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RESEARCH

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Preparation of nano-fertilizer blend from banana peels

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Abstract

Background: Banana contains important nutrients, which could be recycled into useful materials to be reused in different purposes. Extraction of mixed nano bio stimulant fertilizer from banana peels is the main purpose of this investigation.

Results: Nano-fertilizer extract was subjected to physical and chemical analyses for characterization. The fertilizer constituent size ranged from 19 to 55 nm, and the histogram illustrates that the major nanoparticles were 40 nm with an average percentage of 36% while 55-nm particles were the minor size with an average percentage of 6%. The synthesized nanofertilizers contained chelated potassium, chelated iron, tryptophan, urea, amino acids, protein, and citric acid.

Conclusions: Nano-fertilizer extracted from banana peels was applied in agriculture of two crops, tomato and fenugreek. The data revealed that germination percentage increased with increasing dose of banana peel extract for both crops. For tomato crop, the germination percentage was increased from 14% (control without nano) to 97% after 7 days of plantation. Also, the same trend was noticed for fenugreek crop, the germination percentage was enhanced from 25% (control without nano) to 93.14%.

Keywords: Nano-fertilizer, Banana peel extract, Germination, Tomato, Fenugreek crop

Background

The sustainability and feasibility of utilizing banana by-products are the future prospects and challenges for directing these by-products such as peels, leaves, pseudo stem, stalk, and inflorescence into various food and non-food applications, serving as thickening agent, coloring and flavor, alternative source for macro- and micronutrients, natural cuticles, livestock feed, natural fibers, and sources of natural bioactive compounds and bio-fertilizers (Padam et al. 2014). Banana peels form about 18–33% of the whole fruit mass and are considered as a waste product (Wolfe et al. 2003). At present, these peels were not being used for any other purposes and are mostly dumped as solid waste at large expense (Sudha et al. 2015). With increasing environmental awareness and growing importance of unfriendly agricultural wastes, crops and fruit waste can be used for efficient conversion into biomaterials like bio-plastic, bio-polymer, bio-fiber, and bio-fuels (Sharif Hossain 2015). Banana peels possess many benefits as they are an important source of soluble and insoluble fiber, fight cholesterol, are antioxidants, protect eyesight, and have other uses such as meat tenderizer, teeth whitening, polishing agent, and skin beauty and boost garden. Also, bananas produce an anti-cancer that combats cancer cells. Uses of the banana peel at home are polishing of shoes and silver: forks, knives, and spoons till sparkle (http://caloriebee.com). Moreover, the peel of a banana contains some metals such as manganese, magnesium, and potassium which can help whiten the enamel of the teeth. Moreover, the addition of a banana peel to the roast adds moisture during cooking. Aphids do not like banana peels, so bury the peels around roses and cauliflower to deter the crawling pests. Rubbing of a banana peel on dry skin may help heal psoriasis, and a banana peel can also help heal acne. Certainly, the nutrients found in a banana peel are essential and break down quickly (Brad berry 2017). Also, banana peels were utilized for the production of bioethanol by using the yeast *Saccharomyces cerevisiae* (Gebregergs et al. 2016). Additionally, banana peels were used for α-Amylase production using *Bacillus* subtitles by bioprocessing (Shaista Kokab et al. 2003) and potential

