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Influence of Nano Nitrogen on Yield and Quality of Potato under Humid, Sub-Tropical Region of West Bengal, India

Samima Akhtar [a], Amrit Tamang [a*], Koushik Ghosh [a], Mandira Saha [a], Sagar Tamang [b], Dipta Som [a], Partha Sarathi Patra [a], Hriday Kamal Tarafder [a], Jakir Ali Mallick [a] and Manoj Kanti Debnath [a]

[a] Uttar Banga Krishi Viswavidyalaya Cooch Behar, West Bengal, India.
[b] Purba Medinipur Krishi Vigyan Kendra, BCKV, Mohanpur, Nadia, West Bengal, India.

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

Potato (*Solanum tuberosum* L.) is the fourth most important food crop globally and served as a staple food in western countries. Recently, nanotechnology-based farming has gained much attention for improving nutrient use efficiency, maximizing yields and environmental sustainability. A field experiment on potato variety 'Kufri Jyoti' were conducted with 11 treatments considering RBD design with combinations of conventional nitrogen fertilizer and nano-urea. The study evaluated the effects treatments like T_1 = 0 % N (Control), T_2 = RDF (NPK@200:150:150 kg ha^{-1}), Conventional fertilizer i.e. 0 % N, 25% N, 50% and 75% of different combination with Nano-Urea sprayed at various dosage to find out the yield, quality parameters and economic returns. Results indicated that the combined application of conventional (75%) N and twice spray of nano-

**Corresponding author: E-mail: tamang_amrit@rediffmail.com;*

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Urea 6ml/lit (T_9) produces the highest economical yield (26.79 t ha^{-1}) and confirms 76.64 % increase in yield over the control. Highest haulm fresh yield (22.63 t ha^{-1}) was found in T_9 treatment. Though, haulm dry yield, tuber dry yield and biological yield was also associated highest with T_9 treatment i.e. 4.70, 5.83 and 49.42 t ha^{-1} respectively and highest harvest index (%) was observed in T_7 (54.27) treatment. Carbohydrate and starch content of tuber showed minor variation, whereas protein content was significantly higher (22.65%) than the control. Although the highest benefit-cost ratio (2.28) was observed in T_3 followed by T_9. After systematic analysis the T_9 (75% Nano spray 6ml/lit twice) treatment significantly overcame the better combination among all the treatment combination. While these 75:25 ratio of conventional and nano fertilizer had better nutrient absorption with minimum loss improving potato cultivation.

Keywords: Nano-N; nutrient contents; N use efficiency; crop quality; B:C ratio.

1. Introduction

Potato is the most important vegetable and is regarded as a staple diet in many parts of the country. It ranks fourth in terms of strategic and economic importance among crops, following wheat, rice and maize. Additionally, it is a highly nutritious diet that contains plenty amounts of proteins, carbs, starch, essential amino acids and vital minerals necessary for human nourishment. India achieved the second highest potato production globally. In West Bengal, potato is produced in an area of 4.60 lakh hectares with a productivity of 29,017 kg ha^{-1} (DES, 2023). Potatoes are a cost-effective food that serves as a readily available and affordable source of energy in the human diet. Potatoes are a highly abundant source of starch, as well as vitamins, including vitamin C and vitamin B_1 and minerals. Potato contains 21% carbs, 2.1% protein, 0.15% fat, 2.1% crude fiber, 544 mg potassium, 7 mg sodium and 0.9% ash. In addition, they are rich in important amino acids such as leucine, tryptophan, and isoleucine (USDA Food Data Central, 2019, Abd El-Azeim et al., 2020). India's production remains significantly lower compared to other countries mostly due to the imprudent and unbalanced usage of fertilizers. Nitrogen (N) is the primary nutritional element that restricts agricultural production on a worldwide level. The pursuit of specific crop yields has led to excessive utilization of nitrogen (N), posing significant economic and environmental issues on a global scale. Recently, researchers have focused on studying various contemporary methods in agriculture, specifically exploring the potential of nanotechnology to enhance the efficiency of fertilizer usage. Nano fertilizers are a highly promising type of manufactured materials currently undergoing testing for their potential use in soil or foliar treatments (Mejias, 2021). The indiscriminate use of synthetic fertilizers not only decline crop productivity and quality but also affected soil fertility status (Tamang et al*.,* 2026). Research on current nanotechnology-based nanofertilizers demonstrates their ability to increase crop output, improve nutrient utilization efficiency, and ensure environmental sustainability (Ghosh et al*.,* 2026). To address the drawbacks of traditional chemical fertilizers, there are nano-fertilizers that can decrease the amount of fertilizer needed and address soil nutrient deficiencies by enhancing nutrient utilization efficiency (Qureshi et al*.,* 2018).

2. Materials and Methods

2.1 Location and Climatic Conditions of the Study Area

The field experiment was conducted during 2022-23 and 2023-24 in the Terai region of West Bengal at 26.5243° N latitude and 89.1075° E longitude, with an elevation of 48 m above mean sea level, under a sub-humid climate of Agro-ecological Zone. The region receives an average annual rainfall of 2000-3500 mm, with nearly 80% occurring during the southwest monsoon (June-September).

