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Review

Salinity as eustressor for enhancing quality of vegetables

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ABSTRACT

Vegetable crops show variable responses to stressful conditions with physiological, biochemical, metabolic and morphological changes that occasionally lead to changes in chemical composition and visual appearance of the final products. Eustressors are various biological, physical or chemical stressful factors that trigger the *signaling pathways* leading to a higher bioactive compounds content and quality attributes of plant products. Therefore, its application could be a useful tool in modern horticulture towards fulfilling the agro-food industry and consumers' demands for high quality and functional vegetable products. Salinity is considered an chemical eustressor which has been proved to affect both physical quality and chemical composition of various vegetable commodities. The present review focuses on the application of an *eustress* in particular salinity as chemical eustressor towards quality improvement of various vegetable crops, with special interest in quality attributes such as physical quality (color, texture, visual appearance and firmness), flavor and nutritional value (aroma, taste), health promoting properties (antioxidants and bioactive compounds). Moreover, the physiological mechanisms behind the responses of plants to salinity and the functions that directly or indirectly affect vegetable quality will be elucidated, while a case study on tomato where salinity eliciting has been extensively applied will be presented in order to highlight the benefits of this technique. Finally, this review concludes with remarks about the efficiency and valorization of this technique in advanced horticultural cropping systems, as well as with prospects and research breakthroughs that have to be considered in order to make production of high added value products feasible.

1. Introduction

Eliciting of plants is considered the application of biological, physical and chemical factors that induces stressful conditions and physiological changes, and trigger defense mechanisms through the production of various phytochemicals and bioactive compounds (i.e., ascorbate, carotenoids, glucosinolates, polyamines and tocopherols; Baenas et al., 2014). This technique has been proved as useful tool for increasing vegetable quality and their health benefits and many research studies have been carried out during the last two decades in order to elucidate the mechanisms involved in plant physiology during and after eliciting, as well as to provide detailed information about potential esustressors, their effects and best practice guides (Viacava et al., 2018). Many treatments can be classified as eustressors including physical (UV-B and ozone) or chemical (jasmonic acid and methyl jasmonate) eustressors, biotic and abiotic ones, as well as those with complex or defined composition, depending on their mode of action, origin and composition, respectively (Angelova et al., 2006).

Soil and water salinization is an ever-growing problem which is amplified by the irrational use of fertilizers and agrochemicals, overpumping of groundwater for irrigation (mainly to coastal areas), consequent sea-water infiltration into fresh aquifers and crop intensification in general (Daliakopoulos et al., 2016; Libutti and Monteleone, 2017). Plants grown under excessive sodium chloride (NaCl) concentration usually exhibit morphological, biochemical, physiological as well as metabolic changes that affect severely plant growth and consequently crop productivity and quality of the final product (Colla et al., 2008; Arshi et al., 2010; Rouphael et al., 2016; 2017a; Petropoulos et al., 2017). However, despite the implementation of sustainable cropping practices, there are certain cases where degradation of agricultural land is severe and variable approaches have to be considered in order to turn soil salinity problem into an opportunity for vegetable products of increased quality and bioactive compounds contents. Apart from soil cropping systems which are more prone to problems that intensification agriculture may cause, soilless culture and hydroponics in particular may also use favorable saline conditions for increasing

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bioactive compounds content via modulation of electrical conductivity (EC) of nutrient solution composition and/or concentration (Fanasca et al., 2006a,b; Fallovo et al., 2009a,b; Borgognone et al., 2014; Lucini et al., 2016) and accurate control of plant nutrition (Rouphael et al., 2012a). Numerous research studies report the effect of growing conditions and nutrient solution composition and/or concentration on quality of vegetable crops, with special focus being given to secondary metabolites and their bioactive properties (Petropoulos et al., 2017; Kyriacou and Rouphael, 2018). Vegetable quality is a complex parameter defined by multiple-factors including directly perceived properties such as taste, visual appearance and aroma, which usually define physical quality and determine the consumers' acceptance and the retail price of the final product, as well as factors that affect quality indirectly such as chemical composition, bioactive compounds content, absence of agrochemicals and anti-nutrients and so forth (Kyriacou and Rouphael, 2018). Although physical quality and appearance of vegetable products are the key determinants of the overall quality for most of the stakeholders involved in the horticultural products supply chain (e.g. wholesale and retail markets, the food industry etc.), consumer awareness and increasing concerns regarding the safety issues that arise from time to time have redirected the overall approach about quality towards design and production of products with health beneficial properties, enhanced nutritional value and high content in bioactive compounds (Mahajan et al., 2017).

In the past, efforts were made to increase key bioactive compounds through traditional breeding and genetic engineering, but the development of commercial vegetable hybrids with improved content in health-related compounds is still at its infancy (Kyriacou and Rouphael, 2018). On the other hand, the disproportional increase in some major phytochemicals by traditional breeding and genetic engineering (10–25 fold in carotenoids and 20-fold in glucosinolates) have raised several concerns on their safety among nutritionists, growers and consumers due to their genotoxic effect at high concentrations (Brusick, 1993; Stopper et al., 2005; Poiroux-Gonord et al., 2010;). Therefore, nutritional management of vegetable crops and the application of chemical eustressors such as salinity, offer valuable and cost-effective tools for manipulation of phytochemical content and quality in general that will help towards covering the increasing market trends for high added value products.

