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Effect of nano-fertilizers and gluconates on fruit set and yield of mango (*Mangifera indica* L.) cv. Banganpalli

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Abstract

An experiment was conducted to study the effect of nano-fertilizers and gluconates on fruit set and yield of mango (*Mangifera indica* L.) cv. Banganpalli at Fruit Research station, Sangareddy, Telangana. The experiment was carried out with factorial randomized block design with two factors and 15 treatments, first factor includes macronutrients nano N and K with different concentrations (M₁-Nano N&K -2ml/l, M₂-Nano N&K -4ml/l and M₃-KNO₃-10g/l) and second factor includes micronutrients in the form of nano and gluconates at different concentrations (N₁- Nano Zn+Fe+B+Mg-2ml/l, N₂- Nano Zn+Fe+B+Mg-4ml/l, N₃-Zn+Fe+B+Mg gluconates-2ml/l, N₄- Zn+Fe+B+Mg gluconates-4ml/l and N₅- Micronutrient's mix-2g/l). Selected mango trees were foliar sprayed twice with all the nutrients before flowering and at marble stage. Among different concentrations of nano N and K, nano N & K-2ml/l (M₁) has resulted in 36% significantly increased fruit yield which might be due to increased fruit set (6.58%), fruit weight (386.8 g) and number of fruits/tree (151.1) compared to KNO₃-10g/l (M₃) followed by nano N & K-4ml/l (M₂) and least was recorded by KNO₃-10g/l (M₃). Among micro-nutrients (Zn+Fe+B+Mg), nano (Zn+Fe+B+Mg)-2ml/l (N₁) has resulted in 12.7% significantly increased fruit yield which might be due to increased fruit set (6.14%), and number of fruit tree⁻¹ (136.0) compared to N₅ micronutrient's mix and least was recorded by N₅ micronutrient's mix. Among interactions nano N&K-2 ml/l + nano Zn+Fe+B+Mg)-2ml/l (M₁N₁) has resulted in 51% significantly higher yield which might be due to increased fruit set (6.81%), fruit weight (424.3 g) and number of fruit tree⁻¹ (161.6) compared to (M₃N₅) followed by M₁N₄ - nano N & K at 2ml/l along with (Zn+Fe+B+Mg) gluconates and least was recorded by M₃N₅ - KNO₃-10g/l and micro-nutrient mix.

Keywords: Mango, nano-fertilizers, gluconates, yield, fruit set

Introduction

Mango (*Mangifera indica* L.) is the king of fruits, and belongs to the family Anacardiaceae. It is considered one of the most important tropical fruit of the world. Originated in South East Asia. Mango holds special importance in India due to its origin, attachment to culture, heritage, unique taste, exotic flavour, its nutrition and extensive cultivation and it also widely accepted by other parts of the world.

In present agriculture world use of general conventional fertilizers increasing day by day even though they are not able to produce expected yields as these fertilizers undergo inversion to soluble forms in soil they are not completely accessible to plants, these demand us for repeated and increased use of fertilizers (Correll 1998; Conley *et al.*, 2009) ^[7, 6]. This repeated use of nitrogen, phosphorus and potassium resulted in imbalance in fertilization, decrease in soil organic manure and leading to a major problem *i.e.*, eutrophication (Kumar *et al.*, 2020) ^[22]. Now it's time to handle with such situations by introducing and developing the use of some smart materials which are capable of releasing nutrients to specific targeted sites in plants without affecting natural soil structure. In the field of agriculture with lot of innovations and advancements, a technology called nanotechnology has been developed to provide effective solution for multiple agriculture related problems and to address the increasing challenges of sustainable production. This nano technology created a great scientific interest and also bridges the gap between general bulk materials and other molecular structures.

Nano technology includes materials that are smaller than 100nm, at least in one dimension, these nano-particles are aimed to deliver the nutrients at targeted point, make nutrients available to

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leaves and increases nutrient use efficiency (Kumar *et al.*, 2021) [23]. Nanoparticles covers a large specific area, effective delivery of the required nutrients, more rapid plant response to with only limited use of nutrients and without any wastage compared to bulky materials (Nabil *et al.*, 2020) [29]. Nanoparticles can be easily made into suspensions as the nanoparticles interaction with solvent is very strong such that it can overcome density differences, which otherwise usually result in a material either sinking or floating in a liquid. These nanoparticles exhibit antibacterial, anti-corrosive, antifungal and UV filtering properties (Dubey *et al.*, 2019) [11]. Nano fertilizers are produced by nutrient fortification either singly or in combinations on the adsorbents with nano-dimension. Indian farmers fertilizer cooperative Limited (IFFCO) - the farmer's own fertilizer cooperative has been at the forefront of the promotion of agro-technologies and novel agri-inputs to mitigate problems faced by the farmers (Kumar *et al.*, 2021) [23]. It has indigenously innovated and manufactured nano-fertilizers viz. nano urea, nano zinc and nano copper, other micronutrients based nano-fertilizers are also manufactured by different private agricultural companies.

