

# ABIOTIC STRESS AND ADAPTATIONS IN FRUIT PLANTS-A REVIEW

Manish Bakshi

Domain of Horticulture

Lovely Professional University, Phagwara, Punjab

## ABSTRACT

Stress can be designated as any unwanted external factor that affects the growth, production, reproduction or survival of the plants. Plants grow well under sufficiency of nutrients, moisture, light and the temperature. However, these factors may act contrary to the growth and development of plants should they exceed their tolerable limit in a plant system. These abiotic factors are determinants of many physiological processes in the plants. The damage to plants is caused by an array of abiotic factors which leads to stress. In this article, a brief review is undertaken concerned with temperature, drought, salt, chilling and heat stress and their effects and adaptation related to fruit crops.

## STRESS DAMAGES

While categorizing the stress in plants, primary and secondary damage is often confused with primary and secondary stress. However, stress is the result of the damage that is caused to the plant either mechanically or physiologically. A perfect example to cite for this kind of stress and its outcome is the one caused by production of free oxygen radicals called reactive oxygen species (Randy, 1995), which arises when equilibrium between electron transport and metabolic reducing power in a plant is disturbed. These free oxygen radicals if retained in the plant can cause abnormal metabolism behavior through changes in lipid, protein and nucleic acid configurations (Allen, 1995). However, plants have got their own defense against ROS in the form of certain enzymes viz. catalase (CAT), superoxide dismutase (SOD) and peroxidase (PRX) that help in scavenging the ROS out of the plant system. Chemically peroxidases are heme containing monomeric glycoproteins belonging to family of isozymes that utilize hydrogen peroxide or oxygen for the oxidation of numerous molecules (Yoshida *et al.*, 2002). As such, peroxidases are an important defense tool in a plant that help the plant to cope with the stress conditions (Gaspar *et al.*, 1982).

The secondary stress in the plant is mainly the manifestation of impacts of excess solarization or cold, which may be considered as primary stress factors. The primary effects expressed in the plant as a result of cold or drought stress is termed as strains (Levitt 1980), leading to uncontrolled or controlled effects. The stress specific response of the plant is triggered with the perception of the abiotic stress factor through the strain thereby leading to a subsequent signal transduction. The accompanying secondary strains normally induce responses which are less specific. These plant responses lead to adaptability and tolerance in the plant. Short term adaptations include biochemical changes whereas long-term adaptations include process modifications like changes in morphology of a plant.

### ***High temperature stress***

Light has an overriding effect on rate of photosynthesis. The reduction of CO<sub>2</sub> is preceded by certain biochemical reactions which are mainly temperature dependent. Where light is a limiting factor, temperature has little effect on the rate of photosynthesis. However, when light is not limiting, as in generally the case in dry region, the biochemical process associated with photosynthesis become the limiting factor, so that the effect of favorable temperature on the rate of photosynthesis is increased. The photosynthetic process appears to become heat inactivated at extremely high temperature which however does not inhibit respiration but apparent photosynthesis declines rapidly. Under this condition, growth retardation and fertilization anomalies are seen even in heat loving crops. For instance, Grapefruit is most resistance to high temperature and can thrive well in even up to 120°F (48.8°C), citrons and lemons starts showing injury at 95°C-100°F. High temperature stress like elevated temperatures, increased lux density and rootzone water deficit are common during the dry and hot summer months. In case of papaya, which is otherwise a delicate plant, the net carbon dioxide assimilation and stomatal conductance decline considerably when the plant is exposed to heat stress. By nature, papaya is a heavy bearer and a slight variation in the acceptable temperature levels affects the fruit and latex yield. There is a decrease in chlorophyll fluorescence which ultimately affects the whole photosynthetic process (Jeyakumar *et al.*, 2007). In loquat, the incidence of annual purple spot was correlated with low day temperatures at the colour break stage. Incidence of purple spot was also sunshine dependent as the incidence was highest at beginning of harvesting time (25-30%) followed by sudden decrease in temperature (5-10%) (Gariglio *et al.*, 2003). Pollens from different strawberry cultivars have differing responses to temperature stress. In Toyonoka strawberry, the pollen germination and pollen tube length were dependent on temperature. Poor performance of the pollen under high temperature resulted in greater number of malformed fruits at 30/25°C temperature (Ledesma and Sugiyama, 2005).