The aim of the present review paper was to draw an overview on the effect of salinity as chemical eustressors on vegetable quality including physical characteristics, flavor, nutritional value, bioactive compounds and anti-nutrients content. The physiological mechanisms of vegetable quality as affected by salinity, as well as by elicitation to increase fruit quality of the most representative vegetable crop such as tomato will be also covered.

2. Implications of salinity for physical properties

Texture of vegetable is an important and complex quality feature which is described with measurable parameters such as firmness, crispness, gumminess, elasticity, viscosity and mechanical, geometrical and surface attributes in general (Rosenthal, 1999; Barrett et al., 2010). Considering the high amount of water that most of the vegetable products contain, this trait contributes to overall physical quality and appearance of the shelf-product and affects consumers' preference and acceptance since it is highly correlated with freshness (Coolong et al., 2013). Texture can be affected by various factors that intervene and modify cell wall and lamella composition and thickness, cell size and arrangement and turgor pressure (Barrett et al., 2010). The most important compounds that contribute to texture of vegetable food products are soluble and insoluble fibers which consist mainly of cellulose, hemicellulose and pectins (Perkins-Veazie and Collins, 2001). Fruit firmness constitutes a key sensory characteristics of vegetable crops subject to a wide genotypic variation (Kyriacou et al., 2017). Increasing NaCl concentration in the nutrient solution from 1 to 80 mM incurred significant increase in fruit firmness of grafted and ungrafted soilless melon (Colla et al., 2006a). The increase in fruit firmness under salinity conditions was accompanied with a decrease in peel percentage, whereas the fraction of pulp increased (Colla et al., 2006a). Similarly, Botía et al. (2005) reported that melon firmness increased in a cultivar-dependent manner after application of saline water (increased for 'Amarillo Oro' and decreased in 'Galia'). Contrarily, no significant effects were observed on the fruit firmness of cucumber (non-salt control, 20 mM $CaCl_2$, 30 mM NaCl or 10 mM $CaCl_2$ + 15 mM NaCl) and pepper (non-salt control, 15 or 30 mM NaCl) (Navarro et al., 2010; Colla et al., 2013b).

Other important physical properties that constitute primary criteria of consumer decisions are the fruit shape index as well as the coloration of the skin (Rouphael et al., 2010). Several research studies carried out on various fruit vegetables under open-field and greenhouse conditions (i.e., watermelon, pepper and cucumber) indicated that the application of saline water or nutrient solution do not present significant effect on shape index (Navarro et al., 2010; Colla et al., 2006b, 2013a,b). Contrarily to the previous experiments, the melon shape index increased linearly with increasing the EC of the nutrient solution from 2.0 to 9.7 dS m^{-1} (Colla et al., 2006a). The lack of differences due to the application of salt stress on vegetables fruit shape index could be expected since it constitutes a morphometric attribute normally dominated by genetic material and little affected by agricultural practices (i.e., *eustress*) as well as by environmental conditions (Kyriacou et al., 2017). Regarding color, no significant differences in colorimetric CIELAB component L* (brightness) as well as the ratio a*/b* were reported on the skin of greenhouse cucumber and also on the pulp of melon irrigated with saline and non-saline nutrient solutions (Colla et al., 2006a, 2012). Contrarily to fruit vegetables, color of leafy vegetables was highly affected by the application of NaCl in the nutrient solution. For instance, Neocleous et al. (2014a) demonstrated that adding 5 to 20 mM NaCl to nutrient solution led to a reduction in the lightness (L*) and saturation (C*) indices and an increase in the hue angle of a green pigmented baby lettuce cultivar (Paris Island), whereas the Chroma and hue angle in the red-pigmented cultivar (Sanguine) were not affected, indicating a cultivar-dependent effect. Finally, Kim et al. (2008) also demonstrated that the leaf color components: L*, C* and a* of Romaine lettuce decreased with increasing NaCl concentrations from 0 to 200 mM.

3. Implications of salinity for flavor compounds

Flavor of fruit and vegetables is considered as the combined perception of taste and aroma and is related with multiple factors throughout the supply chain from seed to consumer, including genotype related, pre-harvesting and post-harvesting factors (Kader, 2008). Considering that for consumers the most critical attribute for quality evaluation is the physical appearance of a product, flavor comes second in this process but is equally important since it determines the recurrence of consumers' choice and also defines whether a product will be established in the market or not (Barrett et al., 2010). Moreover, although nutritional value is a hidden quality attribute that sets as prerequisites physical quality and flavor acceptance, it is usually subconsciously associated with these attributes and consumers consider that good looking products have also high nutritional value. Despite the fact that this approach seems to be biased and unsubstantial, literature reports highlight the importance of flavor-related compounds such as organic acids and sugars in nutritional value and bioactive compounds content. The most important effect of these compounds is associated with pH regulation which affects flavonoids biosynthesis, while sugars are used as building ingredients in phenolic compounds and ascorbic acid composition (Perkins-Veazie and Collins, 2001; Kader, 2008).

Flavor is a composite term related with various quality attributes such as astringency, bitterness, sourness (acidity), sweetness and volatile compounds contents, as well as unfavorable parameters (off-flavors