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Controlled Water Stress to Improve Fruit and Vegetable Postharvest Quality

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1. Introduction

Healthier food produced in a sustainable manner at affordable price is a necessity in the contemporaneous society. In this context, studies to devise the minimum necessary amount of water to crops towards development are required not only to save water and/or energy, but also to improve plant fitness to cope with biotic and abiotic stresses, even after harvest, and to improve nutritional, functional and sensorial food properties. The awareness of the growing impact of environmental stress has led to worldwide efforts in adapting agricultural production to adverse environmental conditions, focusing on mitigating quantitative yield losses (Godfray et al., 2010). Far less attention has been devoted to the impact of abiotic environmental stresses on crop quality (Wang & Frei, 2011). Limited water supply (LWS) is a serious threat to agriculture, and often cause yield reduction. However, many plant species are not intolerant to that, otherwise the water input concept should be revised. In this review we describe the effect of limiting water supply during plant development on fruit and vegetables postharvest quality, mainly in terms of sensorial attributes (texture, colour, aroma, and taste) and composition (nutrients and bioactive compounds), and also in terms of gene expression, enzyme activity, yield, and storage behaviour. A brief introduction about regulated deficit irrigation, plant growth regulators and secondary metabolites is presented to illustrate common aspects associated with water stress effects on fruit and vegetable quality.

2. Regulated deficit irrigation

Deficit irrigation (i.e. irrigation below optimal crop water requirements) research to improve productivity of horticultural crops began in the 1970's with the aim to control excessive vegetative vigour in high-density orchards. Tree physiology was intensively studied to examine timing of water deficits that would minimize the impact on fruit growth but maximize effects on shoot growth. This strategy later became known as regulated deficit irrigation (RDI). In recent years there has been resurgence in the application of RDI to horticultural crops due to changes in climate resulting in severe drought. However, focus has now switched from controlling excessive vigour to investigating opportunities to stimulate improvements in fruit and vegetable quality so that any yield loss can be compensated by an increase in crop value (Costa et al., 2007; Stefanelli et al., 2010).

3. Plant growth regulators

Organisms need to adapt themselves to changes in fluctuating environmental conditions. The plants, since they are not able to scape from adverse environmental conditions, have to rely entirely on their developmental plasticity to survive (Krouk et al., 2011). These adaptations include the responses to temperature fluctuations, water and nutrients imbalance, UV radiation, pathogens, and insects, among other biotic and abiotic stresses. Plant growth regulators (phytohormones), compounds derived from plant biosynthetic pathways, mediate these responses by acting either at the site of synthesis or following their transport, elsewhere in the plant. Collectively, plant hormones regulate every aspect of plant growth, development and the responses of plants to biotic and abiotic stresses (Peleg & Blumwald, 2011). Classical phytohormones are abscisic acid (ABA), ethylene, cytokinin (CK), auxin, gibberellin, jasmonate, as well as brassinosteroids, salicylic acid, nitric oxide, and strigolactone, and it is likely that additional growth regulators are yet to be discovered (Santner & Estelle, 2009). ABA synthesis is one of the fastest responses of plants to water stress, triggering ABA-inducible gene expression and causing stomatal closure, thereby reducing water loss via transpiration and eventually restricting cellular growth (Wilkinson & Davies, 2010; Yamaguchi-Shinozaki & Shinozaki, 2006). Many ABA-mediated physiological processes induced by water deficit, including closure of the stomata and acceleration of leaf senescence, are counteracted by CKs which increase stomatal aperture and/or delay ABA-induced stomatal closure. It has been suggested that in longer-term responses to stress, hormones such as ABA and CK may function to regulate the production, metabolism and distribution of metabolites essential for stress survival and recovery (Pospíšilová & Dodd, 2005; Stoll et al., 2000).

