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Effect of Organic Nano-NPK Formulation on Fruit Yield and Quality in Banana Cv. Nendran (*Musa* AAB)

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ABSTRACT

The present study was carried out in the Department of Fruit Science, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India during October, 2020 to November, 2021 to evaluate the effect of soil application of organic Nano-NPK formulation on fruit yield and quality in banana cv. Nendran. The earliest bunch emergence (164.62 days) was noticed in T_7 (soil test-based KAU POP recommendation) and it was on par with T_6 (45 g Nano-NPK in 6 splits). Application of 45 g Nano-NPK in 6 splits (T_6) resulted in the highest number of hands bunch^{-1} (4.84), maximum values for length of finger (23.59 cm), girth of finger (13.26 cm), pulp-peel ratio (3.55) and total biomass yield. T_6 and T_7 significantly improved the bunch weight, number of fingers bunch^{-1}, number of fingers in D hand and weight of fingers. T_6 recorded the highest values for total sugars (19.94%), reducing sugars (15.17%), total carotenoids (303.67 mg 100 g^{-1}), sugar-acid ratio (63.92), ascorbic acid content (2.2%) and moisture content (24.95%). T_6 recorded the highest peel thickness (3.06 mm), which was on par with T_7. T_6 (45 g Nano-NPK in 6 splits) also recorded the longest shelf life (10.15 days) and the fruits took longer time for ripening (6.32 days). The study revealed that the application of 45 g granular organic Nano-NPK in 6 splits along with 10 kg FYM and 100 g lime plant^{-1} year^{-1} increased the overall growth, yield and quality of banana cv. Nendran with high net income and B:C ratio.

KEYWORDS: Banana Nendran, fruit yield, Nano-NPK, organic, quality

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1. INTRODUCTION

Banana is an important fruit crop in the tropics and subtropics (van Asten et al., 2011, Hinge et al., 2022) and it is native to the tropical region of Southeast Asia (Archith et al., 2021). Banana is a leading crop in world agricultural production and trade (Lamassa, 2021). It is an important source of livelihood for marginal farmers of Asia and South-east Asia (Sreedharan et al., 2013) and it provides staple food for more than four hundred million people worldwide (Thangavelu et al., 2021). Banana fruit is easily digestible and is rich in carbohydrate. It is one of the best sources of potassium. Moreover, it is affordable and available throughout the year (Wardhan et al., 2022).

Nendran is a popular variety of banana in Kerala and other parts of southern India. (Meghwal et al., 2021), where the production is largely market oriented. It is a dual-purpose banana, and the crop gives an attractive net income. Being nutrient exhaustive (Leonel et al., 2020), proper scheduling of plant nutrition is very important in banana for realising potential yields (Bashma and Sudha, 2020). The efficiency of nutrient uptake and utilization by plants seems to be significantly affected by the application of excessively high doses of chemical fertilizers (Kalwani et al., 2022). On the other hand, nutrient use efficiencies of conventional fertilizers are very low. Around 50–70% of the soil applied nitrogen is lost through various means. The efficiency of phosphate fertilizers is 10–25%, and that of potassium is 35–40% (De Rosa et al., 2020). The intensive use of mineral fertilizers has negatively affected soil and water quality worldwide (Bashir et al., 2020). In particular, the use of conventional N fertilizers has caused substantial N losses to the environment (Banger et al., 2017). The surplus N released from the conventional fertilizers pollutes the environment and causes climate change (Umar et al., 2022). Nano-fertilizers have emerged as promising alternative smart fertilizers to ensure high crop production and soil restoration (Zulfiqar et al., 2019). Owing to the small size, nanoparticles have very high surface area, ion adsorption capacity, cation exchange capacity and complexation capacity (Shang et al., 2019). Nano-fertilizers help in increasing the bioavailability and uptake of minerals thereby decreasing fertilizer wastage, and protecting the environment (Tarafdar et al., 2014). The use of nano-fertilizers is promising for nutrient translocation to the desired areas in plants (Deepa et al., 2015).

