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Original article

Pouteria caimito fruit derived nanoparticles inhibited the apple ring rot disease as well as extended the shelf-life of sliced apples

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ABSTRACT

Background: Apple disease, exaggerated by *Botryosphaeria dothidea*, is a foremost intimidating problem for extending the apple fruit shelf-life and producing substantial economic losses for cultivators and distributors. Alternate sources are urgently needed to prevent or inhibit the ring rot infection of apple fruit instigated by *Botryosphaeria dothidea*

Objective: In this current study, we premeditated to make novel organic nanoparticles as of *Pouteria caimito* fruit extract and calcium chloride (PCNP), which were used to evaluate the preventive outcome of *Botryosphaeria dothidea*-caused apple disease on postharvest apple fruits.

Results: Our findings corroborated that the fruit derived nanoparticle had been confirmed for quality and size by altered estimations such as fourier transform infrared (FTIR), UV–vis spectroscopic analysis, scanning electron microscope and energy dispersive X-ray (SEM and EDX) estimation, and dynamic light scattering (DLS) analysis. In addition, we have investigated the excellent inhibitory action of the pathogen infection in apples initiated by *Botryosphaeria dothidea*. The protective enzymes function was pointedly improved in nanoparticle-treated apple fruits once equated with those of control apple fruits. The catalase (CAT) and superoxide dismutase (SOD) activities were pointedly improved in nanoparticle-treated fruits when compared to those of control fruits. The shelf-life extension studies were conducted for 7 days with a fresh-cut apple. The total soluble solid, pH, weight loss, and sensory studies were analyzed, and they proved the extension of sliced apple shelf life up to 7 days.

Conclusions: The discoveries of this study provided a well-organized, harmless, and environment-friendly substitute to control the apple disease as well as the durability postponement of sliced apples 7 days or may longer.

1. Introduction

Apple fruit is most widely available nutrition fruit, and it is consumed by a great many of people worldwide. *Botryosphaeria dothidea* is among the most causative pathogens for plants and fruits, especially apples. Apple infection is instigated by *Botryosphaeria dothidea*, and it has given rise to challenging concerns for apple production and storage in recent years. The plant trunks and branches showed wart-like symptoms when caused by the *Botryosphaeria dothidea* pathogen. In an exceedingly severe case of this pathogenic disease, plant trunks and shoots were killed. Apple fruit showed brown rings and altered tan and sunken lesions when it was caused by this pathogen. Consequently, oozes of brown mucus and a sour smell have occurred in apple fruit ring rots. The *Botryosphaeria dothidea* pathogen does not only affect apple fruit; it also affects many other fruits such as pomegranate, mulberry, cherry, guava, fig, avocado, kiwi, and apricots. The range of decayed fruits has been increasing day by day by around 10 to 20% each year, and it may have reached 70% as early as soon because of the enormous fungal development arising now days due to environmental pollution. *Botryosphaeria dothidea* pathogenic affect is a major challenge, and a safe antifungal agent is desperately needed to protect the fruits economy. Fungicidal applications are one of the most important methods to prevent apple ring rot worldwide (Sun et al., 2022; Huang et al., 2021). Studies by Prier have exposed that synthetic fungicides, including tebuconazole, pyrisoxazole, and pyraclostrobin, have frolicked a decisive role in

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controlling apple infection. Nevertheless, the synthetic fungicidal agents are having numerous side effects and causing health issues and environmental pollution (Liu et al., 2018). Therefore, the safest and most compatible alternative natural active sources are urgently needed to inhibit the apple ring rot problem.

Natural plants and their derived phytochemicals are the most promising alternative source, and they have acted as excellent antimicrobial and antifungal agents. Early study has confirmed the phytochemicals such as β-citronellol, geraniol, and cuminaldehyde have potential fungicidal properties against *B. dothidea* (Eliaser et al., 2018). Moreover, Lemon oil, γ-terpinene, 4-hydroxycinnamic acid, alcarindiol, matrine, chelidonine, sesquiterpenoids, etc. are having a better effect against the *B. dothidea* pathogen (Sun et al., 2022). Another study has revealed that the *Allium tuberosum* leak extract can inhibit fungal growth against *B. dothidea*. However, the proper mechanism of action of the above plant and its phytochemically associated anti pathogenic properties remains elusive (Sun et al., 2022).

Currently, nanotechnology has proven and played an important role in agricultural science-related industries and pathogenic fields, particularly in the development of antimicrobial and antifungal agents. This technology has proven numerous applications, especially for agricultural industries in the way of food processing, storage, and transport of their products. The nanotechnology-associated products play a vital role for the food industry in maintaining food safety, preservation, quality, and the extent of the shelf-life duration. Pathogenic control is a very helpful technology for the food industry because microbial contamination affects food products taste, quality, and shelf life. Numerous studies have proved that the nanoparticles can be increasingly applied to control or inhibit pathogenic bacteria and fungi (Ameen et al., 2021). Numerous direct metal nanoparticles are the most extensively studied method, and they possess several biomedical applications, including anti-diabetic, anti-cancer, anti-microbial, and anti-fungal properties. Alumina, titanium oxide, iron oxide, copper oxide, selenium, silver, zinc oxide, and calcium oxide are the methods developed by the researchers and have proven some potential antimicrobial properties against several microorganisms (Merkl et al., 2021; Eid et al., 2022). Particularly, calcium oxide has high potential antimicrobial properties, is used as an acid regulator for food additives, and also acts as a food preservative. However, direct metal nanoparticle consumption has the same side effects as biological consumption. Hence, researchers are developing a new novel plant and metal fusion method in nanotechnology fields.