In planting orchards the maximum and minimum temperature must be within the limit of tolerance of the fruit. The effect of temperature on a cloudy day is different from that on a clear day. The rest period of temperate fruit need be broken by low temperature and where it is not possible due to certain reasons, the crop may be late or even lost. High temperature is involved in determining adaptability of a species or varieties. Temperature influences are great and well marked. Peaches tolerate more cold than citrus whereas apple is the best among these. The region selected must be suitable for the cultivars to be grown from the viewpoint of temperature requirements. The optimum temperature for most crop plant is 22 to 27°C, whereas the maximum temperature limit may be 40 to 52°C at which most of the plants of temperate zone may not survive. Leaves of 2 year old seedling of longan and mango showed reduced net CO<sub>2</sub> assimilation rates as the temperature increased, but decline was more in longan than mango. However, stomatal conductance showed a decline while intercellular CO<sub>2</sub> concentration increased for both species. There was a negative association between the intercellular CO<sub>2</sub> concentration and net carbon assimilation at 36 °C in both mango and longan. There was a declining trend in the net carbohydrate assimilation rates which was caused due to non-stomatal limitation at elevated temperatures. Extent of degradation of chlorophyll was more in longan than that observed in mango indicating that mango is more tolerant to effects of elevated temperatures

(Yamada *et al.*, 1996).

### **Drought stress**

The prompt response of a plant to diminishing water availability is by suspending growth and minimizing water use through reduced photosynthesis and suspending other plant processes. Initial symptoms of water loss in some plants are the change of leaf colour from green to blue-green. Wilting sets in and if the water deficit continues, leaf fall takes place and ultimately plant dies. The symptoms of water stress on plants are comparable to the saline stress due to high concentration of salts in the root zone. Though drought injury may not be immediately noticed in grown up plants as it is dependent on the soil porosity, soil moisture content, ecophysiological conditions of that particular place, stage of plant growth and most importantly the inherent capacity of the plant species to cope with the drought stress. Poor soils with more sand having low moisture holding capacity offer more risk of drought stress damage to the plants as compared to the soils having more clay content. Plant anatomical features like limited root system also hastens the effect of drought stress on the plant. The foliage cover on the plant is also an indicative of the potential drought tolerance of the plant. More foliage leads to rapid loss of water from the surface of the leaves. New plantations with poor root systems/under developed systems are also prone to drought stress as the rate of loss of moisture from the leaves is not compensated by the supply of moisture from the roots. Response to drought stress also depends upon the cultivars within the species. A study on effect of water stress on loquat showed reduced shoot dry matter but on the contrary, the root dry weight increased. Other physical growth parameters registered a decline. The physiological justification could be increase in the  $\text{NH}_3\text{-NH}_4^+$  ions, agrenine and proline that resulted in the negative correlations between water content in leaves and proline accumulation (Xie *et al.*, 2007).

Modifications in the landscape and environment can be made by various management and cultural practices such as irrigation, mulching, providing shade and windbreaks. To minimize the water requirements in a landscape, initial planning of water resources and other irrigation related aspects should be properly planned. Evolution has made modification in some species especially growing in the arid areas which enable them to survive the drought conditions. Some modifications or adaptations are on the anatomical or physiological level that enable the plants cope with the drought like conditions. Wax coating on the leaves is an added character of xerophytic plants growing in the arid regions with high mean temperature. This wax layer called cuticle reduces evaporation from leaf surface. Yet another modification is the presence of leaf hairs which slow down the movement of air over the leaf surface thus reducing the evaporation of water from the leaf surface. Reduction in the leaf surface area is another adaptation to minimize the evaporative loss of water from the leaf surface. In some species, the extraordinarily large root system enables the plant to quickly absorb the water in the event of rainfall. Some plant species tend to shed their leaves to avoid water loss and and put forth new growth when the environmental conditions become favourable. Methyl jasmonate (MJ) a volatile compound used in plant defense. Plant produces methyl jasmonate in response to many abiotic stresses, which build up in the damaged parts of the plants. In strawberry, there is an increased production of methyl jasmonate in the plants under stress that suppresses the activity of peroxidase, catalase and superoxide dismutase (Wang, 1999). Drought resistance tendencies of ber and peach were studied

