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RESEARCH ARTICLE

Influence of post-vegetative foliar application of nitrogen and selenium on micrometeorological parameters, phenology, and yield of wheat (*Triticum aestivum* L.)

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Abstract

Excessive and continuous use of commercial-grade fertilizers in large quantities during the post-Green Revolution era has led to significant environmental impacts, besides escalating the cost of production in staple crops. Such over-reliance on chemical fertilizers in intensive agriculture and a limited focus on balanced nutrient management have led to an increase in micronutrient deficiency in the sub-tropical part of India. This micronutrient deficiency leads to stunted growth, poor flowering, and reduced grain and fruit formation, directly impacting overall crop productivity. Hence, the introduction of nano form of fertilizers and integration of them with bulk/commercial form will help in improving the nutrient use efficiency, reduce production costs vis-a-vis enhancement in the plant growth, and yield more effectively than the traditional fertilizers. Proper nutrient management promotes healthy development at each stage, from seedling establishment to maturation and ripening, ensuring optimal yields and quality. Hence, fertilization directly and profoundly impacts the phonological stages of the crops. In this respect, a field experiment was conducted at Ludhiana and Fatehgarh Sahib, Punjab, India, during the *rabi* season of 2021-22. The experiment was laid out in a Randomized Completely Block Design (RCBD) with four replications and 11 treatments. Besides an absolute control where no fertilizer was applied (T1), ten other treatments were commonly fertilized with the recommended dose of fertilizers (RDF), i.e., 125 kg N and 62.5 kg P_2O_5 ha^{-1}). The treatment varied in applying bulk and nano N (6% urea) and Se (15 ppm) at reproductive phases. The normalized difference vegetation index (NDVI) score and chlorophyll index improved with foliar spray of both bulk and nano urea forms alone or in combination with Se (bulk or nano). The effect of foliar sprays of urea and selenium, either in bulk or nano form, alone or in combination, was insignificant. The reproductive stages, viz. heading, grain filling, and physiological maturity, are prolonged with late season spray of 6% bulk or nano urea alone or in addition to bulk or nano selenium. Maximum days to grain filling was in a foliar spray of nano urea 6% along with nano selenium 15 ppm, further leading to higher grain and biological yield.

Keywords

Foliar spray; nano form; nitrogen; selenium; wheat

Introduction

Wheat (*Triticum aestivum* L.), a winter-season cereal crop belonging to the family Poaceae, is crucial in ensuring the food security of the Indian subcontinent and our country. Globally, wheat is grown over 215.9 million hectares (m ha), with an annual production of more than 765.8 million tonnes (1). In India, wheat is the second most important crop after rice, grown over an area of 31.6 m ha with an annual production of 109.5 million tonnes (2).

The changing climate is affecting the crop yield. Although the aerial environment can't be controlled, certain agronomic management practices can be adopted to provide climate resilience to the cultivated crops. Nitrogen, the essential nutrient the crop requires, is known to prolong the crop phenological phases (3) and thus can relieve the crop's aberrations in changing climate. During the post-vegetative phase, foliar application of nitrogen is suitable as diverse N-immobilisation processes involving complexation with the soil organic matter render this nutrient not adequately available to the crop plant. Moreover, the diminishing root activity due to the aging of the crop further decreases the uptake of the applied N by the root tissue (4). On the other hand, Selenium is a micronutrient that plays a role in maintaining ecosystem health. Continuous deficiency in soils without Se fertilization may create a broader imbalance in soil nutrient composition, which could eventually affect plant and microbial communities. Although selenium (Se) is not considered an essential nutrient for plant growth, it has significant implications for human and animal nutrition and offers several crop benefits (5-7). Stress, either biotic or abiotic, affects plant normal metabolism and produces reactive oxygen species (ROS), *viz*., superoxide anion, singlet oxygen, hydroxyl free radical, and hydrogen peroxide (8). Selenium is reported to improve plant tolerance to oxidative stress by reducing lipid peroxidation and increasing the activity of anti-oxidative enzymes (9). Plants have enzymatic and non-enzymatic antioxidant systems for scavenging the ROS (10).

The conventional agrochemicals for fertilization, pest, and disease control lead to soil degradation (11) and surface and groundwater contamination (12) due to their low efficacy. While nitrogen is essential for plant growth, its overapplication in conventional nitrogenous fertilizer can lead to several environmental and health issues. When crops absorb more nitrogen than they need, the excess often leaches into groundwater or runs off into nearby water bodies, causing water pollution and contributing to problems like eutrophication (13), where water ecosystems become overly enriched with nutrients, leading to algal blooms and reduced oxygen levels (14). In soil, nitrogen imbalance can degrade soil health by disrupting the natural nutrient cycle. Sustainable farming practices, such as precision agriculture, crop rotation, and the use of nitrogen-efficient fertilizers like slow-release or nano-fertilizers, are being encouraged to combat nitrogen pollution. These practices aim to optimize nitrogen use efficiency, minimizing environmental damage while maintaining crop productivity (15). Therefore, producing more food with limited resources and a changing environment, along with the conservation of resources, is a global challenge.

Nanotechnology seems to be a possible alternative for upgrading agricultural practices (16-17). It could be documented that nano-fertilizers are important in protecting the environment due to low application rates (18). The introduction of nanoparticles, which range in size from 1 to 100 nm (nano-meter), can penetrate easily into the plant cells upon application and thus result in efficient and targeted nutrient delivery. A multi-fold increase in the surface area of nanoparticles may reduce the leaching losses and, therefore, increase the effectiveness over conventional bulk fertilizer (19). The conventional granular urea with a much larger particle size is generally used in solid form, where it first dissolves before releasing nitrogen very slowly. A significant portion of nitrogen from granular urea is often lost through leaching, runoff, or volatilization, leading to lower nitrogen use efficiency (NUE). The nanoform of fertilizer reduces production costs through increased efficiency of nutrient use, thereby improving plant growth and yield parameters better than traditional fertilizers (20). Hence, there is a need to evaluate the efficacy of nano forms of fertilizers over traditional fertilizers.

Materials and Methods

Experimental site

A field experiment was conducted at two locations of Indo Gangetic plains during the *rabi* season of 2021-22. The first location was the Research Farm of Wheat in the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. The second was a farming field at village Panjoli Khurd, district Fatehgarh Sahib, Punjab. Ludhiana is situated at 30° 54' N latitude and 75° 51' E longitude at a height of 247 m above mean sea level. Fatehgarh Sahib is located at 30°40' N latitude and 76°24' E longitude at a height of 246 m above mean sea level. The information on various meteorological parameters like temperature, relative humidity, and rainfall at two different locations at Ludhiana and Fatehgarh Sahib are given in Fig. 1 and 2, respectively.

