Effect of Different Level of Nano Urea on Yield, Quality and Shelf life of Strawberry (*Fragaria X ananassa)* cv. Winter Dawn under Prayagraj Agro Climatic Condition, India

Abstract

Nano fertilizers are the modern day concept of fertilizers and possess several benefits over conventional fertilizers. In very small quantity nano fertilizers have significant impact on the growth of crop. The present study consisted of 11 treatments utilising various combinations of conventional urea and nano urea, administered at varied doses and concentrations, with each treatment replicated three times in a Randomised Block Design. The main objective of the experiment was to assess the impact of varying concentrations of nano urea on the yield and quality characteristics along with shelf life of Strawberry (*Fragaria X ananassa*) cv. Winter Dawn. Treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was found best with [15.69 (2022-23), 16.23 (2023-24) and 15.96 (Pooled)] number of fruits per plant, [168.57 (2022-23), 177.28 (2023-24) and 172.92 (Pooled)] g yield per plant, [55.07 (2022-23), 57.92 (2023-24) and 56.49 (Pooled)] q/ha yield per hectare,) [11.21 (2022-23), 11.54 (2023-24) and 11.38 (Pooled)] °Brix TSS, [0.60 (2022-23), 0.49 (2023-24) and 0.55 (Pooled)] % titrable acidity, [55.14 (2022-23), 56.86 (2023-24) and 56.00 (Pooled)] mg/100g ascorbic acid, [5.80 (2022-23), 6.00 (2023-24) and 5.90 (Pooled)] % total sugar, [4.17 (2022-23), 4.26 (2023-24) and 4.22 (Pooled)] % reducing sugar, [1.54 (2022-23), 1.65 (2023-24) and 1.60 (Pooled)] % non-reducing sugar and [4.34 (2022-23), 4.38 (2023-24) and 4.36 (Pooled)] days shelf life.

Keywords: Nano urea, Quality, RDN, Shelf life, Strawberry, Urea, Yield, Winter Dawn.

1. INTRODUCTION

The strawberry is classified under the scientific name *Fragaria x ananassa* and is a member of the *Rosaceae* family, known for its notable medicinal properties. The inclusion of the letter "*x*" in the botanical nomenclature indicates that the strawberry is a hybrid derived from two species, namely *Fragaria virginiana* and *Fragaria chiloensis* (Panico *et al.*, 2009). *Fragaria virginiana* is native to North America, whereas *Fragaria chiloensis* originates from Chile (Rapuru *et al.*, 2022).

According to FAOSTAT (2021), the top five producing countries worldwide are as follows: The People's Republic of China, with a production volume of 2,964,263 tonnes; the United States of America, at 1,296,272 tonnes; Mexico, with 653,639 tonnes; Turkey, producing 440,968 tonnes; and Egypt, at 362,639 tonnes. The cultivation in India spans an area of 3,000 hectares, resulting in an annual production of 14,000 metric tonnes (NHB 2021). Haryana is the largest producer, generating 1,650 metric tonnes. Mizoram follows with a production of 1,080 metric tonnes. Additional contributors to production include Meghalaya, Maharashtra, and Himachal Pradesh (Anonymous, 2019). The agro climatic conditions in Uttar Pradesh support the cultivation of strawberries, offering a viable opportunity for profitable crop production.

This herbaceous perennial plant exhibits white flowers and is pollinated by wind or bees. It is characterized by its short stature, rapid growth rate, and brief reproductive cycle (Andres *et al.*, 2022). The fruits, categorized as false fruits, contain multiple small, hard seeds referred to as achenes, which are situated on their outer surface (Michel *et al.*, 1981). The fruits display various shapes, such as ovoid and oblong forms, which are appreciated for their unique aroma and distinct flavour (Schieberle and Hofmann, 1997).

The cultivated strawberry is utilized as fresh fruit, as well as in value-added applications and processed products, including jam, jelly, preserves, pies, ice cream, milkshakes, wine, and various soft beverages (Joshi *et al.*, 2005). Their composition includes fat-soluble vitamins such as A, E, and K, with particularly high levels of vitamin C at 60 mg·100g^{-1} of fresh fruit, vitamin B_9 (folate) at 24 µg·100g^{-1} of fresh fruit, and vitamin E (Considine, 1982). Newerli-Guz *et al.* (2023) and Basu *et al.* (2014) report the presence of ellagitannins (ellagic acid), flavonoids (quercetin), catechin, anthocyanins, and kaempferol, which contribute to antioxidant, antidiabetic, antihypertensive, antihyperglycemic, and potential carcinogenic properties.

