Environment, Biodiversity & Soil Security (EBSS)
http://jenvbs.journals.ekb.eg//

Foliar Application of Nano-Fertilizers for Fruit Cracking: A Short Communication

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THE growth and fruit yield of many trees are totally depended on several factors, including environmental and soil conditions, cultivars, agricultural operations particularly the fertilization and irrigation, as well as the tree nutritional status. Many wrong agricultural operations might cause serious problem for the crop productivity like cracking in fruits. Many strategies for protecting crop from fruits cracking and its management are essential to guarantee producing the high yield. The application of nanomaterials to overcome a lot of problems facing crop productivity with high quality especially abiotic/biotic stress has been confirmed by several studies. Nanofertilizers as nanomaterials have several benefits, which can support the crop production under stressful conditions through improving shell life, quantity and quality of crops, increasing nutrient use efficiency and plant bioavailability and extending the duration of nutrients release into rhizosphere up to 30-50 days. The using of nanofertilizers for cracked fruits is still a new approach in fighting fruit cracking, which needs more investigations. These studies open many questions including which kind of nanofertilizers could be used against fruit cracking? And which applied dose could be used and when?

Introduction

Base on the several problems of conventional fertilizers, which have raised due to high demand for food production after the green revolution. Beside low and poor use efficiency of conventional fertilizers (about 18-20, 30-35, 35-40% or less of the applied PNK-fertilizers) (Guo et al. 2018), which is used by the crop plant, the rest being leached to the ground water and rivers or mineralized, causing issues of costs, eutrophication problem and pollution for human health (Fatima et al. 2021; Sharma et al. 2021). Nanofertilizers are considered promising tools for both sustainable agriculture and environment (Al-Mamun et al. 2021; El-Saadony et al. 2021a; Rahman et al. 2021). Nanofertilizers are alternative fertilizers that have unique properties of nanoparticles, which include physicochemical characteristics at the nanoscale. There are several benefits of nanofertilizers such as enhancing fruit productivity, improving yield quality and shelf life *via* their positive effects on morphological, anatomical, physicochemical physiological, and molecular traits (Fatima et al. 2021; Sharma et al. 2021).

Cracking of fruits is a physiological phenomenon, by which pericarp cracks due to the pressure from fruit internal growth exceeds the strength given by pericarp growth (Wang et al. 2021). Cracks over the skin of fruits reduce the quality, decrease shelf life and cold storage of the fruits, then impact consumer preferences

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Received 2/9/ 2021 ; Accepted 10/11/ 2021
DOI : 10.21608/jenvbs.2021.94013.1142

(Khadivi-Khub 2015). Cracking rates varied among crops depending on the cultivars and the precipitations during different stages of the fruit growth (Fan et al. 2021). Several factors are controlling the cracking in fruits including external factors (i.e., all factors related to the environment and orchard management like light, temperature, humidity, applied nutrients, etc.), internal factors (i.e., all factors related to cultivated crop including nutrient content, plant hormone regulation, sugar content, mechanical properties of the fruit skin, fruit shape and size, and expansion rate of the skin and fruit)(Li and Chen 2017; Zhu et al. 2020; Volschenk 2021). The cracking of fruit is considered one of the serious physiological disorders in many fruit species such as apple, avocado, banana, citrus, grape, litchi, pomegranate, plum, persimmon, pistachio, and sweet cherry, which decreases the yield and quality of fruits (Davarpanah et al. 2018; Zhu et al. 2020).

Therefore, this work is a call for submission articles about the cracking of fruits as a serious problem in fruit production using new approaches (like nanofertilizers) and new tools like portable Near Infrared Spectrometer. The main causes of cracking and how to mange this problem will be also discussed.

Are nano-fertilizers emerging fertilizers?