Phytochemically associated nanoparticles are a potential novel, simple, and friendly model, and they are being focused on by numerous scientists because of their best mechanical way of biological and agricultural industries applications (Veeramani et al., 2022a, 2022b, 2022c). Plants and their constituents for phytochemical-based nanoparticle production are very important in current drug and agent deployment fields because of their effective target regions, low-cost production, and non-toxic properties. The plant parts contain extracts of vitamins, minerals, terpenoids, flavonoids, and essential oils. These organic ingredients performance an identical character in the production of nanoparticles and their improved properties. Several plant parts are used for the synthesis of nanoparticles, such as seeds, leaves, and stems. Root, flower, and fruit (Veeramani et al., 2022a, 2022b, 2022c; Roy, 2021). However, the making of organic calcium nanoparticles from the calcium chloride and fruit extract of *Pouteria caimito* has not yet been scrutinized. Due to this, in this research, we have designed to produce calcium nanoparticles from a fruit extract of *Pouteria caimito* and calcium chloride.

Pouteria caimito is a sweet-tasting fruit that is eaten all over the world. It is dispersed worldwide, especially in Brazil and America. *Pouteria caimito* is commonly called a yellow fruit, and it belongs to the *Sapotaceae* family. Very few scientific reports have been conducted on this fruit so far, but the antioxidant properties of this extract have been reported by Cecilia et al., (2016). It is a highly nutritious fruit, especially for protein, calcium, vitamin A, vitamin C, iron, and thiamin. In a prior analysis, we proved the anticancer efficacy of these fruit extract-based synthesis nanoparticles (Veeramani et al., 2022a, 2022b, 2022c). *Pouteria caimito* fruit extracts associated with calcium oxide nanoparticles and their protective properties against apple ring rot disease and the life extension of sliced apples have not yet been studied; therefore, we planned to conduct the synthesis of calcium nanoparticles and their above-illustrated biotic actions.

2. Materials and procedures

2.1. Green source and chemicals

Apples and *Pouteria caimito* fruits were purchased freshly in a neighborhood supermarket, Saudi Arabia and others chemicals were bought from Sigma Aldrich.

2.2. Pouteria caimito fruit

Cubed size sliced *Pouteria caimito* fruit were dried in dark rooms a 3 day period at room temperature, and they were completed into a powder using a homemade mixer speed at 18,000 to 20000 rpm for 3 mins.

2.3. Pouteria caimito-derived, eco-friendly calcium oxide nanoparticles (PCNPs)

Pouteria caimito powder was weighed at 10 g and kept immersed in 500 mL refined water for 24 hrs. After being immersed, the extract was sieved through Whatman filter paper (Suriyaprom et al., 2022). 200 mL of 1 M calcium chloride were added to this 200 mL extract, and they were mixed thoroughly for 20 mins. 06 mL of sodium hydroxide was gently added and carefully blended over the following 25 min. For one day, this reaction mixer was left at room temperature, at that time the residue particles were taken and eroded 3 times with distilled water and 15, 000 rpm centrifugation. These particles were powdered by drying them for 24 to 48 hrs in an air-dry oven at 37 degrees Celsius (Veeramani et al., 2022a, 2022b, 2022c).

2.4. Confirmation and characterisation studies of nanoscale

Estimates of the shape, size, and purity of this synthetic PCNP by different methodologies using SEM and EDX, UV–visible spectroscopy, FTIR, and DLS analysis (Veeramani et al., 2020).

2.5. Isolation of Botryosphaeria dothidea

Botryosphaeria dothidea was secluded from illed apple fruit. This isolated pathogen was cultured by using the following culture mixture: 200 g of potato extract and 15 g of agar in 1 L, and 20 g of glucose in PDA plates. It was maintained at 4 ℃ for 3 days.

2.6. Procedure for effective treatment and apple ring rot disease induction

Firstly, apple fruits were pretreated with PCNP followed by induction of apple ring rot disease, and we used the same procedure with a small modification as described by Yang et al. (2017). The PCNP was applied to apple fruits at various concentrations for 15 min, including 25, 50, 100, and 200 g/mL FW. After-

wards, the fruits were air desiccated and used for the following pathogenic induction. A 3 mm deep and 5 mm wide similar wound was made in each apple, and then each apple wound received 10 µl of *B. dothidea*. The apples were wholly reserved at 25 degrees Celsius in a humidified environment. The rates of disease induction and prevention were calculated for 3-, 5-, and 7-day intervals, and they were recurrent three times in every test.

2.7. Sample collection of fruit

Other biotic tests were steered using the active dosage of PCNP, and these apple fruits were dipped in 100 µg/mL FW as well as 0.1% methanol (control). Afterwards, the fruits were air dried and used for the following pathogenic induction. A 3 mm deep and 5 mm broad similar wound was made in each apple, and then each apple wound received 10 µl of *B. dothidea*. Every apple was stored at 25 degrees Celsius in a humidified environment. The rates of disease induction and prevention were calculated for 3-, 5-, and 7-day intervals, and they were repeated three times in each experiment. The apple fruit equator area of PCNP was used for further biochemical and biological studies after 7 days.

2.8. Sialic acid content, antioxidants, as well as defensive enzyme activities

Polyphenol oxidase (PPO), phenylalanine ammonia lyase (PAL), β-1,3-glucanase (GLU), and CHI were estimated by the methods of Zhang Y. et al. (19) and Zhang et al. (2016) (14). The superoxide dismutase (SOD) and catalase (CAT) of antioxidant markers were calculated by using communal test kits. It was appraised that sialic acid (SA) and SA glucoside (SAG) levels by Verberne et al. (2002).

2.9. Life-time extension studies of apple fruits

The 4–5-inch royalkala apples were chosen in this shelf-life extension study and sliced in cubed size. Weight loss, PH, and total soluble solid (TSS), as well as the sensory analyses, were assessed by Waghmare and Annapure (2015) and Memon et al., (2015).