Fertilizers constitute a significant portion of agricultural expenditures (Shukla *et al.,* 2022). Nitrogen is recognized as the most critical fertilizer element among the major nutrients, considering the energy required for its synthesis, the volume used, and its economic significance (Mandapaka *et al.,* 2017). The nitrogen use efficiency (NUE) in crops is significantly lower when compared to the amounts of nitrogen applied to the soil (Govindasamy *et al.*, 2023). Conventional fertilizers, particularly those containing plant nutrient formulations with particle sizes greater than 100 nm, lead to nitrogen losses between 50 and 70% due to leaching and the release of gaseous ammonia (Duhan *et al*., 2017). Thus, advancements in nanoparticle fabrication have led to the production of nanoparticles exhibiting a range of sizes and shapes (Albrecht *et al.,* 2006).

Norio Taniguichi, a professor at Tokyo University of Science, introduced the term 'nanotechnology' in 1974 (Khan and Rizvi, 2014). Encapsulation of fertilizer within nanoparticles has the potential to enhance the efficiency of nutrient uptake (Subraya *et al.,* 2015). Nano-fertilizers are specifically designed to provide nutrients in a controlled manner, customized to satisfy the exact needs of the crop (Derosa *et al.*, 2010).

The incorporation of nanotechnology in agriculture, particularly via the formulation of nano urea, represents a significant advancement. Nano-urea has been developed and patented by the Indian Farmers Fertilizer Cooperative (IFFCO). The physical particle size of nano-urea is between 20 and 50 nm, while its hydrodynamic size ranges from 20 to 80 nm. It contains 4% nitrogen (N) and exhibits a zeta potential exceeding 30 (Kumar *et al.,* 2021). The functional nutrients are derived from urea, which is treated with non-ionic surfactants and stabilized within polymer matrices, resulting in the formation of nanoclusters measuring less than 100 nm (Raliya *et al.*, 2017). The implementation of nano-urea presents potential benefits for sustainable agricultural practices by decreasing the reliance on agro-chemicals, mitigating environmental pollution, and improving soil health (Mahapatra *et al.*, 2022).

With the advancement in agriculture field the method of providing fertilizer has also been improved. The nano urea has emerged as a cutting edge technology having better delivery efficiency and cheaper price could help the farmers to reduce the cost of cultivation to a considerable level. However, being new in the field every product must be tested on all the major crops to find out the exact results which would help in gaining confidence of farmer and also will open new door of research in the coming times.

Considering this, the present study titled "**Effect of Different Level of Nano Urea on Yield, Quality and Shelf life of Strawberry (*Fragaria X ananassa)* cv. Winter Dawn, under Prayagraj Agro Climatic Condition**" was structured and carried out.

MATERIALS AND METHODS

The field study was carried out over the academic years 2022-23 and 2023-24, specifically from October to March. The strawberry cultivar Winter Dawn (runners) was obtained from Joshi Plants Enterprise, located in Solan, Himachal Pradesh. The plot was cultivated to achieve a fine tilth through a systematic series of repeated ploughing and planking procedures. Weeds, grasses, and plant residues were removed, and raised beds were created for planting purposes. The beds were then covered with silver-black polythene sheets to effectively control weed growth. Tissue-cultured plants underwent fungicide treatment before being planted in the field, with a spacing configuration of 60 cm by 30 cm. FYM was applied at a rate of 25 tonnes per hectare two weeks prior to the planting of the strawberry plantlets. The specified fertiliser dosage, consisting of NPK in a ratio of 100:60:40, was administered following the established treatment combinations. The total dosage of phosphorus (P) and potassium (K) was applied through single super phosphate (SSP) and muriate of potash (MOP) as a basal application during the field preparation phase. A basal dose of nitrogen was applied at half the recommended rate using Urea, with the remaining half applied based on treatment combinations at 45 days after transplanting. The application of water-soluble IFFCO Nano Urea (Liquid) was performed three times following the treatment combination, specifically during the transplanting phase, and subsequently at 20 and 40 days after transplanting.

The experiment was conducted at the Horticulture Research Farm, Department of Horticulture at Sam Higginbottom University of Agriculture, Technology, and Sciences in Allahabad. The experimental site is located on the left side of the Allahabad-Rewa Road, near the Yamuna River, approximately 8 kilometres from the city of Allahabad. The coordinates are 25.57°N latitude and 81.51°E longitude.

The experimental field exhibited a sandy loam texture in its soil composition, with pH levels recorded at 6.3 for the year 2022-23 and 6.0 for 2023-24, which indicates a neutral acidity level. The analysis revealed organic carbon concentrations of 0.20% and 0.21%. Additionally, available nitrogen was measured at 173.18 kg N/ha and 175.14 kg N/ha. The analysis indicated low levels of available phosphorus, measured at 13.80 and 14.38 kg P/ha, in conjunction with high levels of available potassium, recorded at 216.40 and 219.34 kg K/ha. The experiment recorded a cumulative rainfall of 13.86 mm and 10.02 mm for the crop across both years of the study.