Among various organic acids, gluconic acid is the major one produced by phosphate solubilization by gram-negative bacteria. Gluconic acid is produced by the oxidative metabolism of glucose by dehydrogenase enzyme through microbial fermentation with different types of *Aspergillus niger* strains. Gluconic acid and its salts (gluconates) are being used extensively as chelating micronutrient agents in agriculture presently as they are suitable for soil or foliar applications and also suitable for drip irrigation. The chelated micronutrients of gluconates are required in lower quantities as compared to inorganic compounds as they are completely assimilated by crops (Elisha *et al.*, 2014; Prasanna *et al.*, 2022) [13, 31]. These micronutrient chelated gluconic acid are available in different forms like calcium gluconate, ferrous gluconate, potassium gluconate, zinc gluconate, magnesium gluconate, manganese gluconate and sodium gluconate.

Depiction of important phenophases in mango

BBCH 510 - Buds closed and covered with green or brownish scales
BBCH 610 - First flower open
BBCH 615 - Full flowering: more than 50% of panicle flowers open
BBCH 701 - Fruits at 10% of final size, styles still visible, Beginning of physiological fruit drop
BBCH 703 - Fruits at 30% of final size, end of physiological fruit drop
BBCH 705 - Fruits at 50% of final size
BBCH 709 - Fruits at standard cultivar size, shoulders fully developed
BBCH 800 - Physiological maturity: fruits fully developed (Shailendar Rajan <i>et al.</i> 2011)

Methodology

Flowering scenario of mango cv. Banganpalli in Telangana conditions

In Telangana, Banganpalli is the choicest variety of mango in which flower bud differentiation occurs in November-December, comes to flowering in December-January because night temperatures will be 15°C or less in December-January. In mango, flowering is a complex process that involves differentiation of apical buds under the influence of low temperature and/or attaining of certain degree of shoot maturity followed by bud burst and panicle emergence (Davenport, 2007) [8].

Selection of Orchard

A 15 years old, well-grown, uniform-statured tree of mango cv. Banganpalli were selected for this experiment. The trees were

Keeping the above information in view, the present investigation was proposed to study the “Effect of nano-fertilizers and gluconates on fruit set and yield of mango (*Mangifera indica* L.) cv. Banganpalli” with the following objectives:

Objective

To study the effect of nano-fertilizers and gluconates on fruit set and yield of mango (*Mangifera indica* L.) cv. Banganpalli.

Materials and Methods

The present investigation “Effect of nano-fertilizers and gluconates on fruit set and yield of mango (*Mangifera indica* L.) cv. Banganpalli” was carried out during 2021-23 at Fruit Research Station, Sangareddy, SKLTSHU, Telangana state. The climate of Sangareddy is a sub-tropical, semi-arid and dry climate.

Table 1: Properties of experimental soil.

Particulars	Values
Texture class	Red sandy loam
pH	6.87
Electrical conductivity (dS m ⁻¹ at 25°C)	0.26
Organic carbon (%)	0.82
Availabale N (Kg ha ⁻¹)	212.22
Availabale P ₂ O ₅ (Kg ha ⁻¹)	19.02
Availabale K ₂ O (Kg ha ⁻¹)	250.81

Table 2: Initial leaf NPK and micro-nutrients (Zn, Fe, B, Mg) content of experimental plants

Particulars	Values
Nitrogen (N %)	0.75
Phosphorus (P %)	0.14
Potassium (K %)	0.77
Zinc (ppm)	40.08
Iron (ppm)	125.36
Boron (ppm)	76.29
Magnesium (%)	0.77

spaced at 8 X 8 and planted in a square system.

Method of preparation of nutrient solutions

a. Nano N & K (13:45)

Nano N & K (13:45) formulation has 13 parts of nano nitrogen particles and 45 parts of nano potassium particles, 2ml and 4ml of nano N & K are prepared by diluting 2ml and 4ml of nano N & K in one liter of water respectively, ten liters of water was used for one mango plant (*i.e.*, 20ml/10l and 40ml/10l of water).

b. Nano Zn+Fe+B+Mg (5:2:2:3)

For the preparation of 2ml and 4ml of nano micronutrients mix 2 ml and 4ml of nano micronutrients mix is diluted in one liter of water respectively, ten liters of water was used for one mango plant (*i.e.*, 20ml/10l and 40ml/10l of water).

c. Zn+Fe+B+Mg (5:2:2:3) Gluconate

For the preparation of 2ml and 4ml of micronutrients gluconate 2ml and 4ml of micronutrients gluconate are diluted in one liter of water respectively, ten liters of water was used for one mango plant (i.e., 20ml/10l and 40ml/10l of water).

d. KNO₃

For the preparation of 10g/l of KNO₃ 10g of KNO₃ is dissolved in one liter of water, and ten liters of water was used for one mango plant (i.e., 100g/10l of water).

e. Micronutrient mix

For the preparation of 2g/l of micronutrient mix, 2g of it is dissolved in one liter of water, and ten liters of water was used for one mango plant (i.e., 20g/10l of water).