Nano-fertilizers mainly delay the release of the nutrients and extends the fertilizer effect period. (Veronica et al., 2014). Crops can absorb nutrients slowly and sustainably because the nanostructure of these fertilizers provides a high surface-to-volume ratio (Monreal et al., 2016) which in turn reduces the frequency of application (Mandal and Lalrinchhani, 2021). The intervention of nanotechnology along with organic farming practice can help in minimizing the mass volume requirement of conventional chemical fertilizers (Kumar et al., 2022).

According to Jubeir and Ahmed (2019), using nano fertilizers and NPK enhances the vegetative and fruit characteristics of date palm. The greenhouse cucumber fertigated with 40% RDF as nano fertilizer recorded maximum number of pickings and number of fruits per vine accounting for maximum increase in marketable yield compared to water soluble fertilizers (Modi et al. 2021). Benefits of nanoparticle application in fruit crops include fruit productivity, quality and shelf life through their positive effects on anatomical, morphological, physiological, physicochemical and molecular traits (Sharma et al. 2021)

The utilization of nanotechnology in fruit crops especially banana still remains unexplored. Hence, the present study was conducted to assess the effect of soil application of organic Nano-NPK formulation on fruit yield and quality of banana cv. Nendran.

2. MATERIALS AND METHODS

The present study was carried out in the Department of Fruit Science, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India from October, 2020 to November, 2021. The commercially available granular organic Nano-NPK formulation was used as the Nano-NPK source. Before the experiment, sample of the Nano-NPK formulation was analysed using the standard procedures. It contained N (1.97%), P (1.82%), K (2.96%), Ca (0.33%), Mg (0.28%), S (0.62%), pH (7.79), EC (0.14 dS m^{-1}), organic carbon (2.35%) and humic acid (19.19%). It recorded a pH of 7.79 and an EC of 0.14 dS m^{-1}.

The field experiment was carried out in the Organic Farm at the College of Agriculture, Vellayani, Thiruvananthapuram, which is located at 8°25'38" North latitude and 76°59'14" East longitude and at an altitude of 19 m above MSL. The major soil type of the site is laterite, and the texture are sandy clay loam, moderately acidic with a pH of 5.9. Good quality sword suckers of uniform size were used as planting material for the field experiment. The experiment was laid out in Randomized Block Design with eight treatments and three replications and the suckers were planted at spacing of 2 m×2 m. The experiment was conducted with combinations of 3 fertilizer doses (15 g, 30 g and 45 g) and 2 times of application (2 splits and 6 splits). The treatments were 15 g organic Nano-NPK formulation $plant^{-1}$ in 2 splits (T_1), 15 g organic Nano-NPK formulation $plant^{-1}$ in 6 splits (T_2), 30 g organic Nano-NPK formulation $plant^{-1}$ in 2 splits (T_3), 30 g organic Nano-NPK formulation $plant^{-1}$ in 6 splits (T_4), 45 g organic Nano-NPK formulation $plant^{-1}$ in 2 splits (T_5), 45 g organic Nano-NPK formulation $plant^{-1}$

