



RESEARCH ARTICLE

Improving fruit quality and shelf-life of banana (*Musa paradisiaca* L.) cv. Grand Naine through foliar sprays of nano urea and sulphate of potash

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Abstract

Banana (*Musa* spp.) belongs to the family Musaceae in the order Scitamineae and one of the most important fruit crops. Foliar application of nano-fertilisers and sulphate of potash (SOP) allows direct nutrient absorption through the leaf epidermis, reducing nutrient losses associated with soil application and minimising environmental risks. The experiment was conducted during 2022–23 and 2023–24 to evaluate the effect of foliar application of nano urea and SOP on fruit quality and shelf-life of banana cv. Grand Naine. The study comprised 10 treatments arranged in a randomised block design (RBD) with 3 replications. The treatments under study included SOP, nano urea and combination of nano urea and SOP, along with control (water). The pooled results from tissue-culture and sucker-propagated plants showed that treatment T₈ (1.5 % SOP + 0.3 % nano urea) produced the highest values for all major fruit quality parameters such as reducing sugar, non-reducing sugar, total sugar, total soluble solids (TSS) and shelf life. In tissue-culture plants, the treatment T₈ exhibited the reducing sugars of 16.01 %, non-reducing sugars of 2.79 %, total sugars of 18.79 %, TSS of 19.89 °Bx, acidity of 0.28 % and a shelf-life of 10.0 days. Corresponding values in sucker-propagated plants were similarly superior, recording 15.64 % reducing sugars, 2.53 % non-reducing sugars, 18.18 % total sugars, 19.45 °B TSS, 0.38 % acidity and a shelf-life of 9.33 days. Combined application of 1.5 % SOP + 0.3 % nano urea produced the most favourable effects on fruit quality and shelf-life of banana cv. Grand Naine under field conditions. Hence, the approach of integrated nutrient management offers substantial potential for enhancing fruit marketability and meeting consumer quality preferences.

Keywords: fruit quality and shelf-life; *Musa* spp. cv. Grand Naine; nutrient management; post-harvest physiology

Introduction

Banana (*Musa* spp.) belongs to the family Musaceae under the order Scitamineae, which comprises two genera, *Musa* and *Ensete*, with about 50 species. Edible bananas are believed to have originated in the tropical regions of Southeast Asia (1). Banana is widely consumed as a dessert fruit and serves as a staple food in many regions because it is rich in easily digestible carbohydrates, vitamins and minerals. Due to its nutritional and therapeutic value, banana is an important fruit crop for both domestic consumption and international trade. 'Grand Naine', a widely cultivated cultivar of the Cavendish group, is preferred for its high yield potential, superior fruit quality, dwarf growth habit, strong market demand, seedless fruits and comparatively lower incidence of diseases. In addition, it is suitable for both fresh consumption and processing purposes. Banana is a mesophytic crop that requires a continuous supply of nutrients and adequate soil moisture to support vigorous growth, heavy bunch production and high fruit quality. As a heavy feeder of both macro and micronutrients, the banana demands consistent nutrient availability throughout its growth cycle. Proper nutrient management is therefore essential, as deficiencies during critical growth stages can significantly reduce plant growth, yield and fruit

quality. Foliar application of nutrients has emerged as a promising strategy to overcome these limitations, providing rapid and targeted delivery of essential elements directly to the plant (2). Earlier studies have shown that the combined application of nitrogen (N) and potassium (K) improves growth and yield more effectively than N alone (3). Increasing levels of N and K fertilisation have been reported to enhance plant growth and positively influence crop performance, particularly under higher K application after flowering (4).

Potassium is widely regarded as a key quality element in crop production due to its crucial role in numerous physiological and biochemical processes. Along with primary nutrients, secondary nutrients such as calcium (Ca), magnesium (Mg) and sulphur (S), as well as micronutrients like boron (B), are also essential for the proper growth and development of the banana. Although required in smaller quantities, these nutrients are equally important for sustained plant performance. In this context, the application of sulphate of potash (SOP) enhances fruit quality attributes by improving bunch weight, number of fingers, finger weight, pulp-to-peel ratio and overall fruit appearance, thereby increasing market value. The SOP also significantly influences the sugar-to-acid ratio, as K plays a vital role in carbohydrate synthesis, degradation,

translocation, protein synthesis and neutralisation of organic acids (5) as well as the development of fruits via activation of starch synthase (6). Post-flowering K application also aids in converting starch to simple sugars during ripening by activating sucrose synthase, resulting in fruits with higher sugar content.