The experiment consisted eleven treatments viz. T_1: 100% RDF (NPK @ 100-60-140 kg/ha), T_2: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T_3: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T_4: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T_5: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T_6: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T_7: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T_8: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T_9: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T_{10}: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) and T_{11}: 100% PK + 2% Nano urea (20 ml/l) which was analyzed in randomized block design with three replications.

The experiment utilized a Randomized Block Design **(Panse and Sukhatme, 1985)**, incorporating three replications for each of the eleven treatment combinations. Yield attributes like Number of fruits per plant, Yield per plant (kg) and Yield per hectare; Quality attributes like Total soluble solids (°Brix), Titrable acidity (%), Ascorbic acid (mg/100g), Total Sugar (%), Reducing sugar (%) and Non reducing sugar (%) along with Shelf life (days) were successfully measured.

RESULTS:

The statistical analysis concentrated on the yield, quality attributes, and shelf life of the strawberry (*Fragaria x ananassa*) cv. Winter Dawn. The results demonstrate that the integration of multiple treatments significantly affected all characteristics. Since F Cal is greater than F Tab, the data indicates that the variances are statistically significant.

YIELD ATTRIBUTES

Number of fruits per plant: Data pertaining to Table 1, observed that the treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum number of fruits per plant [15.69 (2022-23), 16.23 (2023-24) and 15.96 (Pooled)] whereas minimum number of fruit per plant i.e., [10.69 (2022-23), 10.92 (2023-24) and 10.81 (Pooled)] was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Yield per plant (g): The data pertaining to yield per plant (g) (Table 1) shows that significant variances were found due to application of different treatments. Treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum yield per plant (g) [168.57 (2022-23), 177.28 (2023-24) and 172.92 (Pooled)] g whereas lowest yield per plant (g) i.e., [68.74 (2022-23), 70.01 (2023-24) and 69.37 (Pooled)] g was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Yield per hectare (q/ha): The variances in yield per hectare (q/ha) (Table 2) due to effect of different treatments was found to be significant during both the years of study as well as pooled basis. The maximum yield per hectare i.e., [55.07 (2022-23), 57.92 (2023-24) and 56.49 (Pooled)] q/ha was found under the effect of treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)]. However, minimum yield per hectare i.e., [22.46 (2022-23), 22.87 (2023-24) and 22.66 (Pooled)] q/ha was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)].

QUALITY ATTRIBUTES

TSS (°Brix): Data pertaining to Table 2, observed that the treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum TSS i.e., [11.21 (2022-23), 11.54 (2023-24) and 11.38 (Pooled)] °Brix whereas minimum TSS i.e., [7.50 (2022-23), 7.72 (2023-24) and 7.61 (Pooled)] °Brix was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Titrable acidity (%): According to the results (Table 3) the differences in titrable acidity (%) were found significant. According to the findings, treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was found with minimum titrable acidity (%) [0.60 (2022-23), 0.49 (2023-24) and 0.55 (Pooled)] % whereas maximum titrable acidity (%) i.e., [0.94 (2022-23), 0.98 (2023-24) and 0.96 (Pooled)] % was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during both the years of study as well as pooled data.

Ascorbic acid (mg/100g): The data pertaining to ascorbic acid (mg/100g) (Table 3) shows that significant variances were found due to application of different treatments. Treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum ascorbic acid i.e., [55.14 (2022-23), 56.86 (2023-24) and 56.00 (Pooled)] mg/100g whereas minimum ascorbic acid i.e., [46.00 (2022-23), 47.22 (2023-24) and 46.61 (Pooled)] mg/100g was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Total sugar (%): The variances in total sugar (%) (Table 4) due to effect of different treatments was found to be significant during both the years of study as well as pooled basis. The maximum total sugar (%) [5.80 (2022-23), 6.00 (2023-24) and 5.90 (Pooled)] % was found under the effect of treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)]. However, minimum total sugar (%) i.e., [4.67 (2022-23), 4.70 (2023-24) and 4.68 (Pooled)] % was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)].

Reducing sugar (%): According to data pertaining to Table 4, it was observed that the treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum reducing sugar (%) [4.17 (2022-23), 4.26 (2023-24) and 4.22 (Pooled)] % whereas minimum reducing sugar (%) i.e., [3.21 (2022-23), 3.26 (2023-24) and 3.23 (Pooled)] % was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Non-reducing sugar (%): According to the above results (Table 5) the variances were found to be significantly different. Treatments T_5 [100% PK + 40% RDN + 1.2% Nano urea (12 ml/l)], T_6 [100% PK + 50% RDN + 1.0% Nano urea (10 ml/l)] and T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded maximum non-reducing sugar (%) [1.54 (2022-23), 1.65 (2023-24) and 1.60 (Pooled)] % whereas minimum non-reducing sugar (%) i.e., [1.38 (2022-23), 1.37 (2023-24) and 1.38 (Pooled)] % was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during both the years of study as well as pooled data.