Method and time of application of nutrients

Foliar application of nutrients are applied through tractor mounted sprayer covering both the upper and lower sides of leaves thoroughly with fine mist on a clear sunny day.

- Potassium nitrate spray was used for bud break in mango cv. Banganpalli, hence it is sprayed before panicle initiation i.e., before flower bud differentiation in 2nd fortnight of November and also at marble stage of fruits.
- In present study nano N and K is also used to see its effect on bud breaking, thus it is also sprayed before panicle initiation i.e., before flower bud differentiation in 2nd fortnight of November and also at marble stage of fruits.
- Micronutrients especially zinc and boron also plays important role in flower initiation and fruit set thus nano Zn+Fe+B+Mg and Zn+Fe+B+Mg gluconates are sprayed in December and also at marble stage of fruit.

Percent fruit set (at peanut stage)

An average of 25 fruited panicles was considered for calculating the fruit set percent (fruits at peanut size). The percentage of fruit set was calculated by taking into account the number of fruits at initial fruit set and the number of fruits at the peanut stage in the panicles (Ram *et al.*, 2020) [32].

Number of fruits tree⁻¹ (at the time of harvest)

The matured fruits were harvested from each tree and the number has recorded at each harvest. The total number of fruits harvested at different intervals was added to calculate the number of fruits per tree (Vijay Krishna, 2019) [42].

Yield tree⁻¹ (kg)

The weight of fruits per tree at each harvest was recorded by using a manual weighing balance and the yield per plant was calculated by adding the weight of each harvest (Vijay Krishna, 2019) [42].

Results and Discussion**Percent fruit set (at peanut stage)**

The results of the percent fruit set with the application of nano-fertilizers and gluconates are presented in Table 3.

The pooled data revealed that there is a significant difference among different concentrations of nano N & K with respect to panicle length. In the present investigation the maximum percent fruit set was recorded in trees sprayed with M₁ - nano N & K at 2ml/l (6.58%) followed by M₂ - nano N & K at 4ml/l (5.69%) and the minimum percent fruit set was recorded by trees sprayed with M₃ - KNO₃-10g/l (5.23%). In the present study, the application of M₁ - nano N & K at 2ml/l has resulted in a

significantly 20.5% increase in the percent fruit set compared to M₃ - KNO₃-10 g/l. Nitrogen fertilization before and during flowering stimulates different enzymes which increase the translocation and mobilization of metabolites and photosynthates towards the developing parts of the plant which improves plant growth, flowering, percent fruit set, etc (Kumar *et al.*, 2020) [22]. This increase in fruit set percent by foliar spray of nano N and K-2ml/l might be due to increased leaf NPK (1.26%N, 0.13%P and 0.87%K) (Table 4) during flowering, fruiting and efficient utilization of nutrients. Similar results of increased leaf nutrient absorption and high percent fruit set were reported by Osama and Mohammad (2017) [30] in mango and Rahman *et al.* (2021) [33] in strawberry with use of nano-fertilizers.

Micro-nutrients in the form of nano-fertilizers and gluconates significantly influenced the percent fruit set in mango. The maximum percent fruit set was recorded with N₁ - nano (Zn+Fe+B+Mg)-2 ml/l (6.14%) followed by N₄ - (Zn+Fe+B+Mg) gluconates-4ml/l (5.94%) and minimum percent fruit set was seen in trees sprayed with N₅ - micronutrient's mix (5.56%). In the present study application of N₁ - nano (Zn+Fe+B+Mg)-2ml/l increased panicle length by 9.5% compared with N₅ - micronutrient mix. This increase in fruit set percent might be due to increased leaf Zn+Fe+B+Mg content (40.79ppm Zn and 24.4 ppm, 71.86ppm B and 0.76% Mg) (Table 5). A similar increase in the percent fruit set was recorded by Abd El-Razek *et al.* (2017) [1] in mango cv. Ewais when sprayed with nano micro-nutrients compared to normal.

Each micro-nutrient has a specific function that plays an important role in flowering and fruiting, zinc plays an important role in flowering by helping in the synthesis of tryptophan, an auxin precursor and in the translocation of metabolites to the site of bud development or the bud itself (Usenik and Stampar, 2002) [41]. Spraying Fe enhances the photosynthesis process and improves carbohydrate translocation to different parts of the plant which improves fruit set per plant. Similar results of increasing percent fruit set were seen in Washington navel orange by El-Gioushy *et al.* (2021) [12] and in apple by Aly *et al.* (2022) [3] when sprayed with nano micro-nutrients. Foliar spray of boron is likely beneficial for fruit set as it plays essential roles in pollen tube formation, elongation and pollen grain germination as boron is rapidly absorbed by flowers (Sarrwy *et al.*, 2012) [39] and it improves the fruit set and development or other metabolic processes such as carbohydrate transport, which are enhanced by its application (Marschner, 2012) [26].