Farmers often rely on non-scientific management practices, leading to inefficient use of fertilisers, demand of large quantity of conventional urea fertiliser and water and ultimately resulting in low productivity with high costs of production. Hence, incorporation of nano urea is an alternative approach to mitigate this. Nano urea, containing approximately 55000 N particles per 1 mm urea prill, enhances N use efficiency and reduces reliance on traditional urea while improving crop productivity, soil health and produce quality. It is also cost-effective, lowering input expenses and increasing farmers' profitability. In banana, nano urea improves fruit quality by enhancing nutrient absorption, thereby promoting better fruit development, higher sugar accumulation, improved firmness, increased total soluble solids and extended shelf life, while also reducing sugars and decreasing titratable acidity due to its efficient penetration (20–50 nm) through leaf tissues and effective assimilation into plant metabolic processes. Hence, Nano urea has emerged as an effective alternative, as it enhances nutrient absorption, improves fruit development and increases sugar content and firmness. The efficient use of nano urea and SOP at appropriate growth stages can therefore significantly enhance banana yield and quality. Therefore, the present investigation was undertaken to evaluate the effect of foliar application of nano urea and sulphate of potash on fruit quality and shelf-life of banana cv. Grand Naine.

Materials and Methods

The present investigation was conducted during two consecutive crop-growing years, 2022–23 and 2023–24, at the experimental farm of the Department of Horticulture, Visva-Bharati, Shantiniketan, West Bengal. The experiment was laid out in a randomised block design (RBD) comprising 10 treatments with 3 replications. A two-month-old tissue culture plant of height 25 cm, girth 5 cm and having 4–5 leaves was used in the present investigation, which was procured from the Agro and Horticulture World nursery, West Bengal. A total of 4 plants per replication was maintained during both the cropping year of the present investigation. The experimental site is located at 23°42' N latitude and 87°40'30" E longitude, at an altitude of 40 m above mean sea level. It falls within the sub-humid, subtropical lateritic zone of West Bengal in eastern India, characterised by hot summers and short, moderately cool winters. During the cropping period (August 2022 to 2024), the average weekly maximum temperature ranged from 22.19 to 33.33 °C, while the minimum temperature varied between 9.60 and 22.71 °C. The soil of the experimental field is Gangetic alluvium with a loamy sand texture. It is slightly acidic in nature (pH 4.97) with an electrical conductivity of 0.28 dS m⁻¹ and organic carbon content of 0.6 %. The available nutrient status of the surface soil, determined by alkaline K permanganate–N, Bray's–P and ammonium acetate–K extraction methods, was 237.44 kg ha⁻¹ nitrogen, 17.13 kg ha⁻¹ phosphorus and 114.68 kg ha⁻¹ potassium, respectively. Pits of 50 × 50 × 50 cm were prepared and planting (tissue culture plant and sucker plant) was carried out in August at a spacing of 1.5 m × 1.5 m in a plot size of 28.50 m × 10.50 m. In each replication, four plants were maintained. The treatments included 1.0 % SOP (T₁), 1.5 % SOP (T₂), 2.0 % SOP (T₃), 0.2% nano urea (T₄), 0.3 % nano urea (T₅), 0.4 %

nano urea (T₆), 1.0 % SOP + 0.2 % nano urea (T₇), 1.5 % SOP + 0.3 % nano urea (T₈), 2.0 % SOP + 0.4 % nano urea (T₉) and a water control (T₁₀). These combinations of nano urea and SOP were chosen to provide sufficient potassium, sulphur and N to the crop without causing nutrient toxicity or leaf injury. The recommended dose of fertiliser (200 g N, 160 g P and 200 g K per plant) was applied in the pit and again one month after planting. Foliar sprays of the respective treatments were applied at 3, 5, 7 and 9 months after planting and all recommended agronomic practices were followed. Plants were randomly selected from each treatment for recording observations. Banana fruits were harvested at 90–120 days after flowering, when the fingers changed from deep green to light green in colour and attained full maturity, as indicated by the transformation of angular edges into a well-rounded shape. Fruit was stored at ambient room temperature (25–30 °C), relative humidity (80–85 %) and the number of days from which the colour of the fruit changed from yellow to black was recorded as the shelf-life of the fruit. Further, three representative fingers from each treatment were collected for quality analysis.