Shelf life (days): Data pertaining to Table 5, observed that the treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum shelf life (days) [4.34 (2022-23), 4.38 (2023-24) and 4.36 (Pooled)] days whereas minimum shelf life (days) i.e., 2.00 (2022-23), 2.05 (2023-24) and 2.02 (Pooled)] days was found to be under the effect of treatment T_{11} [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

DISCUSSION:

All treatments exhibited significant impacts on the yield, quality characteristics, and shelf life of strawberries. However, treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was determined to be the most effective.

The small particle size of nano urea, along with its controlled nutrient release, offers a notable advantage by reducing nutrient fluctuations that could disrupt flowering and fruiting stages (Toksha *et al.*, 2021). The stability enhances the plant's inherent growth patterns and promotes efficient resource allocation for the development of flowers and the setting of fruit. Studies indicate that effective management of nitrogen availability improves fruit set and reduces fruit drop, leading to a higher fruit count per plant (Upadhyay *et al.,* 2023). Similar results have been documented by Gupta and Tripathi (2012) as well as Tripathi *et al.* (2014) concerning Strawberry.

Nano urea, due to its nano-sized particles, improves absorption and utilization by plants when compared to traditional fertilizers (Kumar *et al.,* 2023). The rise in the number of fruits per plant, attributed to elevated chlorophyll levels that are essential for photosynthesis (Sharma *et al.,* 2022), directly facilitates increased carbohydrate synthesis, which is critical for fruit development and yield (Nazari *et al.,* 2024). Besides its involvement in nitrogen dynamics, nano urea influences the hormonal environment of the plant, particularly auxins and gibberellins, which are essential for fruit development (Ijaz *et al.,* 2023). Auxins are essential in the processes of cell elongation and division. In contrast, gibberellins are responsible for promoting stem elongation and facilitating fruit growth, which enhances the transition from flowering to fruiting (Sosnowski *et al.,* 2023). Bhatti *et al*. (2023) observed similar results in guava, and Davarpanah *et al*. (2017) documented analogous outcomes in pomegranate.

The optimal administration of nitrogen is also essential for enhancing fruit quality, especially for total soluble solids (TSS). The incorporation of nano urea improves nitrogen utilisation efficiency, which is essential for the production of amino acids and proteins that serve as precursors to sugars in fruits (Dubey, 2023). Research indicates that nano urea enhances vegetative development and increases chlorophyll content, hence improving photosynthetic efficiency (Suthar, 2023). The increased photosynthetic activity leads to enhanced carbohydrate synthesis (Thakre *et al*, 2024), which is stored as sugars, hence increasing TSS levels, Total sugars as well as reducing and non-reducing sugars in strawberries. Karma *et al*. (2017) and Beniwal *et al*. (2024) in strawberry and Davarpanah *et al*. (2017) in pomegranate reported similar results.

Research has shown that the use of nitrogen, especially when combined in nano fertilizers, can result in increased levels of primary metabolites such as sugars and organic acids. These metabolites are essential for the production of ascorbic acid in fruits, which in turn contributes to a reduction in the titrable acidity of the fruits (Madlala *et al.,* 2024). Karma *et al*. (2017)

and Weber *et al.* (2021) reported comparable findings in their research on strawberries.

Strawberries treated with nano urea have demonstrated increased titratable acidity and firmness relative to untreated controls, indicating superior postharvest quality. Studies have also shown that the use of nutritional solutions, particularly those fortified with nano urea, enhances fruit firmness and decreases respiration rates, both essential for prolonging shelf life (Kessler *et al*., 2023). Similar results were reported by Merghany *et al.* (2019) in cucumber and Deepa *et al.* (2022) in Banana.

Table 1: Effect of different level of Nano urea on number of fruits per plant and yield per plant (g) of strawberry (*Fragaria x ananassa)* cv. Winter Dawn

Treatments	Number of fruits per plant			Yield per plant (g)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	13.11	13.54	13.32	113.64	119.66	116.65
T_2	11.52	11.89	11.7	82.26	86.61	84.43
T_3	12.13	12.52	12.33	95.59	100.64	98.11
T_4	12.47	12.88	12.67	100.16	105.47	102.81
T_5	14.96	15.46	15.21	151.13	159.05	155.09
T_6	15.25	15.77	15.51	159.84	167.91	163.87
T_7	15.69	16.23	15.96	168.57	177.28	172.92
T_8	14.3	14.78	14.54	136.37	143.46	139.92
T_9	14.06	14.53	14.29	131.8	138.77	135.29
T_{10}	13.77	14.23	14	126.25	132.87	129.56
T_{11}	10.69	10.92	10.81	48.11	49.86	48.99
F-Test	**S**	**S**	**S**	**S**	**S**	**S**
S.E. (m) (±)	0.29	0.33	0.22	5.24	5.8	3.91
CD (5%)	0.87	0.98	0.63	15.45	17.1	11.17
CD (1%)	1.18	1.34	0.85	21.08	23.33	14.94

T_1: 100% RDF (NPK @ 100-60-140 kg/ha), **T_2**: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), **T_3**: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), **T_4**: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), **T_5**: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), **T_6**: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), **T_7**: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), **T_8**: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), **T_9**: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), **T_{10}**: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & **T_{11}**: 100% PK + 2% Nano urea (20 ml/l).

