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Grafting of Vegetable Crops in the Era of Nanotechnology: A photographic Mini Review

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It is well known that grafting, as a special plant propagation technique, is forming new plant by joining the scion (an aerial part of a plant) to a rootstock (another root part of a plant). This new plant (grafted plant) is employed to improve plant production, by getting greater plant development, vigour, and defence against abiotic/biotic stresses, as well as improving the uptake of nutrients, and their use efficiency. The grafted vegetable crops are common to overcome many plant diseases like *Fusarium* wilt. The most well-known grafted vegetables include both solanaceous and cucurbitaceous seedlings mainly in Europe, Asia, and North America. How can improve the efficiency of grafting process? Can the applied nanoparticles improve the quality of fruits and their nutrient content in grafted vegetables? This is a call by the Environment, Biodiversity and Soil Security (EBSS) for submitting new manuscripts for more investigations concerning the role of nanoparticles like nanofertilizers in enhancing the productivity of grafted vegetables mainly under different stresses.

Keywords: Grafted vegetables, Nanoparticles, Nanofertilizers, Nano-pesticides, Phytopathogens

1. Introduction

The applications of nanotechnology in agricultural sector are unlimited and uncountable. These applications include the food, energy, wastewater treatment, and the crop production especially in horticultural crops. Nanofertilizers, especially nano-biofertilizers, nano-sensors, and nano-pesticides are the most important applications of nanotechnology along with nano-food processing (Seymen et al. 2022). Nano-biofertilizers are defined as "*the newest and technically advanced eco-friendly and cost-effective way of sustained and slow delivery of nutrients to plants to promote their growth, yield, and quality parameters along with the benefits of increasing the nutrient use efficiency, minimizing volatilization and leaching, and reducing soil and water pollution*" (Vinod et al. 2022). Among agricultural practices, grafting is a special plant propagation technique, by which could produce and form a new plant as joining an aerial part of the plant (scion) and root part (rootstock) (Bayoumi et al. 2021; Shalaby et al. 2022). The success of grafting mainly depends on the compatibility between the rootstock and the scion, which can support the grafted plants against stresses by improving the nutrients uptake, transport, and their use efficiency (Uresti-Porras et al. 2021). Several published reviews and original articles on grafting in vegetables crops have been published such as Keatinge et al. (2014), Fernández-Garcí et al. (2015), Nawaz et al. (2016), Gaion et al. (2017), Nawaz et al. (2018), Wei et al. (2019), Singh et al. (2020), Cardarelli et al. (2020), Birkas et al. (2021), and Kubota et al. (2022). Like other sectors and

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fields, grafting was also investigated under the using of applied nanomaterials especially applied nanofertilizers as reported by Uresti-Porras et al. (2021) and Sayed et al. (2022). Several open questions are still needed to be answered in particular the nano-grafting by using grafting of vegetables under applied nano-pesticides. Nanofertilizers could be applied to vegetable crops due their enhancing the productivity because they can easily penetrate the stomata, then translocated by the vascular bundles of the xylem and phloem to other tissues (Uresti-Porras et al. 2021).

Therefore, this work is a call for submitting articles including reviews and mini-reviews as well as photographic form about the nano-grafting in vegetable crops. The role of grafting under different stresses in presence of nanofertilizers and nano-pesticides will be also discussed.

2. Grafting of vegetables for abiotic/biotic stress

The sector of vegetable crop production is one of the main sectors in agriculture, which supply humans with essential food (**Figs. 1-6;** the photos talk about the grafting, different stages in cucumber, watermelon and tomato in some experiments in Egypt). As an old technique, grafting of vegetable seedlings is considered a unique horticultural technology, which already has been practiced all over the world since 2000 BC (Kyriacou et al. 2020). Grafting is considered an effective and sustainable tool in producing the intensive vegetables growing system by securing the stability of yield and its quality in vegetable crops (Birkas et al. 2021), to overcome soil-borne diseases and pests (Keatinge et al. 2014; Cardarelli et al. 2020), and/or to increase plant vigor under various environmental stress conditions such as salinity (Singh et al. 2020), drought (Luo et al. 2020), flooding and low nutrient stress (Kubota et al. 2022; Zhang et al. 2022). In simple meaning, grafting is a successed approach to avoid the soil borne diseases or soil factors prevent growing and productivity of cultivated vegetables by using new grafted plant (scion and rootstock). Several published articles on grafted vegetables including different topics such as the sustainable production of grafted vegetables (Kyriacou et al. 2020), studied different rootstocks and growing media in sweet pepper (*Capsicum annuum* L.) (Birkas et al. 2021), and more are listed in **Table 1**. The main grafting techniques may include splice grafting, hole insertion, single cotyledon, tongue approach, self-rooted control (Kyriacou et al. 2020) and automatic approach (Kubota et al. 2022).