Representative fingers were allowed for natural and uniform ripening and these fruits were utilised for determining different quality parameters. The total soluble solids (TSS) were determined with the help of an Erma Hand Refractometer according to standard procedure as given in AOAC and the results were expressed in degrees Brix (°Bx) at room temperature (1). The total sugar, reducing sugar and non-reducing sugars were estimated as per the previously known method (6) and expressed in percentage. Titratable acidity was determined by adopting the procedure suggested by AOAC and expressed in terms of malic acid equivalents as a percentage (1). The brief procedure of estimation of biochemical traits under study was given as follows:

Titrateable acidity

Weighed 5 g of pulp was transferred to a volumetric flask and the volume was made up with distilled water up to 50 mL. After 30 min, the suspension was filtered through a Whatman No. 1 filter paper and the filtrate was used subsequently. An aliquot was taken and titrated against standard sodium hydroxide (0.01 N NaOH) using phenolphthalein as an indicator. Titration was carried out and the end was determined by the appearance of pink colour and its persistence for at least 2 sec. Titratable acidity was expressed as percentage malic acid equivalent (Fig. 1).

Reducing sugar

A weighed amount (25 g) of the pulp was taken in a volumetric flask and 2 mL of 45 % basic lead acetate solution were added for clarification. After 10 min, the solution was diluted by adding K oxalate crystals in excess and the volume was made up to a known amount with distilled water and filtered through Whatman No. 1 filter paper. The filtrate was taken in a burette and titrated against boiling Fehling's mixture (5 mL of Fehling's solution A + 5 mL of Fehling's solution B) till the blue colour faded. Then 1 mL of methylene blue indicator (1 %) was added and the titration was continued till the contents attained a brick red colour and the titre value was noted (Fig. 2).

Total sugar

For the estimation of total sugars, the filtrate obtained in the above estimation was used. An aliquot of 25 mL from the filtrate was taken and to one-fifth of its volume of hydrochloric acid (1 : 1) was added and the inversion was carried out at room temperature for 24 hr.

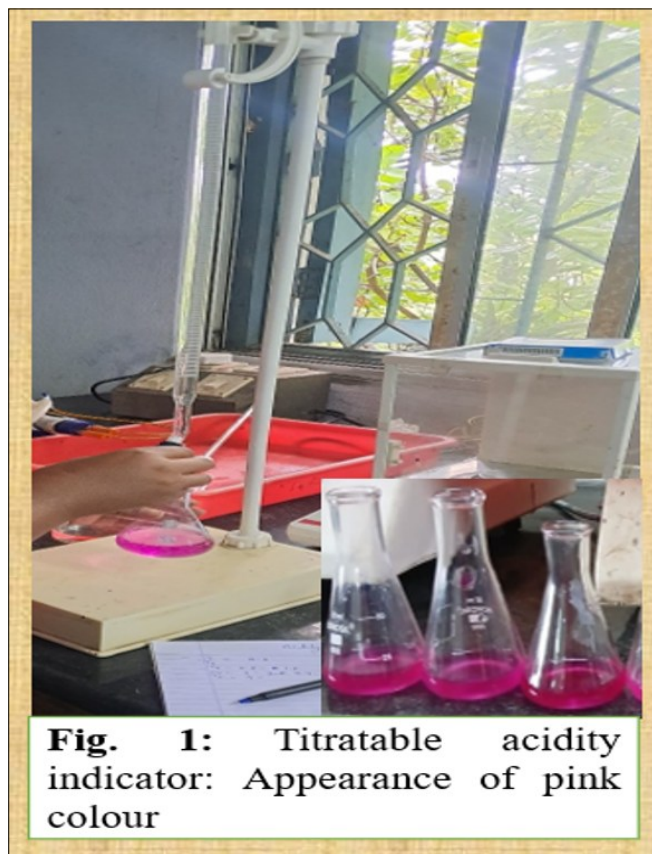


Fig. 1. Determination of titratable acidity in banana fruit juice showing the appearance of a persistent pink end point.

Subsequently, the contents were cooled and neutralised with 40 % sodium hydroxide using phenolphthalein as an indicator and the final volume was made up to 100 mL. The solution was filtered and titration was carried out using the filtrate as detailed for reducing sugars.

Non-reducing sugar

The value of non-reducing sugars was recorded by subtracting the value of reducing sugars from total sugars.

