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Nutrient content and uptake in mustard (*Brassica juncea* L.) crop as influenced by foliar application of nano nitrogen and nano zinc fertilizers

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Abstract
The aim of this present investigation is to study the effect of foliar application of nano N and Zn on nutrient content and nutrient uptake by mustard (*Brassica juncea* L.) crop. The field experiment was carried out during October to March 2022 season at Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur which lies in agro-climatic zone IV-A of Rajasthan, India. The field was designed in a randomized block design having 10 treatments which were replicated thrice. The treatments include the various combination RDF and nano fertilizers of N and Zn. The application treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) has significantly increased the nutrient content and nutrient uptake by mustard crop.

Keywords: Foliar application, nano fertilizer, mustard, nutrient content, nutrient uptake

1. Introduction

World population is expected to increase from 6.0 billion in 1999 to 8.5 billion by 2025. Such an increase in population growth will intensify pressure on the world's natural resource base (land, water, and air) to achieve higher food production. Increased food production could be achieved by expanding the land area under crops and by increasing yields per unit area through intensive farming (FAO, 2017) [5]. Intensive cultivation invariably leads to the degradation of land and lowers its fertility and productivity. Nano fertilizers have gained significant attention in recent years as a promising approach to enhancing crop productivity and mitigating the challenges faced by modern agriculture. These novel fertilizers, engineered at the nanoscale, offer unique properties and capabilities that can revolutionize nutrient management in plants. With their ability to deliver nutrients in a controlled and targeted manner, nano fertilizers have the potential to significantly improve nutrient use efficiency, reduce environmental impacts, and ensure sustainable agricultural practices. One of the key advantages of nano fertilizers is their high nutrient-loading capacity. By encapsulating or attaching nutrients to nano particles, these fertilizers can deliver a concentrated and readily available nutrient supply to plants. This targeted delivery ensures that nutrients are released in a controlled manner, minimizing losses through leaching or volatilization. Moreover, nano fertilizers can protect nutrients from interactions with soil components, reducing nutrient immobilization and enhancing their bioavailability to plants (Rameshaiah *et al.*, 2015) [18].

Nano fertilizers offer several advantages that contribute to their positive impact on nutrient content and uptake. Firstly, their nanoscale size provides a larger surface area, facilitating better contact and interaction with plant roots and leaf surfaces. This increased surface area enhances the efficiency of nutrient absorption and uptake by plants. Furthermore, nano fertilizers can be designed to have controlled-release properties, allowing for a sustained and targeted supply of nutrients to plants. This controlled release ensures a continuous nutrient availability to plants, supporting their growth and development over an extended period (Hassan *et al.*, 2019) [8].

The enhanced nutrient uptake and content observed with nano fertilizers can be attributed to their unique properties, including their small size, high reactivity, and ability to bypass certain barriers in plants. These properties enable efficient nutrient absorption and transport within plants, resulting in higher nutrient accumulation (Hu *et al.*, 2018) [9]. Furthermore, nano fertilizers have been shown to improve the nutrient use efficiency of plants. Their targeted delivery and controlled-release properties minimize nutrient losses through leaching, volatilization, and fixation in the soil.

This increased efficiency allows plants to utilize nutrients more effectively, leading to higher nutrient content in plant tissues. Overall, the use of nano fertilizers has shown great potential in improving nutrient content and uptake by plants. By enhancing nutrient availability, uptake efficiency, and utilization, nano fertilizers contribute to improved plant growth, development, and nutrient status, ultimately leading to increased crop productivity and quality (Singh *et al.*, 2017) [22].