by Stefan *et al.*, (2000), under natural rainfed conditions. The leaf water potential of peach tree dropped considerable whereas the leaf water potential of ber plant remained constant after a 100 day drought period. Ber is naturally adapted to drought conditions as compared to peach which requires irrigation for normal growth and development. However, prolonged exposure to the drought conditions enable to study the mechanism of response of these two species to drought stress. In peach, both leaves and roots showed osmotic adjustment alongwith a considerable accumulation of sugars, anions and cations in the leaves. For *Z. mauritiana* leaves, there was no osmotic adjustment observed during the dry season. The acquired data revealed different strategies of these two species to cope with the dry period.

### **Salt stress**

Salinity most directly affects seeds and root system because salts are commonly concentrated in the upper layers of soils. Above ground parts are directly affected by salt strain or by inadequate filtration of water moving from the soil into the xylem. Xylem water contains few ions even in halophytes that concentrate salts in leaves. In glycophytes a small increase in the soil salinity can rapidly lead to damaging salt build up in leaf tissues and reaching 500 mill moles in a few days. The direct effects of excessive ions on plants varies with the species of ions such as  $\text{Na}^+$  are more toxic than  $\text{Ca}^{++}$  and  $\text{SO}_4^-$  are more toxic than  $\text{Cl}^-$ . Olives respond to salinity stress by increased sodium and chloride concentration, decreased potassium, calcium and magnesium alongwith decreased K: Na ratio all over the plant parts. Magnesium was found to decrease in olive leaves as a function of increased salinity (Demiral, 2005).

Glycophytes generally maintain ion homeostatic by salt exclusion while halophytes accumulate salt as a mechanism of maintaining ion homeostasis. Ion transport in the cytoplasm is determined by electrochemical gradient across cell membranes and tonoplast, carrier proteins and ion ports. ATPase pumps in the plasma membrane and  $\text{H}^+$  pump in tonoplast that moves  $\text{H}^+$  into the apoplast.  $\text{Na}^+$  and  $\text{Cl}^-$  diffuse across the plasma membrane into the cell based on the electrochemical gradient. The high internal concentration of  $\text{K}^+$  related to outside the cell is maintained by  $\text{K}^+$  carrier's antiports. When  $\text{Na}^+$  concentration is high internal homeostasis is regulated by  $\text{H}^+$  and  $\text{Na}^+$  antiport. The movement of  $\text{Na}^+$  out and  $\text{H}^+$  into the cytoplasm therefore under saline conditions the level and activity of  $\text{H}^+$  and  $\text{Na}^+$  antiports,  $\text{H}^+$  and ATPase pump should be critical to maintaining cytoplasm ion homeostasis. In Chemlali olive, the development of thicker leaves was observed on exposure to higher salinity treatments as compared to other cultivars. The roots showed higher concentrations of Na and Cl as compared to shoots and leaves in most of the cultivars. All the cultivars under study showed effectiveness of  $\text{Na}^+$  exclusion mechanism in the roots though the response was different among cultivars. It was efficient in chemlali olive and was least in Arbequina 118. Furthermore, in olive, leaf abscission is an additional tolerance mechanism allowing the elimination of leaves that had an accumulated  $\text{Na}^+$  and  $\text{Cl}^-$ . Tolerance to salinity stress was as follows: chemlali>chetoui>Arbosana143>koroneiki>Arbequina118 (Kchaou *et al.*, 2010). In citrus, salt tolerance of a species is measured by its capacity to maintain low leaf  $\text{Cl}^-$  accumulation through high plant growth and high water use efficiency (WUE) under saline conditions. Leaf  $\text{Cl}^-$  concentration was negatively related to plant growth, but leaf  $\text{Cl}^-$  increased with transpiration rate in low-saline in Carrizo seedlings grown under salt stress in sand. Overall, leaf  $\text{Cl}^-$  was positively correlated to the water use and was negatively correlated