Statistical analysis

The data recorded from the experiment were subjected to statistical analysis using packages such as, OPSTAT and D × D Stratfield



Fig. 2. Estimation of reducing sugars in banana fruit juice showing the development of a brick-red colour reaction.

software. Analysis of variance (ANOVA) was performed to determine the significance of treatment effects and mean differences were evaluated using the *F*-test at the 5 % level of significance. Whenever the *F*-test indicated significant differences among treatments, the critical difference (CD) at the 5 % level of significance was calculated to facilitate pairwise comparison of treatment means.

Results

The effects of foliar application of SOP and nano urea on key fruit quality parameters, i.e., reducing sugars, non-reducing sugars, total sugars, TSS, titratable acidity and shelf-life were evaluated in both tissue-culture and sucker-propagated banana plants during 2022–23 and 2023–24 (Table 1–3). Across all traits, treatments

Table 1. Effect of foliar application of sulphate of potash and nano urea on reducing and non-reducing sugar in fruits of tissue culture and sucker plant during the cropping year 2022–23 and 2023–24

Treatments	Reducing sugar						Non-reducing sugar					
	Tissue culture plant*			Sucker plant*			Tissue culture plant*			Sucker plant*		
	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled
T ₁ - 1 % SOP	14.62	12.69	13.66	13.56	12.98	13.27	1.62	1.82	1.72	1.78	1.69	1.73
T ₂ - 1.5 % SOP	15.56	14.29	14.93	14.92	15.01	14.97	1.15	1.89	1.52	1.93	1.78	1.85
T ₃ - 2 % SOP	15.13	14.01	14.57	15.09	14.98	15.03	2.95	1.76	2.36	1.81	1.8	1.8
T ₄ - 0.2 % nano urea	14.9	14.09	14.50	15.01	14.71	14.86	1.81	1.59	1.7	1.72	1.58	1.65
T ₅ - 0.3 % nano urea	14.18	13.87	14.02	15.2	14.62	14.91	2.04	1.52	1.78	1.67	1.62	1.65
T ₆ - 0.4 % nano urea	13.69	13.27	13.48	15.00	14.57	14.79	1.62	1.91	1.77	1.61	1.59	1.6
T ₇ - 1 % SOP + 0.2 % nano urea	15.49	15.05	15.27	15.21	15.42	15.31	2.74	2.12	2.43	2.28	2.51	2.39
T ₈ - 1.5 % SOP + 0.3 % nano urea	15.78	16.23	16.01	15.61	15.67	15.64	3.04	2.53	2.79	2.51	2.56	2.53
T ₉ - 2 % SOP + 0.4 % nano urea	15.50	16.08	15.79	15.50	15.51	15.50	2.74	2.49	2.61	2.43	2.53	2.48
T ₁₀ - Control	12.8	12.01	12.40	12.45	12.20	12.32	1.31	1.25	1.28	1.21	1.09	1.15
C.D.	1.09	1.69	0.98	1.01	1.06	1.17	0.35	0.24	0.29	0.12	0.19	0.16
SE(m)	0.37	0.91	0.98	0.98	0.42	1.07	0.12	0.08	0.14	0.04	0.07	0.68
C.V.	4.34	8.07	8.29	8.65	5.05	8.94	6.75	7.56	8.85	3.7	6.12	5.03

*Mean of three replications.

Table 2. Effect of foliar application of sulphate of potash and nano urea on total sugar and total soluble solids (°Bx) in fruits of tissue culture and sucker plant during the cropping year 2022–23 and 2023–24