A significant difference was observed in the interaction effect between nano macro-nutrients and micro-nutrients in the form of nano-fertilizers and gluconates. Spraying of M₁N₁ - nano N & K at 2ml/l in combination with nano (Zn+Fe+B+Mg)-2ml/l recorded maximum percent fruit set (6.81%) followed by M₁N₃ - nano N & K at 2ml/l in combination with (Zn+Fe+B+Mg) gluconates-2ml/l (6.58%) and minimum percent fruit set was seen in trees sprayed with M₃N₅ - KNO₃-10g/l in combination with micronutrient's mix-2g/l (4.89%). In this study M₁N₁ - nano N & K at 2ml/l in combination with nano (Zn+Fe+B+Mg)-2ml/l recorded 28.2% increase in fruit set percent compared to M₃N₅ - KNO₃-10g/l in combination with micronutrient's mix-2g/l, this might be due to combined effect of both nano macro and micro-nutrients on percent fruit set. This increase in percent fruit set during at marble stage may be due to synergistic effect of spraying both nano macro and micro nutrients and an increase in leaf NPK and Zn+Fe+B+Mg content (1.28%N, 0.13%P and 0.89% K) and (42.92ppm Zn, 130.4ppm Fe, 85.67ppm B and 0.78% Mg) during flowering and fruiting. A similar result was

reported of increased leaf nutrient absorption and fruit set by James and Prasad (2020)^[21] in phalsa when sprayed with nano N, K and zinc and in Washington navel orange by El-Gioushy *et al.* (2021)^[12] and in apple by Aly *et al.* (2022)^[3] when sprayed with nano micro-nutrients.

Number of fruits tree⁻¹

The results on the total number of fruits per tree with the application of nano-fertilizers and gluconates are presented in Table 3 and Fig 2.

The pooled data revealed that different concentrations of nano N & K have shown statistically significant differences with respect to the number of fruits per tree cv. Banganpalli. In the present investigation the maximum number of fruits per tree was recorded in trees sprayed with M₁ - nano N & K at 2ml/l (151.4) followed by M₂ - nano N & K at 4ml/l (131.6) and a minimum number of fruits per tree was recorded by trees sprayed with M₃ - KNO₃-10g/l (115.4). N and K when applied before and during flowering might stimulate the functioning of many enzymes which in turn increase the translocation and mobilization of metabolites and photosynthates towards the developing fruits which increases fruit number per plant. Hasani *et al.* (2016)^[18] have reported that pomegranate trees have recorded an increased number of fruits per tree with foliar nano N fertilization as foliar nano sprays are insensitive to nutrient absorption with low activity of roots and low temperature around roots, unlike soil application of roots. Similar results of increasing number of fruits per plant after application of nano N and K in mango was recorded by Malshe *et al.* (2018)^[25], Sarkker and Rahim (2013)^[28], El-Otmani *et al.* (2022)^[14] in citrus, Amiri *et al.* (2008)^[4] in apple, James and Prasad (2020)^[21] in phalsa, Mitre *et al.* (2012)^[28] in sweet cherry, and Davarpanah *et al.* (2017)^[10] in pomegranate (62.8 and 70.1/tree).

The trees sprayed with M₁ - nano N & K at 2ml/l significantly increased 24% higher number of fruits as compared to M₃ - KNO₃-10g/l. The increase in number of fruits per tree by application of nano N & K - 2ml/l may be due to greater absorption into leaf NPK (1.26%N, 0.13%P and 0.87%K) (Table 4) during flowering and fruiting and increased fruit set percent (6.58%) (Table 3) compared to M₃ - KNO₃-10g/l. A similar increase in the total number of fruits per tree with lower and safer concentrations of nano fertilizers was earlier reported by Elsheery *et al.* (2020)^[16] in the mango cultivar 'Ewais'. Hussein *et al.* (2018)^[20] reported that spraying of nano NPK increased the number of mango fruits by 32% compared with control. Similar results were also reported by James and Prasad (2020)^[21] in phalsa.

Micro-nutrients in the form of nano-fertilizers and gluconates significantly influenced number of fruits per tree in mango. A maximum number of fruits was recorded with N₁ - nano (Zn+Fe+B+Mg)-2ml/l (136) which was on par with N₄ - (Zn+Fe+B+Mg) gluconates-4ml/l (135.5) and a minimum number of fruits per tree was seen in trees sprayed with N₅ - micronutrient's mix (128). Increase in number of fruits might be due to spraying of Zinc and Boron involved in auxin synthesis and translocation of starch to fruits. Zinc maintain balance of auxin in plant regulates the fruit drop or retention in plants, which altered the control of fruit drop and increased the total number of fruits per tree. Iron enhance the photosynthesis process and improve the translocation of carbohydrates to different parts of the plant in turn plant records improved flowering and fruiting (El-Gioushy *et al.*, 2021)^[12].

The present study emphasized that N₁ - nano (Zn+Fe+B+Mg)-2ml/l, has significantly increased 6.5% more number of fruits as

compared to the common N₅ -micronutrient mix. Further, this increase in the number of fruits per by application of nano (Zn+Fe+B+Mg)- 2 ml/l may be due to increased leaf nutrient absorption of content (40.79 ppm Zn and 24.4ppm Fe, 71.86ppm B and 0.76% Mg) (Table 5) which helps in increased fruit set percent (5.96%) (Table 4) and resulted in maximum number of fruits per tree compared to N₅ - micronutrient's mix. Similar results were earlier reported by Osama and Gad (2017)^[30] in the mango cultivar 'Ewasy' where trees treated with nano zinc have a maximum number of fruits per tree compared to untreated trees. A similar result was found by Shalaby *et al.* (2022)^[40] in bananas.