4. Secondary metabolites

Plants produce a huge variety of secondary metabolites with roles in various biological processes, such as pollination, seed dispersal, and resistance to biotic and abiotic stresses (Wink, 1999). Until recently it was thought that genes for plant metabolic pathways were not clustered, and this is certainly true in many cases. However, five plant secondary metabolic gene clusters have now been discovered, all of them implicated in synthesis of defence compounds, with enzymes for the first committed steps apparently recruited directly or indirectly from primary metabolic pathways involved in hormone synthesis (Chu et al., 2011). The genes and corresponding gene products for the first committed steps in these pathways can be regarded as signature genes/enzymes, as they are required for the synthesis of the skeleton structures of the different classes of secondary metabolite (Osbourn, 2010). The signature genes all share homology with genes from plant primary metabolism, and so are likely to have been recruited directly or indirectly from primary metabolism by gene duplication and acquisition of new functions (Chu et al., 2011). Plant secondary metabolites have long been associated with ecological roles in antagonistic or mutualistic interactions between plants and their herbivores, pathogens, competitors, pollinators or seed dispersers. However, many of these substances have been demonstrated to function in the primary processes of growth and development or resistance to abiotic stresses (Fig. 1). Clearly, more attention should now be devoted to looking for internal roles. In the past decade, several substances that were once considered to be secondary metabolites, such as jasmonic acid, salicylic acid and brassinosteroids, have been shown to be important internal signals (D'Auria & Gershenzon, 2005).

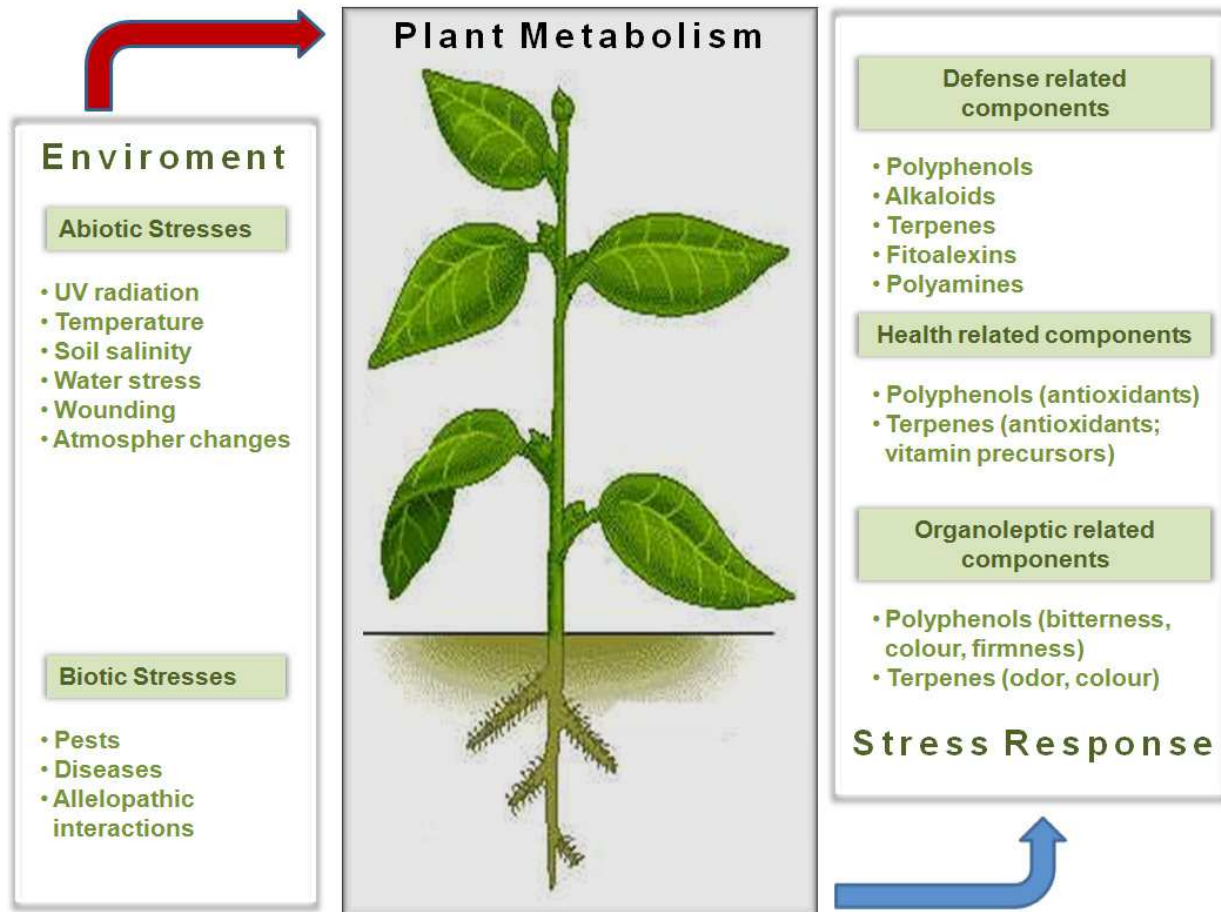


Fig. 1. Schematic representation of plant metabolism response to environmental stress.