in 6 splits (T_6), soil test based KU POP recommendation-133.86: 28.8: 338.4 g N: P_2O_5: K_2O plant^{-1} in 6 splits (T_7) and the control (T_8). Organic manure (10 kg FYM plant^{-1}) was applied uniformly to all the treatments including the control as basal dose. Lime was applied @ 100 g pit^{-1} based on the soil analysis report in all the pits 2 weeks prior to planting of suckers. The date of planting and date of visual bunch emergence were recorded and the total duration from planting to visual bunch emergence was expressed as duration for bunch emergence in days. The date of planting and date of harvest were recorded and the total duration from planting to harvest was expressed as crop duration in days. The total number of suckers produced after bunch emergence in each plant was recorded. The weight of bunch was measured including the portion of the peduncle up to the first scar and was expressed in kg. After harvest, number of hands in each bunch was counted and recorded. After harvest, number of fingers in each bunch was counted and recorded. After harvest, number of fingers in the D hand (second hand from the top of the bunch) was counted and recorded. For the finger characters, the index finger (middle finger in the top row) of the D hand was selected as the representative finger. The index finger in D hand was separated and weighed and the weight was recorded in g. Length of finger was recorded by measuring the index finger through the convex side from the tip to the point of attachment of the peduncle using a thread and a scale and was expressed in cm. The girth of mid portion of the index finger was measured using a thread and a scale and was expressed in cm. The weight of pulp and weight of peel of index finger were measured separately and the pulp-peel ratio was worked out. The rhizome, pseudostem, leaves and bunch were weighed separately and by using this the total biomass yield was calculated and was expressed in kg. The index finger was used as the representative sample for the quality analysis.

Ripe fruits were used for the quality analysis except for starch analysis where unripe fruit was used. The top, middle and bottom portions from each fruit sample were pooled and macerated before analysis. The TSS was measured using a hand refractometer. The fruit pulp was used to determine the titratable acidity and it was expressed in % anhydrous citric acid. The total carotenoids in the fruit pulp were determined and was expressed in mg 100 g^{-1}. Raw banana was used to determine the starch content and it was expressed in % on fresh weight basis. The peel thickness was measured using screw gauge and it was expressed in mm. The total sugars of the sample were estimated by using the method suggested by Anonymous (1975) and it was expressed in % on fresh weight basis. The reducing sugar of the sample was estimated and was expressed in % on fresh weight basis. The non-reducing sugar of the sample was estimated by deducting the values of reducing sugar from total sugars of the sample. The sugar acid ratio of sample was estimated by dividing the value of total sugars by the value of acidity of the sample. Ascorbic acid present in the sample was estimated and was expressed in mg 100 g^{-1} of pulp. Moisture content of fruit was estimated with the help of moisture meter and was expressed in %. Days from harvest of bunches to ripening of fingers were counted and recorded. The shelf life of fruit at room temperature was determined by counting the days from harvest till the appearance of black spots on the surface of peel without reducing the edible qualities.

The Benefit-cost ratio (BCR) was calculated using the following formula, BCR=(Gross income (₹ ha^{-1}))/(Cost of cultivation (₹ ha^{-1}))

Statistical analysis of observed data was done by applying the technique of analysis of variance for Randomized Block Design (Panse and Sukhatme, 1985).

3. RESULTS AND DISCUSSION

3.1. *Fruit yield parameters*

3.1.1. *Duration for bunch emergence and crop duration*

The study revealed that the duration for bunch emergence ranged from 164.62 days in soil test-based POP recommendation to 180.60 days in the control plot (Table 1). The shortest duration for bunch emergence was noticed in T_7 (164.62 days) and it was on par with T_6 (167.57 days). Both these treatments were applied in six splits. The shortened duration for bunch emergence with split application of major nutrients could be due to the vigorous growth of plants which accelerated the achievement of

Table 1: Effect of treatments on duration for bunch emergence, crop duration and sucker production after bunch emergence

Treatments	Duration for bunch emergence (days)	Crop duration (days)	Sucker production after bunch emergence
T_1	179.41a	265.55	5.23
T_2	170.56bcd	256.52	4.56
T_3	173.82b	263.26	4.62
T_4	169.61cd	257.69	6.11
T_5	171.93bc	258.26	6.67
T_6	167.57de	253.63	9.78
T_7	164.62e	255.55	6.22
T_8	180.60a	268.23	3.78
SEm±	1.35	1.25	0.31
CD (p=0.05)	4.11	3.78	0.93

the required net assimilation rate leading to early bunch emergence. A similar trend was observed in crop duration also. The longest crop duration (268.23 days) was exhibited by T_8 (control) and it was on par with T_1. This might be attributed to the unavailability of sufficient nutrients during the critical growth stages of the crop which in turn resulted in the delayed bunch emergence. Thangaselvabhai et al. (2009a) also reported early bunch emergence and shorter crop duration with split application of major plant nutrients.