to leaf. Such relationships can be used as indicators of salinity tolerance (Syvertsen and Melgar, 2010). Yilmaz and Kina (2008) reported better growth of Kabarla cultivar under saline conditions as compared to Gloria. Salt stress had its effect on vegetative growth with significant damage to the leaves. It was also summarized that the chlorophyll content in leaves and malondialdehyde levels were affected with increasing salt concentrations in the soil but these parameters were not sufficient to classify the cultivars as salt resistant.

### ***Chilling stress***

The term 'chilling damage' and 'chilling breakdown' can be used as synonyms of chilling injury. The term chilling stress applies to the action of the low temperature those results in chilling injury. Chilling injury should not be confused with freeze injury, the former taking place in temperatures close to freezing temperatures wherein chilling sensitive plants are affected without the formation of icicles in the cells. Anatomically, plant species of sub-tropical and tropical regions are susceptible to chilling injury. Chill sensitive plants have a high percentage of saturated fatty acid chains in their lipid bilayer and this type of membrane at lower temperature well above 0°C. As the membrane become less viscous, the functionality of the proteins reduces dramatically. There is a greater proportion of unsaturated fatty acids in plants resistant to chilling as compared to chilling sensitive plants. When tissue is cooled under natural conditions, formation of ice is prior within the cell walls. Physical change at this point of time is reversible if tissue is warmed quickly. However, if there is extended exposure to freezing temperatures, the crystals in the walls continue to grow and extend into the protoplast, causing lethal damage. Freeze-resistant species have adapted well to reduce the growth of crystals into the cell walls and intercellular spaces. Rapid freezing super cools the protoplast along with the vacuole maintaining the liquid state of water even at freezing temperatures. Peach flower buds seeded with ice just below 0°C were more likely to exhibit deep super cooling, and water in the primordia would super cool to lower temperatures than in seeded excised flower buds (Ashworth and Davis, 1987). Some large polysaccharides and proteins function as ice nucleates and help in ice crystal formation. Numerous ice nucleates lead to formation and amalgamation of relatively larger masses of ice crystals that ultimately damage the cell wall. In Monique apricot, there was a clear internal damage caused by freezing temperatures at bud break. External and Internal damage symptoms were observed during the pre-bloom and bloom period following incidence of frost (Rodrigo *et al.*, 2006).

Herbaceous temperate plants have adapted to low non freezing temperatures. Acquired freezing tolerance involves extensive remodeling of gene expression and metabolism. Full-genome transcript profiling studies have provided an insight of the transcriptional mechanism that operates under cold stress. Gene expressions in response to cold temperatures initiates increased levels of hundreds of metabolites that act as protective shield against adverse effects of cold stress.

### ***Heat stress***

Turning to the other temperature extreme, to what extent are plants able to resist excessively high temperatures. Few higher plant species survive a steady temperature above 45°C. Dehydrated and non-growing cells can survive heat stress effectively as compared to hydrated, vegetative, and growing cell. A clear example can be cited here for growing tissues and seeds. Growing tissues rarely have a threshold

tolerance limit of nearly 45°C, but on the contrary, dry seeds can withstand temperatures up to 120°C. Photosynthesis and respiration are temperature dependent and get inhibited at high temperatures. When compared on degree rise in temperature basis, photosynthetic rates decrease faster than respiratory rates. Utilization of carbon for substrate formation is temperature dependent. It is apt at compensation point wherein amount of carbon fixed during photosynthesis is equal to the amount of carbon released during respiration. Above the temperature tolerance levels, photosynthesis can no longer replace the amount of carbon being used as substrate which results in insipid quality of fruits. This shift of balance in carbon formation and carbon release is the main reason for declining productivity and quality of plants. Even the compensation point varies within the canopy of the same plant. It can be lower for the shaded leaves whereas it can be higher for the leaves exposed to sun. Demonstrations were conducted in strawberry seedlings grown using perlite for a period of 3 weeks at 25/10°C day/night temperature and supplemented daily with nutrient solution. Strawberry seedlings (half of the plants) were transferred to a growth chamber maintained at 25°C for a week. The temperature of the growth chamber was increased stepwise (5°C/48 h) to 30, 35, 40°C and finally to 45°C. Fresh plants were transferred to the growth chamber at each temperature increment step to impose a heat shock. It was observed that plants responded to elevated temperatures by promoting PRX activities. However, there was a decrease in the total protein content. All the plant samples depicted one basic PRX band ( $r_f = 0.22$ ) with different intensity. There was less leakage of electrolytes from plant samples exposed to GH compared with the plants exposed to SHS (Gulen and Eris, 2004).