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production of fermented products (Patel et al. 2012). Phenol content, minerals, and antioxidant activity were extracted from banana peels by drying at 60 °C and using 70% acetone solvent in water bath for 2 hours at 55°C. The concentration of antioxidant activity and phenol content at this optimal extraction conditions was 1061.33 ± 0.03 μmol/g and 1474.17 ± 0.02 mg/L respectively (Azmi 2010). Also, bananas are rich in minerals including potassium, phosphorus, calcium, and others. Potassium is the most important element that is used as fertilizer. It is essential for promoting general plant vigor, build up, and resistance to pest and disease; necessary to help fruit grow; involved in regulating around 50 enzymes in a plant; and literally hang onto tree trunks in nature and vertical vegetables (DIY Fertilizers 2012). The signs of potassium deficiency in plants can be seen as the older leaves have brown veins. Potassium content in banana peels is about 200 mg of the fruits or 40%. Using banana peels in the garden provides nutrients that plants need to thrive, and it acts also as a pest repellent (Haider 2013; Hulbert 2014). The aim of this research is to investigate the optimum operating conditions for extracting the most fertilizer nutrients present in banana peels using alkaline digestion via potassium hydroxide addition at boiling conditions then converting these nutrients into the nanoform in acidic medium to be used as nanofertilizers suitable for the alkaline soil in Egypt. William banana peels in the ripe stage were used to complete this investigation. The extraction process involved collecting peels and drying peels by hugging in an open air for 1 week. Then, boil the dry grinded peels with potassium hydroxide addition, filter the boiled mixture to get rid of any solid material, and concentrate this solution by boiling to obtain solid impure dark brown concentrate containing potassium, iron, amino acids, and protein (Hulbert 2014). Then, the resultant solution is converted into nanoform via the addition of urea and citric acid with vigorous stirring.The problems associated with inorganic nutrient supplementation in soil are that it leads to pollution of ground water after harvest. Also, it does not improve soil structure (Gordon et al. 1993); then, decrease in organic matter content leads to nutrient imbalance and soil acidification (Ojeniyi 2000). Moreover, it has negative impact on microorganism activities; besides, it is not readily available to farmers over the year and high in cost. Other problems include most inorganic fertilizer in the soil is gradually depleted by crops (Law Ogbomo 2011). Recently, huge revolution concerning the utilization of agriculture waste as organic fertilizer was growing over the last years. Natural organic components can be obtained from plant wastes which are transferred to compost rich by the nutritious organic matter to be returned to the soil for fertilization. Banana peels as organic waste drew a great attention due to its extract rich in natural phenolic compound antioxidants such as vitamins, flavonoids, essential amino acids, growth promoters, and potassium element which are necessary for plant growth (Lee et al. 2010; Emaga et al. 2007). Banana peel has been used to induce significant effects on various biological aspects in plants (Bakry et al. 2016). One of these biological aspects is increasing seed germination rate due its high content of potassium, amino acids (i.e., L-tryptophan), and growth promoters as indicated in previous investigations (Lee et al. 2010; Emaga et al. 2007). According to the abovementioned applications, the proposed banana peel nanoextract will be tested in farming fenugreek and tomato as preliminary investigation for its efficiency.

Methods

Materials

The used materials were Egyptian banana peels (William Ripe stage), commercial grade potassium hydroxide produced by El-Gomherya Company, commercial citric acid obtained from El-Gomherya Company for chemical production, and finally commercial grade urea obtained from Abu-Quire Fertilizer Company.

Extraction preparation of nanofertilizer from banana peels

0.5 kg of the Egyptian banana peels was washed well with tap water to remove the dust and any impurities adhered to the outer surface. The cleaned peels were shredded to small pieces then blended with tap water using a high-speed mechanical blender. The obtained viscous slurry was mixed with the determined quantity of potassium hydroxide and stirred for 1 min to get homogenous slurry. The alkaline blended peel slurry was subjected to boiling with stirring for 30 min. After boiling, the slurry was kept for cooling at room temperature to be ready for further processing. The cold slurry was subjected to vacuum filtration to get clear brown filtrate and thick dark brown sludge. Hence, the clear filtrate was heated to about 70 °C, with continuous stirring at 300 rpm. After that, urea and citric acid (5% solution) were added dropwise till pH 5. The obtained sludge was dried at 105 °C, then grinded to fine powder. The product was subjected to physical and chemical analyses for characterization as shown in Fig. 1.

Characterization of extracted fertilizer

Determination of quantity of extract

The obtained alkaline filtrate of extract was treated with conc. nitric acid in a closed vessel at elevated temperature and pressure. The resulting solution was diluted, and extract contents were determined by atomic absorption spectroscopy (AAS) using a flame method (Jońca and Lewandowski 2004).