2.10. Statistical investigation

As a result, the mean average and standard error of reaping experiments were mentioned. An ANOVA of statistical insinuation was calculated using Duncan's multiple range tests, with a P value of 0.05.

3. Results

3.1. PCNP analysis using FTIR and UV–visible

Recently, in the fields of nanoparticles, the oxidation reactions of fused plant phytochemicals and the chemical are popularly estimated by UV–vis spectra analyses; therefore, in our study, the oxidation of *Pouteria caimito* fruit extract with calcium chloride was estimated by means of the same method, and the outcome is shown in Fig. 1. The absorbance spectra of our result were shown at 303.2 nm, and these single absorption spectra confirmed the nanoparticle conversion.

The FTIR is a chemical spectrum, and it is commonly used to examine the constituents of biomolecules from plant extracts and nanoparticles, etc. In our study, we also analyzed this spectrum with the PCNP, and the results are shown in Fig. 2. The bonds, including the 3424.20, 1617.06, 1416.02, 1073.28, 869.84, and 599.85 cm^{-1} are showed the spectrum and represented the different functional groups, with the O—H, C—H, C—N, C═C, and the C—H, respectively.

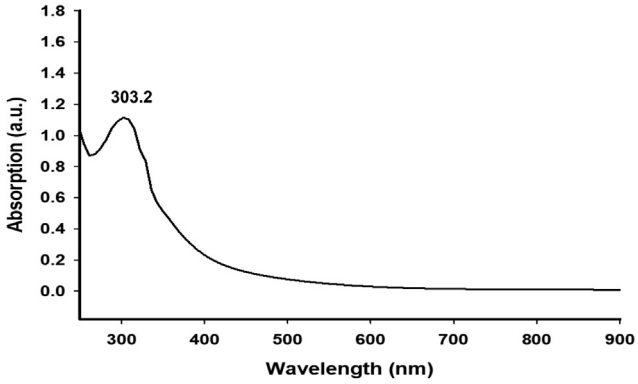


Fig. 1. Image of spectroscopic from pcNP.

3.2. Morphology, elements, size, and zeta potential analyses of PCNP

SEM and EDx analysis are reimbursement techniques for analyzing the morphology and elements of produced nanoparticles, and in our study, we have also conducted an analysis of PCNP morphology and elements, and the results are shown in Fig. 3. The morphology of our PCNP was shown in crystal shape, and the elements are found in Ca, Na, Sn, C, and O, and from these, Ca and C were the two most abundant in PCNP.

The PCNPs zeta potential was proven by analyses of DLS, and the consequences are shown in Fig. 4. In our study, the DLS spectra consequence showed lowered zetapotential; therefore, it proved that the PCNP had been produced without impurities.

3.3. Protective result of PCNP on apple disease

The rate of disease incidence in *Botryosphaeria dothidea* caused apple disease and the protective role of PCNP were examined, and the consequences are shown in Fig. 5. The disease incidence in lesions and the percentage were significantly increased in ring rot disease, and it was prevented by treatment with PCNP when compared to disease control in apple fruits.

3.4. Protective effect of PCNP on GLU, PPO, PAL, and CHI

Enzyme activity of the GLU, PPO, PAL, and CHI were estimated in ring rot disease control as well as in PCNP-treated fruits, and the results are shown in Fig. 6. activities of the GLU, PPO, PAL, and CHI enzymes were significantly increased in ring rot disease-control apple fruits, and these were prevented compared to apple fruits that are disease-controlling.

3.5. Antioxidant properties of PCNP

The antioxidant markers SOD and CAT studied in control and PCNPs-treated apples, and the discoveries are exhibited in Fig. 7. SOD and CAT of PCNPs treated apples were significantly increased; hence, these increased activities may have protected the apples from the ring rot disease.

3.6. SA and SAG projections

SA and SAG of control and PCNPs-treated apples were calculated, and the conclusions are exhibited in Fig. 8. SA and SAG levels of PCNP-treated apples were significantly increased; hence, these increased levels may have protected the apples from the ring rot disease.