3.1.2. Sucker production after bunch emergence

The sucker production after bunch emergence ranged from 3.78 in the control to 9.78 in the treatment T_6 (Table 1). The number of suckers is dependent on the nutritional status of the mother plant. Application of 45 g organic Nano-NPK formulation plant^{-1} in 6 splits (T_6) might have resulted in greater uptake of nutrients leading to enhanced sucker production. It was also observed that the number of suckers was markedly influenced by the application of higher levels of nitrogen (133.86 g plant^{-1}). The highest sucker production (9.78) associated with the treatment T_6 could be due to the availability of nitrogen, which might have increased the overall vegetative growth of the plants thereby increasing the number of suckers per plant. This finding is in agreement with that of Tomer et al. (2021) in banana.

3.1.3. Number of hands and fingers and bunch weight

The study revealed that there was an increase in the number of hands bunch^{-1}, number of fingers bunch^{-1}, number of fingers in D hand and total bunch weight with increase in the quantity of nutrients as well as number of splits of application. Regarding the bunch weight and number of fingers bunch^{-1}, treatments T_6 and T_7 were on par and were found to be significantly superior to other treatments (Table 2 and Figure 1). The treatment T_6 (4.84) showed the highest number of hands bunch^{-1}. Bunch weight ranged from 4.69 in T_1 to 8.85 in T_7 and the number of fingers bunch^{-1} ranged from 29.22 in T_8 to 46.33 in T_6. This finding agrees with the report of Thangaselvabai et al. (2009b) who concluded that in order to ensure high yield of superior quality bananas under tropical conditions, nutrients should be applied in small doses at shorter intervals. In the case of organic Nano-NPK formulation, slow-release nature of the fertilizer and increased surface area of nano particles might have enhanced the nutrient availability throughout the growing period resulting in increased number of hands

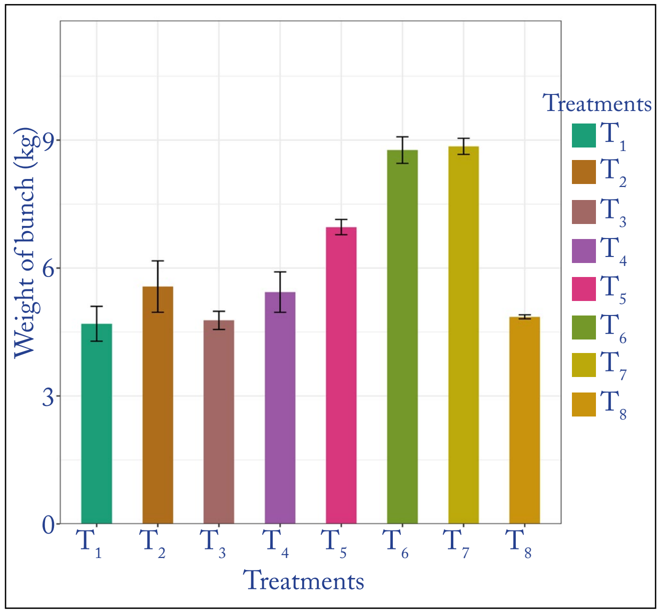

Figure 1: Effect of treatments on bunch weight

Table 2: Effect of treatments on weight of bunch, number of hands per bunch, number of fingers bunch^{-1}, number of fingers in D hand, peel thickness, pulp - peel ratio, length, weight and girth of finger and total biomass yield