5. Water stress effects on fruit quality

5.1 Kiwi

Miller et al. (1998), performed a two year experiment in New Zealand to determine the responses of kiwifruit (*Actinidia deliciosa* cv. Hayward) to water stress conditions. Plants were submitted to a stress regime composed of three different treatments: Control (water received according to culture demands), water stress in early summer and water stress in late summer. They observed a significant loss in fruit weight, especially in plants exposed to stress in early summer (fruit set period). In contrast, an increase in the total soluble solids occurred. Differences in firmness and performance during storage were not detected for stressed kiwifruit. However, in a similar experiment conducted by Reid et al. (1996), kiwifruit harvested from vines exposed to a less severe drought stress were unaffected in size and fruit firmness was retained for 30 days longer in comparison to control (fruit harvested from fully irrigated vines).

5.2 Strawberry

Bordonaba & Terry (2010), testing strawberry (*Fragaria X ananassa* Duch. cvs. Elsanta, Sonata, Symphony, Florence and Christine) response to water deficits obtained promising results. Stressed plants received a quarter of irrigation water compared to control plants

(cultivated under field capacity). Water suppress started when most fruit from the primary truss were at flower initiation stage. The different cultivars responded in a specific manner to water stress, expressing specific water usage. Berry size was equivalent (Florence and Christine) or smaller (Sonata and Symphony) than control plants. Dry mater, as proportion of fruit weight, was considerably greater in fruit from water stressed plants than from plants kept at or near field capacity. Berries from stressed plants showed lower redness (higher h^o value) than control berries. Considering that the main components of red colour in strawberries are anthocianins is plausible to presume that these fruit have lower contents of this secondary metabolite. However, in a previous study, Terry et al. (2007) observed the same reduction in red colour, but anthocianins measurements pointed to a higher content of this metabolite. Authors attribute that to an artefact of the objective colorimeter due to smaller berry size. No significant differences were found in sugar contents among treatments. However, monosaccharides (fructose and glucose) were in higher concentrations in stressed plants, thus berries were sweeter. Acids are also important flavor components in strawberries. The stressing condition increased the acidity in all cultivars except Elsanta and Sonata.

5.3 Apple

Mpelasoka et al. (2001b) demonstrated that deficit irrigation (DI) has effects on fruit maturation and ripening depending on timing of application. They tested early deficit irrigation (EDI), applied from 63 to 118 days after full bloom (DAFB), late deficit irrigation (LDI), applied from 118 DAFB to final harvest on 201 DAFB, whole-season deficit irrigation (WDI), irrigated only twice during the late growing season, when volumetric soil water content (θ) declined below $0.15 \text{ m}^3 \text{ m}^{-3}$. These DI treatments all reduced volumetric soil water content. Control consisted in commercially irrigated (CI) trees, irrigated to maintain soil moisture at or close to field capacity. All DI treatments increased fruit total soluble solids (TSS) and firmness regardless of maturity but had little or no effect on titratable acidity. According to the authors the DI fruit may be harvested over a longer period due to their earlier increased TSS and their higher firmness prior to harvest and for most of the storage period. However, the advanced ripening of the DI fruit is responsible for the loss of advantage by DI regarding firmness after long-term storage. Fruit thinning has been proposed as a feasible strategy to compensate the loss in fruit size caused by water stress (Mpelasoka et al., 2001a). Irrigation treatments did not affect the crop load. Irrespective of fruit thinning treatment, deficit irrigated stress resulted in lower fruit weight, total yield and fresh-market yield at harvest than control. However, under deficit treatment, thinned trees resulted higher fruit weight and equal fresh-market yield. Regarding quality parameters, deficit irrigated plants exhibited higher contents of TSS than fully irrigated plants. This could have a positive impact on fruit taste. An equal increase was observed in fruit firmness. Although this attribute correlates to a smaller fruit size due to dehydration during water restriction. In a similar experiment, with apple, the fruit firmness was higher under water restriction treatments compared to fully irrigated treatments despite of fruit size (Mpelasoka et al., 2000). Regarding postharvest conditions, fruit exposed to water restrictions had lower weight loss during cold storage than those originated from fully irrigated treatments. According to the authors, the reduced weight loss can be explained by the structure and/or composition of the skin or the epicuticular waxes covering the skin. This reduction in weight loss could prolong the cold storage life.