A significant difference was observed in the interaction effect between nano macro-nutrients and micro-nutrients in the form of nano-fertilizers and gluconates. Spraying of M₁N₁ - nano N & K at 2ml/l in combination with nano (Zn+Fe+B+Mg)-2ml/l recorded maximum number of fruits per tree (161.6) followed by M₁N₄ - nano N & K at 2ml/l in combination with (Zn+Fe+B+Mg) gluconates-4ml/l (153) and minimum number of fruits per tree was seen in trees sprayed with M₃N₅ - KNO₃-10g/l in combination with micronutrient's mix-2g/l (106), this might be due to combined effect of both nano macro and micro-nutrients on fruits formation and development. Reports of Hmamam *et al.* (2021)^[19] on mango are in close conformity with our results and Saini *et al.* (2021)^[36] on strawberries.

The treatment with interaction of nano N & K at 2ml/l and nano (Zn+Fe+B+Mg)-2ml/l has significantly increased 34% higher number of fruits per tree KNO₃-10g/l in combination with micronutrient's mix-2g/l. Further N & K at 2ml/l in combination with (Zn+Fe+B+Mg) gluconates-2ml/l is also on par with nano N & K at 2ml/l and nano (Zn+Fe+B+Mg)-2ml/l with 33% more number of fruits per tree. Higher total number of fruits per tree with nano M₁N₁ - N & K at 2ml/l and nano (Zn+Fe+B+Mg)-2ml/l might be due to synergistic effect of spraying nano macro and micro-nutrients and increased leaf leaf NPK and Zn+Fe+B+Mg content (1.28%N, 0.13%P and 0.89% K) and (42.92ppm Zn, 130.4ppm Fe, 85.67ppm B and 0.78% Mg) during flowering and fruiting and percent fruit set (6.81; Table 3) which is directly proportional to increased number of fruits per tree compared to M₃N₅ - KNO₃-10g/l. Hussaien *et al.* (2018)^[20] in Keitte mango trees have recorded improved growth and number of fruits per tree over control with the spraying of nano NPK and Mg at 0.1%. Similar results of increased leaf nutrient absorption and increased number of fruits per tree with a combination of nano macronutrients and micronutrients (nano NPK and Mg) were reported earlier by Rasha *et al.* (2019)^[35] in flame seedless grape.

Yield per tree (kg tree⁻¹)

The results on yield per tree with application of nano-fertilizers and gluconates are presented in Table 3 and Fig 2.

The pooled data revealed that different concentrations of nano N & K have shown statistically significant differences with respect to yield per tree. In the present investigation the maximum yield per tree was recorded in trees sprayed with nano M₁ - N & K at 2ml/l (58.84 kg) followed by nano M₂ - N & K at 4ml/l (46.03 kg) and the minimum percent fruit set was recorded by trees sprayed with M₃ - KNO₃-10g/l (37.55 kg). Hasani *et al.* (2016)^[18] have reported that pomegranate trees have recorded an increased number of fruits per tree and fruit yield with foliar nano N fertilization as foliar nano sprays are insensitive to nutrient absorption with low activity of roots and low temperature around roots, unlike soil application of roots. Nitrogen fertilization in plants improves flowering and fruit set

including the supply of carbohydrates which are necessary for flower bud growth, flower initiation, development, pollination and fertility (Anwar and Lovatt, 1994) [5]. As potassium is a mobile nutrient it is well adapted as foliar fertilizer because it is rapidly translocated from the leaves to other parts of the plant and consequently increases yield (Alebidi *et al.*, 2021) [2], El-Salhy *et al.*, 2021 [15] in date palm, Gad *et al.*, 2021 [17] in Ewais mango

The trees sprayed with M₁ - nano N & K at 2ml/l have significantly increased 36% yield per tree as compared to M₃ - KNO₃-10g/l. The increase in yield per tree by application of nano N & K - 2ml/l may be due to greater absorption into leaf NPK (1.26%N, 0.13%P and 0.87%K) (Table 4) during flowering and fruiting, increased fruit set percent (6.58%) (Table 3), increased number of fruits per tree (151.4; Table 3) during harvest *i.e.*, BBCH-800 phenophase compared to M₃ - KNO₃-10g/l. A similar increasing trend of yield with foliar N fertilization was recorded by Sarker and Rahim. (2013) [38] in mango, Alebidi *et al.* (2021) [2] in date palm, Sajid *et al.* (2022) [37] in pear, (El-Otmani *et al.*, 2002: Anwar and Lovatt, 1999) [14, 5] in citrus, Amiri *et al.* (2008) [4] in apple, Mitre *et al.* (2012) [28]. Similar results with spraying of nano NPK and Mg at 0.1% in Keitte mango were recorded by Hussien *et al.* (2018) [20], a 17% to 44% increase in fruit yield in pomegranate by Davarpanah *et al.* (2017) [10], Rahman and Elkarim (2022) [34] in date palm.