2.2 Initial Soil Status of the Field

The experimental soil was sandy loam in texture and soil pH was acidic in nature. Organic carbon content in the soil also medium range. In case soil nutrients status, the value of nitrogen, phosphorus and potassium were low to medium range.

2.3 Experimental Design and Treatment Details

The experiment was laid out in a Randomized Block Design (RBD) with 11 treatments having three replications. Detailed descriptions of the treatments are presented in Table 1.

2.4 Crop Management Practices

Potato variety Kufri Jyoti was planted on 17th December 2022 and 23 November 2023 and harvested on 22 March 2023 and 2 March 2024, respectively. The plot size of the experimental field was 5 × 5 m² and maintained 30 cm intra-row spacing. The recommended dose (NPK @200:150:150 kg ha^{-1}) for potato crop was mentioned. Treatments consisted of combinations of conventional nitrogenous fertilizer (0, 25, 50, 75, and 100% recommended dose) and IFFCO Nano-Urea (liquid) containing 4.0% total nitrogen (w/v), applied as foliar sprays at 30, 45, and 60 days after sowing (DAS).

Table 1. Treatment details of the field experiments

Treatment	Treatment Combination
T_1	0 % N (RD of Inorganic P & K)
T_2	RDF (NPK@200:150:150 kg ha^{-1})
T_3	N 75% + Nano Twice Foliar spray 4ml/lit
T_4	N 50% + Nano Twice Foliar spray 4ml/lit
T_5	N 75% + Urea Foliar spray Twice (2%)
T_6	N 50% + Urea Foliar spray twice (2%)
T_7	N 75% + Nano and Sagarika Foliar spray 2ml/l (Twice)
T_8	N 50% + Nano and Sagarika Foliar spray 2ml/l (Twice)
T_9	N 75 % + Nano Twice Foliar spray 6ml/l
T_{10}	N 50% + Nano Twice Foliar spray 6ml/l
T_{11}	N 25% + Nano Thrice Foliar spray 4ml/l

[Note: RDF- Recommended doses of fertilizers; Sagarika (plant growth promotor) contains 8-10% biopotash and micronutrients like Zinc, Iron etc.]

2.5 Methodology

Tuber yield was recorded after harvesting and expressed in t ha^{-1} using standard conversion procedures. Biochemical parameters including total carbohydrate and starch contents were estimated following the Sadasivam and Manickam (1992) method using anthrone reagent, while protein content was determined according to AOAC (1960) by multiplying nitrogen percentage with a conversion factor of 6.25.

2.6 Statistical Analysis

The experimental data was statistically analysed using SPSS v28–v29 software.

3. Results and Discussion

3.1 Effect of Nano Urea on Yield and Yield Attributes of Potato

3.1.1 Haulm Fresh Yield

The pooled data indicated on an average 20.52 t ha^{-1} haulm fresh yield whereas, highest yield (22.63 t ha^{-1}) recorded in T_9 and lowest yield (13.07 t ha^{-1}) in T_1 (control) after the harvest at 110 DAS (Table 2). The treatment T_{10} (21.52 t ha^{-1}) was statistically at par with T_2 (RDF) (21.60 t ha^{-1}). Compared with control, the average haulm fresh yield increased by 57.03%, with the highest increase (73.22%) observed in T_9, followed closely by T_7 (70.40%). Improved nutrient availability, enhanced nutrient uptake, and favorable crop growth conditions may have contributed to these increases. Similar findings were reported by Chauhan et al. (2023) and Abd El-Azeim et al. (2020), who observed enhanced potato growth and yield with nano-fertilizer application.

3.1.2 Haulm Dry Yield

The experiment exhibited nano-urea application significantly influenced haulm dry yield, with an average value of 3.96 t ha^{-1}. The maximum haulm dry yield (4.70 t ha^{-1}) was recorded under T_9, whereas the lowest (2.49 t ha^{-1}) was found in T_1 after the harvest (Table 2). Though, the T_3 (4.82 t ha^{-1}) and T_7 (4.55 t ha^{-1}) had almost at par

haulm dry yield with T_9 treatment. Similarly, the trend between T_{10}, T_5 and T_2 also had non-significant with each other among all the treatments. It was also noted that the average haulm dry yield increased by 59.11% over control, with the highest increase (88.77%) in the best treatment T_9 (N 75%+Nano twice sprays 6ml/lit) followed by (83.41%) in T_3 (N 75% + Nano twice spray 4ml/lit) which may have been brought about by optimal moisture management and use, optimal nutrient absorption, nutrient availability and release throughout the crop growth period. Enhanced nitrogen use efficiency and activation of metabolic processes through Nano-Urea application may have contributed to the improved biomass production. Similar observations were reported by Al-Juthery and Al-Maamouri (2020).