Experimental design and treatments

The experiment was laid out in a randomized complete block design with 11 treatments and four replications. Except for absolute control (T1), the wheat crop in treatments T2 to T11 received the recommended dose of fertilizers, i.e., 125 kg N and 62.5 kg P_2O_5 ha^{-1}. For each of the treatments (T3 to T11), the sprays of 6% urea (nano or bulk form) and/or 15 ppm Se (nano or bulk form) water were done at the booting and grain milk stage of the wheat crop. Treatment details are as follows:

T1: Absolute control (no fertilizer)

T2: Recommended dose of fertilizers (RDF) only

T3: RDF + water spray

T4: RDF + Urea spray @ 6%

T5: RDF + Se spray @ 15 ppm

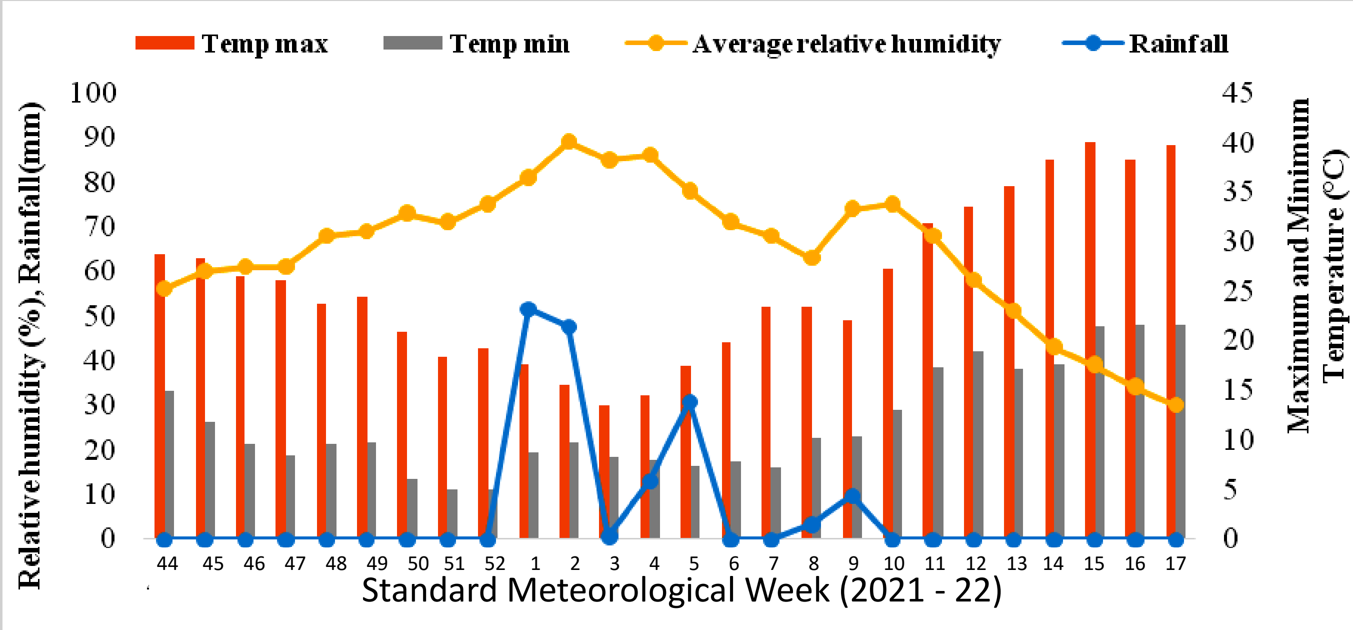

Fig. 1. Standard weekly meteorological data during the *rabi* season 2021-22 at Ludhiana

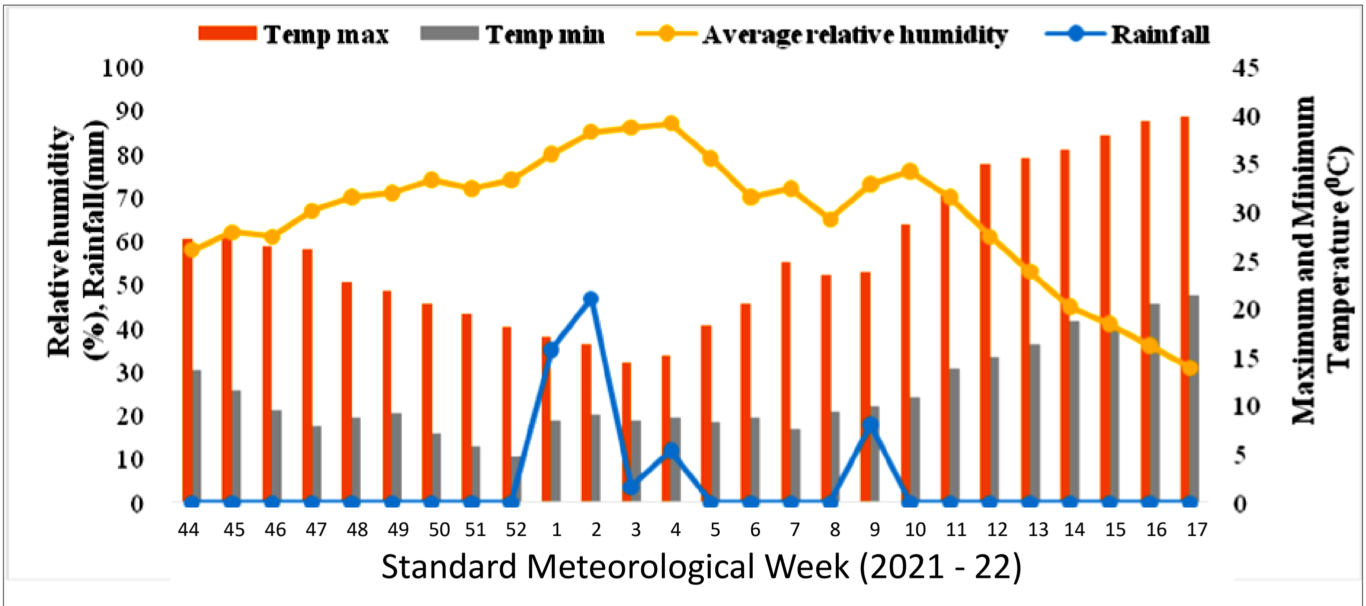

Fig. 2 Standard weekly meteorological data during the *rabi* season 2021-22 at Fatehgarh Sahib.