Table 2: Effect of different level of Nano urea on yield per hectare (q/ha) and TSS (°Brix) of strawberry (*Fragaria x ananassa)* cv. Winter Dawn

Treatments	Yield per hectare (q/ha)			TSS (°Brix)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	37.12	39.09	38.11	9.21	9.48	9.35
T_2	26.87	28.29	27.58	7.95	8.19	8.07
T_3	31.23	32.88	32.05	8.53	8.78	8.65
T_4	32.72	34.46	33.59	8.72	8.98	8.85
T_5	49.38	51.96	50.67	10.67	10.99	10.83
T_6	52.22	54.86	53.54	10.92	11.25	11.08
T_7	55.07	57.92	56.49	11.21	11.54	11.38
T_8	44.55	46.87	45.71	10.18	10.49	10.33
T_9	43.06	45.34	44.2	9.92	10.21	10.07
T_{10}	41.25	43.41	42.33	9.7	9.99	9.85
T_{11}	22.46	22.87	22.66	7.5	7.72	7.61
F-Test	**S**	**S**	**S**	**S**	**S**	**S**
S.E. (m) (±)	1.71	1.89	1.28	0.11	0.13	0.08
CD (5%)	5.05	5.59	3.65	0.32	0.38	0.24
CD (1%)	6.89	7.62	4.88	0.44	0.52	0.32

T_1: 100% RDF (NPK @ 100-60-140 kg/ha), **T_2**: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), **T_3**: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), **T_4**: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), **T_5**: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), **T_6**: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), **T_7**: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), **T_8**: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), **T_9**: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), **T_{10}**: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & **T_{11}**: 100% PK + 2% Nano urea (20 ml/l).

Table 3: Effect of different level of Nano urea on titrable acidity (%) and ascorbic acid (mg/100g) of strawberry (*Fragaria x ananassa)* cv. Winter Dawn

Treatments	Titrable acidity (%)			Ascorbic acid (mg/100g)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	0.79	0.73	0.76	49.99	51.55	50.77
T_2	0.88	0.88	0.88	46.83	48.29	47.56
T_3	0.86	0.83	0.85	48.11	49.61	48.86
T_4	0.82	0.77	0.79	48.71	50.23	49.47
T_5	0.64	0.54	0.6	53.85	55.53	54.69
T_6	0.63	0.52	0.58	54.5	56.2	55.35
T_7	0.6	0.49	0.55	55.14	56.86	56
T_8	0.68	0.6	0.64	52.57	54.21	53.39
T_9	0.72	0.64	0.68	51.88	53.5	52.69
T_{10}	0.73	0.66	0.7	51.27	52.87	52.07
T_{11}	0.94	0.98	0.96	46	47.22	46.61
F-Test	S	S	S	S	S	S
S.E. (m) (±)	0.01	0.01	0.02	0.64	0.7	0.47
CD (5%)	0.02	0.02	0.07	1.88	2.06	1.35
CD (1%)	0.02	0.03	0.09	2.56	2.81	1.81

T_1: 100% RDF (NPK @ 100-60-140 kg/ha), **T_2**: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), **T_3**: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), **T_4**: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), **T_5**: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), **T_6**: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), **T_7**: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), **T_8**: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), **T_9**: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), **T_{10}**: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & **T_{11}**: 100% PK + 2% Nano urea (20 ml/l).

Table 4: Effect of different level of Nano urea on total sugar (%) and reducing sugar (%) of strawberry (*Fragaria x ananassa)* cv. Winter Dawn

Treatments	Total sugar (%)			Reducing sugar (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	5.22	5.4	5.31	3.66	3.74	3.7
T_2	4.85	5.02	4.93	3.35	3.42	3.38
T_3	5	5.17	5.09	3.48	3.55	3.51
T_4	5.09	5.27	5.18	3.55	3.62	3.58
T_5	5.7	5.9	5.8	4.08	4.16	4.12
T_6	5.75	5.95	5.85	4.12	4.21	4.17
T_7	5.8	6	5.9	4.17	4.26	4.22
T_8	5.53	5.72	5.62	3.93	4.01	3.97
T_9	5.47	5.66	5.56	3.87	3.96	3.92
T_{10}	5.38	5.57	5.47	3.8	3.88	3.84
T_{11}	4.67	4.7	4.68	3.21	3.26	3.23
F-Test	S	S	S	S	S	S
S.E. (m) (±)	0.06	0.07	0.05	0.05	0.06	0.04
CD (5%)	0.18	0.2	0.13	0.15	0.16	0.11
CD (1%)	0.25	0.27	0.17	0.2	0.22	0.14