Table 1. List of some published articles on grafted vegetables under stress conditions.

Vegetable crop	Stress conditions	The main findings of the study	Refs.
Tomato (*Solanum lycopersicum* L.)	Salt stress (4000, and 8000 mg L^{-1} NaCl)	Grafting and applied nano-Si increased shoots contents of nutrients, phytohormones, peroxidase and proline compared to control	[1]
Tomato (*Solanum lycopersicum* L.)	Salinity stress from different studies	Grafting tomato as a tool to improve salt tolerance by salt exclusion or retention in root zone, activation of antioxidant defense system, osmotic adjustment, nutrient homeostasis, plant hormonal balances	[2]
Tomato (*Solanum lycopersicum* L.)	Water deficit stress	Grafted plants under stress recorded reduction in yield compared full irrigation, but WUE was highly improved with grafting and application of deficit irrigation	[3]
Cucurbitaceae species (melon and watermelon)	Salt stress (150 mM NaCl)	Different morphological and physiological traits between studied species and genotypes are main reason for their response to salt stress	[4]
Cucumber (*Cucumis sativus* L.)	Combined Fusarium wilt disease and heat stress (43°C)	The current study highlights the importance of heat stress and its biotic stress on grafted greenhouse cucumber, including the adverse impacts on physiological, morphological, biochemical and anatomical responses	[5]
Cucumber (*Cucumis sativus* L.)	Combined heat (43°C) and soil salinity (4.49 dS m^{-1})	Grafting can improve fruit yield of cucumber plants under combined studied stresses by improving the vegetative growth, biochemical, mineral content traits, yield quality	[6]
Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai.)	Vanadium stress (at 50 mg L^{-1})	Grafted watermelon onto bottle gourd and pumpkin rootstock improved watermelon tolerance to V stress by reducing the V content in leaf tissues, improving photo-synthetic assimilation, and enhancing SOD & CAT activities	[7]
Pepper (*Capsicum annuum* L.)	Salt stress (1 and 8 dS m^{-1})	Grafted plants have strong vegetative growth, high photosynthesis rate, higher content of carotenoid, proline,	[8]

		glycine betaine, nutrients compared non-grafted plants	
Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai.)	Water stress (at different irrigation levels (100, 75, 50, 35% of full rainfed)	Using wild watermelon rootstock could contribute to the fruit quality in arid and semi-arid areas with limited water resources	[9]
Eggplant (*Solanum melongena* L.)	Bacterial wilt caused by *Ralstonia solanacearum*	Root dipping method of artificial inoculation could be used as an efficient and reliable alternate to sick plot screening against bacterial wilt disease	[10]
Tomato (*Solanum lycopersicum* L.)	Cadmium stress (Cd in the soil was 10 mg kg^{-1})	Grafted tomato can reduce uptake of Cd and alleviates its stress, depending on type of used rootstock	[11]

List of refs.: [1] sayed et al. (2022), [2] Singh et al. (2020), [3] Urlic et al. (2020), [4] Modarelli et al. (2020), [5] Shalaby et al. (2022), [6] Bayoumi et al. (2021), [7] Nawaz et al. (2018), [8] Al Rubaye et al. (2021), Seymen et al. (2021), [10] Kumbar et al. (2021), [11] Xie et al. (2020).

Fig. 1. The production of vegetables starts with the growing of the transplants in the protected nursery, then move them to the open field or under protective or greenhouse conditions (the upper photos). The lower photos are harvesting the vegetables, sorting, packaging and be ready for transportation to consume by the humans. All photos by Zakaria Fawzy.

Selecting the proper scion and rootstock

Cutting the scion

Removing one cotyledon and cut it down of the rootstock

Matching the cut surfaces of both rootstock and scion

Hold the union by the clip

Standing the seedling and planting it in the seedlings tray

Fig. 2. Different grafting stages in cucumber plants in an Egyptian nursery: the used method in grafting was slant cut grafting method. All photos by house grafting nursery.