5.4 Pear

Lopez et al. (2011) submitted pear (*Pyrus communis* L. cv. Conference) to water restrictions and fruit thinning at the Stage II (80 and 67 days before harvest in 2008 and 2009, respectively). The experiment was composed of two simple irrigation treatments: fully irrigated plants (100% Evapotranspiration, ET_c) and deficit irrigated (20% ET_c , preceded by three weeks of total water deprivation to induce the stress response). Each irrigation treatment was spliced in two thinning treatments: no thinning (approximately 180 fruit per tree) and thinning (approximately 85 fruit per tree). Fruit thinning has been proposed as a feasible strategy to compensate the loss in fruit size caused by water stress (Mpelasoka et al., 2001c). Different Irrigation regimes did not affect the crop load between irrigation treatments. Irrespective of fruit thinning treatment, deficit irrigated trees had lower weight, total yield and fresh-market yield at harvest than control. However, under deficit treatment, thinned trees had higher fruit weight and equal fresh-market yield. Regarding quality parameters, deficit irrigated plants exhibited higher contents of total soluble solids than fully irrigated plants. Deficit irrigated-thinned trees had equivalent fruit weights at harvest compared to full irrigated-non thinned trees, confirming that fruit size can be improved by fruit thinning. Considering that fruit size is an important attribute in pear, deficit irrigation can improve fruit marketability.

5.5 Apricot

Perez-Pastor (2007) evaluated postharvest fruit quality of apricot (*Prunus armeniaca* L. cv. Búlida) harvested from trees exposed to three different treatments: control treatment (100% of evapotranspiration); regulated deficit irrigation (RDI), which consists in fully irrigation during critical periods; and 50% water regime compared to control. At harvest was not observed differences in weight, equatorial diameter and firmness of the fruit among the different treatments. In addition, fruit from water stressed plants had higher values of total soluble solids (TSS), titratable acidity (TA) and h^o value (skin colour). During storage, stressed plants had lower decreases in fruit colour (skin and pulp) compared to fully irrigated plants. During the first 20 days of storage, stressed plants conserved higher values of TSS and TA, after that the differences disappeared between treatments. During a simulated retail sale, fungi of the genera *Rhizopus*, *Monilinia*, *Penicillium*, *Alternaria*, *Botrytis* and *Cladosporium* caused fruit losses. Interestingly, a lower fungal attack was observed in stressed fruit. The authors link this fact to a thicker cuticle and/or to the absence of microcrackings. Perez Sarmiento et al. (2010) using nine year-old apricot-trees (*Prunus armeniaca* L. cv. 'Búlida') grafted on 'Real Fino' rootstock analyzed the effects of RDI on fruit quality. Two irrigation treatments were established. The first, a control treatment, was irrigated to fully satisfy the crop water requirements (100% ET_c) during the critical periods (stage III of fruit growth and two months after harvest period), and the second, a RDI treatment, was subject to water shortage during the non-critical periods of crop development, by reducing the amount of applied irrigation water to: a) 40% of ET_c from flowering until the end of the first stage of fruit growth; b) 60% of ET_c during the second stage of fruit growth and c) 50% and 25% of ET_c during the late postharvest period (that starts 60 days after harvesting), for the first 30 days and until the end of tree defoliation, respectively. They found that some qualitative characteristics such as the level of soluble solids, fruit taste and the colour of the fruit are enhanced.

5.6 Peach

Gelly et al. (2003) evaluated the effects of water deficit on fruit quality of peaches (*Prunus persica* L.). It was shown an increase in soluble solids content and coloration of fruit when

during production was applied RDI. Water deficit was applied during either stage II of fruit development (RDI-SII) or during stage II and postharvest (RDI-SII-PH), as compared with non-droughted (control) and postharvest (RDI-PH) treatments. Significant higher concentration of soluble solids and accentuated red colour were observed at harvest in fruit from RDI treatments when compared to control fruit. Accordingly, fruit submitted to RDI during development had greater ethylene production when detached. Ethylene production by RDI-PH fruit did not change, but their quality did in terms of increased soluble solids concentration and improved skin colour, similar to the RDI-SII treatment. Buendía et al. (2008) investigated the influence of regulated deficit irrigation (RDI) on the content of vitamin C, phenolic compounds and carotenoids of peaches. Fruit were harvested from five-year-old early ripening peach trees (cv. "Flordastar", grafted on GF677 rootstock) in Santomera, Murcia, Spain. Two irrigation strategies, fully irrigated (FI) and RDI, were compared at two levels of thinning, commercial and half of the commercial crop load. RDI caused fruit peel stress lowering the content of vitamin C and carotenoids, while increasing the phenolic content, mainly anthocyanins and procyanidins. Fruit weight was the only quality index influenced by the crop load as it increased in FI fruit at low crop load. According to the authors, the decrease in the antioxidant constituents could be due to a higher sunlight exposure of fruit collected from RDI trees as a result of a low vegetative growth of those trees. The increase in the anthocyanin content could be also explained as a response mechanism of peaches against UV irradiation, to mitigate the photooxidative injury of plant tissue.