T_1: 100% RDF (NPK @ 100-60-140 kg/ha), **T_2**: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), **T_3**: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), **T_4**: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), **T_5**: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), **T_6**: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), **T_7**: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), **T_8**: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), **T_9**: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), **T_{10}**: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & **T_{11}**: 100% PK + 2% Nano urea (20 ml/l).

Table 5: Effect of different level of Nano urea on non-reducing sugar (%) and shelf life (days) of strawberry (*Fragaria x ananassa)* cv. Winter Dawn

Treatments	Non-reducing sugar (%)			Shelf life (days)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	1.48	1.58	1.53	3.09	3.12	3.11
T_2	1.42	1.52	1.47	2.29	2.31	2.3
T_3	1.45	1.54	1.49	2.61	2.64	2.62
T_4	1.46	1.56	1.51	2.76	2.79	2.77
T_5	1.54	1.65	1.6	4.07	4.11	4.09
T_6	1.54	1.65	1.6	4.19	4.23	4.21
T_7	1.54	1.65	1.6	4.34	4.38	4.36
T_8	1.52	1.63	1.57	3.72	3.76	3.74
T_9	1.51	1.62	1.57	3.58	3.62	3.6
T_{10}	1.5	1.61	1.55	3.42	3.45	3.44
T_{11}	1.38	1.37	1.38	2	2.05	2.02
F-Test	S	S	S	S	S	S
S.E. (m) (±)	0.01	0.01	0.02	0.12	0.11	0.08
CD (5%)	0.04	0.03	0.06	0.36	0.34	0.24
CD (1%)	0.05	0.05	0.08	0.49	0.46	0.32

T_1: 100% RDF (NPK @ 100-60-140 kg/ha), **T_2**: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), **T_3**: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), **T_4**: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), **T_5**: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), **T_6**: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), **T_7**: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), **T_8**: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), **T_9**: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), **T_{10}**: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & **T_{11}**: 100% PK + 2% Nano urea (20 ml/l).

CONCLUSION

From the present investigation it may be concluded that effect of Treatment T_7 [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was found to be best. It is best in terms of Yield attributes like Number of fruits per plant, Yield per plant (kg) and Yield per hectare; Quality attributes like Total soluble solids (°Brix), Titrable acidity (%), Ascorbic acid (mg/100g), Total Sugar (%), Reducing sugar (%) and Non reducing sugar (%) along with Shelf life (days).

Disclaimer (Artificial intelligence)

Option 1:

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 the writing or editing of this manuscript.

REFERENCES

Albrecht, M. A., Evans, C. W. and Raston, C. L. (2006). Green chemistry and the health implications of nano particles; *Green Chemistry*, **8**: 417-32.

Andres, J., Caruana, J., Liang, J., Samad, S., Monfort, A., Liu, Z., Hytonen, T. and Koskela, E. A. (2022). Erratum to: Woodland Strawberry Axillary Bud Fate Is Dictated by a Crosstalk of Environmental and Endogenous Factors; *Plant Physiology*, **188**: 674.

Anonymous. (2019). Indian Production of Strawberry (HSCODE-1060). http://apeda.in/agriexchange.

Basu, A., Nguyen, A., Betts, N. M. and Lyons, T. J. (2014). Strawberry as a Functional Food. An Evidence-Based Review; *Critical Reviews in Food Science and Nutrition*, **54**: 790-806.

Beniwal, M., Mishra, S., and Bahadur, V. (2024). Effect of Foliar Application of Nano Urea, Boron and Zinc Sulphate on Growth Fruit Yield and Quality of Strawberry (*Fragaria× ananassa* Duch.) cv. Winter Dawn. *Journal of Advances in Biology & Biotechnology*, **27**(6): 725-735.

Bhatti, D., Varu, D. K. and Dudhat, M. (2023). Effect of different doses of urea and nano-urea on growth and yield of guava (*Psidium guajava* L.) Cv. Lucknow-49; *Pharma Innovation Journal*, **12**(7): 464-468.

Considine, M. (1982). Food and Food Products Encyclopedia. Van Nostrad Company Inc, New York, USA.

Davarpanah, S., Tehranifar, A., Davarynejad, G., Aran, M., Abadia, J. and Khorassani, R. (2017). Effects of foliar nano-nitrogen and urea fertilizers on the physical and chemical properties of pomegranate (*Punica granatum* cv. Ardestani) fruits; *Horticulture science*, **52**(2): 288–294.