3.1.3 Biological Yield

The pooled data of two years was significantly influenced by Nano-Urea treatments, with an average yield of 44.07 t ha^{-1} after the harvest. (Table 2). The highest biological yield (49.42 t ha^{-1}) was obtained under T_9, while the lowest (28.23 t ha^{-1}) was recorded in T_1. Treatments T_7 (48.68 t ha^{-1}) and T_3 (48.22 t ha^{-1}) showed values statistically at par with T_9, whereas RDF treatment T_2 (47.13 t ha^{-1}) was comparable with T_5 (47.69 t ha^{-1}). The average biological yield increased by 56.10% over control, with the highest increase (75.04%) under T_9, followed by T_7 (72.42%), while T_2 showed a 66.93% increase. Although RDF treatment T_2 had the biological yield increase 66.93% over control. The improved biological yield may be attributed to enhanced nutrient absorption and sustained nutrient availability throughout the crop growth period, supporting findings by Al-Hayani et al. (2023).

3.1.4 Harvest Index

The pooled data collected over the two consecutive years for the harvest index ranged from 50.14 to 54.27 (Table 2). The treatment T_7 (N 75%+Nano and Sagarika 2ml/l twice) registered the greatest value of harvest index (54.27%) and lowest was recorded with T_6 (N 50%+Urea spray twice) compared to other treatments. The average mean value of harvest index was 53.40%. There was no significant difference between the treatment when we compare all of them, T_6 (50.14) and T_{11} (51.00) had slight significant difference. In a study conducted by Abd El-Azeim et al. (2020), the researchers investigated the impact of recommended rates of NPK chemical fertilizer (control treatments) compared to NPK Nano-fertilizers at equivalent or lower rates (100%, 50%, 25%).

3.2 Nano Fertilizer Responses in Yield

The effect of the Nano-Urea application, either alone or in combination with conventional fertilizer, significantly influenced potato tuber yield (Fig. 1). The yield trend was highest with 75% conventional with nano application followed by RDF. The yield and yield increased over control was slightly above the RDF, but 50% conventional couldn't attained the satisfactory yield. Similar findings by Tiwari et al. (2021) reported increased potato yield with a 50% reduction in conventional nitrogen supplemented with Nano-Urea sprays. The improved productivity may be attributed to enhanced nutrient uptake, reduced nutrient loss, increased photosynthetic activity, chlorophyll synthesis, biomass production, and better vegetative growth resulting from foliar Nano-Urea application.

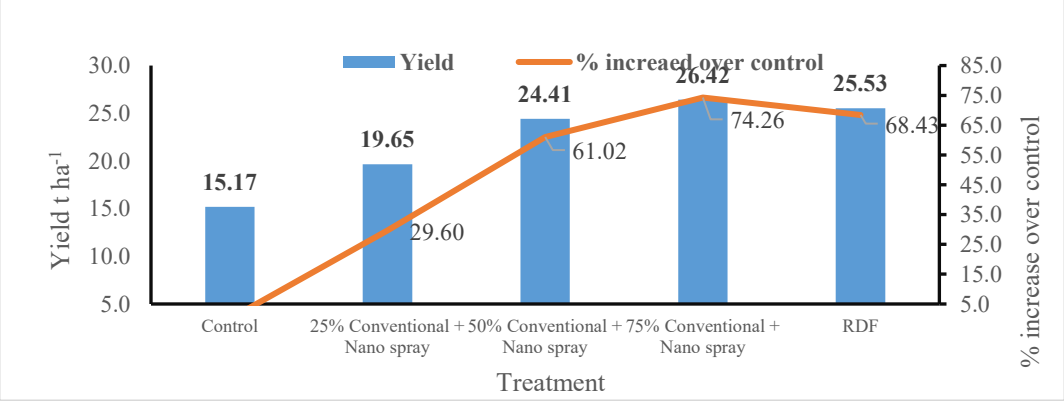

Fig. 1. Response in yield increase with different combination of nutrient applied