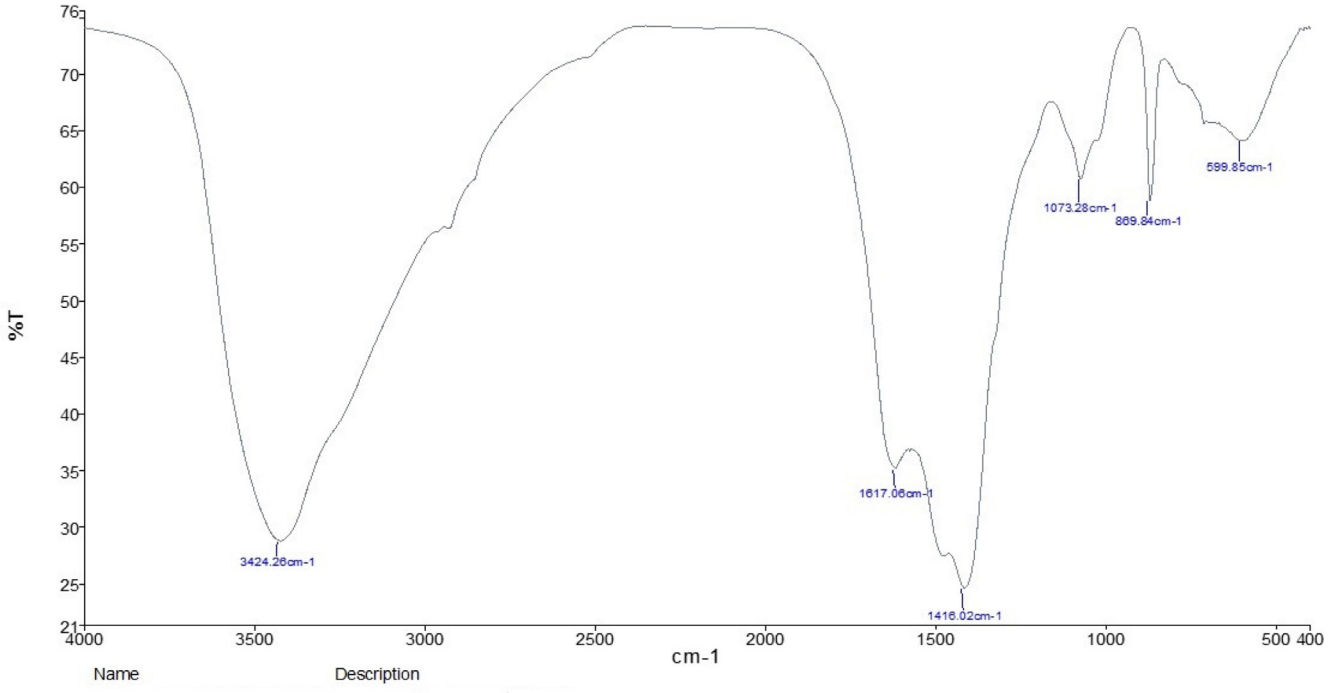


Fig. 2. Image of ftir from pcnp.

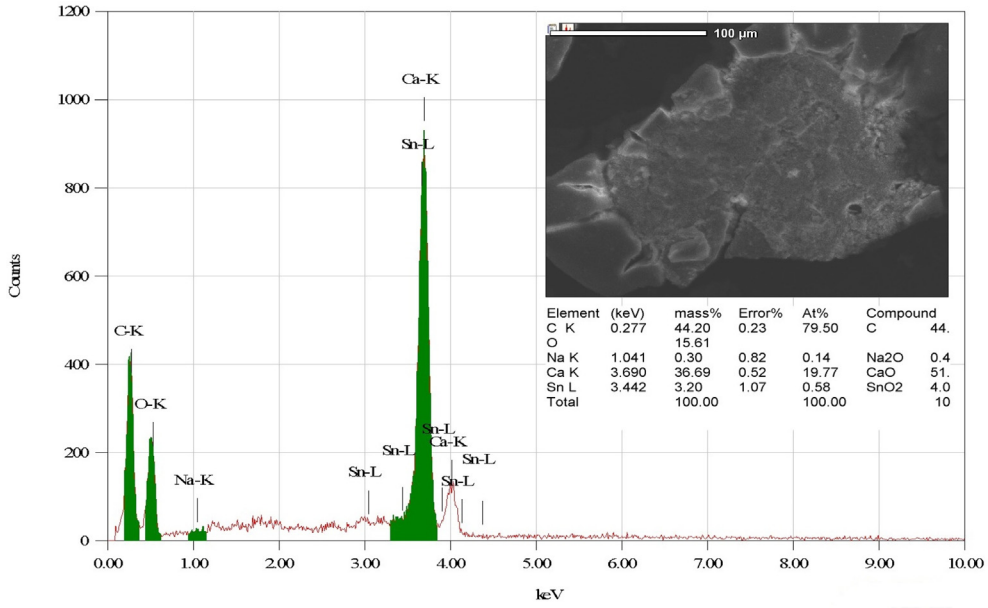


Fig. 3. Image of sem and edx from pcnp.

3.7. Sliced apple storage studies

The storage studies were conducted for sliced apples up to 7 days, and the results are shown in Figs. 9 and 10. The pH value moderately decreased in control apples for the 7th day, and this was prevented by treating with PCNP and standard calcium chloride. The slightly decreased weight was observed in the control apples for the 7th day, and this was prevented by treatment with PCNP and standard calcium chloride. The sensory analyses, including texture, aroma, appearance, and decay, are directly associated with the fruit eminence, and these were slightly decreased in the control apples for the 7th day. These sensory analyses were prevented from decreasing by being treated with PCNP and standard calcium chloride. Hence, these observed sensory analyses, weight loss, and pH studies proved that the PCNP is the best natural agent for storing the sliced apples.

4. Discussion

Nanotechnology has a wide variety of applications in the food industry, such as adding antibacterial and antifungal agents to