Indian mustard (*Brassica juncea* L.) holds significant economic importance as one of the primary oilseed crops in India (Prasad, 2015) [16]. It accounts for approximately 29% of the total oilseeds production among the seven edible oilseeds cultivated in the country (Choudhary *et al.*, 2021) [4]. In the 2021-22 period, the estimated production of rapeseed mustard reached 10.95 million metric tonnes, with a total coverage area of 8.744 million hectares and an average yield of 1,270 kg/ha. The oilseed sector plays a crucial role in India's agricultural economy, positioning the country as one of the world's largest oil economies, following the USA, China, and Brazil in terms of vegetable oil (Yadav *et al.*, 2018) [25]. Rajasthan, Uttar Pradesh, and Haryana are the major mustard-growing states, with Rajasthan leading in terms of both area and production, encompassing 2.72 million hectares. It is projected that production in Rajasthan will increase to 4.95 million metric tonnes in the 2021-22 period, as reported by the Central Organization for Oil Industry Trade, New Delhi. Within Rajasthan, Bharatpur and Eastern districts contribute around 48% of the state's total production. Mustard oil is highly regarded for human consumption due to its rich source of unsaturated fatty acids, such as erucic acid (40-60%), linolenic acid (up to 4.5-13%), and its relative proportions of glucosinolates, including sinigrin, gluconapin, and progoitrin, which can be influenced by sulphur application (Hassan *et al.*, 2007) [7]. The oil content of mustard seeds typically ranges from 38% to 46%, while the combined oleic acid and linoleic acid, which hold higher nutritive value, constitute approximately 25-30%.

Nitrogen plays a crucial role in the growth and development of mustard crops (*Brassica juncea*). It is considered one of the most important nutrients required by mustard plants due to its involvement in various vital physiological processes. Nitrogen is a key component of chlorophyll, the pigment responsible for capturing sunlight and initiating photosynthesis. Adequate nitrogen supply ensures the efficient synthesis of chlorophyll, promoting robust photosynthesis and energy production in mustard plants. This, in turn, contributes to the production of carbohydrates, which are essential for plant growth and development (Singh *et al.*, 2018) [22].

Nitrogen is a fundamental building block of proteins. Proteins are vital for the structural integrity and functioning of cells, enzymes, and hormones. Nitrogen is necessary for the synthesis of amino acids, the building blocks of proteins. Adequate nitrogen availability supports protein synthesis, enabling mustard plants to develop healthy tissues, enzymes, and other essential molecules (Shukla *et al.*, 2019) [20]. Furthermore, nitrogen influences the vegetative growth of mustard crops. It contributes to the development of a robust root system, promoting efficient water and nutrient uptake. Nitrogen also stimulates leaf and shoot growth, leading to increased plant biomass and canopy development. This, in turn, can enhance the light interception capacity of the crop, optimizing photosynthetic activity and overall productivity (Bhullar *et al.*, 2018) [1].

Insufficient nitrogen can lead to stunted growth, reduced yield, and lower oil content in mustard seeds. On the other hand, excessive nitrogen application can result in excessive vegetative growth, delayed flowering, and reduced seed formation. Moreover, nitrogen management should be balanced with other essential nutrients to ensure optimum plant nutrition and avoid nutrient imbalances (Kaur *et al.*, 2019) [12].

Zinc has diverse physiological functions in biological systems. It interacts with a large number of enzymes and other proteins in the body and performs critical structural, functional and regulatory roles. It is estimated that about 10% of all the proteins in the human body, corresponding to nearly 3000 proteins, are Zn-dependent. About a third of the world's population is estimated to be at risk of Zn deficiency. Deficiencies of Zn and other micronutrients in developing countries are also reported to cause great economic losses and have a considerable effect on the gross national product by decreasing productivity and increasing the health care costs (Cakmak and Kutman, 2018) [3]. According to recent, deficiency of zinc is widespread and covers about 48% area in the country. Zinc deficiency is a very important nutrient problem in the Indian soils. Total Zn concentration is sufficient in many agricultural areas, but available Zn concentration is deficient because of different soil and climatic conditions. Zinc was one of the first micronutrients, essentiality of which for plant growth has been confirmed. Zinc also plays a role in nucleic acid and protein synthesis and helps in the utilization of phosphorus and nitrogen, as well as in seed formation. Zinc is an important element for terrestrial life since it is required as either a structural component or reaction site in numerous proteins Zinc deficiency in mustard resulted in a severe reduction in growth, seed yield and seedling vigour, and enhance the s sensitivity of plants to pathogens.