Agriculture is a very vital sector in our life, which supply us with our necessary demands from food, feed, fiber and fuel. This industry depends on several factors including water (irrigation or soil moisture content) and soil supply (soil fertility and its nutrient content), beside different agricultural operations (**Fig. 1**), which may decrease the agricultural productivity (El-Ghamry et al. 2021). Agricultural production needs some requirements like the fertilizers, which are essential resources for crop growth and development (Olad et al. 2018). The conventional fertilizers have many problems including insolubility, degradation, leaching, and decomposition, which lead to lower crop yield as well as low quality due to insufficient bioavailability of nutrients for plants (Basavegowda et al. 2021).

No doubt that, nano-fertilizers have caused a "revolution" in the world of fertilizers because they can provide some nutrients in a nano-form, which enhance plant growth and its production (Dimkpa and Bindraban 2016). Nano-fertilizers could be classified into three categories based on the nutrient needs of plants including macro-nanofertilizers, micro-nanofertilizers, and nanoparticulate fertilizers. Nanofertilizers have many features, which could be presented in **Table (1**). Nano-fertilizers have distinguished properties like a high sorption capability, large surface area, and continuous release of nutrients in the rhizosphere up to 50 days, making them a smart delivery system (Rahman et al. 2021). Nanofertilizers have many other names like nano-carriers, nano-enabled fertilizers, bio-nanofertilizers, controlled released nano-fertilizers, NPs-based nutrient, nano-based delivery systems of micronutrients, which often deliver nutrients at the right time and in the right place (Fellet et al. 2021; Gomes et al. 2021; Al-Mamun et al. 2021). Therefore, several studies discussed the uptake and translocation of nano-fertilizers through the roots and leaves, their role of plant tolerance to abiotic/biotic stress, their impacts on crop productivity and its yield quality, as well as their role in mitigating the heavy metal toxicity reduction (**Table 1**).

Cracking of fruits: causes and control

The fruits cracking is a common phenomenon in several orchards, which could be described as a physiological disorder (like in pomegranate fruits, that occurs when the cuticle fractures or fruit peel or split). Cracking of fruits may be triggered by insufficient and irregular irrigation system or due to excessive rainfall, especially during fruit ripening (Volschenk 2021). Cracking in fruits may reduce the marketability of fruits and provide access for diseases and pests, causing significant income loss in the fresh market and processing industries (Khadivi-Khub 2015; Volschenk 2021). The cracking rate of some grape cultivars in South China may reach 90% during the ripening stage. The main features of fruit cracking, as a physiological disorder, include appearing cracks in the both flesh and skin. This disorder of cracking may affect fruit appearance, increasing its susceptibility to pathogen infection, and then lead to enormous commercial losses to grape yield (Zhu et al. 2020). Cracking of fruits is a serious problem for many fruits such as apple (Kasai et al. 2008; Ginzberg and Stern 2019), sweet cherry (Correia et al. 2018; Michailidis et al. 2020; Schumann et al. 2020; Quero-García et al. 2021), citrus (Cronjéet al. 2013; Li and Chen 2017), grape (Yuet al. 2020; Zhang et al. 2020; Zhu et al. 2020), litchi (Marboh et al. 2017; Wang et al. 2019, 2021), peach (Gibert et al. 2010), pears (Choi et al. 2020), and pomegranate (Davarpanahet al. 2018; Singh et al. 2021; Volschenk 2021), as reported in **Table 2 and Fig. 2**.