Deepa, H. L., Reshmi, C. R., Rafeekher, M. and Aparna, B. (2022). Effect of organic nano-NPK formulation on fruit yield and quality in Banana Cv. nendran (*Musa* AAB). *International Journal of Bio-resource and Stress Management*, **13**(11): 1141-1147.

Derosa, M. C., Monreal, C., Schnitzer, M. and Walsh, R. P. (2010). Nanotechnology in fertilizers; *Nature Nanotechnology*, **5**(2): 91.

Dubey, P. M., Upadhyay, J., Chowdhury, S. and Bagare, V. (2023). Response of Onion (*Allium cepa* L.) to Foliar Application of Nano Urea and Urea. *Int. J. Environ. Clim. Change*, **13**(11): 1816-1821.

Duhan, J. S., Kumar, R., Kumar, N., Kaur, P., Nehra, K. and Duhan, S. (2017). Nanotechnology: The new perspective in precision agriculture; *Biotechnology Reports,* **15**: 11-23.

FAOSTAT (2021). Food and Agriculture Organization of the United Nations Statistical Database. Statistical Division, FAO, Rome.

Govindasamy, P., Muthusamy, S. K., Bagavathiannan, M., Mowrer, J., Jagannadham, P. T. K., Maity, A., Halli, H. M., Sujayananad, G. K. Vadivel, R., Das, T. K., Raj, R., Pooniya, V., Babu, S., Rathore, S. S., Muralikrishnan, L. and Tiwari, G. (2023). Nitrogen use efficiency—a key to enhance crop productivity under a changing climate*; Front Plant Sci.*, **14**: 1121073.

Gupta. A. K. and Tripathi. V. K. (2012). Efficacy of Azotobacter and vermicompost alone and in combination on vegetative growth, flowering and yield of strawberry (*Fragaria* x *ananassa* Duch.) cv. Chandler. *Progressive Horticulture,* **44**(2): 256-261.

Ijaz, M., Khan, F., Ahmed, T., Noman, M., Zulfiqar, F., Rizwan, M., Chen, J., Siddique, K. H. M. and Li, B. (2023). Nano biotechnology to advance stress resilience in plants: Current opportunities and challenges; *Materials Today Bio,* **22**: 100759.

Joshi, V. K., Sharma, S. and Bhushan, S. (2005). Effect of method of preparation and cultivar on the quality of strawberry wine; *Acta Aliment,* **34**: 339- 355.

Karma, B., Kumar, S., Gupta, A. K. and Syamal, M. M. (2017). Effect of organic, inorganic and bio-fertilizer on growth, flowering, yield and quality of strawberry (*Fragaria x ananassa* Duch.) cv. Chandler. International Journal of Current Microbiology and Applied Sciences. **6**(5):2932-39.

Kessler, S. J., Cooksey, K., Pometto III, A. L., Hurley, A. and Bridges, W. (2023). Shelf-life extension of fresh strawberries packaged in vented clamshells through an in-package widget designed to promote chlorine dioxide gas distribution. *ACS Food Science & Technology*, **3**(3): 394-403.

Khan, M. R. and Rizvi, T. F. (2014). Nanotechnology: Scope and Application in Plant Disease Management; *Plant Pathology Journal*, **13**(3): 214-231.

Kumar, A., Ram, h., Kumar, S. and Kumar, R. (2023). A Comprehensive Review of Nano-Urea vs. Conventional Urea; *International Journal of Plant & Soil Science,* **35**(23): 32-40.

Kumar, Y., Singh, T., Raliya, R. and Tiwari, K. N. (2021). Nano fertilizers for sustainable crop production, higher nutrient use efficiency and enhanced profitability; *Indian Journal of Fertilisers*, **11**: 1206-1214.

Madlala, N. C., Khanyile, N. and Masenya, A. (2024). Examining the Correlation between the Inorganic Nano-Fertilizer Physical Properties and Their Impact on Crop Performance and Nutrient Uptake Efficiency. *Nanomaterials*, **14**(15): 1263.

Mahapatra, D. M., Satapathy, K. C. and Panda, B. (2022). Biofertilizers and nanofertilizers for sustainable agriculture: Phycoprospects and challenges; *Science of the total environment*, **803**: 149990.

Mandapaka, M., Murthy, A. N. G. and Shanker, A. K. (2017). Nitrogen Nutrition in Crops and Its Importance in Crop Quality; In book: The Indian Nitrogen Assessment,175-186.

Merghany, M. M., Shahein, M. M., Sliem, M. A., Abdelgawad, K. F. and Radwan, A. F. (2019). Effect of nano-fertilizers on cucumber plant growth, fruit yield and it's quality. *Plant Archives,* **19**(2): 165-172.