Various genetic improvement approaches can be employed to improve the plant response to increased temperature tolerance. Nevertheless heat tolerance of a plant species varies at different developmental stages but surely it affects the plant throughout its growth. To cite an example, seed germination may be inhibited at particular heat levels, higher temperature may affect the rate of photosynthesis, respiration, water uptake and stability of plant cell membranes. There may be alterations in the levels of hormones, primary and secondary metabolites in the plant system. Moreover, plant may respond to heat stress by producing heat shock proteins, reactive oxygen species which further affect plant behavior. Plants have mechanisms to cope with the elevated temperatures which include antioxidant production, scavenging of reactive oxygen species, enhanced membrane stability through lipid bilayer alterations, accumulation of solutes, induction of MAPK and CDPK cascades. All these mechanisms, which are regulated at the molecular level, enable plants to thrive under heat stress. Apart from genetic improvement approach, heat tolerance in plants can be enhanced by acclimation of plants to different environmental stresses. Exogenous application of osmoprotectants such as glycinebetaine and proline is also effective in such environmental scenarios.

### ***Oxidative stress***

Oxidative stress arises when ROS or free radicals generated in plants in response to stress express their toxic effects to the cells. Ozone may react with ethylene and other alkenes in the apoplastic fluid to form hydroxyl ion, super oxides anion and hydrogen peroxide ( $O_2$ ) and reactive oxygen species react with membrane lipids to form reactive lipid peroxides which will perpetuate reactive oxygen species formation. Some  $O_2$  and ROS may succeed in entering the cytoplasm after membrane damage that promote inside the

cell. O<sub>2</sub> and ROS estimate damage of the plasma membrane alter ion transport, increase membrane permeability, inhabitation of H<sup>+</sup> pump activity, collapse membrane potential and increase Ca<sup>2+</sup> uptake from the apoplast. Ozone zone exposure causes rapid inhibition of photosynthesis due to change in the activity of synthesis of chloroplast, proteins. In several plants chronic exposure to ozone reduce the abundance of rubisco enzyme in mature leaf tissue and reduced activity of photo system-I and photo system-II. Degradation of large subunit of rubisco is also observed in response to high intensive light and oxidant herbicide i.e. paraquat.

### *Secondary metabolites*

Plant secondary metabolites play an important role in plant interactions with the changing environment. Secondary metabolites not only protect the plant against environmental stresses (Seigler, 1998) but associated changes include specific odors, tastes and colours in plants (Bennett and Wallsgrove, 1994). Production of secondary metabolites often occurs in plants subjected to stresses and have importance in plant stress physiology for adaptation (Seigler, 1998). In some of the earlier works it has been reported that plants under stress produce methyl jasmonate and jasmonic acid which act as elicitors for the production of secondary metabolites in plants. Similar findings were reported for strawberry plants (Perez, 1997) and *Vitis vinifera* (Zhang, 2002).

