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Nano-Management of Bitter Pit in Apple Crop: A Short Communication

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Bitter pit is a physiological disorder in apple, which may happen during the end of season or during the postharvest. This phenomenon causes high economic losses for farmers and exporters as well. It is thought that calcium has a very strong relationship with bitter pit in apple, which appears as browning points due to the phenolic oxidation mainly during storage and death of cells directly below the fruit peels. The management of bitter pit depends on the enough and continues supplying Ca to cultivated apple trees before harvesting the fruits. The impacts of applied nano-Ca treatment on fruit quality of apple were more significant comparing to the conventional application of calcium chloride. These impacts included improving several quality characteristics such as total soluble solids in fruits, fruit firmness, titratable acidity, total antioxidant activity, total phenolic and anthocyanins content, as well as the contents of total sugars, starch, fiber, and calcium content. Therefore, there is an urgent need for further investigations concerning using of different nanofertilizers to avoid the problems of bitter pit in apple. Other applications of nanomaterials may support apple trees against this problem, which may open many fields in agro-nanotechnology.

Keywords: Calcium deficiency, Nano-calcium, Nano-magnesium, Phenolic oxidation.

1. Bitter pit and its incidence

In 2016, the world apple production was around 85 million tonnes (FAOSTAT, 2019). Bitter pit is considered a serious physiological disorder in several apple cultivars under different growing regions (A1 Shoffe et al. 2019; McCormick et al. 2021). The main symptoms of bitter pit include forming circular sunken lesions on fruits (1-4 mm) and bitter in taste, which could be found scattered in the flesh of the fruits (Jemrić et al. 2016). These lesions are found either below the peel, or as scatters in the flesh of the fruit, especially in the calyx. These symptoms could be appeared in the orchard late in the season and/or during storage, which causes high economic losses (Torres et al. 2021).

It was reported long time ago that more than 50% of fruit production of some apple varieties is unmarketable due to bitter pit and the rest percentages can be even less after long-term storage (Rosenberger et al., 2004). The main causes of this phenomenon may include Ca-deficiency (Qui et al. 2021; Torres et al. 2021), Ca-deficiency and high

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gibberellins activity in apple trees (do Amarante et al. 2019) and due to the accumulation of abnormal amyloplasts in pulp cells in apple fruits (Qui et al. 2021). Some studies also reported that the nutritional unbalance in apple (mainly in Ca, Mg, K and N) may lead to the incidence of pitting in fruits (Bonomelli et al. 2020). The role of Ca in apple nutrition is mainly associated with its potential as a secondary messenger, stabilizer of plant cell wall and cell membrane as well as its importance for the quality of fruits and their postharvest life. The strong relation between Ca in apple plants and its ratio to others nutrients (Mg/Ca and K, Ca/K + Mg/Ca) may play a crucial role in plant cell and tissue metabolism more than the role of each element alone (Al Shoffe et al. 2019, 2020). Many tools or techniques have been used in detecting of bitter pit in apple such as using computed tomography images (Jarolmasjed et al. 2016; Si and Sankaran 2016), using the mineral and non-mineral prediction methods (Al Shoffe et al. 2019), using the non-destructive sensors (Osinenko et al. 2021), using the integral procedure based on Ca-content and symptom induction (Torres et al. 2021), and using near infrared (NIR) spectral models (Jarolmasjed et al. 2017; Mogollón et al. 2021). More information about bitter pit in apple could be found in Table 1 and Figs. 1 and 2.

Table 1: The main information about the "bitter pit" in apple and its historical background