Watermelon grafted for *Fusarium* wilt

Fusarium wilt in ungrafted watermelon

Watermelon grafting using different rootstocks compared to control and showing wilting in control

Fig. 3. Impacts of grafting in watermelon plants on resistance to *Fusarium* wilt in an Egyptian cultivation (Balteem district). All photos by Bayoumi.

Ungrafted cucumber

Grafted cucumber onto Super Shintoza

Grafted cucumber onto “Ferro”

Grafted cucumber onto Bottle gourd

Grafted cucumber onto VSS-61 F_1

Grafted cucumber onto Cobalt

Fig. 4. Impact of grafting cucumber plants on different rootstocks on the resistance to *Fusarium oxysporum* f. sp. *cucumerinum* in an Egypt. All photos by N. Taha.

Ungrafting of tomato (control) after 35 days

Grafting of tomato (rootstock 1) after 35 days

Grafting of tomato (rootstock 3) after 35 days

Grafting of tomato (rootstock 2) after 35 days

Self-grafting after 60 days from transplanting

Ungrafted tomato (control) after 60 days

Grafted tomato (rootstock 1) after 60 days

Grafted tomato (rootstock 2) after 60 days

Fig. 5. Impact of grafting in tomato plants on different rootstocks in open field after grafting by 35 and 60 days from transplanting on the growth of plants and fruits as well. All photos by Bayoumi.

Fig. 6. Some photos of the grafting process in China, which includes different tools and vegetable seedlings. All photos by Zakaria Fawzy.

The main phyto-diseases may include the following diseases:

(I) Fungal and oomycete diseases: (1) Fusarium wilt (caused by *Fusarium oxysporum*) in tomato, pepper, eggplant, cucumber, watermelon, and melon; (2) Fusarium crown and root rot (caused by *Fusarium oxysporum*; *Fusarium solani*) in tomato, pepper, watermelon, and cucumber (Fusarium root and stem rot); (3) Verticillium wilt (caused by *Verticillium dahliae*) in eggplant, tomato, watermelon, melon, and cucumber; (4) Southern blight (caused by *Sclerotium rolfsii*) in tomato; (5) Phytophthora blight (caused by *Phytophthora capsici*) in tomato and pepper; (6) Monosporascus sudden wilt (caused by *Monosporascus cannonballus*) in melon and watermelon; (7) Corky root (caused by *Pyrenochaeta lycopersici*) in tomato and eggplant; (8) Black root rot (caused by *Phomopsis sclerotioides*) in cucumber; (9) Gummy stem blight (caused by *Didymella bryoniae*) in melon (although not a soilborne disease, it occurs at the lower crown of the plant and may be managed by using resistant rootstocks);

(II) Bacterial diseases: Bacterial wilt (caused by *Ralstonia solanacearum*) in tomato, eggplant, and pepper;