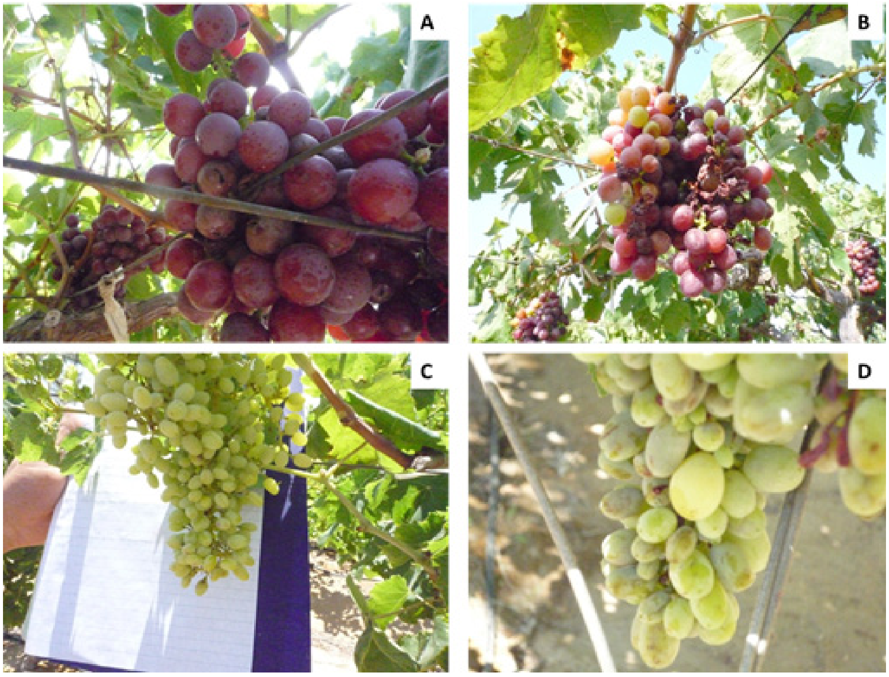

Fig. 1. Several abnormal disorders could be noticed in many cultivated fruit crops like in grapes, which might result from errors in agricultural operations such as (A) cracked fruits, (B) dry fruits, (C) irregular fruit size, and (D) boron deficiency

Fig. 2. Cracked fruits is a common phenomenon, which may as a result of errors in agricultural operations. (A) orange fruit (B) peach fruit (C) mango fruitcomparing with (D) cracked stem mango.

TABLE 1. The main features of nano-fertilizers that can be used for plant nutrition.

Main features (items)	Nano-fertilizer details	References
Definition	Nano-fertilizers are nanomaterials or nanoform or nanoparticles of some nutrients, which could support plant growth and its production	Dimkpa and Bindraban (2016); Chhipa (2017); El-Ghamry et al. (2018); El-Saadony et al. (2021)
Methods of fabrication	Mainly physical, chemical and biological methods with preferring the biological one (ecofriendly, safe, economic and high yield)	Hassanien et al. (2020); Siddiqi and Husen(2020); El-Saadony et al. (2021e)
Benefits for crop and fruit production	1- Improving shell life, quantity and quality of crops	Sharma et al. (2021)
	2- Increasing nutrient use efficiency and plant bioavailability (up to 70%)	Basavegowda and Baek (2021)
	3- Extending the duration of nutrients release into rhizosphere up to 30-50 days	Rahman et al. (2021)
	4- Preventing the environmental pollution	Astaneh et al. (2021)
	5- Promoting growth and production under biotic and abiotic stress	Badawy et al. (2021); Shalaby et al. (2021); Jośko et al. (2021)
Nanofertilizer types	Any nano-nutrient of essential (Nano-Cu, Zn, N, P, K, Ca, Fe, B, Mo, Mn) or beneficial nutrients like silicon (Si), selenium (Se)	Siddiqi and Husen (2020); Tarafder et al. (2020); Fellet et al. (2021)
Possible mechanism of the uptake	The root and foliar uptake could be achieved by apoplast or symplast pathways	Rahman et al. (2021)
Phytotoxicity	May include cell membrane integrity, lipid oxidation, ion leakage then cell death	Rahman et al. (2021)
Mechanism of action of phytotoxicity	1- Protein and DNA damage, 2-Generation of reactive oxygen species (ROS), 3- Damage to cell membrane integrity, 4-Altered gene expression, and 5-Altered enzyme activities	El-Saadony et al. (2021a); Rahman et al. (2021)
Nano-fertilizer kinetics	Maybe nano-nutrients penetrate stomatal pores less than 50 nm (like *Vicia faba* L.), NPs link to carrier proteins by ion channels, aquaporin, and endocytosis, which allows NPs to uptake	Nair et al. (2010); Javazmi et al. (2021)
Other common names of nano-fertilizers	Nano-enabled fertilizers,bio-nanofertilizers, controlled released nano-fertilizers, NPs-based nutrient, nano-based delivery systems of micronutrients	Guo et al. (2018); Fellet et al. (2021); Rahman et al. (2021); Gomes et al. (2021); Al-Mamun et al. (2021)
Nano-fertilizer limitations	- Lack of risk management for nano-fertilizers, - Higher production costs, - Difficulty in Controlling the nutrient size, - Higher and continuous applied might increase the heavy metals and phytotoxicity	León-Silva et al. (2018); Rahman et al. (2021); Sharma et al. (2021)
Some common applied dose to different crops		
- Nano-ZnO	Wheat, maize, eggplant (20, 10, 5-20 mg L^{-1}, res.)	Xin et al. (2020); Seliem et al. (2020); Shalaby et al. (02021); Seleiman et al. (2021); Rahman et al. (2021);Basavegowda and Baek (2021)
- Nano-Cu	Lettuce, coriander, spinach, wheat (10-660, 20-80, 200, 500 mg kg^{-1})	
- Nano-apatite	Lettuce, soybean, (200, 100 mgL^{-1})	
- Nano-Fe	Cumin (500-1000 mg L^{1-})	
- Nano-Se	Cucumber, chrysanthemum (25, 150 mg L^{-1})	
-Nano-silica (SiO_2)	Maize, wheat (15 kg ha^{-1}, 30–60 mgL^{-1})	