Therefore, the objective of the present work was to assess the effects of foliar applications of nano nitrogen and zinc on nutrient content and nutrient uptake by mustard in the sub-humid southern plains of Rajasthan.

2. Materials and Methods

2.1 Study area

The experiment was conducted during *rabi* 2021-22 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur. The region falls under the agro-climatic zone-IVA (Sub-humid Southern Plains and Aravalli Hills) of Rajasthan. The climate of the study area is sub-humid with an average minimum and maximum temperature (October-February) ranging between 3.2º to 30.4 ºC.

2.2 Experimental design and treatments

The experiment was laid out in a randomized block design with three replications. The gross plot size was 15 m^2 (5 x 3 m). The experiment consisted of ten treatments *viz.*, T_1 (Control), T_2 (100% NPK Zn), T_3 (75% N Zn + 100% PK), T_4 (50% N Zn + 100% PK), T_5 (T_2+1st spray of Nano N and Zn at 30 DAS), T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS), T_7 (75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS), T_8 (75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS), T_9 (50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS), T_{10} (50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) were applied to mustard var. Giriraj (DRMRIJ 31) in *rabi* session, 2021-22. The recommended dose of fertilizer was 60 kg N, 40 kg P_2O_5, 40 kg K_2O and 5 kg $ZnSO_4$ ha^{-1} and also other agronomic practices recommended for Zone IVa were followed as per Package of Practices, Government of Rajasthan.

2.3 Application protocol of foliar spray

Foliar sprays were given as 1st application at 30 days after sowing and 2nd application at 45 days after sowing in selected treatments with the help of a knapsack sprayer with h flat fan nozzle. Nano N were applied @ 4 ml l^{-1} water while Nano Zn @ 2 ml l^{-1} water as per scheduled treatments.

2.4 Nutrient content and uptake

The N, P, K, Zn, Fe, Mn and Cu contents in the seed and stover samples were examined after the threshing of the harvested mustard crop. Plant analysis for the determination of nutrient content in seed and stover were done with the standard procedures *viz*., Nitrogen concentration in plant (both seed and stover) was determined by Kjeldahl's method, Phosphorus by colorimetric method, Potassium by flame photometer (Jackson, 1973) [11] and Fe, Mn, Zn and Cu content is determined by atomic absorption spectrophotometer (Lindsay and Norvell, 1978) [15]. The concentration of nitrogen, phosphorus and potassium were expressed in percent whereas concentration of zinc, iron, manganese and copper as ppm. The uptake of these nutrients was calculated using following methods and nitrogen, phosphorus, and potassium uptake expressed in kg ha^{-1} whereas zinc, iron, manganese and copper in g ha^{-1}.

$$\text{Major nutrient uptake by seed (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) in seed x Seed yield}}{100}$$

$$\text{Major nutrient uptake by stover (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) in straw x Straw yield}}{100}$$

$$\text{Micro nutrient uptake by seed (mg kg}^{-1}\text{)} = \frac{\text{Nutrient content (\%) in seed x Seed yield}}{1000}$$

$$\text{Micro nutrient uptake by stover (mg kg}^{-1}\text{)} = \frac{\text{Nutrient content (\%) in straw x Straw yield}}{1000}$$

2.5 Statistical Analysis

The obtained data were statistically analyzed with the techniques of analysis of variance as described by Steel and Torrie, 1960 [24]. The comparison in the treatment mean was tested by critical difference (CD) at 5% (P=.05) level of significance.

3. Results

3.1 Nutrient content and uptake by crop

3.1.1 Nitrogen Content and Uptake

The higher value of nitrogen content in seed ((4.92%) and stover ((0.51%) (Table 1) was noticed with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The lowest values of nitrogen content in seed (2.59%) and stover (0.28%) were observed in control (T_1) where no fertilizer was given to mustard.

The highest nitrogen uptake in seed (78.67 kg ha^{-1}) and stover (18.05 kg ha^{-1}) of mustard (Table 3) was observed with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). However, minimum nitrogen uptake in seed (21.71 kg ha^{-1}) and stover (5.67 kg ha^{-1}) was observed in control (T_1).