Apparatus includes the PerkinElmer 2100 atomic absorption spectrophotometer and a hollow cathode lamp

Fig. 1 Photo of banana peel & banana peel extract

for the element to be analyzed. Tryptophan and total protein were measured according to the procedures described in Bakry et al. (2016).

Transmission electron microscope test (TEM)

The obtained nanoparticles were characterized by means of a JEOL-JEM1200 transmission electron microscope (TEM). The TEM sample was prepared by adding a drop of the nanosolution on a 400 mesh copper grid coated by an amorphous carbon film and letting the sample dry in an open air at room temperature. The average diameter of nanoparticles was determined within the range of 100 nm that was found in several chosen areas in enlarged microphotographs.

Application of extracted nanofertilizer in agriculture

Seeds of two vegetative crops (tomato and fenugreek), 33 seeds of each crop, were used, and the seeds were cultivated in Egyptian clay loam texture soil taken from the middle Nile delta soil in a village near Tanta city with physical properties and composition of sand 25%, silt 37%, clay 38%, bulk density 1.1 g cm^{-3}, and saturated hydraulic conductivity 0.69 cm h^{-1}. The seeds were irrigated using water of total salinity of 450 ppm amount of 40% of soil weight with the addition of different doses (4, 8, 12, and 16 ml/l) of nanofertilizer extracted from banana peels. After 7 days, data concerning with germination percentages were recorded and variances were analyzed according to the Duncan method (Duncan 1959).

Results

Banana peel extract characterization

TEM analysis

Figure 2 shows the TEM analysis of the obtained banana peel extract using potassium hydroxide as extracting agent. It is clear that nanospherical structure particles were obtained with size ranged from 19 to 55 nm, while Fig. 3 shows the histogram of the obtained nanoparticles from banana peel extract. Additionally, the major nanoparticles are of 40 nm with an average percentage of 36% while 55-nm particles were the minor size with an average percentage of 6%. Figure 4 represents the effect of potassium hydroxide concentration on the potassium extraction process from banana peels at boiling conditions. The operating conditions were solid to liquid ratio 1:2, temperature 100 °C, and cooking time 30 min. So it is obvious that as the potassium hydroxide concentration increases the extracted potassium from banana peels increases starting from 46 g/l at 4 g potassium hydroxide to 87.8 g/l at 20 g potassium hydroxide. However, the potassium extraction efficiency increases from 44 to 94% via adding potassium hydroxide from 4 to 20 g. Also, more

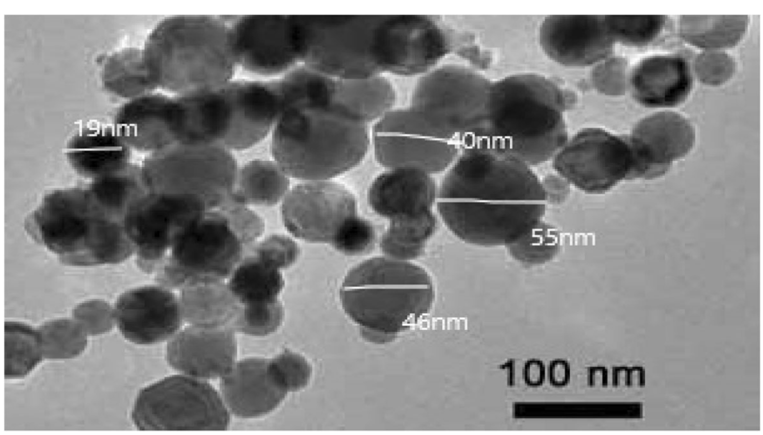

Fig. 2 TEM analysis of banana peel extract using alkaline extraction

Table 1 Effect of potassium hydroxide dose on tryptophan and total protein extraction