TABLE 2. The main features of fruits cracking.

Main features (items)	Details about each item of cracking	References
Definition		
"*Cracking of fruit is a physiological disorder in which cracks appear in the skin and flesh, which increases its susceptibility to pathogen infection, resulting in loss marketability*"		Jiang et al. (2019); Zhu et al. (2020)
Main causes of cracking phenomenon		
- External factors	Orchard management and the environmental conditions (light, temperature, humidity, applied nutrients, etc.)	Li and Chen (2017); Zhu et al. (2020)
- Internal factors	Mineral nutrition, plant hormone regulation, sugar content, mechanical properties of the fruit skin, fruit shape and size, and expansion rate of the skin and fruit	
Cracking fruits in general	Maybe triggered by insufficient and irregular irrigation or by excessive rainfall, especially during fruit ripening	Volschenk (2021)
Cracking management and their strategies		
1- Rain covers protection	Plastic rain covers	Correia et al. (2018)
2- Foliar mineral nutrient	Foliar application of Ca, B, or Cu	Ghanbarpour et al. (2019)
3- Foliar antitranspirants	Like Vaporgard^R and RainGard™	Khadivi-Khub (2015)
4- Plant growth regulators	Gibberellic acid (GA_3)	Xue et al. (2020)
5- New approaches	Foliar nanofertilizers, salicylic acid, and biostimulants	Sharma et al. (2021)
6- New techniques (tools)	Portable Near-infrared (NIR) spectrometer	Fan et al. (2021)
Possible mechanism of fruit cracking		
On the physiological level	Based on microscopic structure of grape skin, it has lower ratio of longitudinal and radial subepidermal cell dimensions, and fewer cells in subepidermal cell layer	Zhu et al. (2020)
On the genetic level	The thickness of cell wall and the size of subepidermal cells were closely related to the susceptibility gene	Wang et al. (2021b)
On the physical level	Water penetration through the cuticle causing separation of the cuticle from the epidermal cell wall	Correia et al. (2018)
Most common cracking fruits		
	- Sweet cherry (*Prunus avium* L.)	Michailidis et al. (2020)
	- Citrus (*Citrus* sp.)	Li and Chen (2017)
	- Pomegranate (*Punica granatum*)	Volschenk T (2021)
	- Grape (*Vitis vinifera* L.)	Zhu et al. (2020)
	- Apple (*Malus domestica* L.)	Opara et al. (2000)
	- Pears (*Pyrus pyrifolia*)	Choi et al. (2020)
	- Litchi (*Litchi chinensis* Sonn.)	Wang et al. (2019, 2021a)