### REFERENCES:

1. Ashworth, E. N. and Davis, G. A. 1987. Influence of ice nucleation temperature on the freezing of peach flower buds. *HortScience*, 22(5):923-925.
2. Bravdo, B.2000. Effect of mineral nutrition and salinity on grape production and wine quality. *Acta Hort*, 512:23-30
3. Chen, T. H. H. 1994. Plant adaptation to low temperature stress. *Canadian J. Plant Patho.*, 16:231-236.
4. Cochard, H., Barigah, S. T., Kleinhentz, M. and Eshel A. 2008. Is xylem cavitations resistance a relevant criterion for screening drought resistance among Prunus species? *J. Plant Physiol.* 165:976—982.
5. Demiral, M. A. 2005. Comparatives response of two olive (*Olea Europaea* L.) cultivars to salinity. *Turk. J. Agric. For.* 29:267-274.
6. Deshmukh M.R. and Patil S.G.2010. Screening of grape rootstocks for sulphate salinity. *Indian J. Plant Physiol.*, Vol. 15, No. 1, (N.S.) pp. 65-68.
7. Gariglio, N., Castillo, A., Alos, E., Juan, M., Almela, V. and Agusti, M. 2003. The influence of environmental factors on the development of purple spot of Loquat fruit (*Eriobotrya japonica* Lindl.). *Scientia Hort.* 98: 17-23.

8. Gariglio, N.F., Mendow.M., Weber,M.E., Favaro,M.A.,González-Rossia, D. E. and Pilatti, R. A. 2009. Phenology and reproductive traits of peaches and nectarines in Central-east Argentina. *Sci. Agric.(Piracicaba, Braz.)*, v. 66, n.6, p.757-763.
9. Gill, S. S. and Tuteja, N. 2010 Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiol Biochem.* 30: 1-22.
10. Gulen, H. and Eris, A. 2004. Effect of heat stress on peroxidase activity and total protein content in strawberry plants. *Plant Science* 166: 739–744.
11. Jan, N., Hussian,M-ul, and Andrabi, K.2009. Cold resistance in plant: A mystery unresolved. *Electronic J. Biotech.* 12(3): 1-15.
12. Jeyakumar, P., Kavino, M., Kumar, N and Soorianathasundaram, K. 2007. Physiological performance of papaya cultivars under abiotic stress conditions. *Acta Hort.* 740:209-215.
13. Jo, Y. S., Cho, H. S., Park, M.Y., Bang, G. P. and Kim, W. S.2008. Drought stress tolerance of *Actinidia arguta* and *Actinidia eriantha*. *Acta Hort.*, 773: 283-287.
14. Kchaou, H., Labri, A., Gargouri, K., Chaieb, M., Morales, F. and Msallem. M. 2010. Assessment of tolerance to NaCl salinity of five olive cultivars, based on growth characteristics and Na<sup>+</sup> and Cl<sup>-</sup> exclusion mechanisms. *Sci. Hort.*124:306-315.
15. Kostopoulou, Z., Therios, I.Tsirakoglou, V. and Molassiotis, A. 2012. The role of potassium nitrate in physiological parameters of *citrus aurantium* seedling exposed to salinity. *Acta Hort*, 928:337-344.
16. K. K., Upreti and G.S.R. Murti. 2010. Response of grape rootstocks to salinity: changes in root growth, polyamines and abscisic acid. *Biologia Plantarum* , 54 (4): 730-734.
17. Klamkowski K. and Treder, W. 2008. Response to drought stress of three strawberry cultivars grown under greenhouse conditions. *J. Fruit Orn. Plant Res.*, 16: 2008: 179-188.
18. Ledesma, N. and Sugiyama, N. 2005. Pollen quality and performance in strawberry plants exposed to high-temperature stress. *J. Am. Soc. Hortic. Sci.* 130: 341-347.
19. Levitt , J. 1980. Responses of plants to environmental stresses. Vol. I Chilling, freezing, and high temperature stress (London, New York, Toronto: Academic Press).
20. Levy, Y., Lifshitz, J., Malach, Y. D. and David, Y. 1999. The response of several citrus genotypes to high salinity irrigation water. *Hortscience*, 34(5): 878-881.
21. Randy, R. D. 1995. Dissection of oxidative stress tolerance using transgenic plants; *Plant Physiol.* 107: 1049-1054.
22. Stefan, K. A., Wolfgang, W., Sean, C. C. and Marianne, P. 2000. Contrasting adaptations to drought stress in field-grown *Ziziphus mauritiana* and *Prunus persica* trees: water relations, osmotic adjustment and carbon isotope composition. *Aust. J. plant phy.* 27(11); 985-996.
23. Syvertsen, J. P. and Melgar, J. C. 2010. Salinity tolerance and leaf water use efficiency in citrus. *J. Amer. Soc. Hort. Sci.* 135(1):33-39.
24. Wahid, A., Gelani, S., Ashraf, M. and Foolad, M. R. 2007. Heat tolerance in plants: An overview. *Env. Exp. Bot.* 61: 199–223.