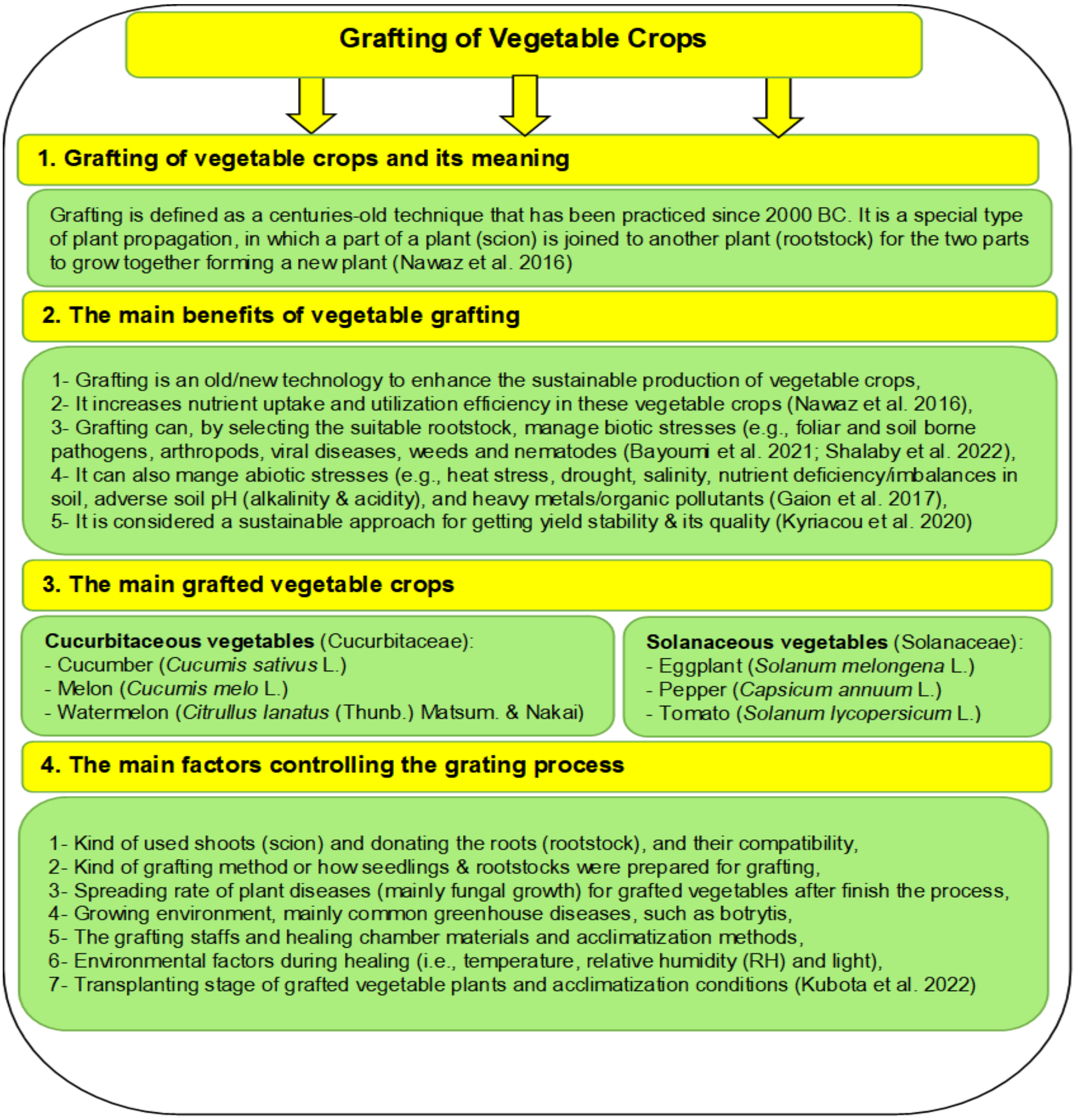
(III) Nematodes: Root-knot nematodes (Meloidogyne spp.) in tomato, eggplant, pepper, melon, watermelon, and cucumber;

(IV) Viral diseases: Melon necrotic spot virus in watermelon and melon (Kubota et al. 2022).

3. Grafted vegetables under applied nanomaterials

In general, the family of Like other sectors, the agricultural sector has several applications of nanotechnology. A few studies can be found regarding the grafted vegetable plants under application of nanoparticles, which mainly are nanofertilizers such as Uresti-Porras et al. (2021) and Sayed et al. (2022). These previous studies focus mainly on the grafting of vegetables under stress like salinity stress (Sayed et al. 2022) or under normal growth conditions like Uresti-Porras et al. (2021).

The main information about the grafting process, the main vegetable crops that could be grafted and factors controlling this process are listed in drawn **Figs. 7, 8, 9 and 10**. The good grafted vegetables require also a perfect incubator, and healthy transplants as shown in **Fig. 11.**



Figs. 7. The main information about the grafting process, the main vegetable crops that could be grafted and factors controlling this process.

Fig. 8. Some photos for some grafted vegetables that are common in China. All photos by Zakaria Fawzy.