T6: RDF + Nano Urea spray @ 6%

T7: RDF + Nano Se spray @ 15 ppm

T8: RDF + Urea 6% + Se 15 ppm spray

T9: RDF + Urea 6% + Nano Se 15 ppm spray

T10: RDF + Nano Urea 6% + Se 15 ppm spray

T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray

Sodium selenate (Na_2SeO_4) was used as a source of selenium. Nano urea and nano Se were formulated in electron microscopy and nanoscience laboratory, Department of Soil Science, PAU, Ludhiana, India.

Crop management

Wheat variety Unnat PBW 550 was sown in a rice residue retained field using ten tined happy seeders with the recommended seed rate of 125 kg ha^{-1} at 5 cm depth with row spacing of 22.5 cm (9 inches). According to the recommended package of practices, the crop was fertilized with nitrogen (125 kg ha^{-1}) and phosphorus (62.5 kg ha^{-1}) using DAP (18:46:0) and urea (46:0:0) as a source of phosphorus and nitrogen, respectively. In all the treatments except absolute control (T1- no nitrogen), phosphorus was applied at sowing as band placement. In contrast, nitrogen through urea was broadcast in two equal splits before the first and second irrigations. For control of both grass and broadleaf weeds, the herbicide "Total" of 75 WG (sulfosulfuron + metsulfuron) was sprayed @ 40 g ha^{-1} using 375 litres of water 35 days after sowing using a knapsack sprayer fitted with a flat fan nozzle. To control yellow/stripe rust disease and to produce grains free from Karnal bunt, the fungicide Tilt 25 EC (propiconazole) @ 500 ml ha^{-1} was sprayed during the grain filling stage. The crop was harvested manually using a sickle from net plot size and threshed with a syndicator-type thresher.

Synthesis of nano selenium (Se)

The Se nanoparticles were synthesized according to the procedure, which involved the reaction of two solutions, *viz.*, sodium selenite (0.4725 g in 25 ml distilled water) and ascorbic acid (6.6045 g in 75 ml distilled water) in 1:3 (21). The ascorbic acid solution was added dropwise while the sodium selenite solution was placed on a stirrer at 800 rpm at room temperature (25±2°C). After the formation of red particles, these were centrifuged for 15 minutes. The pellet was scrapped, and the nanoparticles were dried.

Synthesis of nano urea

As described by (22), the chitosan nano urea was formulated. The procedure involved the ionotropic gelation of urea in chitosan (1.5%) with acetic acid (1% v/v) and between 80 as surfactant. Analytical grade urea was added @ 6% w/v in the suspension. After that, the sodium tripolyphosphate solution (0.25% w/v in 5:1) was added dropwise while keeping the suspension on the stirrer at 800 rpm. To reduce the size of the formed nanoparticles, the formulation was sonicated for 15 minutes.

Data collection and analysis

Micrometeorological observations

Normalized difference vegetation index (NDVI): NDVI measures the state of plant health based on how the plant reflects light at specific frequencies. The plot with higher vegetation exhibits a higher value of NDVI. Observation for NDVI was recorded using a handheld crop sensor, and the green seeker of 'Trimble' was made periodically ten days after the booting stage and grain milk stage. It is based on the principle of reflection of light from the crop canopy related to the vigor of the crop. The value of the green seeker ranged between 0 to 0.99. The higher the value, the higher the crop vigor.

Canopy temperature: An infrared canopy temperature analyzer was used to record canopy temperature periodically ten days after the booting and grain milk stages. The trigger was pressed at two different spots in a plot, and the canopy temperature was recorded.

Leaf chlorophyll: Observation for chlorophyll content was taken ten days after the booting stage and grain milk stage from a fully opened leaf from three plants in a single plot using the portable, non-destructive 'atLEAF' chlorophyll meter. This meter calculates a chlorophyll index (CI) based on reflectance or absorbency at particular wavelengths. It needs to be calibrated for given species to estimate the actual chlorophyll or N content. The observation was recorded by putting a leaf into the aperture or leaf sensor of the 'atLEAF' instrument (22-23). The leaf sensor was placed on leaf mesophyll tissue only, avoiding veins. Measurements were made at a photon flux density of 800 to 1200 µmol m^{-2} s^{-1}. Each leaf's measurements were averaged to provide a single chlorophyll index (CI) per leaf. The instrument emits the burst of two different wavelengths, red (640 nm) and infrared red (940 nm), then measures the amount of red light absorbed.

Phenology

Days taken to 50% heading: The observation was recorded by counting the days the crop took from sowing to when 50% of heads emerged from the top of the plant in each plot.

Days taken to 50% grain milk: It was recorded by counting the days the crop took from sowing to the day in each plot when 50% of spikes of grain plants exhibited the milk stage. This stage was noticed when the milky fluid came out of grains when pressed with fingers.

Days taken to physiological maturity: It was observed by taking five spikelets randomly from each plot after the dough milk stage daily. When the grains started giving a yellowish look from the outside, they were taken as days to physiological maturity.

Duration of grain filling: The grain-filling duration was recorded by counting the days from flowering to physiological maturity.

Yield

Biological yield (q ha^{-1}): The biological yield was recorded from the net plot size after discarding the border rows. The crop was harvested and allowed to dry. Before threshing, it was tied in bundles, and its weight was recorded and expressed in q ha^{-1}.

Grain yield (q ha^{-1}): After threshing the bundle plot-wise, the grain weight from each plot was recorded separately, and the grain yield data were expressed in q ha^{-1}.

Statistical analysis

ANOVA was performed to evaluate the influence of post-vegetative foliar application of nitrogen and selenium on micrometeorological parameters, phenology, and wheat yield. The statistical analysis was done using CPCS 1 software. The difference between means was compared with Fisher's least significant difference test at a 5% probability level.