Treatments	Weight of bunch (kg)	No. of hands bunch^{-1}	No. of fingers bunch^{-1}	No. of fingers in D hand	Peel thickness (mm)	Pulp-peel ratio	Weight of finger (g)	Length of finger (cm)	Girth of finger (cm)	Total biomass yield (kg)
T_1	4.69^{d}	3.61^{d}	32.22^{d}	8.38^{de}	2.46^{f}	2.67^{e}	158.33^{d}	20.30^{d}	12.09^{d}	30.99^{e}
T_2	5.57^{c}	4.04^{c}	33.33^{d}	8.89^{cd}	2.61^{d}	2.88^{d}	172.36^{c}	21.12^{c}	12.46^{bc}	32.63^{de}
T_3	4.77^{d}	4.00^{c}	33.66^{d}	8.94^{cd}	2.54^{e}	2.86^{de}	160.78^{d}	21.37^{c}	12.30^{cd}	35.15^{cd}
T_4	5.44^{c}	4.29^{bc}	37.22^{c}	8.89^{cd}	2.82^{c}	3.13^{bc}	171.56^{c}	21.38^{c}	12.71^{b}	37.99^{c}
T_5	6.96^{b}	4.37^{b}	42.56^{b}	9.57^{bc}	2.56^{de}	2.98^{cd}	190.89^{b}	21.96^{b}	12.47^{bc}	41.73^{b}
T_6	8.77^{a}	4.84^{a}	46.33^{a}	10.25^{ab}	3.06^{a}	3.55^{a}	201.11^{a}	23.59^{a}	13.26^{a}	49.73^{a}
T_7	8.85^{a}	4.52^{b}	45.11^{a}	10.33^{a}	2.99^{b}	3.21^{b}	196.89^{a}	21.60^{bc}	12.42^{bcd}	45.33^{b}
T_8	4.86^{d}	3.27^{e}	29.22^{e}	7.77^{e}	2.31^{g}	2.46^{f}	152.78^{e}	19.75^{d}	11.64^{e}	26.76^{f}
SEm±	0.17	0.10	0.82	0.23	0.02	0.06	1.79	0.19	0.12	0.85
CD (p=0.05)	0.51	0.29	2.49	0.71	0.07	0.19	5.42	0.57	0.36	2.58

bunch^{-1}, fingers bunch^{-1} and number of fingers in D hand.

3.1.4. Length and girth of fingers, pulp-peel ratio and total biomass yield.

The highest values for length of finger (23.59 cm), girth of finger (13.26 cm), pulp peel ratio (3.55) and total biomass yield (49.73kg) were recorded in T_6 which was immediately followed by T_7 (Table 2). This could be attributed to the better growth during vegetative phase and balanced availability of major nutrients during reproductive phase due to the split application of nutrients. The split application of nitrogen might have increased the availability of nitrogen which improved the cell expansion process, pulp development, length of fruit and girth of fruits. Increased biomass yield could be due to application of optimum quantity of fertilizers during the critical stages of crop growth. In maize, an increased yield and biomass production was obtained with the application of zeolite based nano nitrogen because of increased N availability and reduced N loss (Manikandan and Subramanian, 2015)

3.2. Fruit quality parameters

The fruit quality parameters were found to be influenced by the different treatments. The treatment T_6 recorded the highest values for TSS (25.67°B), total carotenoids (303.67 mg 100 g^{-1}), starch content (22.76%), total sugars (19.94%), reducing sugars (15.17%), sugar-acid ratio (63.92), ascorbic acid content (2.24 mg 100 g^{-1}), moisture content (24.95%), days taken for ripening (6.32 days) and shelf life (10.15 days) of fruits (Table 3 and 4). According to Mustaffa et al. (2004), nutrient composition of banana fruits depends on the available nutrients in the soil. Nano-fertilizers have larger surface area, which made the nutrient absorption easier by the plants, and ultimately improved the quality traits also. Tisdale and Nelson (1966) also concluded that the increased uptake of potassium counteracts the functions of organic acids and thus reduce the acidity in banana fruits. Similar observation was made in the present study where the split application of organic Nano-NPK formulation at a higher dose (45 g) increased the uptake of potassium and thus reduced the acidity in fruits. In the case of peel thickness of fruits, the lowest value was recorded by the plants in the control plot. This might be attributed to the unavailability of major plant nutrients to the plant during its critical growth stages.