Sample code	Potassium hydroxide g/kg dry peel	Tryptophan mg/l extract	Tryptophan extraction efficiency % extract	Total protein g/l extract	Protein extraction efficiency %
1	4	119	23	1.9	36.53
2	7	217	41.97	3.3	63.46
3	10	494	95.55	4.9	94.23
4	15	497	96.13	4.96	95.38
5	20	497	96.13	4.97	95.57

addition of potassium hydroxide over 10 g shows no significant increment in potassium extraction efficiency. Hence, about 10 g potassium hydroxide was taken as an optimum concentration. Table 1 represents the effect of potassium hydroxide concentration on the extraction of tryptophan and total protein from banana peels. The results show that as the potassium hydroxide concentration increases both of tryptophan and total protein extraction efficiency increases to reach its maximum value (on addition of 20 g potassium hydroxide). However, with respect to the differences in extraction efficiency and the economic aspects, 10 g of potassium hydroxide was taken as the optimum weight and Table 2 shows the composition of banana peels extracted at optimum extraction conditions.

Effect of banana peel extract on germination percentage of two vegetable crops (tomato and fenugreek)

The collected data in Table 3 indicate that irrigated tomato seeds and fenugreek seeds using banana peel extract as fertilizer increased germination percentage compared with the control sample. Also, data revealed that germination percentage increased with increasing dose of the banana peel extract for both crops.

Figure 5 collects photos from 1 to 10 showing the improvement of germination for both tomato and fenugreek after the addition of banana peel extract. The germination ratio increased as the addition of banana peel extract increased from 4 to 16 ml. As shown in the photos (1 to 5), the germination ratio of tomato plant in control was about 14% after 1 week. This ratio was increased to nearly 54% after the addition of 4 ml of banana extract and reached to 80% by adding 8 ml of the same extract. Finally, the ratio increased to 98% in using 16 ml of banana extract. Also, in the case of fenugreek plant, the germination ratio in control was 25% after 1 week and this ratio was increased to nearly 80% after the addition of 8 ml of banana extract and reached to 93.1% on adding 16 ml as shown in the photos (6 to10). For example, if the inorganic iron salt (iron sulfate) is supplied to some soils, much of the iron is transformed into forms that are not readily assimilated. They are converted to “plant unavailable” forms. This problem can be overcome on using cheated form.

Table 2 Composition of banana peel extract using alkaline extraction

Element	Concentration g/ kg dry peel
Potassium	78
Iron	0.6
Protein	52
Tryptophan	0.517

Discussion

Banana peel extract characterization

Nano-fertilizer was prepared from banana peels (as seen in Fig. 1), using potassium hydroxide as extracting agent at optimum operating conditions (solid to liquid ratio 1:2, temperature 100 °C, and cooking time 30 min). The results of TEM showed that the major nanoparticles are of 40 nm with an average percentage of 36%. Conversion to nanostructure is attributed to the presence of both urea and citric acid, as citric acid reacted with the minerals, forming mineral citrate, while urea is used as a carrier for these mineral citrate in the nanoform.

As shown in Fig. 4, increment of potassium hydroxide concentration enhances the extracted potassium from banana peels and 10 g was taken as optimum. Also, it is known that alkaline medium increases cellulose solubility during a digestion process of banana peels that results in liberating the micronutrients of tryptophan and total protein extraction efficiencies which reaches maximum value on using 20 g potassium hydroxide. However, with respect to the differences in extraction efficiency and the economic aspects, 10 g potassium hydroxide was chosen as the optimum value (Tables 1 and 2).

Table 3 Effect of banana peel extract in nanoform on germination percentage on tomato and fenugreek

Dose of banana peel extract	Germination %	
	Tomato	Fenugreek
Zero	14	25
4 ml/l	54.5	42
8 ml/l	79.5	79.5
12 ml/l	91	89
16 ml/l	97.7	93.1