Treatments	Total sugar						Total soluble solids (°Bx)					
	Tissue culture plant*			Sucker plant*			Tissue culture plant*			Sucker plant*		
	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled
T ₁ - 1 % SOP	16.24	14.51	15.38	15.34	14.67	15.01	17.56	16.57	17.07	17.27	17.28	17.28
T ₂ - 1.5 % SOP	16.71	16.18	16.45	16.85	16.79	16.82	18.08	17.16	17.62	17.47	17.73	17.60
T ₃ - 2 % SOP	18.08	15.77	16.93	16.90	16.78	16.84	18.35	17.01	17.68	17.70	18.8	18.25
T ₄ - 0.2 % nano urea	16.71	15.68	16.19	16.73	16.29	16.51	16.99	15.31	16.15	16.78	16.46	16.62
T ₅ - 0.3 % nano urea	16.22	15.39	15.8	16.87	16.24	16.56	18.56	15.03	16.79	16.27	15.95	16.11
T ₆ - 0.4 % nano urea	15.31	15.18	15.25	16.61	16.16	16.39	16.95	15.00	15.97	15.79	16.33	16.06
T ₇ - 1 % SOP + 0.2 % nano urea	18.05	17.17	17.61	17.43	17.75	17.59	19.07	18.20	18.63	18.49	18.83	18.66
T ₈ - 1.5 % SOP + 0.3 % nano urea	18.82	18.76	18.79	18.12	18.23	18.18	20.24	19.53	19.89	19.27	19.63	19.45
T ₉ - 2 % SOP + 0.4 % nano urea	18.30	18.24	18.27	17.69	18.02	17.86	18.27	18.98	18.63	18.65	19.35	19.00
T ₁₀ - Control	14.11	13.26	13.69	13.66	13.29	13.48	12.52	13.10	12.81	10.28	10.6	10.44
C.D.	2.39	2.94	2.58	1.39	0.9	1.13	2.09	1.7	1.84	3.3	3.56	3.27
SE(m)	0.8	0.99	1.27	0.47	0.3	0.56	0.7	0.57	0.91	1.08	1.2	1.61
C.V.	8.28	10.72	7.52	4.87	3.2	4.13	4.89	3.97	5.48	4.1	5.14	6.64

*Mean of three replications.

Table 3. Effect of foliar application of sulphate of potash and nano urea on titratable acidity (%) in fruits and shelf-life of fruits of tissue culture and sucker plant during the cropping year 2022–23 and 2023–24

Treatments	Titratable acidity (%)						Shelf-life (days)					
	Tissue culture plant*			Sucker plant*			Tissue culture plant*			Sucker plant*		
	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled	2022–23	2023–24	Pooled
T ₁ - 1 % SOP	0.36	0.38	0.37	0.42	0.45	0.44	7.67	7.33	7.50	7.33	7.00	7.17
T ₂ - 1.5 % SOP	0.32	0.33	0.32	0.40	0.41	0.41	9.00	8.67	8.83	8.67	8.00	8.33
T ₃ - 2 % SOP	0.37	0.37	0.37	0.41	0.40	0.40	8.67	8.00	8.33	8.00	8.00	8.00
T ₄ - 0.2 % nano urea	0.39	0.39	0.39	0.44	0.45	0.44	8.33	8.00	8.17	8.33	7.67	8.00
T ₅ - 0.3 % nano urea	0.41	0.42	0.41	0.45	0.45	0.45	8.00	7.67	7.83	8.00	8.33	8.17
T ₆ - 0.4 % nano urea	0.44	0.45	0.45	0.49	0.50	0.49	8.00	7.67	7.83	7.33	7.33	7.33
T ₇ - 1 % SOP + 0.2 % nano urea	0.30	0.33	0.31	0.42	0.41	0.41	9.00	8.67	8.83	9.00	8.67	8.83
T ₈ - 1.5 % SOP + 0.3 % nano urea	0.27	0.30	0.28	0.39	0.37	0.38	10.67	9.33	10.00	9.67	9.00	9.33
T ₉ - 2 % SOP + 0.4 % nano urea	0.29	0.32	0.31	0.40	0.38	0.39	9.67	9.00	9.33	9.33	9.00	9.16
T ₁₀ - Control	0.48	0.50	0.49	0.52	0.52	0.52	6.67	6.67	6.67	6.33	6.67	6.50
C.D.	0.06	0.06	0.06	0.10	0.08	0.09	1.00	0.98	0.96	1.66	1.79	1.99
SE(m)	0.02	0.02	0.03	0.03	0.03	0.04	0.34	0.33	0.47	0.90	1.17	1.48
C.V.	4.51	9.44	5.32	6.77	5.33	6.03	6.81	7.05	6.93	8.91	6.53	7.46

*Mean of three replications.

differed significantly, indicating a pronounced influence of foliar nutrient application on fruit biochemical quality.