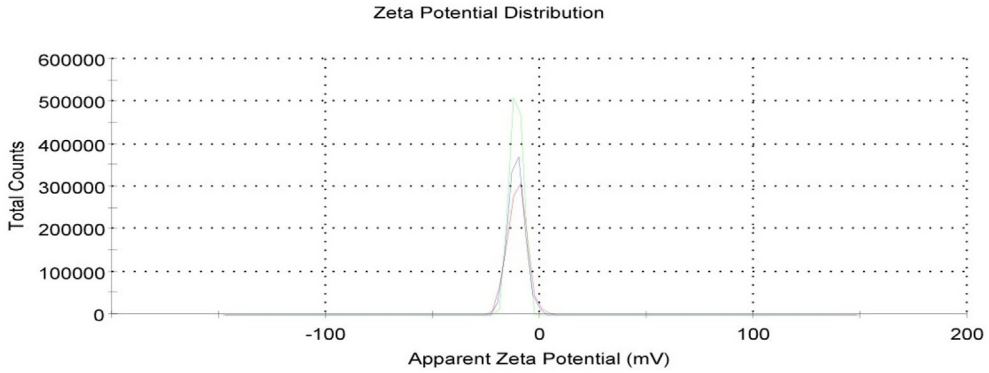
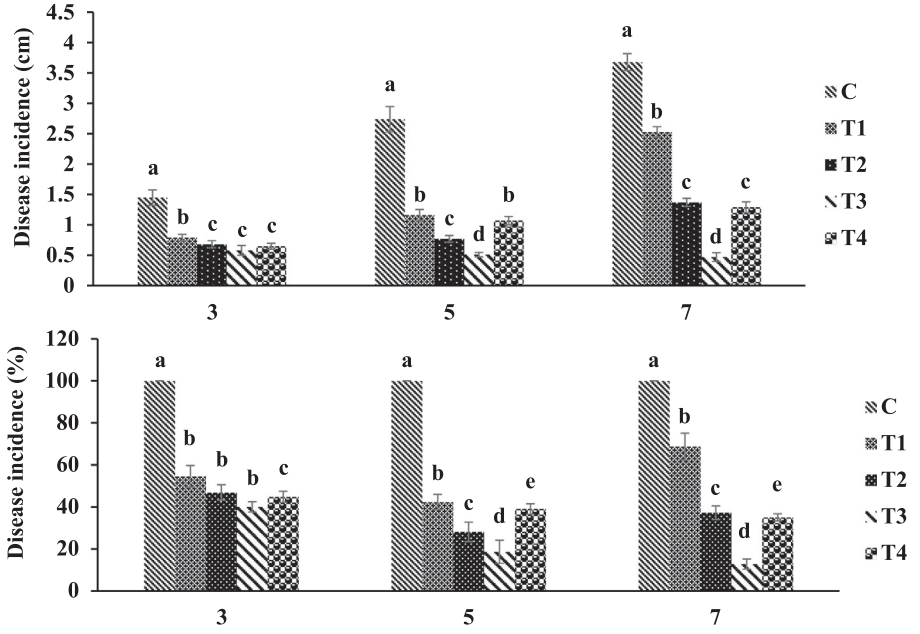


Fig. 4. Image of dls from pcnp.



C, control, T1, T2, T3 and T4 are various concetrations of PCNP (25, 50, 100, and 200 µg/mL).

Fig. 5. Efficacy of PCNP on ring rod infection of apple during the storage. C, control, T1, T2, T3 and T4 are various concetrations of PCNP (25, 50, 100, and 200 µg/mL).

the food, increasing the food's flavor and taste, identifying the foodborne pathogen, increasing the food's shelf life, and enhancing food storage and transport. Recent studies in nanotechnology have many kinds of scientific approaches, including those involving food industries (Su et al., 2022). Currently, nanotechnology applications are urgently needed for food processing, food science, and the food microbiological fields, therefore, in our study, we have planned to synthesize organic nanoparticles from *Pouteria caimito* fruit extract and calcium chloride. The produced nanoparticles sizes and characterizations were stabilized by different scientific methods. Primarily, the size of the produced nanoparticles was estimated by UV–visible spectroscopic analysis, and the results showed an absorption peak at 303.2 nm, and this single peak obviously designates the nanoparticles formation. Previous studies have been supported in our UV-spectrum observed results by a showing of a single peak and the ranges from 300 to 460 nm, which clearly indicate the nanoparticles production in a regular and uniform manner (Veeramani et al., 2020). Secondly, our produced nanoparticles zeta potential was estimated by DLS analysis. The zeta potential spectrum showed very low values. Previous numerous scientific reports have been supported in our findings by the approach of the observed lower zeta potential value and the nanosize distribution of the spectrum (Veeramani et al., 2022a, 2022b, 2022c). Hence, these spectra clearly indicate that the nanoparticles produced at nanoscale approach with clear purity.

Nemours soundings employed the scanning electron SEM/EDX to authenticate the nanoparticles elements analysis properly (Veeramani et al., 2020). The elements of nanoparticles were also analyzed using the same methods in our study. Calcium was discovered to be a substantial element, as well as other factors such Na, Sn, C, and O were also discovered. Previous nanoparticle characterization studies also supported our study and provided the nanoparticle dimensional and elemental analysis (Veeramani et al., 2020; Veeramani et al., 2022a, 2022b, 2022c). The crystal nature and the major elements Ca and C clearly indicated the nanoparticles formation without structural changes and the biological properties of plant ingredients. One of the most advanced FTIR techniques used by scientists today for characterization and functional group analyses of manufactured nanoparticles. In our study, the FTIR spectrum shows four large peaks, and these indicate the C = C, O–H, C–H, and C–N, and functional groups. The formed calcium oxide nanoparticles were clearly indicated by the