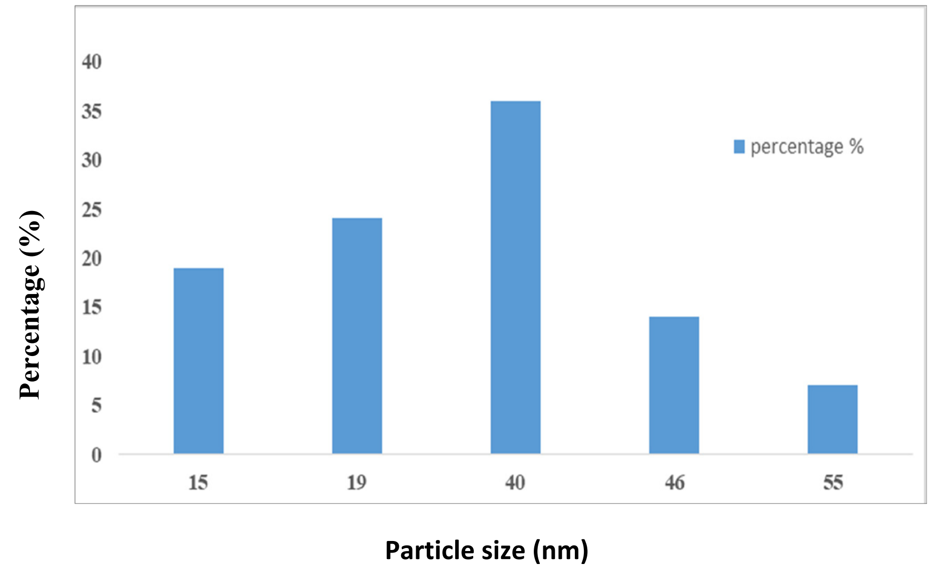

Fig. 3 Histagram of banana peel extract using alkaline extraction

Application of extracted nanofertilizer in agriculture

Effect of banana peel extract on germination percentage

On applying banana peel extract as fertilizer in tomato and fenugreek irrigation, it was noticed that the germination percentage increased compared with the control sample as seen in Table 3. These results may be referred to the high content of amino acids (i.e., L-tryptophan), nutrient elements such as potassium, and growth promoters as mentioned previously in Lee et al. (2010) and Emaga et al. (2007) and that was collected in (Table 4, Aboul-Enein et al. 2016). The authors investigated the effects of tryptophan on the growth of plants (wheat, periwinkle) and showed that tryptophan may improve many physiological processes. For example, it regulated the plant growth, metabolism of plants under water stress, and increasing physiological availability of water and nutrients, besides the effect of tryptophan on increasing levels of endogenous hormones. Consequently, it can stimulate cell division and/or cell enlargement and subsequently growth (El-Bassiouny 2005; Talaat et al. 2005; Sadak and Orabi 2015). The effects of banana peel extract application on quinoa were studied. It was clear that banana peel extract at 500 mg/l surpassed tryptophan treatments and adding 50 or 75 mg/l resulted in increasing endogenous indole-3yl-acetic acid (IAA) and phenol and total free amino acids (Bakry et al. 2016). Regarding banana peel composition which contains K^{+}, Ca^{++}, Na^{+}, Fe^{+++}, P, and Mg^{++}, addition of potassium hydroxide breaks lignin and cellulose. While urea and citric acid utilization liberated minerals, amino acids, tryptophan, and total protein, the presence

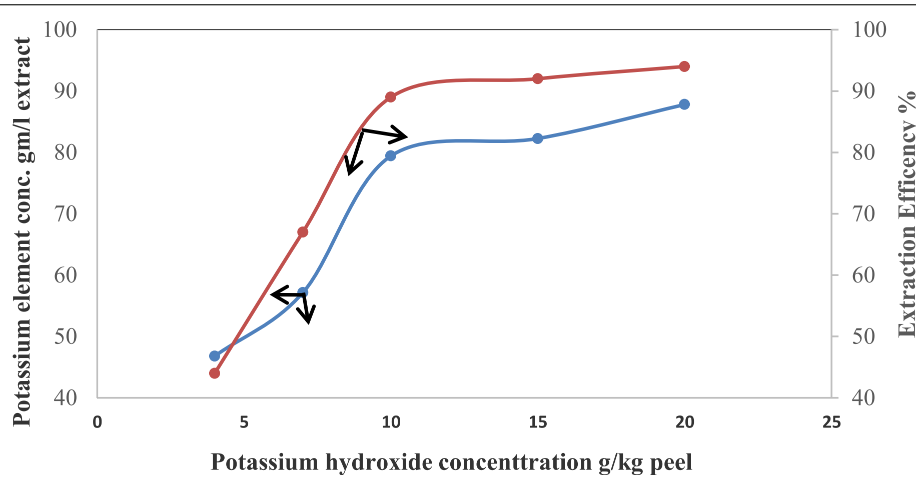

Fig. 4 Effect of potassium hydroxide concentration on potassium element extraction from banana peel