Micro-nutrients in the form of nano-fertilizers and gluconates significantly influenced yield per tree in mango. Maximum yield per tree was recorded with N₁ - nano (Zn+Fe+B+Mg)-2ml/l (51.19 kg) followed by N₄ - (Zn+Fe+B+Mg) gluconates-4ml/l (49.43 kg) and minimum yield per tree was seen in trees sprayed with N₅ - micronutrient's mix (44.73 kg). Nano zinc along with nano silicon improves tree resistance, crop load and fruit quality under salinity stress in mango (Elsheery *et al.*, 2020) [16]. Osama *et al.* (2017) [30] 0.5 g/l and 1g/l nano zinc gave significantly the highest yield in mango. Foliar application of nano micro-nutrients has a positive effect on leaf mineral content increasing fruit number per tree and fruit yield in Eawais mango (Abd El-Razek *et al.*, 2017) [1]. Similar results with spraying of nano zinc 0.4ppm increased total carbohydrates, number of clusters, cluster weight and yield in grape (Rasha *et al.*, 2019) [35], in phalsa (James and Prasad, 2020) [21], A single foliar spray of nano zinc and boron led to increase in pomegranate fruit yield (Davarpanah *et al.*, 2016) [9], Rahman *et al.* (2021) [33] in

strawberry, 48.3% increase in strawberry yield (Saini *et al.*, 2021) [36].

The present study emphasized that N₁ - nano (Zn+Fe+B+Mg)-2ml/l, has significantly increased by 12.7% more number of fruits as compared to the common N₅ -micronutrient mix, this increase in the number of fruits per by application of nano (Zn+Fe+B+Mg)- 2ml/l may be due to increased leaf nutrients Zn+Fe+B+Mg (40.79ppm Zn and 24.4ppm Fe, 71.86ppm B and 0.76% Mg) (Table 5), increased fruit set percent (5.96%) (Table 3), maximum number of fruits per tree (136; Table 3), during harvest *i.e.*, BBCH-800 phenophase compared to N₅ - micronutrient mix. Application of nano iron increases by 32% of yield compared to control in Washington navel orange by enhancing photosynthesis processes and improving carbohydrate translocation to different parts of the plant (El-Gioushy *et al.*, 2021) [12], Aly *et al.* (2022) [3] in apple.

A significant difference was observed in the interaction effect between nano macro-nutrients and micro-nutrients in the form of nano-fertilizers and gluconates with respect to yield per tree. Spraying of M₁N₁ - nano N & K at 2ml/l in combination with nano (Zn+Fe+B+Mg)-2ml/l recorded maximum yield per tree (68.15 kg) followed by nano M₁N₄ - N & K at 2ml/l with (Zn+Fe+B+Mg) gluconates-4ml/l (58.78 kg) and minimum yield per tree was seen in trees sprayed with M₃N₅ - KNO₃-10g/l in combination with micronutrient's mix-2g/l (33.29 kg). The treatment with interaction of M₁N₁ - nano N & K at 2ml/l and nano (Zn+Fe+B+Mg)-2ml/l has significantly increased 51% of yield per tree when compared with M₃ x N₅ - KNO₃-10g/l in combination with micronutrient's mix-2g/l. Higher total number of fruits per tree with nano M₁N₁ - N & K at 2ml/l and nano (Zn+Fe+B+Mg)-2 ml/l might be due to the combined effect of both nano macro and micro-nutrients, increased leaf NPK and Zn+Fe+B+Mg content (1.35%N, 0.15%P and 0.92% K) and (44.38ppm Zn, 130.8ppm Fe, 85.87ppm B and 0.78% Mg) (Table 5) during flowering and fruiting, maximum percent fruit set (6.81%) (Table 3), maximum number of fruits per tree (161.6) (Table 3) respectively during harvest *i.e.*, BBCH-800 phenophase as fruit yield increases with increase in fruit weight and fruit volume compared with M₃ x N₅ - KNO₃-10g/l. These results are in close conformity with the findings of Osama *et al.* (2017) [30] in mango which recorded increased yield due to increased leaf nutrient absorption by use of nano nutrients and Rahman and Elkarim (2022) [34] in date palms.

Table 3: Effect of nano-fertilizers and gluconates on percent fruit set, Number of fruits/tree and Yield/ tree of mango (*Mangifera indica* L.) cv.Banganpalli.