3.1.2 Phosphorus content and uptake

The data related to phosphorus content in seed and stover of mustard presented in Table 1. Highest phosphorus content in mustard seed (0.98%) and stover (0.30%) was recorded by application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) and the lowest values of phosphorus content in seed (0.52%) and stover (0.16%) were observed with control (T_1).

Highest phosphorus uptake by mustard seed (78.67 kg ha^{-1}) and stover (18.05 kg ha^{-1}) is recorded with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum nitrogen uptake by seed (21.71 kg ha^{-1}) and stover (5.67 kg ha^{-1}) was obtained under treatment T_1 (Control).

3.1.3 Potassium content and uptake

The data presented in Table 1 indicates that the maximum potassium content of mustard seed (1.04%) and stover (2.49%) was recorded with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum concentration of potassium in mustard seed and stover was recorded under the treatment T_1 (Control) which was 0.55 and 1.31 percent.

The data related to potassium uptake by seed and stover of mustard presented in Table 3. The potassium uptake by seed and stover was influenced by the application of foliar spray of nano N and nano Zn. Maximum K uptake in seed (16.69 kg ha^{-1}) and stover (87.53 kg ha^{-1}) was noted with application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) and minimum potassium uptake by seed (4.62 kg ha^{-1}) and stover (25.89 kg ha^{-1}) at control (T_1).

3.1.4 Zinc content and uptake

The data (Table 2) clearly reflects that zinc uptake by mustard seed was significantly influenced by foliar application of nano nitrogen and nano zinc over control. The highest zinc content of mustard seed (94.52 mg kg^{-1}) and stover (25.41 mg kg^{-1}) was obtained under application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum zinc content in seed (31.10 mg kg^{-1}) and stover (13.94 mg kg^{-1}) was observed under the treatment T_1 (Control).

The maximum zinc uptake by mustard seed (94.52 g ha^{-1}) and stover (89.21 g ha^{-1}) was obtained under application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum zinc uptake by mustard seed (26.06 g ha^{-1}) and stover (27.57 g ha^{-1}) was reported under T_1 (Control).

3.1.5 Iron Content and Uptake

Highest iron content in mustard seed (124.12 mg kg^{-1}) and stover (229.38 mg kg^{-1}) was registered with an application of the treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum concentration of iron in mustard seed (72.00 mg kg^{-1}) and stover (139.56 mg kg^{-1}) were recorded under treatment T_1 (Control).

The experimental results (Table 4) revealed that highest iron uptake by mustard seed (198.11 g ha^{-1}) and stover (805.34 g ha^{-1}) is recorded with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum uptake of iron by mustard seed (60.35 g ha^{-1}) and stover (275.47 g ha^{-1}) was reported under treatment T_1 (Control).

3.1.6 Manganese content and uptake

Highest manganese content in mustard seed (91.96 mg kg^{-1}) and stover (75.88 mg kg^{-1}) was recorded under treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum concentration of manganese in mustard seed (52.09 mg kg^{-1}) and stover (42.20 mg kg^{-1}) were recorded under treatment T_1 (Control).

The maximum manganese uptake by mustard seed (146.78 g ha^{-1}) and stover (266.41 g ha^{-1}) was obtained by application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum manganese uptake by mustard seed (43.62 g ha^{-1}) and stover (83.47 g ha^{-1}) was reported under T_1 (Control).

3.1.7 Copper content and uptake

Maximum copper concentration in seed (12.86 mg kg^{-1}) and stover (9.13 mg kg^{-1}) in mustard was recorded with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum concentration of copper in mustard seed and stover is recorded with the application of treatment T_1 (Control) which is 7.23 mg kg^{-1} and 5.22 mg kg^{-1} respectively.

The highest copper uptake by seed (20.52 g ha^{-1}) and stover (32.06 g ha^{-1}) was recorded with the application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). The minimum copper uptake by seed (6.06 kg ha^{-1}) and stover (10.32 kg ha^{-1}) was recorded under treatment T_1 (Control).