Fig. 5 Photos of irrigated crops of tomato and fenugreek and their control

of these liberated materials has great effects on the plant germination (Aboul-Enein et al. 2016); according to these results, the following mechanism could be proposed as in the following equations (Fig. 6).

As the metals combined with organic compound, the organic complex was formed (chelates) that tightly trapped the metallic elements, preventing their release to the soil. Trapped metals in chelates lost their cationic characteristics, making them less prone to precipitation that is useful in agriculture. When natural products decomposes, they can generate naturally chelating agents such as organic acids, amino acids, lignin-sulfonates, lignin poly carboxylates, sugar acids and derivatives, phenols, poly flavonoids, siderophores, and phytosiderophores. Other chelating agents could be developed synthetically, both types of chelating/complexion causing increment of micronutrient solubility. One of the most important characteristics of chelating agents used is the relative stability of various metal chelates, especially if one is considering synthetically developed chelates. In other words, it is the degree of affinity of a given agent for a metal. From the stability constant data, the ability of one metal to compete with another can be estimated. Stability of micronutrient chelate bonded generally determines "plant availability" of the applied micronutrient. An effective chelate relationship is one in which the rate of substitution of the chelated micronutrients for cations already in the soil is low, thus maintaining the applied micronutrient in the chelated form for length of time sufficient to be absorbed by the plant roots. The chelated forms of micronutrients have advantages over traditional forms of inorganic fertilizers such as smaller quantities required, are much more easily absorbed, more easily translocate within the plant, easily assimilated within the plant system, chances of "scorching" of crops, while using chelates is less because they are organic substances, compatible with a wide variety of pesticides and liquid fertilizers, and are not readily leached from the soil as they adsorb on to the surface of soil particles. It has been found that in the alkaline soils, where Fe solubility and availability to plants are extremely low, adding soluble Fe salts is not very effective, unless the soluble Fe is in a form that does not react with the soil system and yet can be readily assimilated by plants. There are two alternatives available to deal with iron deficiency. These are soil application of iron chelates and foliar sprays containing chelated iron. If the soil pH is alkaline, chelates must be preferred to inorganic salts. In citrus cultivation, application of about 10–20 g Fe/tree in chelate form has proved satisfactory. The application of Fe-EDDHA and Fe-sugar acid chelates at 7 mg Fe/l resulted in re-greening of leaves in iron-deficient plants. Chelating agents, from which iron has been released and under conditions favorable to chelation of Mn, compete with plant roots for Mn. Chelating agents have the ability to keep iron sufficiently in solution to provide enough iron at the root surface to effect competition with manganese. Organic zinc fertilizer sources are the che1ates of EDTA, NTA, HEDTA, and iron citrate. Other organic sources include Zn-lignin sulfonate, Zn-poly flavonoid, and by-products of the wood pulp industry. Mn is mainly transported as Mn and not as an organic complex. Thus, Mn chelates are effective only

Table 4 Nutrient content in banana peel (Aboul-Enein et al. 2016)

