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Editorial

Grafting as a Sustainable Means for Securing Yield Stability and Quality in Vegetable Crops

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Grafting is among the most ancient agricultural techniques, having been practiced since 2000 BC. Nowadays, this old technique holds a significant margin for improvement by adding contemporary advances in plant science and technology. Vegetable grafting is widely used in Cucurbitaceous (cucumber, melon and watermelon) and Solanaceous crops (eggplant, pepper and tomato) [1,2]. Grafting provides opportunities to exploit natural genetic variation for specific root traits to influence the phenotype of the shoot. By selecting a suitable rootstock, grafting can manipulate scion morphology and physiology and can manage biotic stresses including foliar and soil borne pathogens, arthropods, viral diseases, weeds and nematodes, as well as abiotic stresses such as thermal stress, drought, salinity, nutrient deficiency and imbalances in soil, adverse soil pH (alkalinity and acidity), heavy metals contamination and organic pollutants [3–5]. The current research topic "*Grafting as a sustainable means for securing yield stability and quality in vegetable crops*" compiles 12 research papers and 2 review articles that examine the implications of vegetable grafting for crop growth and productivity, resource use efficiency (water and fertilizer), nutritional and functional quality of the produce as well as tolerance to biotic and abiotic stress. The present research topic contains scientific articles of high standard coming from several prestigious research groups. As such, it is geared to increase knowledge among scientists, breeding companies and farming communities on the benefits of grafting vegetables towards securing productivity and stability of the agricultural sector, thus improving food security.

Grafting methods vary considerably depending on the kind of crop, the growers' experiences as well as the availability of grafting facilities (hand grafting, automatic or semi-automatic machines). In their review paper, Lee et al. [6], summarized the major grafting methods in cucurbits and solanaceous crops as follows: (i) cleft grafting, (ii) hole insertion, (iii) pin grafting, (iv) splice and (v) tongue approach grafting. In the same review, Lee et al. [6] affirmed that the differences in diameter between the scion and rootstock have a significant effect on the grafting success. However, the alignment of rootstocks and scions of variable diameters is an arduous task, liable to human error that may consequently impact the success of seedling grafting [6]. Pardo-Alonso et al. [7] carried out an experiment aiming to determine the combined effect of cutting angle and different rootstock/scion random diameters on the grafting success of tomato using the splice technique. In their research, the authors reported that an increased grafting angle is associated with a higher survival rate of grafted tomato plants irrespective of the variations in diameter between scion and rootstock. The authors concluded that using the splicing technique in tomato with a cutting angle ranging between 50° and 70° could definitely improve the grafting conditions and consequently simplify the demands for manual and automated (i.e., robotized) grafting systems. The same research group in a successive experiment investigated the influence of different robot working speeds (from 100 to 600 mm/s) on the tomato grafting success [8]. In their work, the authors showed that the use of low speeds (between 100 and 300 mm/s) allows a success rate around

90%; at medium speeds (between 400 and 500 mm/s) the success rate remains above 80%, while at a test speed of 600 mm/s the success rate dropped significantly below 70%. The authors concluded that professional nurseries dealing with automated tomato grafting should use a velocity close to 300 mm/s, which results in significantly higher speeds compared to manual grafting by expert workers while securing high success rates. Moreover, Wei et al. [9] carried out a glasshouse experiment to assess the physiological and molecular responses of supplementary light intensity (50, 100, or 150 μmol m^{-2} s^{-1} PPFD) for a period of 10 days on grafted tomato seedlings ('Super Sunload' and 'Super Dotaerang') grafted onto the commercial rootstock 'B-Blocking'. Light intensity of 100 or 150 μmol m^{-2} s^{-1} boosted the seedling performance of tomato in terms of fresh and dry biomass, leaf area, SPAD index and root biomass compared to those supplied with 50 μmol m^{-2} s^{-1}, with no significant differences observed between the 100 and 150 μmol m^{-2} s^{-1} LED treatments. A putative mechanism involved in the superior seedling performance at 100 and 150 μmol m^{-2} s^{-1} implicates the enhanced expression of photosynthesis-related genes PsaA and PsbA compared to their expression at 50 μmol m^{-2} s^{-1}. The authors concluded that supplemental light at 100 μmol m^{-2} s^{-1} should be adopted by growers to achieve grafted tomato seedlings of high quality.