Reducing sugars (%)

Reducing sugar content exhibited significant variation among the treatments in both propagation methods across both years 2022–23 and 2023–24 (Table 1; Fig. 2). In tissue-culture plants, treatment T₈ (1.5 % SOP + 0.3 % Nano Urea) consistently produced the highest reducing sugar levels (15.78 % and 16.23 %) respectively, followed by T₉ (2 % SOP + 0.4 % nano Urea), which recorded 15.50 % and 16.08 %, respectively. These treatments were statistically superior to the control (12.08 % and 12.01 %). A similar trend was observed in sucker-propagated plants, where T₈ again recorded the highest reducing sugars (15.61 % and 15.67 %), followed by T₉ (15.50 % and 15.51 %). Both treatments significantly outperformed the control (12.45 % and 12.20 %) in the years 2022–23 and 2023–24, respectively. The consistent superiority of T₈ and T₉ across crops, years and propagation systems underscores the strong synergistic effect of integrated foliar K and nano-N nutrition on sugar accumulation. Pooled analysis further validated the above findings, wherein treatment T₈ (1.5 % SOP + 0.3 % nano urea) exhibited the

maximum reducing sugar content in both tissue culture and sucker-derived plants, recording 16.01 % and 15.64 %, respectively. This was followed by treatment T₉ (2 % SOP + 0.4 % nano urea), which had reducing sugar contents of 15.79 % and 15.50 %, respectively. Both treatments showed significantly higher reducing sugar levels compared with the control treatment, which recorded 12.40 % and 12.32 %, respectively.

Non-reducing sugars (%)

During 2022–23 and 2023–24, non-reducing sugars also varied significantly among treatments in both years (Table 1). In tissue-culture plants, T₈ produced the highest non-reducing sugar content (3.04 % and 2.53 %), followed by T₉ (2.74 % and 2.49 %), both of which were statistically superior to the control (1.31 % and 1.25 %) in both year 2022–23 and 2023–24, respectively. In sucker-propagated plants during both year 2022–23 and 2023–24, T₈ again recorded the highest values (2.51 % and 2.56 %), followed by T₉ (2.43 % and 2.53 %), with both outperforming the control (1.21 % and 1.09 %), respectively. The marked improvement in non-reducing sugar content may be attributed to enhanced sucrose synthesis and translocation associated with adequate K nutrition. The combined

foliar application of SOP and nano urea significantly influenced non-reducing sugar accumulation in banana fruits. Among the treatments, T₈ (1.5 % SOP + 0.3 % nano urea) produced the highest pooled mean values of 2.79 % and 2.53 % in tissue culture and sucker plants, respectively, followed by T₉ (2 % SOP + 0.4 % Nano urea). The control treatment recorded the lowest non-reducing sugar content in both planting materials.

Total sugars (%)

Total sugar content exhibited significant treatment variation during both years (Table 2). In tissue-culture plants, T₈ recorded the highest total sugars (18.82 % and 18.76 %), followed closely by T₉ (18.30 % and 18.24 %). Both treatments markedly exceeded the control (14.11 % and 13.26 %) during 2022–23 and 2023–24, respectively. A comparable pattern was observed in sucker-propagated plants, with T₈ registering the highest total sugars (18.12 % and 18.23 %), followed by T₉ (17.69 % and 18.02 %). Both were significantly superior to the control (13.66 % and 13.29 %) during 2022–23 and 2023–24, respectively. The consistent enhancement of total sugar content indicates efficient carbon assimilation and improved carbohydrate metabolism facilitated by K and nano-N synergy. The integrated foliar application of SOP and nano urea had a pronounced effect on total sugar content in banana fruits. Among the treatments, T₈ (1.5 % SOP + 0.3 % nano urea) produced the highest pooled mean total sugar levels in tissue culture and sucker-propagated plants (18.79 % and 18.18 %, respectively), followed by T₉ (2 % SOP + 0.4 % nano urea). The control treatment showed the minimum total sugar content in both planting materials.

Total soluble solids (°Bx)

During both years 2022–23 and 2023–24, TSS values were significantly influenced by treatments across both propagation methods. In tissue-culture plants, T₈ produced the highest TSS (20.24 °Bx and 19.53 °Bx), followed by T₉ (18.27 °Bx and 18.98 °Bx), both significantly superior to the control (12.52 °Bx and 13.10 °Bx), respectively (Table 2; Fig. 3). Sucker-propagated plants showed a similar pattern, with T₈ recording the highest TSS (19.27 °Bx and 19.63 °Bx), followed by T₉ (18.65 °Bx and 19.35 °Bx), while the control remained significantly lower (10.28 °Bx and 10.60 °Bx) in the year 2022–23 and 2023–24, respectively. Increased TSS reflects improved sugar translocation and higher metabolic activity under enhanced foliar K and nano-N nutrition. Among the various nutrient treatments evaluated, T₈ (1.5 % SOP + 0.3 % nano urea) exhibited superior performance with respect to total soluble solids, recording pooled mean values of 19.89 °Bx and 19.45 °Bx in tissue culture and sucker-propagated plants, respectively. This was followed by T₉ (2 % SOP + 0.4 % nano urea), which registered comparatively lower but appreciable values. These treatments were significantly superior compared to the control (12.81 % and 10.44 %).