5.7 Plum

The effects of RDI (RDI) and crop load on Japanese plum (*Prunus salicina*) cv. Black-Gold were investigated by Intrigliolo & Castel (2010). RDI was applied during phase II of fruit growth and postharvest and compared to a control irrigation treatment (full crop evapotranspiration). Plants from each irrigation treatment were thinned to reach a commercial crop load (described as medium) and to approximately 40% less than the commercial practice (described as low). RDI strategy increased the efficiency of water usage, with 30% of water savings, having minimal effect on crop yield and fruit growth. Economic return, calculated from fruit weight distribution by commercial categories, was more affected by RDI than yield. The combination of medium crop load and RDI shifted fruit mass distribution towards the low value categories. This leads to similar or even higher economic returns in the RDI treatment with low crop level than with the medium one. In addition, since both, low crop level and RDI, increased fruit total soluble solids (TSS), fruit produced under RDI and low crop levels had the highest values of TSS. Deficit irrigation improved fruit composition and, in the short-term, increased tree water use efficiency.

5.8 Citrus

Recently García-Tejero (2010) determined the postharvest fruit quality of oranges (*Citrus sinensis* L. Osbeck, cv. Salustiano) exposed to RDI in commercial orchards at the semi-arid region of Andalusia- Spain, in the years 2005, 2006 and 2007. The experiment was composed by four different treatments: Control (irrigation replacing 100% of Evapotranspiration, ET_c), low deficit irrigation (75% of ET_c), moderate deficit irrigation (65% of ET_c) and severe deficit irrigation (50% of ET_c). As a result, fruit quality parameters as TSS and TA increased in all stressed treatments resulting better organoleptic parameters. Significant fruit size reduction was observed in the year 2005 only. However, reduction in fruit size is often associated with an increase in fruit number (Treeby et al., 2007). In the years 2006 and 2007, a significant

yield loss was not observed. The low deficit irrigation treatment proportionate a water saving of 93 mm, which consists in lower irrigation costs that might compensate the slightly yield losses in fruit production. In a similar study Velez et al. (2007), using the “maximum daily trunk shrinkage” method, which is used as an indicator of water stress, was able to obtain water savings reaching 18% without significant decreases in average fruit yield, weight and number. In addition, fruit submitted to deficit irrigation had significantly higher TSS and similar TA. According to the authors, a higher accumulation of sugars is a result of an active response to water deficit.

5.9 Grape

Working with grape (*Vitis vinifera* L. cv. Rizamat), table type, Du et al. (2008) performed a two year experiment to investigate the alternate partial root-zone drip irrigation on fruit quality, yield and water use efficiency in the arid region of northwest China. The treatments consisted of a control (both sides of the root zone irrigated); an alternate drip irrigation treatment (both sides of the root zone irrigated, one at a time with half the water used in control) and a fix drip irrigation (only one side of the root zone was irrigated with half the water used in control). As a result, in alternate drip irrigation condition, the photosynthetic rate was similar to control whilst the transpiration rate kept in the same level. The leaf water use efficiency increased indicating that the plants submitted to water stress needed less water to keep hydrated. In stressing condition significant yield losses were not perceived, in addition a higher percentage of edible grapes were achieved, which consequently improve product price. A plausible explanation for such performance relays on changes in balance, between vegetative and reproductive growth, of plants facing limited water supplies, resulting in a higher flow of photoassimilates to berries. Stressed grapes presented higher concentrations of both, ascorbic acid and total soluble solids, and lower titrated acidity, culminating in healthier and sweeter grapes. In a similar study (Santos et al., 2007) compared the effects of partial root zone drying irrigation system (50% ET_c irrigating one side at a time) with the conventional deficit irrigation system (50% ET_c applied on both sides), full irrigation system (100% ET_c applied on both sides) and non irrigated vines. The one-year experiment was performed in mature “Moscatel” grapevines (*Vitis vinifera* L.) in south Portugal. Plants submitted to partial drying regime showed a decreased vegetative growth, expressed by the smaller values of leaf layer number, percentage of water shoots, shoot weight, pruning weight and total leaf area. In synthesis, plants had a higher control over vegetative growth in face of a stressing condition. The partial drying regime and the conventional deficit irrigation treatments, despite receiving the same quantities of water during the experiment, led to different plant responses. The author argue that in the partial drying regime, roots in the dry side produce chemical signals which restrict plant growth. As a consequence, berry temperature increases in response to augmented solar incidence. In response, the concentrations of anthocyanins, phenols and glycosyl-glucose were higher in water stressed plants culminating in higher quality grapes. Yield loss was significant only in non-irrigated treatment.