Table 3: Effect of treatments on TSS, acidity, total carotenoids, starch content, total sugars, reducing sugars, non-reducing sugars and sugar acid ratio

Treatments	TSS (°B)	Acidity (%)	Total carotenoids (mg 100 g^{-1})	Starch content (%)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)	Sugar-acid ratio
T_1	22.67	0.323	243.12	19.64	17.94	12.98	4.89	55.57
T_2	23.33	0.323	263.20	21.02	17.95	13.63	4.55	55.55
T_3	23.67	0.353	272.47	19.58	18.03	13.39	4.47	51.10
T_4	25.33	0.330	288.33	21.30	18.37	13.85	4.31	55.69
T_5	25.33	0.330	282.86	22.39	19.49	13.71	5.64	59.30
T_6	25.67	0.313	303.67	22.76	19.94	15.17	4.59	63.92
T_7	23.67	0.343	239.96	22.67	18.65	14.11	4.27	54.40
T_8	21.33	0.380	227.48	17.24	16.51	12.62	3.80	43.58
SEm±	0.42	0.012	4.04	0.34	0.14	0.08	0.06	1.94
CD (p=0.05)	1.27	0.037	12.26	1.04	0.42	0.24	0.19	5.87

Table 4: Effect of treatments on ascorbic acid, moisture content of fruits, days taken for ripening after harvest and shelf life of fruits at ambient condition

Treatments	Ascorbic acid (mg 100 g^{-1})	Moisture content (%)	Days taken for ripening (days)	Shelf life (days)
T_1	22.67	0.323	243.12	19.64
T_2	23.33	0.323	263.20	21.02
T_3	23.67	0.353	272.47	19.58
T_4	25.33	0.330	288.33	21.30
T_5	25.33	0.330	282.86	22.39
T_6	25.67	0.313	303.67	22.76
T_7	23.67	0.343	239.96	22.67
T_8	21.33	0.380	227.48	17.24
SEm±	0.42	0.012	4.04	0.34
CD (p=0.05)	1.27	0.037	12.26	1.04

3.3. Economic analysis

The highest net income was obtained from T_6 (₹ 656150 ha^{-1}) and it was on par with T_7 (₹ 637550 ha^{-1}). The lowest net returns were obtained from T_1 (₹ 206900 ha^{-1}). The highest

B:C ratio was recorded by T_6 (2.99) and it was significantly superior to all other treatments (Table 5).

Table 5: Effect of treatments on net income and BCR

Treatments	Net income (₹ ha^{-1})	BCR
T_1	206900	1.64
T_2	305150	1.95
T_3	211400	1.65
T_4	286025	1.88
T_5	452900	2.37
T_6	656150	2.99
T_7	637550	2.78
T_8	229775	1.72
SEm±	18957.31	0.06
CD (p=0.05)	15501.07	0.18

4. CONCLUSION

Although T_6 (45 g Nano-NPK in 6 splits) and T_7 (soil test-based POP recommendation in 6 splits) were on par in terms of the highest net income, the highest B:C ratio was observed in T_6. Conclude, the application of 45 g granular organic Nano-NPK in 6 splits along with 10 kg FYM and 100 g lime $plant^{-1}$ $year^{-1}$ significantly increased the yield and quality of banana cv. Nendran with high net income and BC ratio.

6. REFERENCES

Anonymous, 1975. Official and Tentative Methods of Analysis (12th Edn.). Association of Official Analytical Chemists, Washington, D.C., USA, 76.