Results

Normalized difference vegetative index (NDVI)

The results indicated the lowest NDVI (Table 1) value in absolute control compared to other fertilizer application treatments (T2–T11). The NDVI score with foliar spray of urea and nano urea @ 6% individually (T4, T6) or together with bulk Se (T8, T10) or nano Se (T9, T11) @ 15 ppm were statistically similar. It ranged from 0.64 to 0.66 and 0.67 to 0.69 at the booting stage for Ludhiana and Fatehgarh Sahib, respectively. It ranged from 0.60 to 0.65 and from 0.64 to 0.67 at the grain milk stage again for Ludhiana and Fatehgarh Sahib, respectively. Data revealed that foliar spray of nano urea was more efficient than bulk urea in increasing the NDVI value. Also, nano and bulk urea forms were found to be at par. Further, adding Se (bulk or nano form) to bulk or nano urea showed no significant increase in the NDVI score.

Chlorophyll index

The chlorophyll index (Table 2) recorded ten days after the booting stage showed a higher value with treatments involving foliar sprays of nano urea @ 6% alone or in combination with bulk or nano form of Se @15 ppm for both locations. The chlorophyll index with bulk and nano form of urea was at par. An individual spray of Se @ 15 ppm in bulk

Table 1. Effect of post-vegetative foliar application of nitrogen and selenium on NDVI value of wheat.

Treatments	Ludhiana		Fatehgarh Sahib	
	Ten days after			
	booting stage	grain milk stage	booting stage	grain milk stage
T1: Absolute control (no fertilizer)	0.49	0.43	0.53	0.45
T2: Recommended dose of fertilizers (RDF) only	0.58	0.51	0.60	0.55
T3: RDF + water spray	0.59	0.52	0.60	0.55
T4: RDF + Urea spray @ 6%	0.64	0.61	0.68	0.65
T5: RDF + Se spray @ 15 ppm	0.59	0.53	0.61	0.55
T6: RDF + Nano Urea spray @ 6%	0.66	0.65	0.69	0.66
T7: RDF + Nano Se spray @ 15 ppm	0.59	0.52	0.61	0.56
T8: RDF + Urea 6% + Se 15 ppm spray	0.64	0.60	0.67	0.64
T9: RDF + Urea 6% + Nano Se 15 ppm spray	0.64	0.61	0.68	0.65
T10: RDF + Nano Urea 6% + Se 15 ppm spray	0.66	0.64	0.69	0.67
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	0.66	0.65	0.68	0.67
CD (p=0.05)	0.04	0.06	0.05	0.06

Table 2. Effect of post-vegetative foliar application of nitrogen and selenium on chlorophyll index of wheat.

Treatments	Ludhiana		Fatehgarh Sahib	
	Ten days after			
	booting stage	grain milk stage	booting stage	grain milk stage
T1: Absolute control (no fertilizer)	35.5	31.2	37.9	34.8
T2: Recommended dose of fertilizers (RDF) only	46.2	42.0	47.0	43.2
T3: RDF + water spray	46.3	42.2	47.2	43.4
T4: RDF + Urea spray @ 6%	51.9	49.4	56.0	52.2
T5: RDF + Se spray @ 15 ppm	46.7	42.7	47.8	43.8
T6: RDF + Nano Urea spray @ 6%	55.4	53.2	57.5	54.1
T7: RDF + Nano Se spray @ 15 ppm	46.8	42.9	48.1	44.0
T8: RDF + Urea 6% + Se 15 ppm spray	52.3	49.9	56.5	52.7
T9: RDF + Urea 6% + Nano Se 15 ppm spray	52.6	50.1	56.6	53.0
T10: RDF + Nano Urea 6% + Se 15 ppm spray	56.0	53.6	57.9	54.7
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	56.4	53.9	58.0	54.9
CD (p=0.05)	4.6	4.6	4.6	4.9

or nano form produced chlorophyll index at par with treatments fertilized with recommended fertilizers (T2) or those followed by a foliar spray of water (T3). Absolute control showed the minimum value of chlorophyll index, as this was deprived of soil application of nitrogen. Adding a specific form of Se to any urea did not make a significant difference. The same trend was observed after the second scheduled spray at the grain milk stage. However, the treatments deprived of any form of urea showed a decrease in the value of the chlorophyll index, which could be due to the degeneration of chlorophyll as the crop approaches maturity.

Canopy temperature

The canopy temperature (Table 3) of plants at Ludhiana and Fatehgarh Sahib in absolute control treatment (T1) was significantly higher than the canopy temperature of the plants in all the RDF-based treatments (T2–T11) after both scheduled sprays. Although all the treatments from T2 to T11 showed slight variation, they produced statistically similar canopy temperatures at both locations. The canopy temperature at the grain milk stage was higher than the booting stage due to the increase in the air temperature.

Phenology

Days to 50% heading, 50% grain filling, and physiological maturity

The crop was fertilized with recommended nutrients (RDF) during the vegetative period and later on, sprayed with bulk or nano form of urea @ 6% individually (T4, T6) or in conjunction with bulk or nano Se @ 15 ppm (T8, T9, T10, and T11). Booting took a significantly greater number of days (3.5–4.5 days) to 50% heading both at Ludhiana and Fatehgarh Sahib (Table 4 and Fig. 3). Plants in the absolute control (T1) plot took significantly the lowest number of days to 50% heading compared to all other treatments at both the experimental sites. The days taken to 50% grain filling and physiological maturity at Ludhiana indicated that all the nano urea-based spray treatments - alone (T6)

Table 3. Effect of post-vegetative foliar application of nitrogen and selenium on canopy temperature (^{0}C) of wheat.

Treatments	Ludhiana		Fatehgarh Sahib	
	Ten days after			
	booting stage	grain milk stage	booting stage	grain milk stage
T1: Absolute control (no fertilizer)	22.1	29.2	22.3	28.3
T2: Recommended dose of fertilizers (RDF) only	20.3	27.4	20.7	26.6
T3: RDF + water spray	20.1	27.3	20.6	26.3
T4: RDF + Urea spray @ 6%	19.9	26.5	19.9	25.8
T5: RDF + Se spray @ 15 ppm	20.4	27.1	20.5	26.3
T6: RDF + Nano Urea spray @ 6%	19.7	26.3	19.7	25.6
T7: RDF + Nano Se spray @ 15 ppm	20.5	27.0	20.3	26.1
T8: RDF + Urea 6% + Se 15 ppm spray	19.7	26.5	19.9	25.7
T9: RDF + Urea 6% + Nano Se 15 ppm spray	19.7	26.4	19.8	25.7
T10: RDF + Nano Urea 6% + Se 15 ppm spray	19.6	26.1	19.6	25.6
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	19.3	26.0	19.6	25.3
CD (p=0.05)	1.19	1.56	1.35	1.49

Table 4. Effect of post-vegetative foliar application of nitrogen and selenium on phenology (days to 50% heading, 50% grain filling, and physiological maturity) of wheat.