Michel, J., Clément, J.-M., Mahen, C. and Nerdeux, C. (1981). Larousse Agricole. Librarie Larousse, Canada. 540.

National Horticulture Board (2021). State wise Area and Production estimates of Horticultural crops. Ministry of Agriculture. Government of India.

Nazari, M., Kordrostami, M., Ghasemi-Soloklui, A. K., Eaton-Rye, J. J., Pashkovskiy, P., Kuznetsov, V. and Allakhverdiev, S. I. (2024). Enhancing Photosynthesis and Plant Productivity through Genetic Modification; *Cells*, **13**(16): 1319.

Newerli-Guz, J., Smiechowska, M., Drzewiecka, A. and Tylingo, R. (2023). Bioactive Ingredients with Health-Promoting Properties of Strawberry Fruit (*Fragaria* × *ananassa* Duchesne); *Molecules*, **28**: 2711.

Panico, A. M., Garufi, F., Nitto, S., Di Mauro, R., Longhitano, R. C., Magrì, G. (2009). Antioxidant activity and phenolic content of strawberry genotypes from *Fragaria x ananassa*; *Pharmaceutical Biology,* **47**(3): 203-208.

Panse, V. G. and Sukhatme, P. V. (1985). Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication, 87-89.

Raliya, R., Saharan, V., Dimkpa, C. and Biswas, P. (2017). Nanofertilizer for precision and sustainable agriculture: current state and future perspectives; *Journal of agricultural and food chemistry*, **66**(26): 6487-6503.

Rapuru, R., Bathula, S. K. and Ilango, K. (2022). Phytochemical Constituents and Pharmacological Activities of Strawberry; In book: Strawberries [Working Title], **10**: 5772.

Schieberle, P. and Hofmann, T. (1997). Evaluation of the Character Impact Odorants in Fresh Strawberry Juice by Quantitative Measurements and Sensory Studies on Model Mixtures; *Journal of Agricultural and Food Chemistry*, **45**: 227-232.

Sharma, S. K., Sharma, P. K. and Mandeewal, R. L. (2022). Effect of Foliar Application of Nano-Urea Under Different Nitrogen Levels on Growth and Nutrient Content of Pearl millet (*Pennisetum glaucum* L.); *International Journal of Plant & Soil Science*, **34**(20):149-155.

Shukla, A. K., Behera, S. K., Chaudhari, S. K. and Singh, G. (2022). Fertilizer Use in Indian Agriculture and its Impact on Human Health and Environment; *Indian Journal of Fertilisers*, **18**(3): 218-237.

Sosnowski, J. Truba, M. and Vasileva, V. (2023). The Impact of Auxin and Cytokinin on the Growth and Development of Selected Crops; *Agriculture*, **13**(3): 724.

Subraya, B. K. (2015). Effect of integrated nutrient management on growth and yield of strawberry (*Fragaria x ananassa* Duch.) under naturally ventilated polyhouse condition. *M. Sc. thesis*, Univ. Agric. Hortic. Sci., Shivamogga, Karnataka (India), pp. 84.

Suthar, N. (2023). Nano urea: a review paper. International Journal of Advanced *Biochemistry Research*, **7**(2S): 577-580.

Thakre, N. S., Patil, S. R., Gedam, A. P., Bavankar, A. G., Gharat, P. J. and Temak, S. D. (2024). Influence of nano urea on yield and quality of acid lime in hasta bahar. *International Journal of Advanced Biochemistry Research*, **8**(10): 737-741.

Toksha, B., Sonawale, V. A. M., Vanarase, A. and Bornare, D. (2021). Nanofertilizers: A review on synthesis and impact of their use on crop yield and environment; *Environmental Technology and Innovation,* **24**(499): 101986.

Tripathi, V. K.; Mishra, A. N.; Kumar, Sanjeev and Tiwari, Bharat (2014). Efficacy of Azotobacter and PSB on vegetative growth, flowering, yield and quality of strawberry cv. Chandler. *Prog. Hort*. **46(1)**: 48-53.

Upadhyay, P. K., Dey, A., Singh, V. K., Dwivedi, B. S., Singh, T. G. A. R., Babu, S., Rathore, S. S., Singh, R. K., Shekhawat, K. and Rangot, M. (2023). Conjoint application of nano-urea with conventional fertilizers: An energy efficient and environmentally robust approach for sustainable crop production. *Plos one*, **18**(7): pe0284009.

Weber, N. C., Koron, D., Jakopič, J., Veberič, R., Hudina, M. and Česnik, H. B. (2021). Influence of Nitrogen, Calcium and Nano-Fertilizer on Strawberry (*Fragaria* × *ananassa* Duch.) Fruit Inner and Outer Quality; *Agronomy*, **11**(5): 997.