Table 1: Effect of Foliar Application of Nano Nitrogen and Nano Zinc on N, P and K Content in Seed and Stover of Mustard

Treatments			N content (%)		P content (%)		K content (%)	
			Seed	Stover	Seed	Stover	Seed	Stover
T_1	:	Control	2.591	0.287	0.523	0.165	0.551	1.313
T_2	:	100% NPK Zn	4.331	0.471	0.869	0.262	0.919	2.191
T_3	:	75% N Zn + 100% PK	3.832	0.400	0.770	0.232	0.815	1.941
T_4	:	50% N Zn + 100% PK	3.330	0.347	0.668	0.201	0.707	1.684
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	4.830	0.503	0.969	0.297	1.025	2.443
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	4.929	0.514	0.988	0.300	1.046	2.493
T_7	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	4.753	0.495	0.954	0.293	1.003	2.404
T_8	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	4.837	0.504	0.970	0.298	1.027	2.446
T_9	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	4.492	0.467	0.903	0.272	0.953	2.268
T_{10}	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	4.584	0.478	0.918	0.281	0.973	2.322
S.Em±			0.063	0.006	0.009	0.004	0.009	0.048
CD (P= 0.05)			0.188	0.018	0.027	0.011	0.027	0.143

Table 2: Effect of Foliar Application of Nano Nitrogen and Nano Zinc on micronutrient content in seed and stover of mustard

Treatments			Zn content (mg kg^{-1})		Fe content (mg kg^{-1})		Mn content (mg kg^{-1})		Cu content (mg kg^{-1})	
			Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
T_1	:	Control	31.10	13.94	72.00	139.56	52.09	42.20	7.23	5.22
T_2	:	100% NPK Zn	52.03	22.32	118.80	219.24	87.06	72.20	12.12	8.56
T_3	:	75% N Zn + 100% PK	46.12	19.70	105.68	194.35	77.20	67.00	10.62	7.58
T_4	:	50% N Zn + 100% PK	39.92	17.20	92.20	168.59	66.94	55.60	9.38	6.60
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	57.99	24.89	123.00	228.59	91.02	75.20	12.74	9.00
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	59.22	25.41	124.12	229.38	91.96	75.88	12.86	9.13
T_7	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	57.07	24.48	123.00	228.04	91.04	75.05	12.60	9.00
T_8	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	58.10	24.93	123.32	228.62	91.36	74.54	12.82	9.01
T_9	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	53.82	23.18	122.78	226.80	90.88	74.77	12.35	8.88
T_{10}	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	55.12	23.64	123.00	227.18	91.00	74.98	12.44	8.89
S.Em±			0.663	0.452	1.474	4.155	1.176	1.352	0.200	0.114
CD (P= 0.05)			1.970	1.343	4.380	12.344	3.495	4.016	0.594	0.339

Table 3: Effect of Foliar Application of Nano Nitrogen and Nano Zinc on N, P and K Uptake by Seed and Stover of Mustard

Treatments			N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
			Seed	Stover	Seed	Stover	Seed	Stover
T_1	:	Control	21.71	5.67	4.39	3.27	4.62	25.89
T_2	:	100% NPK Zn	60.70	14.66	12.18	8.16	12.88	68.22
T_3	:	75% N Zn + 100% PK	47.61	11.19	9.57	6.49	10.13	54.29
T_4	:	50% N Zn + 100% PK	35.95	8.44	7.21	4.89	7.63	40.95
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	75.16	16.92	15.08	9.99	15.95	82.18
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	78.62	18.05	15.76	10.53	16.69	87.53
T_7	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	72.82	16.91	14.62	10.00	15.36	82.11
T_8	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	77.29	17.66	15.50	10.43	16.38	85.73
T_9	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	65.23	15.58	13.11	9.07	13.84	75.65
T_{10}	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	68.10	16.27	13.63	9.56	14.48	79.05
S.Em±			2.576	0.684	0.481	0.363	0.481	3.385
CD (P= 0.05)			7.654	2.032	1.429	1.080	1.428	10.058