Treatments	Days to		
	50% heading	50% grain filling	Physiological maturity
Ludhiana			
T1: Absolute control (no fertilizer)	88.5	99.0	119.0
T2: Recommended dose of fertilizers (RDF) only	91.0	104.0	124.0
T3: RDF + water spray	92.0	104.5	124.0
T4: RDF + Urea spray @ 6%	95.0	111.3	130.5
T5: RDF + Se spray @ 15 ppm	92.0	104.5	125.0
T6: RDF + Nano Urea spray @ 6%	96.0	114.0	133.3
T7: RDF + Nano Se spray @ 15 ppm	92.0	104.5	125.0
T8: RDF + Urea 6% + Se 15 ppm spray	95.0	111.5	130.5
T9: RDF + Urea 6% + Nano Se 15 ppm spray	95.5	111.5	131.0
T10: RDF + Nano Urea 6% + Se 15 ppm spray	96.5	114.0	133.5
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	96.5	114.0	133.5
CD (p=0.05)	1.81	1.51	1.90
Fatehgarh Sahib			
T1: Absolute control (no fertilizer)	89.5	106.5	123.5
T2: Recommended dose of fertilizers (RDF) only	94.0	111.0	128.5
T3: RDF + water spray	94.5	112.0	128.8
T4: RDF + Urea spray @ 6%	97.8	115.0	134.5
T5: RDF + Se spray @ 15 ppm	94.8	111.5	129.0
T6: RDF + Nano Urea spray @ 6%	98.5	116.8	136.3
T7: RDF + Nano Se spray @ 15 ppm	95.0	111.3	129.0
T8: RDF + Urea 6% + Se 15 ppm spray	98.0	114.8	134.5
T9: RDF + Urea 6% + Nano Se 15 ppm spray	98.0	115.0	134.8
T10: RDF + Nano Urea 6% + Se 15 ppm spray	98.5	116.8	136.3
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	98.5	116.8	136.5
CD (p=0.05)	1.99	2.13	2.25

or in combination with bulk Se (T10) or nano Se (T11) @ 15 ppm were at par among themselves but significantly took more days for 50% grain filling and physiological maturity than all the treatments involving spray of bulk form of 6% urea alone (T4), or together with 15 ppm bulk (T8) or nano Se (T9), but the differences were non-significant (NS) at Fatehgarh Sahib. The plants fertilized with RDF and later sprayed with water, bulk, or nano Se (T2, T3, T5, and T7)

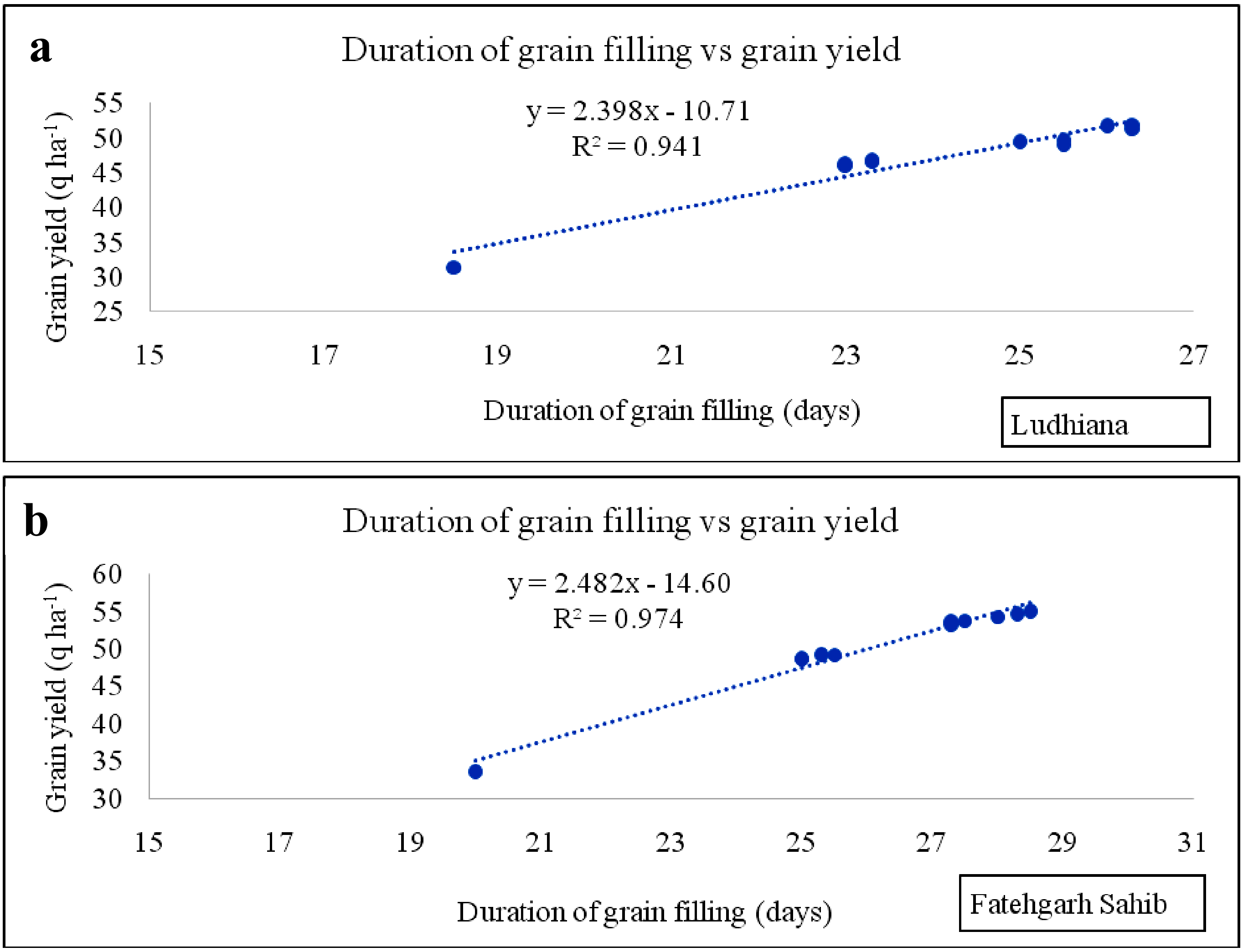

Fig 3. Correlation graph between the duration of grain filling and grain yield of wheat **a**) at Ludhiana and **b**) at Fatehgarh Sahib, respectively.

took almost similar days to 50% grain filling and physiological maturity.

