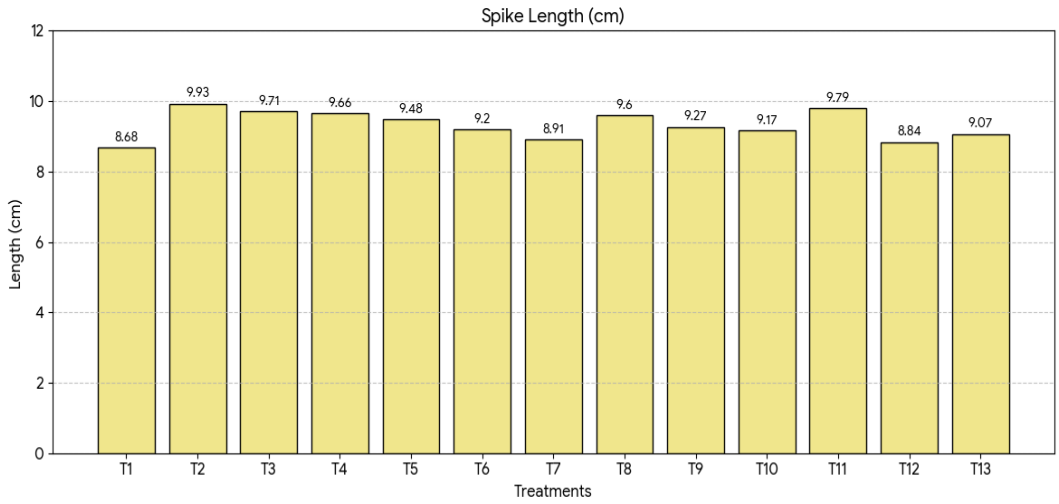

Fig. 5. Bar diagram showing comparative efficacy of spike length

3.6 1000 Grain Weight (g)

The data presented in Table 1 indicate that different nano-fertilizer treatments had no significant effect on the 1000 grain weight. However, numerically higher value of 1000 grain weight (49.87 g) was recorded with application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2). Whereas the control gave the lower 1000 grain weight of 46.63 g.

3.7 Chlorophyll Content

The data regarding chlorophyll content of wheat at 30 DAS and 50 DAS show significant differences among various nano-fertilizer treatments and are summarized in Table 2. At 30 DAS, application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher chlorophyll content (31.90 SPAD value) as compared to rest of treatments. The significantly lowest chlorophyll content was recorded with control (T_1) (20.40 SPAD value).

Application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher chlorophyll content (40.97 SPAD value) at 50 DAS as compared to rest of treatments. Significantly lower chlorophyll content was recorded with control (T_1).

3.8 Grain Yield (kg/ha)

Data presented in Table 3 show that nano-fertilizer treatments significantly affected the grain yield of wheat.

Grain yield of wheat was recorded significantly higher with application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) (5613 kg/ha) and it was followed by treatment T_3: 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI) (5098 kg/ha). Significantly the lowest grain yield of wheat (2047 kg/ha) recorded by control (No fertilizer treatment) (T_1).

"This may be due to improvement in growth and yield parameters *viz.*, plant height, length of spike, number of seeds per spike and the beneficial effects of nitrogen on cell division and elongation, formation of nucleotides and co-enzymes which resulted in increased meristematic activity and photosynthetic area and hence more production and accumulation of photosynthates, yielding higher grain yield" which are in line with those reported by Choudhary et al. (2023), Ojha et al. (2023), Sarkar et al. (2023), Singh et al. (2023), Guriya et al. (2024), Dabhi et al. (2025a), Dabhi et al. (2025b) and Dabhi et al. (2025c).

3.9 Straw Yield (kg/ha)

Straw yield of wheat affected significantly by application of different nano fertilizer treatments are presented in Table 3.

Application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher straw yield of wheat (6695 kg/ha) as compared to rest of the treatments and it was statistically at

par with 75% RDN through chemical fertilizer (50% RDN basal + 25% at CRI) (T_3) (6260 kg/ha) and 50% RDN through chemical fertilizer as basal (T_4) (5666 kg/ha). Significantly lower grain yield was recorded 3203 kg/ha with control (T_1).

"The increased straw yield per plant with the application of 100% RDN seems to be on account of increased photosynthetic efficiency and greater development of vegetative growth, might be due to RDN apply in form of urea alone or in combination with nano urea, which leads to better root and shoot development, while nitrogen improve the supply of nutrients and photosynthetic area and thereby ultimately resulted into higher values of yield and yield attributing characters" which are in accordance with those reported by Shekhar et al. (2021), Rawate et al. (2022), Ojha et al. (2023), Sarkar et al. (2023), Singh et al. (2023), Guriya et al. (2024) and Dabhi et al. (2025c).

3.10 Harvest Index (%)

The data given in Table 3 revealed that varying fertilizer treatments did not exhibit any significant response on harvest index, might be due to sufficient availability of nutrients throughout the growth period which leads to balanced distribution of assimilates to both sink and source, which ultimately maintained similar harvest index.

4. Quality Parameters

Wheat grains were tested for quality parameters such as protein, moisture, starch, gluten content, sedimentation value and test weight. As per Table 4, protein content, gluten content and hectolitre weight were affected significantly by different nano fertilizer treatments.

4.1 Protein Content (%)

A perusal of data in 4 revealed that application of 100% RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) recorded significantly higher protein content (11.44%) which was at par with 75% RDN through nano (50% RDN basal + 25% at CRI) (T_6) (11.38%).

4.2 Gluten Content (%)

The results of the experiment presented in Table 4 shows that significantly higher value of gluten content (27.43%) was reported under treatment 100 % RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2) which was followed by 75% RDN through nano (50% RDN basal + 25% at CRI) (T_6) and control (No fertilizer treatment) (T_1). Significantly highest value of hectolitre weight (83.00 kg/hl) was recorded under treatment 100 % RDN through chemical fertilizer (50% RDN basal + 25% at CRI and 25% at tillering) (T_2).

An appraisal of data in Table 4 revealed that moisture content, starch content and sedimentation value was not altered significantly by different nano fertilizer treatments.

5. Conclusion

This study concludes that the application of 100% RDN through chemical fertilizers (50% basal + 25% at CRI + 25% at tillering; 90 kg N ha^{-1}), along with 60 kg P_2O_5 ha^{-1}, resulted in significantly higher wheat yield, improved yield attributes, and better grain quality. Moreover, the study demonstrates that applying 75% RDN combined with two foliar sprays of nano urea produced yields comparable to those obtained with 100% RDN.

Disclaimer (Artificial Intelligence)

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

Competing Interests

Authors have declared that no competing interests exist.

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