Table 2. Effect on Nano-urea on different yield attributing characters

Treatments	Yield attributes											
	Haulm fresh yield (t ha^{-1})			Haulm dry yield (t ha^{-1})			Biological yield (t ha^{-1})			Harvest index		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	12.80^{f}	13.33^{d}	13.07^{f}	2.36^{e}	2.61^{f}	2.49^{f}	27.72^{h}	28.75^{g}	28.23^{i}	53.85^{ab}	53.62^{a}	53.74^{a}
T_2	21.05^{bcd}	22.15^{ab}	21.60^{bc}	4.19^{ab}	4.39^{bc}	4.29^{bc}	46.56^{bcd}	47.70^{abc}	47.13^{cd}	54.81^{a}	53.58^{a}	54.19^{a}
T_3	21.87^{ab}	22.50^{a}	22.19^{ab}	4.31^{ab}	4.82^{a}	4.57^{ab}	47.82^{ab}	48.62^{ab}	48.22^{abc}	54.29^{a}	53.74^{a}	54.02^{a}
T_4	19.78^{cd}	20.82^{bc}	20.30^{d}	3.37^{cd}	3.89^{d}	3.63^{d}	43.43^{e}	44.77^{d}	44.10^{f}	54.44^{a}	53.52^{a}	53.98^{a}
T_5	21.37^{abc}	22.57^{a}	21.97^{ab}	4.26^{ab}	4.43^{bc}	4.35^{bc}	46.97^{bc}	48.42^{ab}	47.69^{bcd}	54.52^{a}	53.40^{a}	53.96^{a}
T_6	19.65^{d}	21.30^{abc}	20.47^{d}	3.13^{d}	3.98^{d}	3.56^{d}	40.04^{f}	42.03^{e}	41.04^{g}	50.93^{b}	49.34^{b}	50.14^{b}
T_7	22.13^{ab}	22.39^{a}	22.26^{ab}	4.47^{ab}	4.63^{ab}	4.55^{ab}	48.38^{ab}	48.98^{ab}	48.68^{ab}	54.27^{a}	54.28^{a}	54.27^{a}
T_8	20.23^{cd}	21.30^{abc}	20.76^{cd}	3.92^{bc}	4.12^{cd}	4.02^{c}	44.39^{de}	46.10^{cd}	45.24^{ef}	54.44^{a}	53.80^{a}	54.12^{a}
T_9	22.67^{a}	22.59^{a}	22.63^{a}	4.65^{a}	4.75^{ab}	4.70^{a}	49.38^{a}	49.47^{a}	49.42^{a}	54.11^{ab}	54.34^{a}	54.23^{a}
T_{10}	20.77^{bcd}	22.26^{a}	21.52^{bc}	4.03^{b}	4.58^{ab}	4.31^{bc}	45.52^{cde}	47.41^{bc}	46.47^{de}	54.41^{a}	53.06^{a}	53.73^{a}
T_{11}	17.85^{e}	19.97^{c}	18.91^{e}	2.88^{de}	3.37^{e}	3.13^{e}	37.31^{g}	39.82^{f}	38.56^{h}	52.16^{ab}	49.84^{b}	51.00^{b}
Mean	20.02	21.02	20.52	3.78	4.14	3.96	43.41	44.73	44.07	53.84	52.96	53.40
SEm (±)	0.54	0.45	0.35	0.19	0.12	0.117	0.74	0.61	0.48	1.11	0.45	0.60
LSD (P=0.05)	1.60	1.35	1.01	0.57	0.38	0.33	2.21	1.82	1.38	3.28	1.33	1.71

3.3 Effect of Nano Urea on Quality Parameters of Potato

3.3.1 Carbohydrates Content

The most important quality i.e., carbohydrates content ranges from 78.97 to 83.65 % with a mean value of 81.52 % (Table 3). However, there was significant difference of carbohydrates content under different treatments of Nano-urea application. The highest (83.65%) content of carbohydrates was associated with T_9 (N 75% +Nano twice sprays 6ml/lit) and the lowest (78.97%) was observed in T_1 (0% N, P and K inorganic RD) treatments respectively. There were negligible (5.59%) increase in carbohydrate content with best treatment over control. Tiwari et al. (2021) reported that the use of nano-urea led to a significant increase in potato yield and tuber quality compared to conventional fertilizer practices. The increased carbohydrate content in the tubers contributed to their improved size and quality. The nano-forms of fertilizers exhibited higher levels of phosphorus concentration, biomass, crude protein, and soluble carbohydrates in the feed maize compared to chemical forms of fertilizers.

Table 3. Variation in quality of potato tuber (carbohydrate) with applied Nano-Urea fertilizer

Treatment	Carbohydrate (%)		
	2022-2023	2023-2024	Pooled
T_1	78.74^{c}	79.19^{f}	78.97^{e}
T_2	82.11^{ab}	82.92^{abc}	82.52^{ab}
T_3	81.02^{b}	83.18^{ab}	82.10^{b}
T_4	80.12^{bc}	81.54^{cde}	80.83^{cd}
T_5	81.00^{b}	83.52^{ab}	82.26^{b}
T_6	80.00^{bc}	81.41^{de}	80.71^{cd}
T_7	81.47^{ab}	83.84^{ab}	82.66^{ab}
T_8	80.22^{bc}	81.40^{de}	80.81^{cd}
T_9	83.28^{a}	84.01^{a}	83.65^{a}
T_{10}	81.05^{b}	82.43^{bcd}	81.74^{bc}
T_{11}	80.14^{bc}	80.81^{e}	80.48^{d}
Mean	80.83	82.20	81.52
SEm (±)	0.72	0.48	0.43
LSD(P=0.05)	2.12	1.44	1.24