Duration of grain filling

Absolute control (T1) treatment showed significant minimum grain filling days (Table 5) at both locations. The treatments involving spray of 6% urea (bulk or nano) with or without bulk or nano Se @ 15 ppm (T4, T6, T8, T9, T10, and T11) prolonged the grain filling duration, and this could be due to the role of N in delaying crop developmental stages. All the treatments mentioned above were statistically at par among themselves and significantly better than the recommended dose of fertilizers only (T2) or with the inclusion of water (T3), bulk Se (T5), and nano Se (T7) @ 15 ppm for both experimental sites. A foliar spray of urea in either form of urea increased the days of grain filling. However, nano urea showed a slight edge over bulk urea but was at par. Adding Se (bulk or nano) to a specific form of urea did not make any significant variation.

Table 5. Effect of post-vegetative foliar application of nitrogen and selenium on duration of grain filling (days) of wheat.

Treatments	Ludhiana	Fatehgarh Sahib
T1: Absolute control (no fertilizer)	18.5	20.0
T2: Recommended dose of fertilizers (RDF) only	23.0	25.0
T3: RDF + water spray	23.0	25.0
T4: RDF + Urea spray @ 6%	25.5	27.3
T5: RDF + Se spray @ 15 ppm	23.3	25.3
T6: RDF + Nano Urea spray @ 6%	26.3	28.0
T7: RDF + Nano Se spray @ 15 ppm	23.3	25.5
T8: RDF + Urea 6% + Se 15 ppm spray	25.0	27.3
T9: RDF + Urea 6% + Nano Se 15 ppm spray	25.5	27.5
T10: RDF + Nano Urea 6% + Se 15 ppm spray	26.0	28.3
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	26.3	28.5
CD (p=0.05)	1.4	1.5

Yield

Grain yield: The lowest grain yield (Table 6) was reported in absolute control treatment at both locations. Wheat plants in the plot sprayed twice with 6% nano urea + 15 ppm nano Se (T11) at the booting and grain milk stages produced maximum grain yield at Ludhiana and Fatehgarh Sahib. At both the experimental sites, the grain yield obtained with a post-vegetative spray of nano or bulk urea treatments was at par. However, the yields under nano urea-based treatments had an edge over bulk urea treatments. The grain yield at Ludhiana with 6% bulk urea-based treatments was higher than those obtained under RDF. Besides, it was sprayed with water or 15 ppm bulk nano Se, but differences were significant only between T9 and T3 treatments at Ludhiana. In contrast, at Fatehgarh Sahib, all the treatments with a spray of 6% urea (T4, T8, and T9) produced grain yield significantly better than T2, T3, T5, and T7.

Table 6. Effect of post-vegetative foliar application of nitrogen and selenium on grain and biological yield of wheat.

Treatments	Ludhiana		Fatehgarh Sahib	
	Grain yield (q ha^{-1})	Biological yield (q ha^{-1})	Grain yield (q ha^{-1})	Biological yield (q ha^{-1})
T1: Absolute control (no fertilizer)	31.4	93.2	33.5	95.0
T2: Recommended dose of fertilizers (RDF) only	46.1	114.9	48.6	117.1
T3: RDF + water spray	46.0	115.1	48.7	117.9
T4: RDF + Urea spray @ 6%	49.0	120.8	53.2	128.0
T5: RDF + Se spray @ 15 ppm	46.6	115.3	49.1	118.7
T6: RDF + Nano Urea spray @ 6%	51.3	125.1	54.3	130.6
T7: RDF + Nano Se spray @ 15 ppm	46.7	116.1	49.2	119.0
T8: RDF + Urea 6% + Se 15 ppm spray	49.3	121.4	53.5	128.8
T9: RDF + Urea 6% + Nano Se 15 ppm spray	49.5	122.2	53.8	129.5
T10: RDF + Nano Urea 6% + Se 15 ppm spray	51.6	125.9	54.6	131.6
T11: RDF + Nano Urea 6% + Nano Se 15 ppm spray	51.9	126.5	54.9	132.1
CD (p=0.05)	3.5	8.7	3.9	8.9

Biological yield: The maximum biological yield (Table 6) was found under treatment involving a dual foliar spray of 6% nano urea + 15 ppm nano Se (T11) at both locations. The biological yield with all the treatments involving foliar spray of 6% urea (bulk or nano form) alone or in combination with 15 ppm bulk or nano Se was found to be statistically at par at both study locations. The nanoform of urea was more effective in increasing the biological yield than bulk urea due to the reduced size of nano urea, which led to higher efficiency in penetrating the plant cells by providing a large surface area for assimilation. At Ludhiana, the biological yield with bulk urea-based treatments was statistically at par with plots fertilized with the recommended dose of nutrients (T2) or with a spray of water (T3) or 15 ppm Se [bulk (T5) or nano (T7) form]. Still, the differences among them were found significant only at Fatehgarh Sahib. Combining the nano or bulk Se @ 15 ppm with urea (bulk or nano form) did not significantly change the biological yield of wheat crops.

Discussion

Micrometeorological parameters

Nitrogen is an essential macronutrient that plants require and is a chlorophyll component. The results show that foliar urea spray in bulk or nano form increased the NDVI score for both locations. The NDVI measures the plant's vigor and greenness. The higher the NDVI value, the better the vegetative growth. The foliar spray of urea (bulk or nano) increased chlorophyll content and photosynthetic activity, thus increasing the crop greenness and, finally, the NDVI value. The results are per the findings of (23-24).

Nitrogen is the most crucial constituent of chlorophyll and is required by plants in more significant amounts for performing various physiological processes. Therefore, the foliar spray of N in the form of bulk or nano urea at the reproductive stage, besides RDF at vegetative stages, could be the reason for the increase in the chlorophyll index. The nanoform of urea, which has minute particles, offers a better surface area for its absorption by the plant, thereby leading to higher efficiency, as indicated by the numerically higher chlorophyll index over bulk urea. On the other hand, the crop raised without adding nitrogenous fertilizer, as in the absolute control (T1) treatment, might have resulted in improper chlorophyll formation and degraded the present chlorophyll formed due to the presence of native N. Se (nano or bulk) addition to bulk urea or nano urea did not significantly affect the chlorophyll index.