The physiology of fruit cracking could be explained as lose in the ability of tissues of skin to divide and enlarge during drought period, and after a dry spell, water supply is greatly increased, the meristematic tissues (not the strengthened tissues) quickly resume growth (Singh et al. 2020). The main causes of fruit cracking may include all factors related to the environmental conditions or external factors and internal factors, which include all factors linked to cultivated crop like nutrient contents, sugar content, plant hormone regulation, mechanical properties of the fruit skin, fruit shape and size, and expansion rate of the skin and fruit (Li and Chen 2017; Ozturk et al. 2018; Zhu et al. 2020; Volschenk 2021). Many strategies could be adapted to overcome the cracking phenomenon like using plastic rain covers, foliar application of many nutrients (e.g., Ca, B, or Cu)(Correia et al. 2018; Ghanbarpour et al. 2019), foliar antitranspirants (Khadivi-Khub 2015), applied plant growth regulators like gibberellic acid (Xue et al. 2020), using new approaches like foliar nanofertilizers, salicylic acid, and biostimulants (Sharma et al. 2021) and using new techniques like portable Near-infrared spectrometer (Fan et al. 2021). The cracking of fruits may cause lose in the yield of horticultural crops like pomegranateas 65% (Singh et al. 2020).

Nano-fertilizers for cracking of fruits

The modern agriculture faces several troubles, which mainly impact on the global food production. Many problems have been solved by application of nano-enabled agriculture (Wu and Li 2021), which included many new approaches such as nano-plant nutrition (El-Ramady et al. 2018), nano-biofortification (El-Ramady et al. 2021a, b), nano-remediation (Abdul Azeez et al. 2021), bio-nanofertilizer (Kumari and Singh 2020; El-Ghamry et al. 2021), and nano-fertilizers (Al-Mamun et al 2021).Several studies confirmed the promising role of nanofertilizers in delivering controlled nano-nutrients, improving stress tolerance, and promoting yield quality of several crops (Kumari and Singh 2020), but using nanofertilizers against cracking fruits is still in the enfant stage. This is a call for articles concerning the using of nanofertilizers in treating the cracked fruits, which may include different side of this problem basically the physiological level, beside the nutritional level, and environmental dimension. There are few published studies, which focused on the role of nanofertilizer against cracking fruits like foliar nano-Ca fertilizer (Davarpanah et al. 2018), and coating alginate/oil nano-emulsion (Gutiérrez-Jara et al. 2021).

Conclusions

No doubt that, the fruit cracking problem is a complex phenomenon, which control by several factors playing a contributory role. Day by day, advances in research on cracking fruit in relation to its causes, physiology, and effective management clearly elucidate, but this problem should take into account including both external and internal conditions. Much of the work has been attempted to the fruit cracking management based on the role of climate, the anatomical features of the fruit, pericarp thickness, and pattern of fruit growth as well as the genetic constitution and endogenous Ca of the cultivars. The distinguished roles of nanofertilizers in the global food production accelerated by time and a real marketing for nanofertilizers already established in many countries like the USA, China, India and Iran. The role of nanofertilizers in managing crop productivity under different agricultural conditions has been discussed in many studies, but its use against cracking fruits is still need more investigations.

Ethics approval and consent to participate: This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication: All authors declare their consent for publication.

Funding: This research received no external funding.

Author contribution: All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The author declares no conflict of interest.

Acknowledgments: The authors thank the staff members of Physiology and Breeding of Horticultural Crops Laboratory, Dept. of Horticulture, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, Egypt for conducting the most parameters as well as they helped in completing this work.

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