3.3.2 Starch content

Another important quality i.e., starch content varies from 71.15 to 76.42% with an average value of 74.34% (Table 4). However, there was slight difference in starch content under different treatments. The highest (76.42%) starch content observed with T_9 (N 75% +Nano twice sprays 6 ml L^{-1}) and the lowest was associated in T_1 (0%N, P and k inorganic RD) treatments respectively. There were 6.89% increase in starch content by T_9 treatment over the control treatment. In a study conducted by Abd El-Azeim et al. (2020), the impact of recommended rates of NPK chemical fertilizer (control treatments) was compared to NPK Nano-fertilizers at equivalent or lower rates (100%, 50%, 25%). The objective was to determine the effect of foliar or soil application on potato quality and productivity. The results showed that compared to the control treatment, the plot that received foliar application of Nano-fertilizer at 50% or 25% of the recommended level exhibited higher starch content (79.62%). In a similar technique, Gopika et al. (2024) revealed that the quality attributes were much better in the treatments where nano urea was applied, however there were modest differences in the specific contents that were significantly higher. The starch amount in T_1 was the greatest, measuring 76.70%.

3.3.3 Protein Content

The protein content in tuber varies from 13.24 to 16.24 % with an average value of 14.76% (Table 5). However, there was some significant difference in values of protein content under different treatments combination. The highest (16.24%) protein content was detected in T_9 (N 75% +Nano twice sprays 6ml/lit) and the lowest (13.24%) was found in T_1 (0% N, P and K inorganic RD) treatments respectively. There were significant (18.47%) increase in protein content with best treatment over the control. Similarly, Al-Juthery and Al-Shami

(2019) conducted a study on the effect of fertigation with nano-NPK fertilizer on some parameters of growth and yield of potato, has been discovered that the treatments with single, di, and tri nano NPK fertilizers as well as the conventional source have a sizable impact on the tuber's protein content. In comparison to the control treatment (10.00%), the nano N (10.05%) recorded the greatest percentage of protein in the tubers, with no discernible difference. INM maintained higher content of almost all the quality parameters in cauliflower (Batabyal et al., 2016). Here the increase in protein content might be due to nano spray improves more photosynthetic surface, better biomass production, more chlorophyll formation and sufficient nutrient uptake which ultimately resulted higher nutrient accumulation and more protein formation.

Table 4. Variation in quality of potato tuber (Starch) with applied Nano-Urea fertilizer

Treatment	Starch (%)		
	2022-2023	2023-2024	Pooled
T_1	70.77^{c}	71.53^{f}	71.15^{g}
T_2	73.35^{ab}	75.82^{bcde}	74.59^{bcdef}
T_3	73.77^{ab}	77.02^{abc}	75.40^{abc}
T_4	72.65^{abc}	75.25^{cde}	73.95^{def}
T_5	73.12^{ab}	76.70^{abc}	74.91^{bcd}
T_6	72.24^{abc}	74.67^{de}	73.46^{ef}
T_7	73.87^{ab}	77.53^{ab}	75.70^{ab}
T_8	72.78^{abc}	75.44^{cde}	74.11^{cdef}
T_9	74.22^{a}	78.61^{a}	76.42^{a}
T_{10}	73.02^{ab}	76.61^{abcd}	74.82^{bcde}
T_{11}	72.12^{bc}	74.33^{e}	73.23^{f}
Mean	72.9	75.77	74.34
SEm (±)	0.7	0.67	0.48
LSD(P=0.05)	2.07	2.00	1.39

Table 5. Variation in quality of potato tuber (Protein) with applied Nano-Urea fertilizer

Treatment	Protein (%)		
	2022-2023	2023-2024	Pooled
T_1	13.20^{e}	13.28^{e}	13.24^{f}
T_2	14.66^{cd}	14.92^{c}	14.79^{cd}
T_3	15.25^{b}	15.60^{b}	15.43^{b}
T_4	14.44^{d}	14.19^{d}	14.32^{e}
T_5	14.84^{c}	14.88^{c}	14.86^{c}
T_6	14.43^{d}	14.17^{d}	14.30^{e}
T_7	15.53^{ab}	15.90^{b}	15.72^{b}
T_8	14.53^{cd}	14.23^{d}	14.38^{c}
T_9	15.73^{a}	16.75^{a}	16.24^{a}
T_{10}	14.58^{cd}	14.42^{cd}	14.50^{de}
T_{11}	14.75^{cd}	14.44^{cd}	14.60^{cde}
Mean	14.72	14.8	14.76
SEm (±)	0.11	0.2	0.116
LSD(P=0.05)	0.33	0.6	0.33

When the different levels of the 25%, 50%, 75% conventional fertilizer along with nano spray were combined and compared with control and RDF, we found some significant impact on quality parameters of potato (Fig. 2), it was found that the 75% conventional along with nano spray performed better in terms of nutritional quality of potato tuber. The carbohydrate, starch and protein content in the potato tuber were maximum with 75% P through water soluble conventional fertilizer and two Nano urea at 30 and 45 DAS spray compare to the control. In all the combination where 25, 50% and 75% N was combined with Nano-urea spray, twice spray at 30 and 45 DAS achieved better result than single spray of nano urea. The RDF almost had similar quality achieve at par with the 75% conventional N combined with twice Nano-urea spray. The minimum quality was observed with control treatment when we consider the carbohydrate, starch and protein of the potato.