Noor et al. [10] conducted a two-year experiment on greenhouse cucumber, where four rootstocks (bitter gourd, bottle gourd, pumpkin and ridge gourd) and five grafting techniques (hole insertion, splice grafting, single cotyledon, tongue approach and self-rooted control) were tested. Grafting cucumber plants onto bottle gourd significantly increased plant survival rates and yield performance compared to the other rootstocks, most successfully by employing the splice grafting followed by tongue approach, single cotyledon and finally the hole insertion approach. The interactive effects of grafting technique and rootstock combination were less pronounced on fruit quality attributes, since besides the improvement of fruit mineral composition, the fruit dry matter and other quality traits were not significantly influenced by either of the tested factors. Concerning an important solanaceous species such as eggplant, Sabatino et al. [11] investigated the rootstock effect of two accessions of *Solanum aethiopicum* gr. gilo and the interspecific hybrid *S. melongena* × *S. aehtiopicum* gr. gilo on the vigor, productivity and fruit quality composition of eggplants compared to the most commonly used rootstock *S. torvum*. The results of their study clearly showed that *S. melongena* × *S. aehtiopicum* gr. Gilo demonstrated high compatibility and improved the grafting success, vigor, earliness and marketable yield without detrimental effect on nutritional quality traits; thus, they indicated that this interspecific hybrid could be considered a potential rootstock for eggplant that may replace the most commonly used *S. torvum*. The synergistic effect of grafting and arbuscular mycorrhizal fungi (AMF) on crop performance and fruit quality was also demonstrated by Sabatino et al. [12] on greenhouse eggplant. Although, the beneficial effect of grafted (onto *S. torvum*, *S. macrocarpon* and *S. paniculatum*) and inoculated plants was only evident with respect to yield and yield-related components, compared to non-grafted and non-inoculated controls, synergistic action between grafting and AMF was only recorded on the nutritional and functional quality of eggplant fruit. Sabatino and co-workers [12] demonstrated that grafting eggplant onto *S. torvum* or *S. paniculatum* boosted significantly the synthesis and concentration of antioxidant molecules, such as ascorbic and chlorogenic acids, and reduced the accumulation of glycoalkaloids. Similar results were also observed in eggplant grafted onto two tomato (Emperador and Optifort) and four *Solanum* (*S. torvum*, *S. integrifolium*, *S. grandiflorum* × *S. melongena* and *S. melongena* × *S. integrifolium*) rootstocks, which resulted in higher consumer fruit quality parameters compared to non-grafted and self-grafted plants [13]. Particularly, greenhouse eggplant grafted onto tomato rootstocks exhibited the lowest pulp color difference and oxidation potential, while the sweetest taste during the sensory evaluation was recorded in eggplant fruits harvested from plants grafted onto *S. torvum*. Concerning watermelon, Kyriacou et al. [14] investigated how interspecific pumpkin and bottle gourd rootstocks interact with two diploid and two triploid mini-watermelon scions and one large-fruited diploid scion with respect to yield and physicochemical traits and bioactive compounds at harvest and following postharvest storage at 25 °C for 10 days. Watermelon plants grafted onto the interspecific hybrid had improved yield, fruit lycopene content and firmness accompanied with minimal reduction in sugars compared to those grafted onto bottle gourd rootstock. The authors also demonstrated that ambient postharvest storage for 10 days boosted pulp lycopene levels.