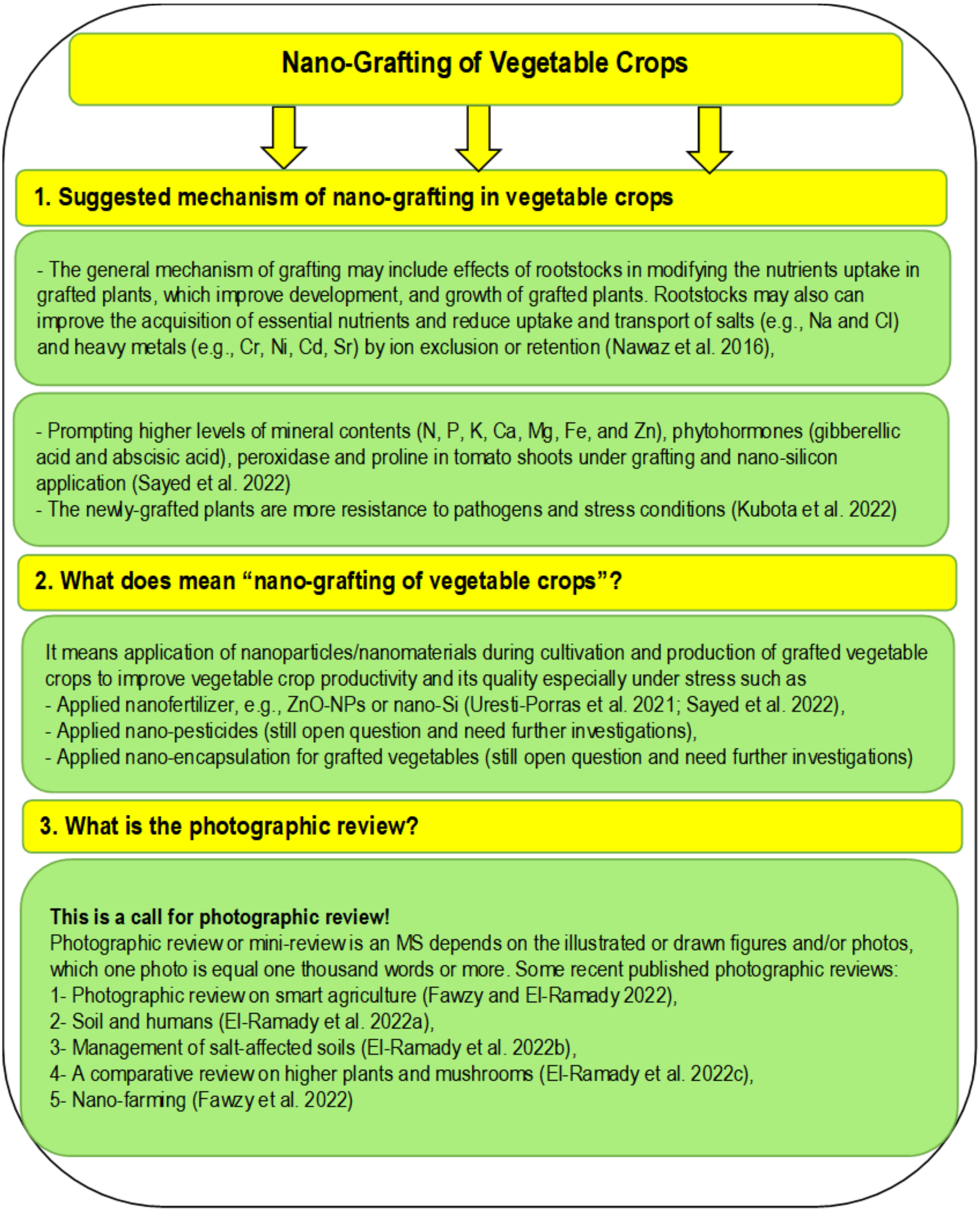


Fig. 9. What is the nano-grafting as explained in the text, and what if the photographic manuscript.