Titrateable acidity (%)

Titrateable acidity decreased significantly with increasing nutrient application (Table 3; Fig. 1). In tissue-culture plants, T₈ recorded the lowest acidity (0.27 % and 0.30 %), followed by T₉ (0.29 % and 0.32 %), both of which were significantly lower than the control (0.48 % and 0.50 %), during 2022–23 and 2023–24, respectively. Similar trends were observed in sucker-propagated plants, where T₈ recorded the lowest acidity (0.39 % and 0.37 %), followed by T₉ (0.40 % and 0.38 %), while the control exhibited the highest acidity



Fig. 3: TSS of fruit by Refractometer

Fig. 3. Measurement of total soluble solids (TSS) of banana fruits using a digital refractometer.

(0.52 % and 0.52 %) in the years 2022–23 and 2023–24, respectively. Reduced acidity under SOP and nano urea treatments is likely associated with enhanced sugar-acid balance and improved fruit ripening physiology. The integrated application of SOP and nano urea significantly influenced fruit acidity in banana. Treatment T₈ (1.5 % SOP + 0.3 % nano urea) resulted in the lowest titratable acidity, recording 0.28 % in tissue culture plants and 0.38 % in sucker plants, followed by T₉ (2 % SOP + 0.4 % nano urea), which recorded 0.31 % and 0.39 %, respectively. These treatments were significantly superior to the untreated control (0.49 % and 0.52 %).

Shelf-life (days)

Shelf-life varied significantly among treatments (Table 3). In tissue-culture plants, treatment T₈ produced the longest shelf-life (10.67 and 9.33 days), followed by T₉ (9.67 and 9.00 days), both significantly superior to the control (6.67 days in both years). In sucker-propagated plants, the treatment T₈ again resulted in the longest shelf-life (9.67 and 9.00 days), followed by T₉ (9.33 and 9.00 days), while the control recorded the shortest shelf-life (6.33 and 6.67 days) in the year 2022–23 and 2023–24, respectively (Table 3). The extended shelf-life under T₈ and T₉ may be attributed to improved cell wall integrity, balanced nutrient metabolism and moderated fruit senescence due to optimal K and nano-N nutrition. The combined foliar spray of SOP and nano urea markedly improved the post-harvest shelf life of banana fruits. Treatment T₈ (1.5 % SOP + 0.3 % nano urea) produced the highest shelf-life in tissue culture and sucker plants (10.00 and 9.33 days, respectively), followed by T₉ (2 % SOP + 0.4 % nano urea), which recorded 9.33 and 9.16 days, respectively. These treatments were statistically superior to the control (6.67 and 6.50 days).

Discussion

The pooled results from tissue-culture and sucker-propagated plants showed that treatment T₈ (1.5 % SOP + 0.3 % nano urea) produced the highest values for all major fruit quality parameters. In tissue-culture plants, T₈ yielded reducing sugars of 16.01 %, non-reducing sugars of 2.79 %, total sugars of 18.79 %, TSS of 19.89 °Bx, acidity of 0.28 % and a shelf-life of 10.0 days. Corresponding values in sucker-propagated plants were similarly superior, recording 15.64 % reducing sugars, 2.53 % non-reducing sugars, 18.18 % total sugars, 19.45 °Bx TSS, 0.38 % acidity and a shelf-life of 9.33 days. In all cases, T₈ remained statistically superior to the other treatments (Tables 1–3). Combined foliar application of SOP and nano urea (T₈) performed better than the individual applications. This may be due to better, more positive complementation between them and the supply of nutrients in a more balanced and efficient manner, which balanced physiological processes and ultimately enhanced crop productivity. Nano urea's extremely small size and very high surface area, which helps the fertiliser spread uniformly on leaf surfaces and enter easily through stomata and leaf pores. This increases foliar absorption, reduces N loss and improves nutrient utilisation efficiency compared to conventional urea.