5.10 Watermelon

Proietti et al. (2008) determined quality parameters of mini-watermelon (*Citrullus lanatus*) cv. Ingrid, ungrafted or grafted onto a squash hybrid rootstock, and grown under different irrigation regimes: 1.0, 0.75, and 0.5 of evapotranspiration (ET_c) rates. The highest fruit yields were observed at 1.0 ET_c and at 0.75 ET_c when compared to 0.5 ET_c , in grafted plants. Grafting of mini-watermelon under irrigation deficit did not modify crop response to water

availability, but increased productivity and induced small positive changes in plant quality and nutritional value.

6. Water stress effects on vegetable quality

6.1 Potato

Bejarano et al. (2000) evaluated the content of glycoalkaloids (GAs, α -solanine and α -chaconine) in drought-tolerant potato (*Solanum tuberosum* L.) grown in the Bolivian highlands under drought stress. Under drought stress conditions GAs concentration increased an average of 43% and 50% in the improved and control cultivars, respectively, but never above the recommended food safety limit (200 mg.kg⁻¹ fresh tubers). GAs are natural toxins synthesised by plants of the *Solanaceae* family and are believed to be associated with resistance to certain insects. At least 95% of total GAs are in the form of α -solanine and α -chaconine. Both compounds are heat-stable and therefore are not destroyed by common cooking processes such as boiling or frying (Friedman, 2006).

6.2 Tomato

Sánchez-Rodríguez et al. (2011) obtained insightful results regarding the phenolic metabolism in response to water stress. Phenolic compounds are the most abundant type of secondary metabolites in plants, being frequently associated with beneficial effects in human health (Dixon & Paiva, 1995; Hooper & Cassidy, 2006). Tomato plants (*Solanum lycopersicum* L.), cultivars Kosaco, Josefina, Katalina, Salomé and Zarina, were submitted to water stress conditions. The experimental design consisted of two watering treatments: Control (100% of field capacity) and moderate water stress (50% of field capacity). Zarina, characterized as a drought tolerant cultivar, presented the best responses. All the cultivars had significant decreases in phenolic compounds when submitted to water stress, except Zarina, which showed an increase, particularly in flavonoids, when cultivated under moderate water stress. This increase was concomitant with a 33% higher DAHPS (EC 4.1.2.15) activity, the key enzyme controlling the carbon flow towards phenolic metabolism, and equivalent increases were observed for other related enzymes. The enzymes that degrade phenols, PPO (EC 1.10.3.2) and GPX (EC 1.11.1.7), declined in activity, 30% and 47%, respectively. Thipyapong et al. (2004) propose that in tomato plants a decrease in PPO activity lowers the H₂O₂ concentration, reducing lipid peroxidation and improving resistance against water stress.

6.3 Lettuce

Coelho et al. (2005) investigated the yield and bioactive amine content of American lettuce (*Lactuca sativa* cv. Lucy Brown) grown under greenhouse conditions and drip irrigation. Spermidine was the prevalent amine, followed by putrescine, cadaverine and agmatine. The contents of every amine, except agmatine, increased with water stress but not capable of negatively affecting the sensory quality of the lettuce. Changes in plant polyamine metabolism occur in response to a variety of abiotic stresses, however, the physiological significance of increased polyamine levels in abiotic stress responses is still unclear (Gill & Tuteja, 2010).

6.4 Cabbage

Supplying irrigation to achieve maximum cabbage (*Brassica oleracea* L. Capitata group) yield will also optimize sensory quality by minimizing the compounds responsible for pungency. However, glucosinolate concentration will be reduced (Radovich et al., 2005). Glucosinolates

are amino acid-derived secondary metabolites that may exhibit antibiotic, anti-carcinogenic and organoleptic activity after hydrolysis. Sinigrin and progoitrin are the most important compounds with regard to flavour, since they are the primary determinants of pungency, bitterness and sulphurous aroma in cabbage (Buttery et al., 1976; Fahey et al., 2001; Talalay & Fahey, 2001).