25. Wang, S. Y. 1999. Effect of methyl jasmonate reduces water stress in strawberry. *Acta Hort*, 516: 89-96.
26. Xie, S. X., Xiong, X. Y., Zheng, Q.M. and Wu, Y.C. 2007. Water stress affects growth, relative water content, gas exchange and nitrogen pools of loquat. *Acta Hort*.750:261-267.
27. Yamada, M., Fukumachi, H and Hidaka, T. 1996. Photosynthesis in longan and mango as influenced by high temperature under high irradiance. *J. Japan Soc. Hort. Sci.*64(4):749-756.
28. Yilmaz,H. and Kina, A. 2008. The influence of NaCl salinity on some vegetative and chemical changes of strawberries (*Fragaria x ananassa* L.) *African J. Biotech.* Vol. 7 (18), pp. 3299-3305.
29. Zhang, J., Huang, W., Pan, Q. and Liu, Y. 2005. Improvement of chilling tolerance and accumulation of heat shock proteins in grape berries (*Vitis vinifera* cv. Jingxiu) by heat pretreatment. *Postharvest Bio. Techno.* 38 : 80–90.
30. Zhou, H.W., Dong, L., Arie, R. B. and Lurie, S. 2001. The role of ethylene in the prevention of chilling injury in nectarines. *J. Plant Physiol.* 158: 55-61.
31. Allen R (1995). Dissection of oxidative stress tolerance using transgenic plants. *Plant Physiol* 107:1049-1054.
32. Yoshida, K., Kaothien, P., Matsui, T., Kawaoka, A. and Shinmyo, A. (2002). Molecular biology and application of plant peroxidase genes. *App Microb Biotech* 60: 665-670.
33. Gaspar, T., Penel, C.L., Thorpe, T., and Greppin, H. (1982). Peroxidases. A survey of their biochemical and physiological roles in higher plants. Universite de Geneve Press, Geneve.
34. Eris, A., Gulen, H., Barut, E., and Cansev, A. (2007). Annual patterns of total soluble sugars and proteins related to cold-hardiness in olive (*Olea europaea* L. 'Gemlik'). *J Hort Sci Biotech* 82: 597-604.
35. Sarnighausen, E., Karlson, D.T., Zeng, Y., Goldsbrough, P.B., Raghothama, K.G. and Ashworth, E. N. (2004). Characterization of a novel YnSKn class of dehydrin-like cDNAs from cold acclimated red-osier dogwood (*Cornus sericea* L.) xylem. In: *Adaptations and Responses of Woody Plants to Environmental Stresses*, (Ed.: R. Arora). The Haworth Press, New York, pp. 17-36.
36. Thomashow, M. F. (1999). Plant cold acclimation: freezing tolerance genes and regulatory mechanisms. *Annu Rev Plant Physiol Plant Mol Biol* 50: 571-599.
37. Perez, A. G., Sanz, C., Olias, R. and Olias, J.M. 1997. Effect of methyl jasmonate on *in vitro* strawberry ripening. *J. Agric. Food Chem.* 45:3733-7.
38. Zhang, W., Curtin, C., Kikuchi, M. and Franco, C. 2002. Integration of jasmonic acid and light irradiation for enhancement of anthocyanin biosynthesis in *Vitis vinifera* suspension cultures. *Plant Sci.* 162:459-68.
39. Seigler, D. S. 1998. *Plant Secondary Metabolism*. Boston MA:Chapman and Hall (Kluwer Academic Publishers): 711.
40. Bennet, R. N. and Wallsgrave, R.M. 1994. Secondary metabolites in plant defence mechanisms. *New Phytol.* 127:617-33.