Archith, T.C., Devappa, V., Mesta, R.K., Honnabyraiah, M.K., Rudresh, D.L., 2021. Survey on panama wilt disease (*Fusarium oxysporum* f. sp. cubense) of banana in Mysuru, Mandya and Chamarajanagar districts of Karnataka. International Journal of Economic Plants 8(2), 073–080.

Banger, K., Yuan, M., Wang, J., Nafziger, E.D., Pittelkow, C.M., 2017. A vision for incorporating environmental effects into nitrogen management decision support tools for U.S. maize. production. *Frontiers in Plant Science* 8, 1270. DOI 10.3389/fpls.2017.01270.

Bashir, I., Lone, F.A., Bhat, R.A., Mir, S.A., Dar, Z.A., Dar, S.A., 2020. Concerns and threats of contamination on aquatic ecosystems. In: Hakeem, K.R., Bhat, R.A., Qadri, H. (Eds.), Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation. Springer, Berlin, Germany, 1–26.

Bashma, E.K., Sudha, B. 2020. Integration of soil and foliar nutrition in influencing the yield related characters, yield and economics of Nendran banana (Musa AAB group) and the soil nutrient status of cropped field. Journal of Crop and Weed 16(1), 127–132.

De Rosa, M.C., Monreal, C., Schnitzer, M., Walsh, R., Sultan, Y., 2010. Nanotechnology in fertilizers. Nature Nanotechnology 5, 91.

Deepa, M., Sudhakar, P., Nagamadhuri, K.V., Reddy, K.B., Krishna T.G., Prasad, T.N.V.K.V., 2015. First evidence on phloem transport of nanoscale calcium oxide in groundnut using solution culture technique. Applied Nanoscience 5, 545–551.

Hinge, V.R., Shaikh, I.M., Chavhan, R.L., Deshmukh, A.S., Shelake, R.M., Ghuje, S.A., Dethe, A.M., Suprasanna, P., Kadam, U.S., 2022. Assessment of genetic diversity and volatile content of commercially grown banana (*Musa* spp.) cultivars. Scientific Reports 12, 7979. DOI https://doi.org/10.1038/s41598-022-11992-1.

Jubeir, S.M., Ahmed, W.A., 2019. Effect of nano fertilizers and application methods to yield characteristics of date palm. Plant Archives 19(1), 1881–1886.

Kalwani, M., Chakdar, H., Srivastava, A., Pabbi, S., Shukha, P., 2022. Effects of nano-fertilizers on soil and plant-associated microbial communities: Emerging trends and perspectives. Chemosphere 287(2), 132107.

Kumar, A., Singh, K., Verma, P., Singh, O., Panwar, A., Singh, T., Kumar, Y., Raliya, R., 2022. Effect of nitrogen and zinc nano-fertilizer with the organic farming practices on cereal and oil seed crops. Scientific Reports 12, 6938.

Lamassa, K., 2021. Performance evaluation of banana varieties, through farmer's participatory selection. International Journal of Fruit Science 21(1), 768–778.

Leonel, M., Bolfarini, A.C.B., da Silva, M.J.R., Souza, J.M.A., Leonel, S., 2020. Banana fruits with high content of resistant starch: Effect of genotypes and phosphorus fertilization. International Journal of Biological Macromolecules 150, 1020–1026.

Mandal, D., Lalrinchhani, 2021. Nano-fertilizer and its application in horticulture. Journal of Applied Horticulture 23(1), 70–77.

Manikandan, A., Subramanian, K.S., 2015. Evaluation of zeolite-based nitrogen nano-fertilizers on maize growth, yield and quality on inceptisols and alfisols. International Journal of Plant & Soil Science 9(4), 1–9.

Meghwal, M.L., Jyothi, M.L., Pushpalatha, P.B., Bhaskar, J., 2021. Yield and fruit quality of banana *Musa* (AAB) Nendran as influenced by nutrient sources. International Journal of Bio-resource and Stress Management 12(2), 131–136.