6.5 Mustard

Similar to cabbage, mustard is a glucosinolate containing plant. This class of secondary metabolites are found almost exclusively in plants of the order *Brassicales*, including horticulturally important crop plants of the *Brassicaceae* family (Fahey et al., 2001). In order to evaluate the glucosinolate metabolism response to environmental stresses, Schreiner et al. (2009) submitted the Ethiopian mustard (*Brassica carinata*), lines Holeta-1 and 37-A, to water restriction treatments. Control plants were maintained at 80% of field capacity during the total growing period. Water restriction consisted of systematic decreases in soil water content (40, 23, 17, and 15% of field capacity in the 6-8, 11-12, 13-14, and 15-16 leaf stages, respectively). The most abundant glucosinolate found in both lines was 2-propenyl glucosinolate, followed by 3-indolyl methyl glucosinolate. The concentration of these two compounds remained constant in control plants from 6-8 to 15-16 leaf stage. In contrast, the stressing condition led plants to a distinct increase (80-120%) of 2-propenyl glucosinolate and 3-indolyl methyl glucosinolate in the leaves of both lines. The increases in leaf glucosinolates was inversely correlated to soil water content, in both lines, leading to severe yield losses.

6.6 Broccoli

We have demonstrated that low soil water content (0.40 MPa of soil water tension) during broccoli growth leads to leaf size reduction, without affecting weight or yield, and contributes to the maintenance of green colour, possibly due to induced cytokinin synthesis (Zaicovski et al., 2008). Cytokinins, which are considered senescence inhibitors acting as ethylene antagonists and protectors of membranes, mitochondria, and plastid metabolism are also known to be induced in response to stresses (Xu & Huang, 2009). However, severe stress (-0.6 MPa of soil water pressure) leads to negative effects on broccoli yield and morphology as observed by Wurr et al. (2002). In another study we cultivated broccoli under low (0.40 MPa) and normal (0.04 MPa, equivalent to field capacity) soil water content, stored it under low (1 °C) and room (23 °C) temperature, and assessed for changes in colour, bioactive compounds, and antioxidant activity. We concluded that low soil water content during plant growth and postharvest cold storage are the conditions that, combined, give the best preservation of colour, antioxidant activity, and l-ascorbic acid and 5-methyl-tetrahydrofolate contents (Cogo et al., 2011).

6.7 Eggplant

Kirnak et al. (2002) investigated the effects of deficit irrigation on fruit yield and quality in eggplant (*Solanum melongena* L.) cv. Pala. The experiment consisted of the following treatments: (1) well-watered, receiving 100% of plant evaporation on a daily basis (C); (2) water-stressed, receiving 90% of plant evaporation at 4-day intervals (WS1); (3) water-stressed, receiving 80% of plant evaporation at 8-day intervals (WS2); and (4) water-stressed, receiving 70% of plant evaporation at 12-day intervals (WS3). The highest yield, the largest and the heaviest fruit was observed in well-watered treatment (C). WS1 did not significantly

affect fruit yield or fruit size but produced fruit slightly lighter, whilst nutrient and chlorophyll concentrations in leaves were the same as in C. WS1 presented higher soluble dry matter (SDM) than C. The WS2 and WS3 treatments caused reductions in most parameters, except SDM concentrations in the fruit, compared to C treatment. WS2 and WS3 reduced marketable yield by 12% and 28.6%, respectively, compared with C. The highest total water use efficiency and irrigation water use efficiency were in WS2, resulting in a 20.4% water saving compared with C.

7. Attributes commonly evaluated in fruit and vegetable under water stress

It became noticeable that in water stress related studies, vegetables are evaluated mainly in terms of health promoting compounds while fruit are evaluated mainly in terms of sensorial related attributes (Table 1)