Vegetable grafting is also developing around the globe as a means to overcome abiotic and biotic stresses which are responsible for 70% and 30% of the yield gap, respectively [15]. Among the major abiotic stresses, salinity and drought are the ones forecasted to rise due to global climate change [15]. In their review, Singh et al. [16] summarized the main physiological and biochemical mechanisms of grafting tomato to improve salt tolerance. The effectiveness of grafting in imparting tomato tolerance/resistance to soil and/or water salinity has been associated to several, biochemical, physiological and molecular mechanisms at scion and rootstock levels: (i) sodium and/or chloride exclusion; (ii) high photosynthetic, proline or antioxidant activities (APX, CAT); (iii) useful QTL's; (iv) increased content of abscisic acid, cytokinines and reduced content of ethylene precursor; as well as (v) increased root growth, length and root-to-shoot ratio [16]. Moreover, Modarelli et al. [17] evaluated the response to salinity (150 mM NaCl and a non-saline control) in different melon, watermelon, bottle gourd, luffa, *Cucurbita maxima* and interspecific *C. maxima* × *C. moschata* rootstocks in terms of plant growth parameters and photosynthetic pigments (chlorophyll and carotenoids). The authors demonstrated that luffa, melon, watermelon and bottle gourd rootstocks were salt sensitive, whereas interspecific hybrid (CMM-R2), melon genotypes (CM6, CM7, CM10, and CM16), along with watermelon (CV2 and CV6) and bottle gourd (LS4) were salt tolerant and proposed as candidate salt-resistant rootstocks to be introduced into breeding programs. Urlic et al. [18] showed that tomato plants grafted onto commercial rootstocks such as Emperador and Maxifort were able to increase yield under both optimal and sub-optimal (deficit irrigation [DI] or partial root-zone drying [PRDZ]) conditions. Interestingly, grafted tomato plants grown under DI exhibited minimal yield reduction compared to the full irrigation water regime, while water use efficiency was highly improved by the combination of grafting and DI or PRZD treatments. Furthermore, Allevato et al. [19] demonstrated in a hydroponic experiment that grafting melon cultivar Proteo onto two intraspecific (Dinero and Magnus) and three interspecific (RS841, Shintoza and Strong Tosa) hybrids was able to mitigate the detrimental effect of a heavy metal such as arsenic. Interspecific hybrid RS841 was the most efficient rootstock in securing crop productivity under heavy metal conditions and was also able to reduce the translocation of arsenic to the fruits.

Concerning the implications of grafting for improving tolerance/resistance to biotic stress, Cardarelli et al. [20] reviewed the potential benefits of grafting in boosting tolerance/resistance to soil borne diseases through modulation of indigenous suppressive microbial communities. In their review, the authors summarized the main disease-resistance/tolerance mechanisms identified in grafted vegetable plants grown in soil infested by pathogens as follows: (i) modulation of the root system architecture; (ii) antifungal rhizodeposits; (iii) microbial barrier; and (iv) sap flow modification. Notwithstanding, the enormous significance of grafting as a means for securing yield stability and quality in vegetables crops, commercial its practice has heavily centered on the production of high-value solanaceous and cucurbit crops. Among future perspectives is the extension of grafting practice to other seasonal crops including combinations where both rootstock and scion deliver harvestable products. In this respect, Gong et al. [21] explored the feasibility of a novel graft within the Brassicaceae family involving pac choi (*Brassica rapa* L. var. *chinensis*) and daikon radish (*Raphanus sativus* L. var. *longipinnatus*) to create a plant with harvestable leafy pac choi above ground and daikon radish taproot below ground. Grafted pac choi–daikon demonstrated no decrease in SPAD value, canopy size, leaf number, leaf area, or aboveground weight compared to self-grafted pac choi plants. Taproot formation (length, diameter, fresh and dry weight), however, was reduced by comparison to non- and self-grafted daikon radish plants. This innovative pilot study nevertheless demonstrated the potential of creating harvestable rootstock–scion combinations as a means of saving growth space and minimizing waste. Such unique grafting model systems may assist in elucidating scion–rootstock synergy and sink competition in horticultural crops.

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