They found an increase in chlorophyll content in wheat with foliar sprays of 1% and 2% urea over the control (25). Chlorophyll content increased in fragrant rice was reported with a foliar spray of 40 µmol L^{-1} of sodium selenate (26). An increase in total chlorophyll content of maize leaf was noted with a foliar spray of Se (sodium selenate) before the onset of the tasselling stage (65 days after sowing) and was repeated after one week under normal and drought conditions (27). It was reported that SeNPs were more effective in increasing the chlorophyll content in cowpeas compared with bulk Se (sodium selenate) (28).

For canopy temperature, foliar applications of urea (nano or bulk), Se (nano or bulk), and water spray during the reproductive phase of the crop do not cause any significant change in the canopy temperature. The abiotic stress created by the absence of recommended nutrients in the absolute control (T1) might have increased the respiration, which ultimately raised the canopy temperature by a few units and resulted in a higher canopy temperature, which could be due to stress conditions experienced by plants as a result of no nitrogen application. The NS effect of nitrogen supplementation on the canopy temperature of wheat was also observed (29).

Phenology

The growth stages of crops were affected by the application of fertilizers. Nitrogen spray during the reproductive phase tends to keep the plant green longer and is thus reported to delay the reproductive stage and the corresponding maturity. This increased days to 50% heading, 50% grain filling, and physiological maturity. The grain filling duration was also enhanced with a foliar spray of urea. However, urea's nano form showed a numerical increase due to higher efficacy. Further addition of Se (nano or bulk) to urea and nano urea numerically increased the days to grain filling. It was reported that foliar application of nitrogen increased the duration of heading, grain filling, and physiological maturity with foliar spray of nitrogen in wheat crops (3). The addition of Se to urea (nano or bulk) had no marked effect on days to heading, grain filling, or physiological maturity. The results are also under the findings of (30).

Grain and biological yield

Post-vegetative foliar spray of urea increased the grain and biological yield. This is due to an increase in the photosynthetic activity of the crop with an increase in NDVI score and chlorophyll index, as well as an increase in grain filling duration. Due to its reduced size, Nano urea led to higher efficiency, but grain and biological yield were at par with both urea forms. Sole spray or adding Se to any specific form of urea did not significantly differ grain and biological yield. An increase in wheat grain yield with a foliar nitrogen spray was noted (3, 31). It was reported that Se fertilization had a non-significant effect on wheat grain yield (32-34). Studies also confirmed increased biological yield with a foliar nitrogen spray (35). It also reported increased biological yield in wheat with a foliar nitrogen spray during the reproductive phase (3).

Conclusion

Foliar spray of 6% nano urea or urea at booting and grain milk stage of the wheat crop was found to increase NDVI score, chlorophyll index, delayed crop development stages, and increased duration of grain filling, which in turn led to an increase in grain and biological yield of the crop. Alone or combined Se (bulk or nano form) with the specific form of urea did not show any significant responses. Studies need to be carried out on whether nano urea could partially be integrated with the recommended nitrogen to become a part of the recommended dose.

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Authors' contributions

Conceptualization, J.S., and R.K.G.; conduct of the experiment, S.S.; Formulation of nano urea and nano selenium, A.K.; data recording, A.K., and A.B.; writing of the manuscript, S.S. and A.S.; writing—review and editing, R.K.G. and J.S. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

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References

1. Bahaudin S, Kumar N, Kumar D, Kumar V. Trends in area, production and productivity of wheat cultivation at global level. Economic Affairs. 2022 Sep 1;67(4):401-06. https://doi.org/10.46852/0424-2513.4.2022.4
2. Anonymous. 2021. Directorate of Economics and Statistics. 2020-21;p. 51-52.
3. Jamil Hossain JH, Khan AA, Islam MA, Islam MR, Mian MA, Mollah MD. Phenology, growth, yield and protein content of wheat as influenced by foliar application of nitrogen. Journal of Biological Sciences. 2017;17:142-150. https://doi.org/10.3923/jbs.2017.142.150
4. Mbangcolo MM, Pieterse PJ. Effect of soil-and foliar-applied nitrogen fertilizer on growth, yield and protein content of spring wheat (*Triticum aestivum* L.) under glasshouse conditions. South African Journal of Plant and Soil. 2018 May 27;35(3):237-39.
5. Yao X, Chu J, Wang G. Effects of selenium on wheat seedlings under drought stress. Biological Trace Element Research. 2009 Sep;130:283-90.
6. Mirza H, Hossain MA, Fujita M. Selenium in higher plants: physiological role, antioxidant metabolism and abiotic stress tolerance. Journal of Plant Sciences. 2010;5(4):354-75. https://doi.org/10.1007/s12011-009-8328-7
7. Feng R, Wei C, Tu S. The roles of selenium in protecting plants against abiotic stresses. Environmental and Experimental Botany. 2013 Mar 1;87:58-68. https://doi.org/10.1016/j.envexpbot.2012.09.002
8. Sieprawska A, Kornas A, Filek M. Involvement of selenium in protective mechanisms of plants under environmental stress conditions-review. Acta Biologica Cracoviensia. Series Botanica. 2015;57(1). https://doi.org/10.1515/abcsb-2015-0014
9. Seppänen M, Turakainen M, Hartikainen H. Selenium effects on oxidative stress in potato. Plant Science. 2003 Aug 1;165(2):311-19. https://doi.org/10.1016/S0168-9452(03)00085-2
10. Apel K, Hirt H. Reactive oxygen species: metabolism, oxidative stress and signal transduction. Annu Rev Plant Biol. 2004 Jun 2;55:373-99. https://doi.org/10.1146/annurev.arplant.55.031903.141701
11. Bashir I, Lone FA, Bhat RA, Mir SA, Dar ZA, Dar SA. Concerns and threats of contamination on aquatic ecosystems. Bioremedia-

tion and Biotechnology: Sustainable Approaches to Pollution Degradation. 2020;1-26. https://doi.org/10.1007/978-3-030-35691-0_1