Item	Details (Reference)
Bitter pit definition	Bitter pit is a physiological phenomenon or disorder, which significantly reduces the quality of apple fruits and formed as a result of calcium deficiency in the fruits (Jemrić et al. 2016), and mainly formed due to the phenolic oxidation mainly during storage and death of cells directly below the fruit peel (Orcheski et al. 2021; Mogollón et al.2021).
Causes of bitter pit	Calcium deficiency (Qui et al. 2021; Torres et al. 2021) Ca-deficiency and high gibberellins activity in apple trees (do Amarante et al. 2019) Accumulation of abnormal amyloplasts in pulp cells in apple fruits (Qui et al. 2021)
Bitter pit timing	During storage or in the late season causing high economic losses (Torres et al. 2021)
Bitter pit symptoms	Symptoms include circular sunken lesions on fruit of 1–4 mm and bitter in taste, which could be found scattered in the calyx end in flesh and peel (Jemrić et al. 2016; Torres et al. 2021)
Soil preferable for this phenomenon	Acidic soils and it could reduce the incidence of bitter pit in apple (75.6 – 78.2%) by application of 200-300 g m^{-2} lime (Wang et al. 2005)
Managing bitter pit	Applied calcium chloride up to 26.34 kg ha^{-1} per season (Biggs and Peck 2015) Applied combined foliar (5.9 kg ha^{-1} per season) and soil supply of calcium at 15% CaO (Torres et al. 2017) Foliar application of mix of ethephon, naphthaleneacetic acid, and 1-aminocyclopropane carboxylic acid combined with calcium chloride (Cline 2019) Spraying prohexadione-calcium (300 mg l^{-1}) or gibberellins (GA_{4+7}; 300 mg l^{-1}) (do Amarante et al. 2019) Pre-harvest hexanal spray at a 0.02 % (v/v) (De Brouwer et al. 2020) Nano-calcium at doses of 1.5 and 2.0% (Ranjbar et al. 2020) Spray both γ-Aminobutyric acid (40 mM) and $CaCl_2$ (0.12%) (Al Shoffe et al. 2021a) Pre- and post-harvest applied 1-methycyclopropene at 60 µl l^{-1} (Al Shoffe et al. 2021b)
Genes associated with bitter pit	There are several differentially expressed genes like MdMADS5 and MdIDL1 (Orcheski et al. 2021)
Detection of bitter pit	Using computed tomography images (Jarolmasjed et al. 2016; Si and Sankaran 2016) Mineral and non-mineral prediction methods (Al Shoffe et al. 2019) Application of non-destructive sensors (Osinenko et al. 2021) Integral procedure based on Ca-content and symptom induction (Torres et al. 2021) Using near infrared (NIR) spectral models (Jarolmasjed et al. 2017; Mogollón et al. 2021)

2. Nano-management of bitter pit in apple

Nano-management is a new approach could be used nowadays in agriculture to overcome many problems like nano-pesticides against plant pests and diseases (Charehgani et al. 2021; Hajji-Hedf and Chhipa 2021; Kumar et al. 2021), nanofertilizers for supplying deficient nutrients (Basavegowda and Baek 2021), and nanoremediation for removing different pollutants from soil (Lian et al. 2021) and water (Puri et al. 2021). The management of bitter pit phenomenon was discussed by many researchers several years ago using different approaches such as:

1- Application of calcium chloride up to 26.34 kg ha^{-1} per season to overcome Ca deficiency (Biggs and Peck 2015),

2- Application combined foliar (5.9 kg ha^{-1} per season) and soil supply of calcium at 15% CaO (Torres et al. 2017),

3- Using the foliar application of mixture of ethephon, naphthaleneacetic acid, and 1-aminocyclopropane carboxylic acid combined with calcium chloride (Cline 2019),

4- Spraying the prohexadione-calcium at rate of 300 mg l^{-1} or gibberellins (GA_{4+7}) at dose of 300 mg l^{-1} (do Amarante et al. 2019),

5- Pre-harvest hexanal spray at a 0.02 % (v/v) (De Brouwer et al. 2020),

6- Application of nano- calcium at doses of 1.5 and 2.0% comparing with $CaCl_2$ at the same previous applied doses (Ranjbar et al. 2020),

7- Spray both γ-Aminobutyric acid (40 mM) and $CaCl_2$ (0.12%) (Al Shoffe et al. 2021a), and

8- Pre- and post-harvest applied 1-methycyclopropene at 60 µl l^{-1} (Al Shoffe et al. 2021b).

Fig. 1. A comparison between apple fruits suffer from bitter pit (left photo) and normal ones (right photo).

Fig. 2. Different features for the bitter pit in apple fruits, which may include some distinguished features like in the two photos (above) and in some sections in fruits as shown in the down photos.

The nano management approach is a new method that could be used to overcome or solve a problem in agriculture such as the phytoplasma diseases in horticultural plants (El-Mahrouk et al. 2021). This is a call by EBSS journal for nano management against the bitter pit in apples. This nano-management may include different approaches to avoid and/or decrease the incidence of the bitter pit phenomenon in apple for example using nano-Ca in different forms as reported by Ranjbar et al. (2020). What is the expected impact of applied some other nano-nutrients like nano-Mg or nano-K or nano-Zn on the bitter pit in apple? How can the farmers and exporters use the nano-benefits to avoid the bitter pit in apple? Which nano-fertilizers (beside nano-Ca) could be used to improve the overall characteristics of apple fruits? Can we depend on different applications of nano-technology in improving the fruit quality of apple including all crop production stages such as cultivation, harvesting, storing, and packaging?

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