Table 4: Effect of Foliar Application of Nano Nitrogen and Nano Zinc on Micronutrients Uptake by Seed and Stover of Mustard

Treatments		Zn uptake (g ha^{-1})		Fe uptake (g ha^{-1})		Mn uptake (g ha^{-1})		Cu uptake (g ha^{-1})	
		Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
T_1:	Control	26.06	27.57	60.35	275.47	43.62	83.47	6.06	10.32
T_2:	100% NPK Zn	72.97	69.49	166.49	682.62	121.99	224.80	16.99	26.65
T_3:	75% N Zn + 100% PK	57.30	55.09	131.31	543.63	95.92	187.54	13.20	21.20
T_4:	50% N Zn + 100% PK	43.09	41.42	99.51	410.01	72.26	135.19	10.13	16.05
T_5:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	90.24	83.72	191.38	768.99	141.62	252.96	19.82	30.29
T_6:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	94.52	89.21	198.11	805.34	146.78	266.41	20.52	32.06
T_7:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	87.44	83.52	188.37	778.01	139.43	256.05	19.30	30.71
T_8:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	92.68	87.27	196.72	800.34	145.73	262.04	20.45	31.56
T_9:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	78.15	77.33	178.23	756.66	131.92	249.45	17.93	29.64
T_{10}:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	81.85	80.59	182.96	774.43	135.36	255.60	18.48	30.31
S.Em±		3.01	3.01	6.37	31.06	4.62	12.36	0.60	1.21
CD (P= 0.05)		8.94	8.94	18.93	92.29	13.73	36.72	1.79	3.61

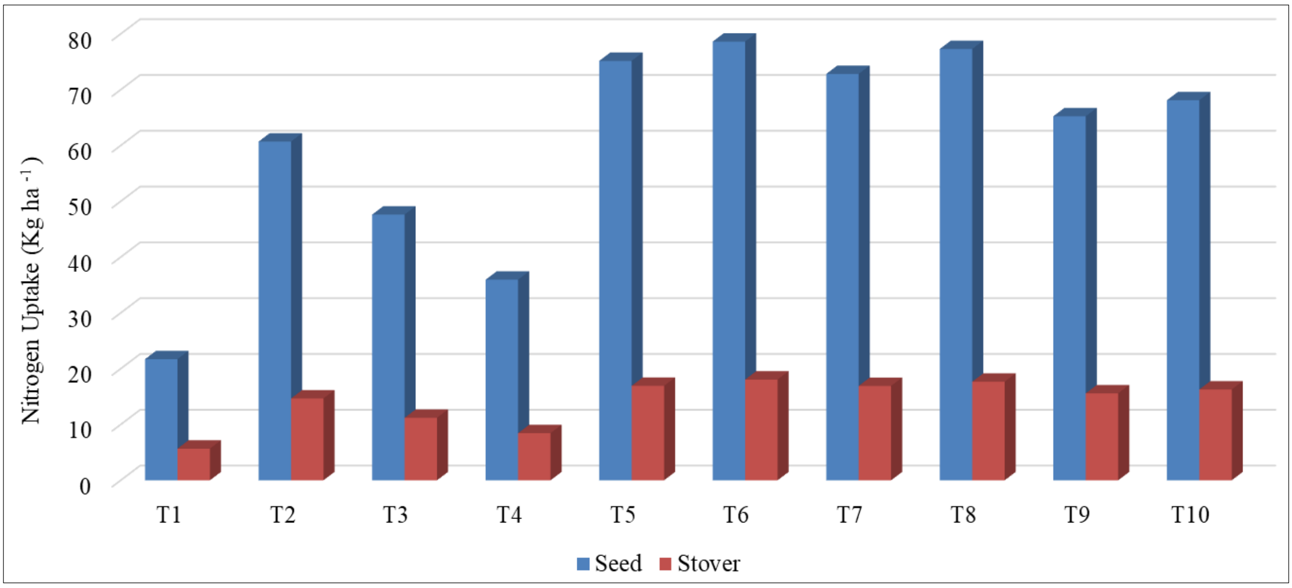

Fig 1: Effect of Nano Nitrogen and Nano Zinc N on nitrogen uptake by seed and stover of mustard