12. Alshaal T, El-Ramady H. Foliar application: from plant nutrition to biofortification. Environment, Biodiversity and Soil Security. 2017 Jun 1;1(2017):71-83. https://doi.org/10.21608/jenvbs.2017.1089.1006
13. Banger K, Yuan M. A vision for incorporating environmental effects into nitrogen management decision support tools for US maize production. Frontiers in Plant Science. 2017 Jul 28;8:271821. https://doi.org/10.3389/fpls.2017.01270. eCollection 2017
14. Gu B, Ju X, Chang J, Ge Y, Vitousek PM. Excessive nitrogen use in Chinese agriculture and its impact on the environment. Environmental Research Letters. 2013;8(2):025002.
15. Zhang X, Davidson EA, Mauzerall DL, Searchinger TD, Dumas P, Shen Y. Managing nitrogen for sustainable development. Nature. 2015;528(7580):51-59. https://doi.org/10.1038/nature15743
16. Duhan JS, Kumar R, Kumar N, Kaur P, Nehra K, Duhan S. Nanotechnology: The new perspective in precision agriculture. Biotechnology Reports. 2017 Sep 1;15:11-23. https://doi.org/10.1016/j.btre.2017.03.002
17. Lowry GV, Avellan A, Gilbertson LM. Opportunities and challenges for nanotechnology in the agri-tech revolution. Nature Nanotechnology. 2019 Jun;14(6):517-22. https://doi.org/10.1038/s41565-019-0461-7
18. Adisa IO, Pullagurala VL, Peralta-Videa JR, Dimkpa CO, Elmer WH, Gardea-Torresdey JL, White JC. Recent advances in nano-enabled fertilizers and pesticides: a critical review of mechanisms of action. Environmental Science: Nano. 2019;6(7):2002-30.
19. Liu R, Lal R. Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. Science of the Total Environment. 2015 May 1;514:131-39. https://doi.org/10.1016/j.scitotenv.2015.01.104
20. Al-Juthery HW, Hardan HM, Al-Swedi FG, Obaid MH, Al-Shami QM. Effect of foliar nutrition of nano-fertilizers and amino acids on growth and yield of wheat. In: IOP Conference Series: Earth and Environmental Science; 2019 Nov 1. Vol. 388(1): p. 012046. IOP publishing.
21. Zhou H, Wang S, Wang Z, Xie W, Wang C, Zheng M. Preparation, characterization and antioxidant activity of polysaccharides selenides from Qingzhuan dark tea. Food Science and Technology. 2022 Mar 18;42:e108421. https://doi.org/fst.102322
22. Kondal R, Kalia A, Krejcar O, Kuca K, Sharma SP, Luthra K, et al. Chitosan-urea nanocomposite for improved fertilizer applications: The effect on the soil enzymatic activities and microflora dynamics in N cycle of potatoes (*Solanum tuberosum* L.). Polymers. 2021 Aug 27;13(17):2887. https://doi.org/10.3390/polym13172887
23. Kizilgeci F, Yildirim M, Islam MS, Ratnasekera D, Iqbal MA, Sabagh AE. Normalized difference vegetation index and chlorophyll content for precision nitrogen management in durum wheat cultivars under semi-arid conditions. Sustainability. 2021 Mar 26;13(7):3725. https://doi.org/10.3390/su13073725
24. Aranguren M, Castellón A, Aizpurua A. Wheat yield estimation with NDVI values using a proximal sensing tool. Remote Sensing. 2020 Aug 25;12(17):2749.. https://doi.org/10.3390/rs12172749
25. Rahman MZ, Islam MR, Karim MA, Islam MT. Response of wheat to foliar application of urea fertilizer. J Sylhet Agril Univ. 2014;1(1):39-43.
26. Luo HW, He LX, Du B, Wang ZM, Zheng AX, Lai RF, Tang XR. Foliar application of selenium (Se) at heading stage induces regulation of photosynthesis, yield formation and quality characteristics in fragrant rice. Photosynthetica. 2019 Oct 1;57(4). https://doi.org/10.32615/ps.2019.114
27. Nawaz F, Naeem M, Ashraf MY, Tahir MN. Selenium supplementation affects physiological and biochemical processes to improve fodder yield and quality of maize (*Zea mays* L.) under water deficit conditions. Frontiers in Plant Science. 2016 Sep 27; 7:226775. https://doi.org/10.3389/fpls.2016.01438
28. El Lateef Gharib FA, Zeid IM, Ghazi SM, Ahmed EZ. The response of cowpea (*Vigna unguiculata* L.) plants to foliar application of sodium selenate and selenium nanoparticles (SeNPs). J Nanomater Mol Nanotechnol. 2019;8(4). https://doi.org/10.4172/2324-8777.1000272
29. Kumar M, Pannu RK, Singh B, Dhaka AK. Response of irrigation frequency and nitrogen levels on relative water content, canopy temperature, water potential and chlorophyll content of late sown wheat. International Journal of Pure and Applied Bioscience. 2017;5(2):173-79.DOI: http://dx.doi.org/10.18782/2320-7051.2580
30. Mahmoodi P, Yarnia M, Amirnia R, Benam MK. Effect of nitrogen foliar application on grain filling rate and period in 3 cultivars of corn (*Zea mays* L.). African Journal of Agricultural Research. 2011 Dec 5;6(29):6226-31. https://doi.org/10.5897/AJAR10.1016
31. Farooqi UM, Tahir M, Saleem MA, Ahmad T. Effect of foliar application of nitrogen and boron on growth, yield and quality of wheat (*Triticum aestivum* L.). Pakistan Journal of Life and Social Sciences. 2019 Jul 1;17(2): 93-99.
32. Manojlovic MS, Loncaric Z, Cabilovski RR, Popovic B, Karalic K, Ivezic V, et al. Biofortification of wheat cultivars with selenium. Acta Agriculturae Scandinavica, Section B—Soil and Plant Science.2019.Nov.17;69(1):1-10. https://doi.org/10.1080/09064710.2019.1645204
33. Wang M, Ali F, Wang M, Dinh QT, Zhou F, Bañuelos GS, Liang D. Understanding boosting selenium accumulation in Wheat (*Triticum aestivum* L.) following foliar selenium application at different stages, forms and doses. Environmental Science and Pollution Research. (2020) 27:717–728. https://doi.org/10.1007/s11356-019-06914-0
34. Radawiec A, Szulc W, Rutkowska B. Selenium biofortification of wheat as a strategy to improve human nutrition. Agriculture. 2021;11:1-12. https://doi.org/10.3390/agriculture11020144
35. Sabir S, Bakht J, Shafi M. Effect of foliar vs. broadcast application of different doses of nitrogen on wheat. Asian Journal of Plant Sciences. 2002;1(4):300-303. https://doi.org/10.3923/ajps.2002.300.303