Macronutrients	Concentration g/100 g DW	Macronutrients	Concentration mg/kg	Compound	g/100 g dry weight basis
K	9.39 ± 1.74	Fe	96.50 ± 19.73	Moisture content	88.10 ± 0.18
Ca	0.44 ± 0.08	Cu	3.73 ± 1.14	Carbohydrate content	68.31 ± 0.83
Na	0.18 ± 0.02	Zn	27.95 ± 3.31	Crude fat	10.44 ± 0.89
P	0.09 ± 0.01	Mn	35.01 ± 4.25	Crude protein	7.57 ± 0.30
Mg	0.71 ± 0.05	–	–	Ash content	13.42 ± 0.35

when used as liquid fertilizer formulation and hydroponics. Application of Cu chelates with different amino acids increased chlorophyll content, grain yield, amino acid content, and the uptake. True amino acid chelates are emerging as state-of-the-art technology for delivering selected micronutrients with maximum bioavailability, tolerability, and safety. In this study, urea is considered as the main source of nitrogen and a carrier for the obtained nanoparticles, while citric acid is the main chelating agent for potassium, iron, magnesium, zinc, manganese, calcium, and amino acids. This is explained as citric acid is one of the most important organic acids in the respiratory pathways into plant cell. Also, it is essential for different biochemical and physiological processes. Potassium citrate increases

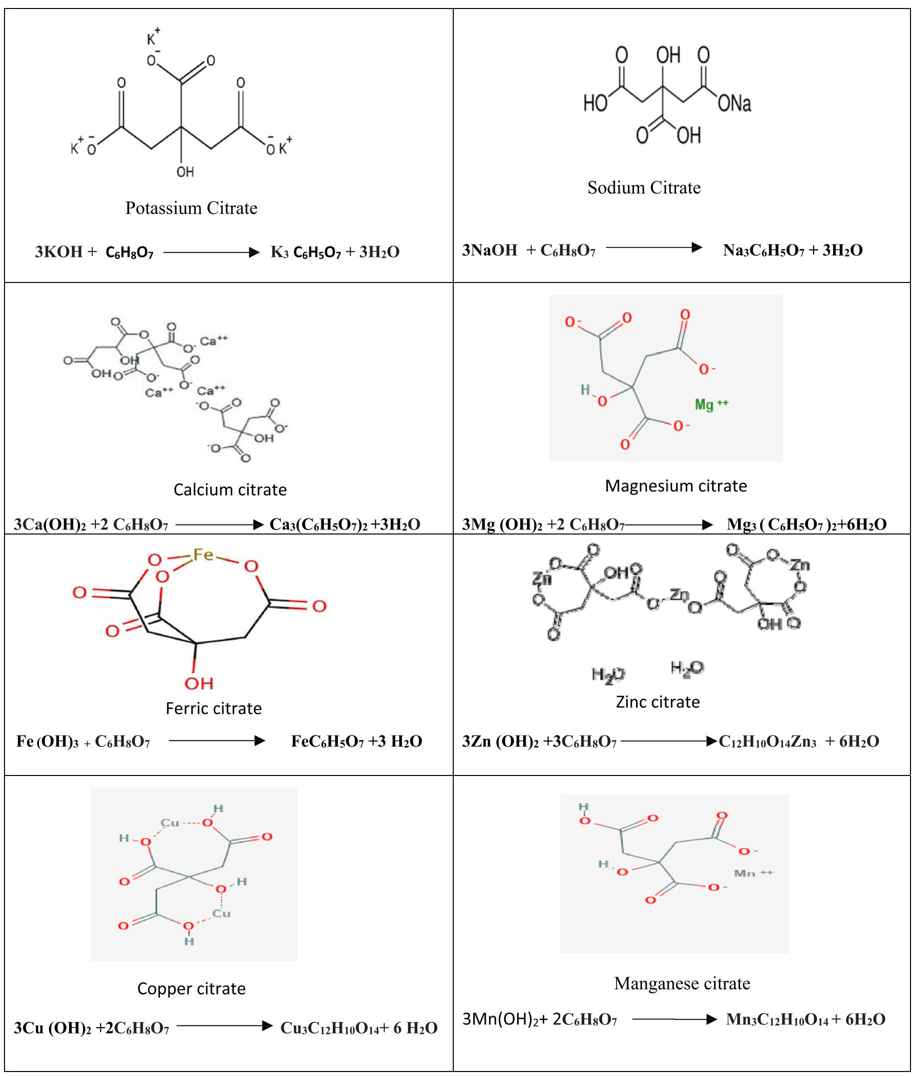

Fig. 6 Chemical equation and mechanism of elements of banana peel with citric acid