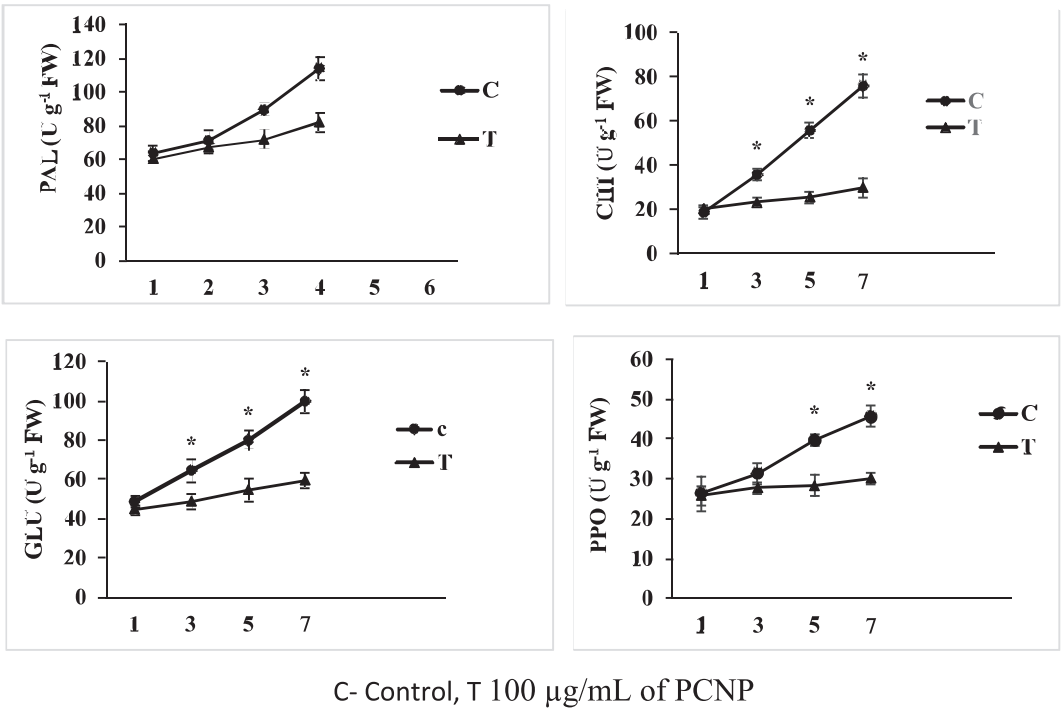


Fig. 6. Efficacy of PCNP on the deeds of PAL, CHI, GLU, and PPO in apple fruits. C- Control, T 100 µg/mL of PCNP.

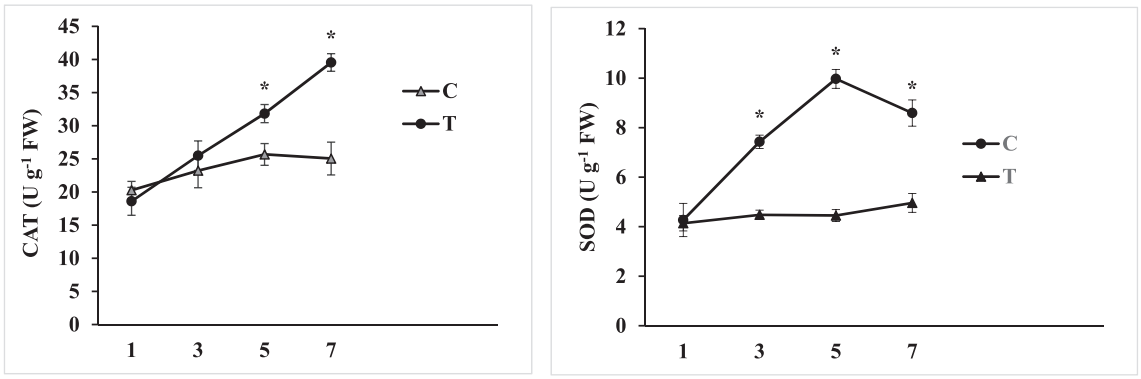


Fig. 7. Efficacy of PCNP on the deeds of CAT and SOD in apple fruits. C- Control, T 100 µg/mL of PCNP.

observed peaks. Due to these different kinds of physical and chemical characterization studies, the nano-sized calcium oxide nanoparticles have formed positively, and as a result, we have confirmed *Pouteria caimito* fruit is the ultimate source for green nanoparticle synthesis.

Synthetic fungicides are currently widely and primarily used to control or manage apple ring rot. Nonetheless, synthetic drugs are extremely toxic and harmful to the environment, animals, and humans. Hence, the natural advanced fungicidal properties of plants and plant-associated nanoparticles have been given more attention by scientists worldwide due to their non-toxic nature and friendly method. *Pouteria caimito* is a natural fruit and it is consumable widely worldwide; therefore, using the *Pouteria caimito* fruit and its associated calcium oxide nanoparticles for production is safe and nontoxic for the environment, animals, and humans. In our study, calcium oxide nanoparticles from *Pouteria caimito* fruit expressively reserved the apple disease on the after the harvest apple fruit. All four doses of calcium oxide nanoparticles, such as 25, 50, 100, and 200 µg/mL have inhibited the apple disease; but, the higher concentration of nanoparticles somewhat faded the apple's red skin. The apple fruit preserved with lower concentrations, such as 50 and 100 g/mL, have perfectly preserved the apple disease and maintained the fruit's quality and taste. Hence, we concluded that the lower two concentrations of calcium oxide nanoparticles have dramatically inhibited the apple ring rot disease and maintained the natural fruit color, taste, and quality. Hence, the calcium oxide nanoparticles have severely suppressed or killed the *B. dothidea* fungal growth, thereby lowering the incidence possibility and eventually reducing the apple ring rot disease. Previous numerous studies have proved that several plants and their ingredients are the ultimate fungicidal agents (Shuping and Eloff, 2017). These important phytochemicals interfere with the synthesized enzymatic reactions of the wall, leading to substantial structural changes in fungal cells such as protoplast leak-