Macro nutrients	Micro nutrients																	
	Percent fruit set (at peanut stage)						Number of fruits tree ⁻¹ (at harvest)						Yield tree ⁻¹ (kg)					
	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean
M ₁	6.81	6.48	6.58	6.43	6.58	6.58 ^a	161.6	148.6	145.1	153.0	148.5	151.4 ^a	68.15	49.68	52.82	64.76	58.78	58.84 ^a
M ₂	6.09	5.95	5.29	5.92	5.20	5.69 ^b	128.3	134.6	130.1	135.4	129.5	131.6 ^b	47.27	50.99	44.77	44.97	42.13	46.03 ^b
M ₃	5.53	5.10	5.19	5.46	4.89	5.23 ^c	118.1	115.0	120.0	118.1	106.0	115.4 ^c	38.16	39.18	38.57	38.56	33.29	37.55 ^c
Mean	6.14 ^a	5.84 ^c	5.68 ^d	5.94 ^b	5.56 ^e		136.0 ^a	132.7 ^b	131.7 ^b	135.5 ^a	128.0 ^c		51.19 ^a	46.62 ^c	45.38 ^d	49.43 ^b	44.73 ^e	
	S.Em±			CD at 5%			S.Em±			CD at 5%			S.Em±			CD at 5%		
M	0.021			0.062			0.219			0.636			0.187			0.543		
N	0.027			0.080			0.283			0.822			0.242			0.701		
M X N	0.048			0.139			0.491			1.423			0.419			1.215		

Macronutrients Micronutrients

M₁- Nano N & K (13:45) - 2ml/l N₁- Nano Zn+Fe+B+Mg (5:2:2:3) - 2ml/l

M₂- Nano N & K (13:45) - 4ml/l N₂- Nano Zn+Fe+B+Mg (5:2:2:3) - 4ml/l

M₃- KNO₃ @ 10g/l N₃- Zn+Fe+B+Mg (5:2:2:3) Gluconates - 2ml/l

N₄- Zn+Fe+B+Mg (5:2:2:3) Gluconates - 4ml/l

N₅- Micronutrient's mix (4%Fe+3%Mn+6%Zn+1% Cu+0.05%Mo+2%B) - 2g/l

Table 4: Effect of nano-fertilizers and gluconates on leaf nitrogen, phosphorus, potassium (%) of mango (*Mangifera indica* L.) cv. Banganpalli at BBCH-703 and at final fruit harvest stage

Treatments	BBCH-703																	
Macro nutrients	Micro nutrients																	
	Nitrogen						Phosphorus						Potassium					
	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean
M ₁	1.35	1.27	1.23	1.28	1.19	1.26 ^b	0.15	0.13	0.12	0.13	0.11	0.13 ^b	0.92	0.87	0.86	0.89	0.80	0.87 ^b
M ₂	1.57	1.53	1.52	1.56	1.32	1.50 ^a	0.20	0.19	0.17	0.19	0.17	0.18 ^a	1.08	0.99	0.95	1.03	0.94	0.99 ^a
M ₃	0.96	0.93	0.92	0.94	0.89	0.93 ^c	0.11	0.10	0.09	0.11	0.08	0.10 ^c	0.83	0.67	0.62	0.78	0.66	0.71 ^c
Mean	1.30 ^a	1.25 ^c	1.22 ^d	1.26 ^b	1.14 ^e		0.15 ^a	0.13 ^c	0.12 ^d	0.14 ^b	0.11 ^e		0.94 ^a	0.84 ^c	0.81 ^d	0.90 ^b	0.80 ^e	
	S.Em±			CD at 5%			S.Em±			CD at 5%			S.Em±			CD at 5%		
M	0.001			0.004			0.001			0.004			0.001			0.004		
N	0.002			0.005			0.002			0.005			0.002			0.005		
M X N	0.003			0.008			0.003			0.009			0.003			0.009		
Treatments	Final fruit harvest stage																	
Macro nutrients	Micro nutrients																	
	Nitrogen						Phosphorus						Potassium					
	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean
M ₁	1.24	1.22	1.16	1.19	1.12	1.18 ^b	0.12	0.11	0.10	0.12	0.10	0.10 ^a	0.92	0.85	0.84	0.87	0.77	0.85 ^b
M ₂	1.41	1.30	1.30	1.36	0.97	1.27 ^a	0.16	0.15	0.14	0.16	0.14	0.14 ^b	1.06	0.95	0.91	1.01	0.81	0.95 ^a
M ₃	0.96	0.86	0.81	0.91	0.80	0.87 ^c	0.08	0.06	0.06	0.07	0.05	0.06 ^c	0.74	0.58	0.56	0.68	0.54	0.62 ^c
Mean	1.20 ^a	1.13 ^c	1.09 ^d	1.15 ^b	0.96 ^e		0.12 ^a	0.10 ^c	0.09 ^d	0.11 ^b	0.09 ^d		0.91 ^a	0.79 ^c	0.77 ^d	0.85 ^b	0.71 ^e	
	S.Em±			CD at 5%			S.Em±			CD at 5%			S.Em±			CD at 5%		
M	0.001			0.004			0.001			0.004			0.001			0.004		
N	0.002			0.005			0.002			0.006			0.002			0.005		
M X N	0.003			0.008			0.003			0.010			0.003			0.008		