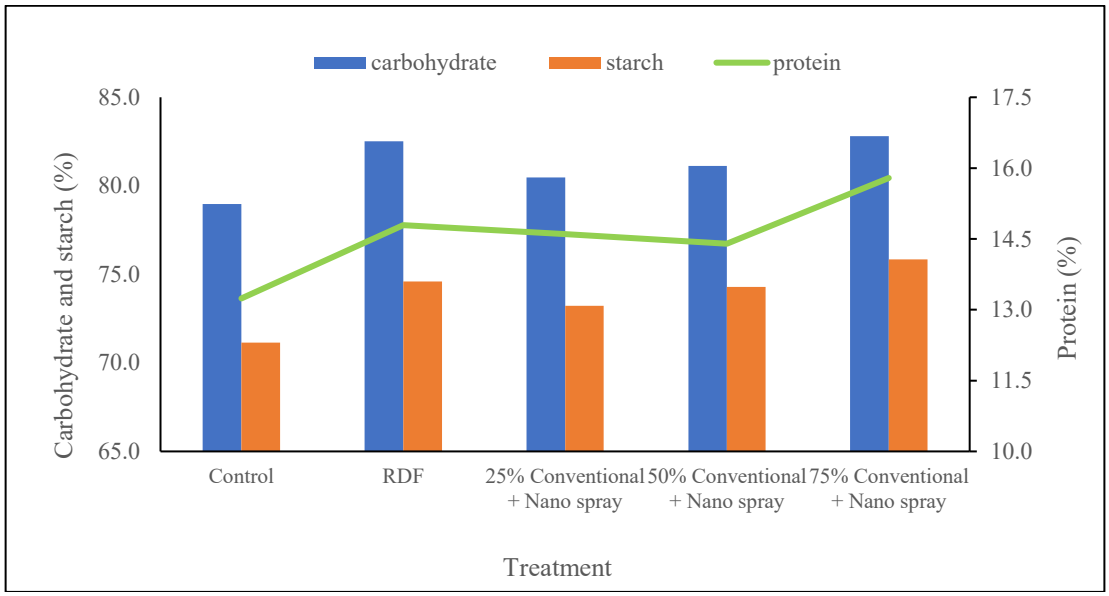

Fig. 2. Response of carbohydrates, starch and protein content by Nano-urea applied

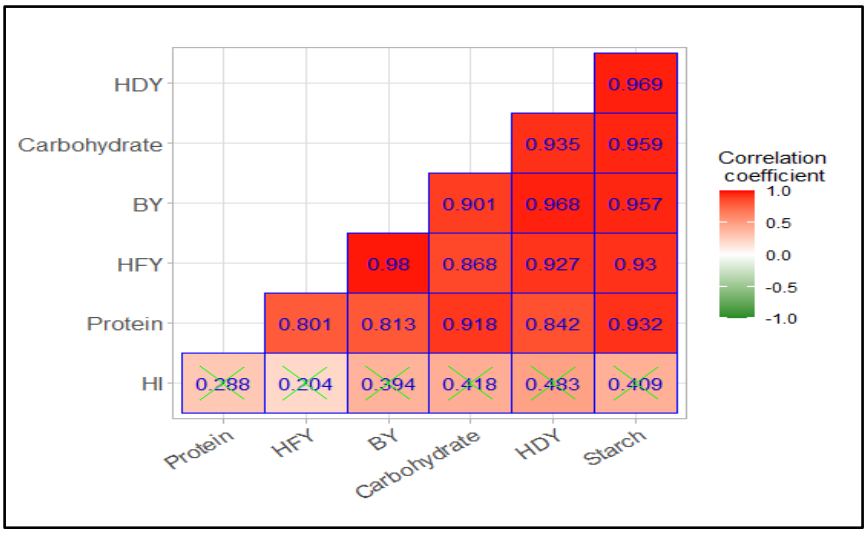

Fig. 3. Correlation heat map among biochemical and yield related parameters of potato. The red color depicts positive correlation and green crosses depicts weak correlation. (Where, HFY, HDY, BY and HI denotes haulm fresh yield, haulm dry yield, biological yield and harvest index, respectively)

3.4 Relationship between Nutritional and Yield Traits of Potato

The experimental data reveals a remarkably strong and positive correlations among the quality and yield-related parameters, indicating their synergistic relationship in the studied samples (Fig 3.). The upper triangular heatmap shows high correlation coefficient (r) values ranging from 0.801 to 0.980, indicating a significant degree of association between the studied variables. Particularly, HFY exhibited a very strong positive correlation with BY (r=0.980), while HDY showed strong correlations with BY (r=0.968), Carbohydrate (r = 0.935), and Starch (r=0.969). Similarly, Protein content was positively associated with Carbohydrate (r=0.918) and Starch (r=0.932), suggesting coordinated enhancement of nutritional and productivity traits. The consistently high positive correlations imply that improvement in one parameter is likely accompanied by a corresponding increase in the others, reflecting synergistic interactions among growth, yield, and biochemical constituents. The lower diagonal values, marked with green crosses, represent comparatively weaker correlations, indicating less significant associations for those parameter combinations.