Plant specie	Cultivar/Var.	Healthy related metabolites	Quality related properties	Yield	Reference
Kiwifruit	Hayward	-	TSS ^a (↑) Firmness (=)	(↓)	Miller et al. (1998)
Strawberry	Hayward	-	Firmness (↑)	(=)	Reid et al. (1996)
	Elsanta	-	Sweetness (↑)	(=)	Bordonaba & Terry (2010)
Apricot	Búlida	-	TSS (↑) TA ^b (↑) Colour (↑) PHDQ ^c (↑)	(=)	Perez-Pastor (2007)
Peach	-	-	TSS (↑) Colour (↑) TA (↑)	(=)	Gelly et al. (2003) Gelly et al. (2004)
Pear	Conference	-	TSS (↑) Firmness (↑) PHDQ ^c (↑)	(↓)	Lopez et al. (2011)
Plum	Black-Gold	-	TSS (↑)	(=)	García-Tejero (2010)
Orange	Salustiano	-	TSS (↑) TA (↑)	(=)	
Table grape	Clementina de Nules	-	TSS (↑) TA (↑)	(=)	Velez et al. (2007)
	Rizamat	Ascorbic. acid (↑)	TSS (↑) TA (↓)	(=)	Du et al. (2008)
Grapevine	Moscatel	Anthocianins (↑) Phenols (↑)	Colour (↑)	(=)	Santos et al. (2007)
Tomato	Zarina	Flavonoids (↑)	-	-	Sánchez-Rodríguez et al. (2011)
Cabbage	Holeta-1 and 37-A	Glucosinolates (↑)	-	(↓)	Schreiner et al. (2009)
Broccoli	Green star	Ascorbic. Acid (↑) Folates (↑)	PHDQ (↑)	(=)	(Cogo et al., 2011)

^a TSS: Total soluble solids.

^b TA: Titratable Acidity.

^c PHDQ: Post-harvest desirable qualities.

Table 1. Effect of limited water supply during the plant production cycle on postharvest quality of fruit and vegetables. The most relevant reference is cited.

8. Conclusion

Environmental sustainability is a current issue in global agenda. This concept comprises, among other concerns, the efficient use of water. Climate change is a reality and the pressure over water reserves will increase in next years, as well over high water consuming activities. Agricultural practices are among the biggest water consuming activities, considering that, alternatives to reduce water use in agricultural practices is of special interest in the present moment. In this review we exposed successful experiences with the intent to reduce water use with minimal losses in yield and quality. Irrigation practices often aims at total replacement of culture evapotranspiration in order to obtain maximum yield. In many occasions experiments demonstrate that is possible to reduce water use without significant losses in yield. In addition, the increases in health/quality related compounds and postharvest preservation are evident in response to environmental stress. The use of regulated stress (water stress, salinity, heat, cold, UV radiation) is a feasibly strategy to enhance accumulation of health promoting compounds in food. Another interesting perspective is the improvement of plant resistance against biotic stresses (e.g. pests and diseases) when submitted to controlled abiotic stresses, as was scientifically demonstrated in experiments presented in this review. However, more studies must be performed to determine the effects of different water stresses on different edible plants.

9. Acknowledgment

The authors acknowledge CAPES and CNPq from Brazilian government for the financial support.

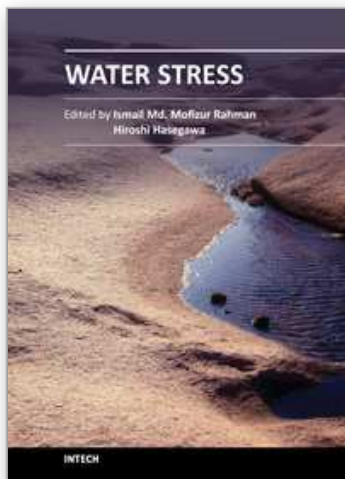
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Water Stress

Edited by Prof. Ismail Md. Mofizur Rahman

ISBN 978-953-307-963-9

Hard cover, 300 pages

Publisher InTech

Published online 25, January, 2012

Published in print edition January, 2012

Plants experience water stress either when the water supply to their roots becomes limiting, or when the transpiration rate becomes intense. Water stress is primarily caused by a water deficit, such as a drought or high soil salinity. Each year, water stress on arable plants in different parts of the world disrupts agriculture and food supply with the final consequence: famine. Hence, the ability to withstand such stress is of immense economic importance. Plants try to adapt to the stress conditions with an array of biochemical and physiological interventions. This multi-authored edited compilation puts forth an all-inclusive picture on the mechanism and adaptation aspects of water stress. The prime objective of the book is to deliver a thoughtful mixture of viewpoints which will be useful to workers in all areas of plant sciences. We trust that the material covered in this book will be valuable in building strategies to counter water stress in plants.

How to reference

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Leonardo Nora, Gabriel O. Dalmazo, Fabiana R. Nora and Cesar V. Rombaldi (2012). Controlled Water Stress to Improve Fruit and Vegetable Postharvest Quality, *Water Stress*, Prof. Ismail Md. Mofizur Rahman (Ed.), ISBN: 978-953-307-963-9, InTech, Available from: <http://www.intechopen.com/books/water-stress/controlled-water-stress-to-improve-fruit-and-vegetable-postharvest-quality>

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