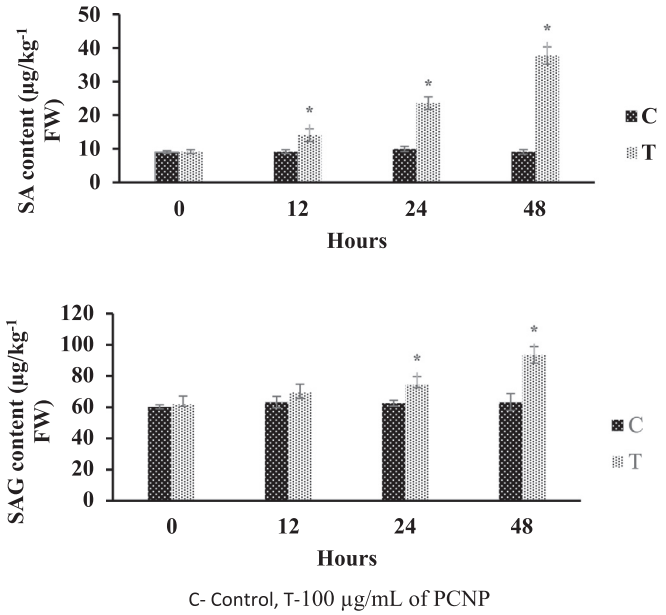


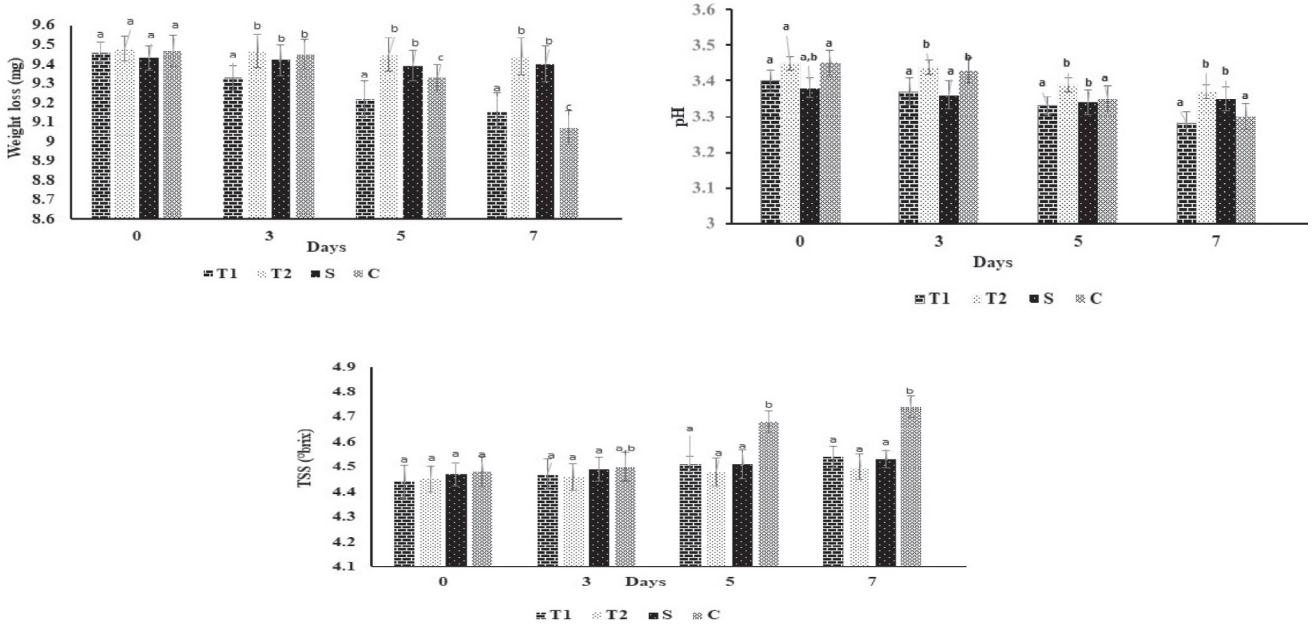
Fig. 8. SA and SAG content of control and PCNP treated apple fruits. C- Control, T-100 µg/mL of PCNP.

age, coagulation, and vacuolations that thereby distress the fungal growth and morphology. Hence, we concluded that the nanosized *Pouteria caimito* fruit phytochemicals may inhibit the apple ring rot disease.

Myriad studies have exposed that the defense-related gene response is indispensable for averting plant and fruit illness. GLU has contributed to resistance against Rhizoctonia solani, blister blight disease, and foot rot (Sandhu et al., 2019; Kaur et al., 2021). POD has contributed to resistance against *P. infestans,* citrus bacterial canker, and *Colletotrichum kahawae* (Diniz et al., 2019; Yang et al., 2020a, 2020b). CAT and SOD have been involved in inhibiting the virus infections (Jiao et al., 2021; Yang et al., 2020a, 2020b). PAL and CHI have contributed to inhibiting action against *B. cinerea* and the bacterium *Xanthomonas campestris* (Navarro-Gonzalez et al., 2019). Hence, we planned to examine the defense genes and antioxidant activities after treating the fruit with PCNP against *B. dothidea*, and these defense genes as well as antioxidant activities such as SOD, CAT, CHI, GLU, PAL, and CHI were significantly decreased in the control fruit and were prevented while the fruit was treated with PCNP.

Salicylic acid (SA) is a hormone, and it plays an extensive range of important roles during fruit ripening, seed germination, flowering, and the disease defense systems against numerous pathogens. Salicylic acid beta-glucoside (SAG) is releasing the free SA; hence, it is very important for storage and as a defense signal against the pathogen (Tiwari et al., 2017; Koo et al., 2020). SA and SAG of PCNP-treated apples were significantly increased; hence, these increased levels may have protected the apples from the ring rot disease. Prior studies have stated that the SA is reducing the decay of fruits and improving their quality properties, including texture and appearance (García-Pastor et al., 2020). Hence, these increased levels of SA and SAG after PCNP treatment could be attributed to the protective role of apples against the *B. dothidea*-caused pathogens.

Fruits and vegetable storage are very important to prevent spoilage and illness and maintain the natural quality of the products. Food-borne diseases are a very important and challenging issue during the storage of fruits and vegetables; hence, ethylene, acetylene, calcium carbonate, calcium sulfate, calcium chloride, propylene, ethanol, glycol, calcium ammonium nitrate, and others are used for fruit and vegetable storage. These preservatives are causing side effects in humans, either directly or indirectly (Allen and Goldenberg, 2012). Fruits and vegetables are the primary source of human food because they contain the digestive form of nutritious and energetic molecules available, including carbohydrates, proteins, amino acids, vitamins, minerals, and also several beneficial phytochemicals. Hence, we have used the biological synthesis of calcium nanoparticles in PCNP to store the sliced apple fruits for



T1- 50 µg/mL of PCNP; T2 100 µg/mL of PCNP; S- 2% Calcium chloride (standard) C-normal

Fig. 9. The weight loss, tss and ph values of control, standard and pcnp treated apple fruits. T1- 50 µg/mL of PCNP; T2 100 µg/mL of PCNP; S- 2% Calcium chloride (standard) C-normal.