These results align with earlier reports documenting maximum reducing sugars (6.09 %), non-reducing sugars (7.80 %), total sugars (13.82 %), TSS (22.81 °Bx) and shelf-life (11.07 days) following the application of SOP with 1.5 % urea (7). Similar improvements in reducing sugar accumulation under foliar K application were earlier reported (8). Fruit quality attributes with SOP + 1.5 % nano urea, reporting 17.62 % reducing sugars, 2.18 % non-reducing sugars, 19.80 % total sugars, 22.62 °Bx TSS, 0.16 % acidity and a shelf-life of 8.7 days (9). Demonstrated that banana bunch feeding with cow dung slurry (300 g) + SOP (10 g) + ammonium sulphate (20 g) significantly increased TSS, reducing sugars, total sugars, ascorbic acid and shelf-life in pooled analysis. Their study also reported maximum non-reducing sugars and minimum acidity under SOP 1.5 % and KNO₃ 2.0 % without trimming. Collectively, these congruent findings highlight the pivotal role of potassium, especially when combined with N sources, in enhancing sugar synthesis, accumulation and overall fruit quality in banana (10). Similarly, the earlier finding highlighted that application of SOP at 2 % in post-shooting sprays in banana improved the fruit TSS and per cent of reducing sugar (11).

The observed reduction in titratable acidity under T₈ may be attributed to enhanced sugar accumulation resulting from adequate K availability. This may be due to the role of K in regulating organic acid metabolism and enhancing carbohydrate synthesis. A higher potassium supply reduces fruit acidity by preventing the diversion of phosphoenol pyruvate (PEP) into alternative pathways that limit acetyl-CoA formation; under K deficiency, oxaloacetate accumulates, leading to increased organic acid content. Higher K levels may therefore promote the neutralisation of organic acids, resulting in lower acidity. The consistently low sugar content recorded in the control treatment reaffirms the essential role of nutrient supplementation in improving fruit biochemical attributes (12).

Potassium is known to play a central role in carbohydrate metabolism, including synthesis, breakdown and translocation, as well as in protein synthesis and the neutralisation of organic acids (13). Additionally, K enhances phloem mobility of sucrose and amino acids and stimulates starch synthase activity, thereby promoting

starch deposition in developing fruits (14). These physiological mechanisms collectively explain the substantial improvements in fruit quality traits observed under the integrated foliar application of SOP and nano urea. Potassium is essential for maintaining cellular osmotic balance, stomatal regulation and activation of numerous enzymes involved in carbohydrate metabolism and protein synthesis. Deficiency of K leads to marked disruptions in several physiological processes, including reduced photosynthetic CO₂ fixation and impaired translocation and utilisation of photosynthates, particularly under abiotic stress conditions. On the other hand, N is a key constituent of amino acids, proteins, nucleic acids and enzymes, thereby directly influencing metabolic activity and growth (12). In contrast, exogenous application of K plays a crucial role in maintaining cell turgor, facilitating osmotic adjustment and regulating stomatal movement in response to environmental signals (15).

Conclusion

The findings of the research experiment, foliar application of 1.5 % sulphate of potash (SOP) + 0.3 % nano urea (T₈) produced the most favourable effects on fruit quality and shelf-life of banana cv. Grand Naine. This treatment consistently resulted in the highest reducing sugar, non-reducing sugar, total sugar and total soluble solids, along with the lowest titratable acidity and the longest shelf-life, all of which were statistically superior to the control and most other treatments. The results confirm that the synergistic foliar application of SOP and nano urea enhances carbohydrate metabolism, sugar accumulation and physiological stability of the fruits, thereby improving fruit quality and extending shelf-life. Hence, this combination of treatments may be recommended as the most efficient and reliable nutrient management strategy for maximising the fruit sweetness, improving ripening behaviour, improving postharvest quality and extending shelf-life in banana for the area under study. This integrated nutrient approach offers substantial potential for enhancing fruit marketability and meeting consumer quality preferences. From the findings of the present investigation, future research may focus on evaluating different concentrations and spray schedules of nano urea and SOP under diverse agro-climatic conditions, impact on postharvest storage behaviour, integration of this fertiliser with other nutrient management practices for improved fruit quality and shelf-life in the banana cv. Grand Naine.

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Authors' contributions

PK carried out the research work and participated in data collection. GM conceived the study, participated in its design and contributed to data collection. RC participated in data collection and assisted with the experimental layout. All authors read and approved the final manuscript.

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