Macronutrients MicronutrientsM₁- Nano N & K (13:45) - 2ml/l N₁- Nano Zn+Fe+B+Mg (5:2:2:3) - 2 ml/lM₂- Nano N & K (13:45) - 4ml/l N₂- Nano Zn+Fe+B+Mg (5:2:2:3) - 4 ml/lM₃- KNO₃ @ 10g/l N₃- Zn+Fe+B+Mg (5:2:2:3) Gluconates - 2ml/lN₄- Zn+Fe+B+Mg (5:2:2:3) Gluconates - 4ml/lN₅- Micronutrient's mix (4%Fe+3%Mn+6%Zn+1% Cu+0.05%Mo+2%B) - 2g/l**Table 5:** Effect of nano-fertilizers and gluconates on leaf zinc, Iron, Boron, Magnesium (ppm) of mango (*Mangifera indica* L.) cv. Banganpalli at BBCH-703 and at final fruit harvest stage

Treatments	BBCH-703																							
Macro nutrients	Micro nutrients																							
	Zinc						Iron						Boron						Magnesium					
	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean	N ₁	N ₂	N ₃	N ₄	N ₅	Mean
M ₁	44.38	73.25	41.49	42.92	40.65	48.53 ^a	130.8	178.2	126.5	130.4	125.1	138.2 ^a	85.87	103.5	81.51	85.67	78.76	87.06 ^a	0.78	0.79	0.78	0.79	0.78	0.78 ^a
M ₂	40.50	70.40	38.24	39.89	37.28	45.26 ^b	124.9	172.5	120.6	123.4	118.6	132.0 ^b	77.00	99.82	60.70	72.61	57.63	73.55 ^b	0.76	0.77	0.76	0.77	0.76	0.76 ^b
M ₃	37.51	65.53	34.19	36.56	34.10	41.57 ^c	117.6	171.1	108.7	113.5	104.8	123.1 ^c	52.72	99.15	47.07	49.84	44.49	58.65 ^c	0.75	0.76	0.75	0.76	0.75	0.75 ^c
Mean	40.79 ^a	69.72 ^a	37.97 ^a	39.79 ^a	37.34 ^a		124.4 ^b	173.9 ^b	118.6 ^b	122.4 ^b	116.2 ^c		71.86 ^b	100.8 ^b	63.09 ^c	69.37 ^c	60.29 ^c		0.76	0.77	0.76	0.77	0.76	
	S.Em±		CD at 5%				S.Em±		CD at 5%				S.Em±		CD at 5%				S.Em±		CD at 5%			
M	0.057		0.167				0.019		0.056				0.073		0.214				0.008		0.024			
N	0.074		0.215				0.025		0.072				0.095		0.276				0.011		NS			
M X N	0.128		0.373				0.043		0.125				0.164		0.478				0.019		NS			
Treatments	Final fruit harvest stage																							
Macro nutrients	Micro nutrients																							
	Zinc						Iron						Boron											
	N1	N2	N3	N4	N5	Mean	N1	N2	N3	N4	N5	Mean	N1	N2	N3	N4	N5	Mean	N1	N2	N3	N4	N5	Mean
M ₁	41.08	69.97	39.57	40.71	39.00	46.06 ^a	96.99	136.3	95.3	96.27	94.44	103.87 ^a	59.57	79.57	55.98	58.22	55.42	61.75 ^a	0.74	0.74	0.73	0.74	0.73	0.73 ^a
M ₂	38.87	67.88	37.74	38.32	37.12	43.98 ^b	94.18	133.0	93.2	94.00	92.86	101.46 ^b	53.84	76.76	47.68	51.71	46.48	55.29 ^b	0.72	0.72	0.71	0.72	0.71	0.71 ^b
M ₃	37.01	64.56	32.94	35.33	31.94	40.35 ^c	92.57	129.9	88.66	90.72	87.97	97.96 ^c	45.22	74.63	43.30	44.91	42.72	50.15 ^c	0.70	0.71	0.70	0.70	0.70	0.69 ^c
Mean	38.99 ^a	67.47 ^a	36.75 ^b	38.12 ^b	36.02 ^c		94.58 ^b	133.1 ^b	92.42 ^c	93.66 ^b	91.75 ^c		52.88 ^b	76.99 ^b	48.98 ^d	51.61 ^c	48.21 ^c		0.72	0.72	0.71	0.72	0.71	
	S.Em±		CD at 5%				S.Em±		CD at 5%				S.Em±		CD at 5%				S.Em±		CD at 5%			
M	0.004		0.012				0.039		0.113				0.034		0.099				0.009		0.025			
N	0.005		0.016				0.050		0.146				0.044		0.128				0.011		NS			
M X N	0.009		0.027				0.087		0.253				0.076		0.221				0.019		NS			

Conclusion

In present study, the use of nano-fertilizers and gluconates gave the promising results when compared with general fertilizers. Nano N & K - 2 ml/l (M₁) in combination with nano (Zn+Fe+B+Mg)-2 ml/l (N₁) has recorded significant results with respect to flowering, fruiting, shelf life and quality of mango when compared to M₃N₅ - KNO₃-10g/l in combination with micro-nutrient mix. As nano-fertilizers are mechanized with targeted delivery and controlled release of active ingredients

All authors read and approved the final manuscript

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