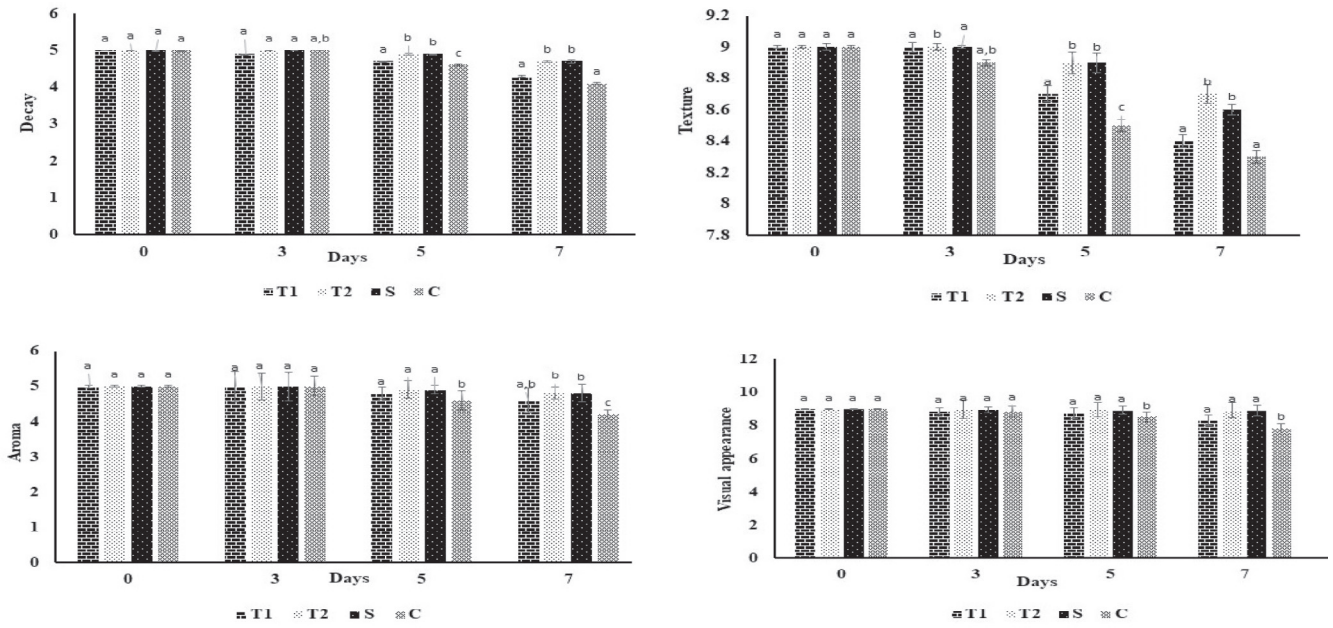


Fig. 10. The decay, texture, aroma and visual appearance of control, standard and pcnp treated apple fruits. T1- 50 µg/mL of PCNP; T2 100 µg/mL of PCNP; S-2% Calcium chloride (standard), C-control.

up to 7 days. In our study, the pH value moderately decreased in control apples for the 7th day, and this was prevented by treating them with PCNP and standard calcium chloride. The slightly decreased weight was observed in the control apples for the 7th day, and this was prevented by treatment with PCNP and standard calcium chloride. The sensory analyses, including decay, aroma, appearance, and texture are directly associated with the fruit eminence, and these were slightly decreased in the control apples for the 7th day. These sensory analyses were prevented from decreasing by being treated with PCNP and standard calcium chloride. Hence, these observed sensory analyses, weight loss, and pH studies proved that PCNP are the best natural preservative for storing sliced apples for up to 7 days. Recently, many studies have used characteristics assessment to manage the postharvest fruit disease to manage the quality of the fruit as well as its pathogenic effect. In our study, we have proved that the PCNP have ultimate fungicidal properties, maintain food quality, and extend sliced apple storage up to 7 days without changing the fruit's quality.

5. Conclusion

Our exploration has led us to the conclusion that the PCNP from *Pouteria caimito* fruit extract and calcium chloride is formed at the nanoscale without any impurities or structural changes. The defensive and antioxidant enzyme activities were suggestively improved in nanoparticle-treated apple fruits once equated with those of control apple fruits. Hence, the PCNP have possessed excellent suppressive action against the *B. dothidea*-caused apple disease on after harvest fruit due to increased levels of SA and SAG. The shelf-life extension studies were conducted for 7 days with a fresh-cut apple. The studies on total soluble solids, pH, weight loss, and sensory analyses were conducted, and they proved the extension of sliced apples have a seven-day or may longer shelf life. Hence, the PCNP clearly proved an excellent alternative source of disease defense the illness known as apple ring rot as well as the sliced apple life extension up to 7 days.

Significance Statement

The first evidence of this study shows that the PCNP from *Pouteria caimito* fruit extract and calcium chloride is formed at the nanoscale without any impurities or structural changes. The PCNP is clearly proved an excellent alternative source of disease defense against the apple ring rot disease as well as the sliced apple life extension up to 7 days. Hence, the PCNP is a well-organized, harmless, and environment-friendly substitute preservative for fruits and vegetables, and these may help to protect economic losses and environmental pollution.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2023.103744.

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