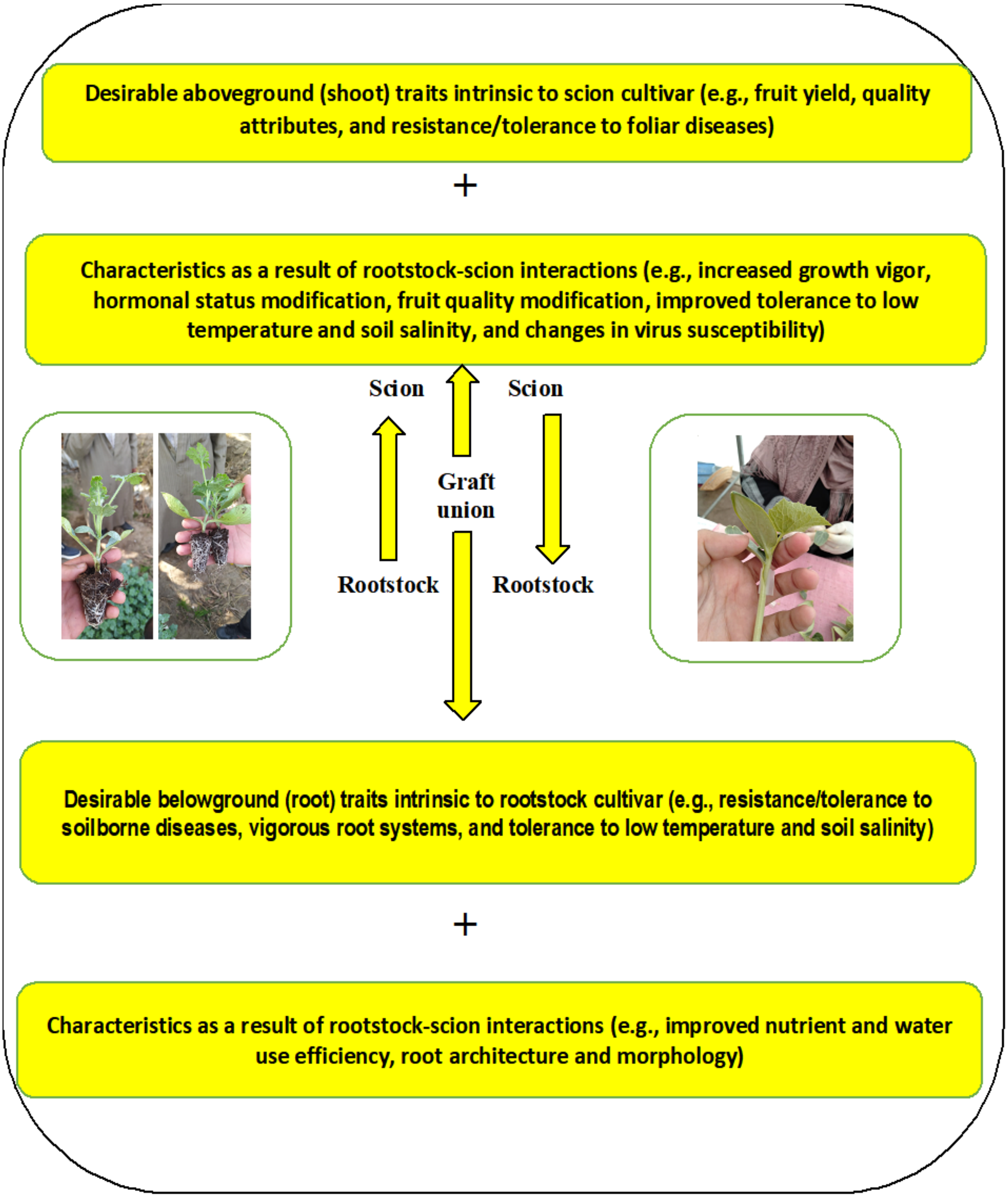


Fig. 10. An illustration of a general concept of vegetable grafting (according to Kubota et al. 2022).

Fig. 11. The good grafted vegetables require a perfect incubator (upper photo), and healthy transplants as shown in middle and lower photos. All photos by Bayoumi.

4. A call for photographic review

This work is a call for the readers to submit an MS (manuscript) based on the pictorial form to the journal of Environment, Biodiversity and Soil Security (EBSS). This photographic article can involve the suitable photos, drawn or illustrated figures, because as said one photo is more than 1000 words. As a mission of EBSS, every year, the board of the EBSS tries to find something worth and value, for example last year, the EBSS adopted a call for a short communication for the good and new ideas, and this year, we have a call for the photographic MSs. We are looking for more and more good works to publish in your journal "EBSS".

5. Conclusions

Day by day, a new approach or technology or tool could be found in the field of agriculture. This field is very fertile and easily to accept several innovations. The grafting is one of the old/new agricultural practice that had been used in vegetable production as well as fruit tree grafting. Simply, it could form a new plant by grafting through a physical combining between two plants with different genetic background, with one donating the roots (rootstock) and the other providing the shoots (scion). The grafting mainly is needed to overcome the environmental problems or stresses including abiotic/biotic stresses. Any supporting agent or material can enhance the grafting process is profitable such as application of nanomaterial/nanoparticles. This is a call for more investigation concerning the role of nanotechnology in grafting process to be publish by EBSS.

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