Modi, S., Kumar, S., Dubey, P.K., 2021. Dynamics of chitosan based NPK-nanofertilizers in greenhouse cucumber production system. Journal of Environmental Biology 42, 162–168.

Monreal, C.M., DeRosa, M., Mallubhotla, S.C., Bindraban P.S., Dimkpa, C., 2016. Nanotechnologies for increasing the crop use efficiency of fertilizer-micronutrients. Biology and Fertility of Soils 52, 423–437.

Mustaffa, M.M., Kumar, V., Tanuja Priya, B., Dhanasekhar, D., 2004. Influence of organic manure on growth and yield of banana. In: Proceedings of International Congress on Musa: Harnessing Research to Improve Livelihoods. Penang, Malaysia, 6–9 July.

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

Shang, H., Guo, H., Ma, C., Li, C., Chefetz, B., Polubesova, T., Xing, B., 2019. Maize (*Zea mays* L.) root exudates modify the surface chemistry of CuO nanoparticles: Altered aggregation, dissolution and toxicity. Science of The Total Environment 690, 502–510.

Sharma, S., Rana, V.S., Pawar, R., Lakra J., Racchapannavar, V., 2021. Nanofertilizers for sustainable fruit production: a review. Environmental Chemistry Letters 19: 1693–1714

Sreedharan, S., Shekhawat, U.K., Ganapathi, T.R., 2013. Transgenic banana plants overexpressing a native plasma membrane aquaporin *MusaPIP1;2* display high tolerance levels to different abiotic stresses. Plant Biotechnology Journal 11, 942–952.

Tarafdar, J.C., Raliya, R., Mahawar, H., 2014. Development of zinc nano-fertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). Agricultural Research 3(3), 257–262.

Thangaselvabai, T., Justin, C.G.L., Johnson, S.B.N., Jayasekhar, M., 2009a. Influence of nutrients on the quantitative and qualitative traits of banana. Indian Journal of Agricultural Research 43(4), 274–278.

Thangaselvabhai, T., Suresh, S., Joshua, P.J., Sudha, K.R., 2009b. Banana nutrition- A review. Agricultural Reviews 30(1), 24–31.

Thangavelu, R., Saraswathi, M.S., Uma, S., Loganathan, M., Backiyarani, S., Durai, P., Raj, E.E., Marimuthu, N., Kannan, G., Swennen, R., 2021. Identification of sources resistant to a virulent Fusarium wilt strain (VCG 0124) infecting Cavendish bananas. Scientific Reports 11(1), 1–14.

Tisdale, S.L., Nelson, W.L., 1966. Soil fertility and fertilizers. Soil Science 101(4), 346.

Tomer, A.K., Prasad, V.M., Bahadur, V., Topno S.E., 2021. Effect of organic manures and inorganic fertilizers on vegetative growth of Banana (Musa spp) cv. Poovan (AAB Group). The Pharma Innovation Journal 10(9), 2047-2055.

Umar, W., Czinkota, I., Gulyas, M., Aziz, T., Hameed, M.K., 2022. Development and characterization of slow release N and Zn fertilizer by coating urea with Zn fortified nano-bentonite and ZnO NPs using various binders. Environmental Technology and Innovation 26, 102250.

Van Asten, P., Fermont, A.M., Taulya, G., 2011. Drought is a major yield loss factor for rainfed East African highland banana. Agricultural Water Management 98(4), 541–552.

Veronica, N., Thatikunta, R., Reddy, N.S., 2014. Crop nutrition management with nano-fertilizers. International Journal of Environmental Science and Technology 14(1), 4–6.

Wardhan, H., Das, S., Gulati, A., 2022. Banana and mango value chains. In: Gulati, A., Ganguly, K., Wardhan, H. (Eds.), Agricultural value chains in India. Springer, Singapore, 99–143.

Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N.A., Bosch, S.M., 2019. Nano-fertilizer use for sustainable agriculture: Advantages and limitations. Plant Science 289, 110270.