4. Discussion

4.1 Nutrient content and uptake by mustard

The appraisal of data given in Tables 1 and 2 revealed that foliar application of nano nitrogen and nano zinc significantly increases the nutrient content in seed and stover. The highest nutrient content by mustard seed and stover was found under treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). Data presented in Tables 3 and 4 showed that nutrient uptake significantly increase also under treatment T_6 (100% NPK Zn + 1st spray of Nano N and Zn at 30 DAS + 2nd spray of Nano N and Zn at 45 DAS). This could be due to the foliar application of nano nitrogen and zinc, which caused quick absorption and movement of nitrogen in plants due to tiny particle sizes than the stomatal openings of leaves of plants. Qureshi *et al.* (2018) [17] also found synergetic effect of nano-nitrogen and nano-zinc application on N-content in plant. They also stated that zinc help in nitrogen metabolism and its uptake, nano fertilizers reduced nitrate leaching and enhanced plant-available nitrogen in the soil. Kaviani *et al.* (2016) [13] observed that foliar application of nano-fertilizers had significant positive effects on leaf N, P, K contents in heated plants as compared to control. Due to the great mobility of nanoparticles, which guarantees that they are transported through phloem to the other sections of the plant, the absorption and content in seed and stover were increased (Gonzalez-Melendi *et al.*, 2008) [6].

Yadav *et al.* (2021) [26] also reported that nano-fertilizers reduces the release of nutrients and boosted the absorption use efficiency of applied fertilizers. This might be because of foliar application of nano fertilizers at critical growth stages of crops which helped in improving nutrient use efficiency and also curtailing nutrient losses. The uptake and content in seed and stover was increased due to fact that nano particles have high mobility which ensures the transport through phloem to the other parts of plant (Gonzalez-Melendi *et al.*, 2008) [6]. This may be due to fertilizer particles can be coated with nano membranes that facilitate slow and steady release of nutrients. Coating and cementing of nano and sub-nano-composites are capable of regulating the release of nutrients from the fertilizer capsule and nano particles having both positive and negative charged binding site that adsorbed available nitrogen in soil to minimize different type losses resulted in increased uptake of nitrogen by crop. These results are agreed by Hussien *et al.*, (2015) [10]. They observed that application of nano-P at the rate of 1.0 g l^{-1} achieved the highest values of nutrients uptake (N, P, K and micro nutrient) in leaves of cotton plants. Soliman *et al.*, (2016) [23] reported that the positive interaction occurs between phosphorus and nitrogen that indicate that the nitrogen uptake was increased with increasing uptake of phosphorus. Singh *et al.*, (2017) [21] observed that highest N content and uptake was recorded with the treatment of 30 kg P ha^{-1} applied. The increase in availability of soil nutrients might be due to the inorganic fertilization process to soil and mineralization and solubilization of available nutrients through direct and indirect mechanism of nutrients in soil and transport of nutrients to plant. Soliman *et al.*, (2016) [23] concluded that the application of nano nitroegn fertilizer may expose the plant nutrient (NPK) to larger surface area than can enhance the fixation of plant nutrient of nano particle which led to minimize the losses and it will release on later stage of crop growth when plant need it. These results are in conformity with Buerkert *et al.*, (1998) [2], Kumar *et al.*, (2014) [17] and Shrivastava *et al.*, (2017) [19].

5. Conclusion

From the forgoing result, it was concluded that the combined application of the conventional and nano fertilizers significantly influenced the nutrient content and uptake by mustard crop. The application of treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) significantly increased the nutrient content, and uptake by mustard. Nano fertilizers used along with conventional fertilizer enhance nutrient use efficiency by delivering nutrients in a targeted and controlled manner. They improve nutrient availability and uptake by plants, minimizing losses through leaching, volatilization, and fixation. This increased efficiency ensures that a larger proportion of applied nutrients are effectively utilized by crops.

6. References

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