leaf area, improves leaf mineral content, enhances yield, and improves fruit quality (Ibrahim et al. 2015). Calcium with urea may improve crop production and increases ammonium, potassium, and phosphorus absorption. It also stimulates photosynthesis and increases the size of sellable plant parts (Feagley and Fenn 1998). It is reported that the most optimum form for increasing iron content in plant system is the citrate form which is a significant nutrition for plants and iron deficiency causes severe problem for the soil (Mordoğan et al. 2013). Taha et al. (2014) also concluded the application of banana peel extract as a potential natural source of antioxidant and antimicrobial sources. To determine the effects of foliar application of amino acid and calcium chelate on Golden Delicious and Granny Smith apple trees, a randomized complete block design with four repetitions was conducted. The combination of amino acid and calcium chelate increased weight of both cultivars (Aboul-Enein et al. 2016). Amino acid chelate fertilizers were conducted to test its effect on the growing of *Pennisetum* American and sorghum (*Sorghum vulgare*) forage crops as well as their effects on some soil properties. The results indicated that organic matter and CEC of soil tended to increase slightly with the use of synthesized fertilizers as compared with unfertilized check; also, they improved the soil content of macro- and microelements. The efficiency of organic synthesized fertilizers was improved when they are applied in combination with 1/2 unit or one unit of NPK recommended rates (Arabloo et al. 2017). The effect of both diphenylamin and tryptophan significantly increased plant growth (in terms of plant height, number of leaves/plant, stem diameter, root length, and leaf area, as well as fresh and dry weights of the different plant parts) and the contents of carotenoids, total soluble sugars, and total free amino acids in the leaves as reported (Mostafa et al. 2014). Short-time application of protein hydrolysates increased the root dry weight of maize plants compared to the untreated plants (Abou Dahab and Abd El-Aziz 2006, Nardi et al. 2016). Based on the abovementioned discussion, potassium hydroxide was used for dissolving the cellulosic material, leading to liberation of the fertilizing agent to the solution; then, carrier and chelating agent were added to convert these agents to the nanochelating biostimulant fertilizers. Due to the presence of minerals (K^{+}, Mg^{++}, Fe^{++}, Mn^{++}, Na^{+}, Zn^{++}, and Cu^{++}), tryptophan, amino acids, and protein, a complicated structure with high fertilizing value from the banana peels was obtained.

Conclusions

Nano bio stimulant fertilizer can be extracted from banana peels under alkaline conditions. In this investigation, it was found that the extract of banana peel contains about 80 g/L of elemental potassium chelated with citric acid. Also, other minerals such as iron, magnesium, copper, sodium, calcium, and manganese chelated with citric acid in a nanostructure form. Extract contains constituents of spherical nanostructure, having major particle size (40 nm). The obtained nano bio stimulant shows great germination efficiency in the first planting week for both tomato and fenugreek, so it is recommended as a biological promoter for seed germination and seedling growth performance. Utilizing nanotechnology to transfer the banana peel extract from normal form to nanoform added a positive value for this extraction and reinforced its positive impacts as growth promoter. Due to the alkalinity of the Egyptian soil, the obtained nano bio stimulant pH was adjusted to 5 using citric acid. Based on the lab scale results obtained in this study, future investigations on the pilot and industrial scale have to be done with cooperation with agriculture engineering and professors taking into consideration the soil types, seeds varieties, irrigation water, and nanofertilizer economics.

Recommendation

More studies should be conducted on other crop wastes to emphasize the positive role of banana peel in nanoform and study its biological effect on soil microorganism activity.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions
All authors participated in the development and implementation of the research plan and subsequently written it. All authors read and approved the final manuscript.

Ethics approval and consent to participate
"Not applicable"

Consent for publication
"Not applicable"

Competing interests
The authors declare that they have no competing interests.

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