Table 6. Effect of Nano-Urea fertilizers on Economics of treatments used for cultivation of potato

Treatments	Economics of treatments used for cultivation of potato											
	Total cost of cultivation			Gross return			Net return			B.C ratio		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	135252.6	142015.2	138633.9	179040.0	185000.0	182020.0	43787.3	42984.7	43386.0	1.32	1.30	1.31
T_2	141292.5	148357.1	144824.8	306120.0	306600.0	306360.0	164827.4	158242.8	161535.1	2.17	2.07	2.12
T_3	136602.6	143432.7	140017.7	311400.0	313440.0	312420.0	174797.3	170007.2	172402.2	2.28	2.19	2.23
T_4	141339.7	148406.6	144873.1	283800.0	287360.0	285580.0	142460.3	138953.3	140706.8	2.01	1.94	1.97
T_5	141223.4	148284.5	144754.0	307200.0	310120.0	308660.0	165976.5	161835.4	163905.9	2.18	2.09	2.13
T_6	140577.7	147606.5	144092.1	244680.0	248800.0	246740.0	104102.3	101193.4	102647.8	1.74	1.69	1.71
T_7	142723.4	149859.5	146291.5	315000.0	319040.0	317020.0	172276.5	169180.4	170728.4	2.21	2.13	2.17
T_8	142077.7	149181.5	145629.6	289920.0	297560.0	293740.0	147842.3	148378.4	148110.3	2.04	1.99	2.02
T_9	143248.4	150410.8	146829.6	320520.0	322480.0	321500.0	177271.5	172069.1	174670.3	2.24	2.14	2.19
T_{10}	142602.7	149732.8	146167.7	297000.0	301800.0	299400.0	154397.3	152067.1	153232.2	2.08	2.02	2.05
T_{11}	150790.6	158330.1	154560.4	233520.0	238120.0	235820.0	82729.3	79789.8	81259.5	1.55	1.50	1.53

3.5 Benefit-cost Analysis

The pooled data of two consecutive years the benefit-cost ratios for potato cultivation under various treatment combination were calculated. The magnitude of ratio for 2022-23 and 2023-24 varied from 1.32 to 1.55 and 1.30 to 1.50 (Table. 6) under different treatment tested. The pooled data observed that the highest (Rs. 321500.0) gross return was recorded with T_9 and the lowest (Rs. 182020.0) was found in T_1 (control) treatment respectively. However, pooled data of two years confirmed that treatment T_3 (75% N+Nano two spray@4ml L^{-1}) had highest B:C ratio (2.23). Chauhan (2023) conducted research and he found that the data regarding the economic impact of nano urea and nano zinc fertilizers on potato cultivation is displayed that the treatment T_{11} had the highest gross revenue (Rs. 229560 ha^{-1}), net income (Rs. 164148 ha^{-1}), and benefit-cost ratio (B:C ratio) (Rs. 2.509448 ha^{-1}). The treatment T_2 had the lowest minimal gross revenue (Rs. 102560 ha^{-1}), net income (Rs. 48980 ha^{-1}), and benefit-cost ratio (B:C ratio) (Rs. 0.770368 ha^{-1}).

4. Conclusion

The study demonstrated about combined application of conventional nitrogen fertilizer with Nano-Urea (foliar) significantly improved potato yield, quality and economic returns under the humid subtropical conditions of the Terai region of West Bengal. Among all treatment combinations, T_9 (75% conventional N + two Nano-Urea sprays at 6 ml L^{-1} at 30 and 45 DAS) exhibited superior performance, recording the highest tuber yield (26.79 t ha^{-1}), haulm fresh yield (22.63 t ha^{-1}), haulm dry yield (4.70 t ha^{-1}), biological yield (49.42 t ha^{-1}) and significant improvement in tuber quality parameters including carbohydrate (83.65%), starch (76.42%), and protein (16.24%) contents. The treatment also resulted in a 76.64% increase in tuber yield over control, indicating improved nutrient use efficiency and enhanced crop performance. Although the highest gross return was recorded in T_9, the maximum benefit-cost ratio (2.23) was obtained in T_3, closely followed by T_9 (2.19). The findings suggest that replacing a portion of conventional nitrogen fertilizer with Nano-Urea can reduce dependence on chemical fertilizers while maintaining or improving productivity and profitability. Therefore, the combination of 75% conventional nitrogen with two Nano-Urea sprays can be considered an efficient and nano based nutrient management strategy for potato cultivation.

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 they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

References

Abd El-Azeim, M. M., Sherif, M. A., Hussien, M. S., Tantawy, I. A. A., & Bashandy, S. O. (2020). Impacts of nano- and non-nano fertilizers on potato quality and productivity. *Acta Ecologica Sinica, 40*(5), 388–397. https://doi.org/10.1016/j.chnaes.2019.12.007

Al-Hayani, A. S., & Sallume, M. O. (2023). Effect of humic acid and the level of nano and traditional nitrogen on the growth and yield of potato. *IOP Conference Series: Earth and Environmental Science, 1213*, 012014. https://doi.org/10.1088/1755-1315/1213/1/012014

Al-Juthery, H. W. A., & Al-Maamouri, E. H. O. (2020). Effect of Urea and Nano-Nitrogen Fertigation and Foliar Application of Nano-Boron and Molybdenum on some Growth and Yield Parameters of Potato. *Al-Qadisiyah Journal for Agriculture Sciences, 10*(1), 253–263. https://doi.org/10.33794/qjas.2020.167074

Al-Juthery, H. W. A., & Al-Shami, Q. M. N. (2019). The Effect of Fertigation with Nano NPK Fertilizers on Some Parameters of Growth and yield of potato (Solanum tuberosum L.). *Al-Qadisiyah Journal for Agriculture Sciences, 9*(2), 225-232. *https://doi.org/10.33794/qjas.Vol9.Iss2.93*

Association of Official Agricultural Chemists. (1960). *Official methods of analysis* (9th ed.).

Batabyal, K., Mandal, B., Sarkar, D., Murmu, S., Tamang, A., Das, I., Hazra, G. C., & Chattopadhyay, P. S. (2016). Comprehensive assessment of nutrient management technologies for cauliflower production

under subtropical conditions. *European Journal of Agronomy, 79*, 1-13. https://doi.org/10.1016/j.eja.2016.05.001

Chauhan, A., Pallavi, Rattan, P., Ludarmani, & Sharma, A. (2023). Effect of pre-soaking of potato (*Solanum tuberosum* L.) tubers in nano-urea and nano-zinc on its growth, quality and yield. *The Pharma Innovation Journal, 12*(7), 980–995. https://www.thepharmajournal.com/archives/2023/vol12issue7/PartM/12-6-444-109.pdf

Directorate of Economics & Statistics, *Department of Agriculture & Farmers Welfare, Government of India. (2023). Agricultural statistics at a glance 2022*. Government of India. https://desagri.gov.in/wp-content/uploads/2023/05/Agricultural-Statistics-at-a-Glance-2022.pdf

Ghosh, K., Tamang, A., Saha, M., Tamang, S., Mitran, T., & Tarafder, H. K. (2026). Nanotechnology: Sustainable nutrient management for modern agriculture. In M. C. Kundu (Ed.), *Recent research trends in soil science* (Vol. 1). Cornous Publications LLP. https://www.cornousbooks.com/book/recent-research-trends-in-soil-science-volume-1/chapter/nanotechnology-sustainable-nutrient-management-for-modern-agriculture

Gopika, K. T., Isaac, S. R., Pillai, S. P., Thomas, U. C., & Sreelatha, A. K. (2024). Yield and quality in Chinese potato as influenced by reduced tillage and nano nitrogen fertilization. *International Journal of Research in Agronomy, 7*(3), 349–352. https://doi.org/10.33545/2618060X.2024.v7.i3e.422

Mejías, J. H., Salazar, F., Pérez Amaro, L., Hube, S., Rodriguez, M., & Alfaro, M. (2021). Nano fertilizers: A cutting-edge approach to increase nitrogen use efficiency in grasslands. *Frontiers in Environmental Science, 9*, 635114. https://doi.org/10.3389/fenvs.2021.635114

Qureshi, A., Singh, D. K., & Dwivedi, S. (2018). Nano-fertilizers: A novel way for enhancing nutrient use efficiency and crop productivity. *International Journal of Current Microbiology and Applied Sciences, 7*(2), 3325–3335. https://doi.org/10.20546/ijcmas.2018.702.398

Sadasivam, S. & Manickam, A. (1992). Phenolics. *In: Biochemical methods for agricultural sciences*, Wiley Eastern Ltd, New Delhi, India, 187-188.

Tamang, A., Sahoo, B., Saha, M., Ghosh, K., Tamang, S., Patra, P. S., & Mitran, T. (2026). Soil pollution: Causes, impacts and management strategies. In M. C. Kundu (Ed.), *Recent research trends in soil science* (Vol. 1). Cornous Publications LLP. ISBN 978-81-993853-4-4. https://doi.org/10.37446/volbook122026

Tiwari, K. N., Kumar, Y., Nayak, R. K., Rai, A., Singh, J., Singh, S. P., & Srivastava, A. (2021). Nano-Urea for enhancing yield and farmers profit with potato in Uttar Pradesh. *Annals of Plant and Soil Research, 23*(4), 495–500. https://doi.org/10.47815/apsr.2021.10109

U.S. Department of Agriculture, Agricultural Research Service. (2019). *FoodData Central*. https://fdc.nal.usda.gov/

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