International Journal of Horticultural Science 2010, 16 (4): 7–14.
Agroinform Publishing House, Budapest, Printed in Hungary
ISSN 1585-0404

Sunburn assessment: A critical appraisal of methods and techniques for characterizing the damage to apple fruit

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Summary: Many methods and techniques have been introduced for measuring alterations in the fruit and in its surrounding environment related to sunburn incidence. The research objectives, fruit materials and the environment to be evaluated dictate the methods to follow. These procedures are either non-destructive and involve techniques that allow us to track the course of sunburn development and related environmental parameters, or destructive and involve the removal of fruit from the tree for field/laboratory measurements. Techniques employed can be used for pre-symptomatic monitoring (before symptoms become visible) or characterizing the symptoms already present. The principles behind the measurements and their usefulness for sunburn assessments are discussed and critically evaluated in this review paper. Descriptions and evaluations of the methods and techniques were made in the following groups: 1. Thermal measurements; 2. Visual assessments; 3. Fruit quality measurements; 4. Measurements of physiological and biochemical alterations; and 5. Practical evaluation of sunburn damage. Thermal measurements involve methods tracking the ambient temperature and fruit surface temperature, and their relation to sunburn formation. Visual assessments cover all measuring techniques (skin color, chlorophyll fluorescence, radiation reflection, electron microscopy) that are able to detect changes on/in the fruit skin related to sunburn formation. Fruit quality measurements are used to point out differences in qualities (soluble solids, firmness, titratable acidity, and water content) between unaffected and sunburned areas of the fruit. The measurements of physiological and biochemical alterations (gas exchange, pigment analysis, enzyme activity, gene expression) give us a better insight to the mechanism of sunburn formation. Practical evaluations involve many procedures that are used by scientists to characterize the susceptibility of cultivars, evaluate protection technology, etc. For this purpose, the following methods are in use: expressing the percentage of the total fruit surface area affected by sunburn or the percentage of the total number of fruits damaged on the tree, or even a scale based on the severity of the symptoms occurred. All assessing methods and techniques described here have their pros and cons as well as their specific applicability, therefore any of these cannot be favored to use exclusively for assessing sunburn incidence. The combination of these techniques will be the best choice to meet a given research objective perfectly.

Key words: apple, sunburn, sunscald, heat stress, temperature, light stress, UV-radiation, chlorophyll fluorescence, electrolyte leakage, heat shock proteins (HSPs), pigments, skin color

Introduction

Many methods have been introduced for measuring alterations in the fruit and in its surrounding environment related to sunburn incidence. The research objectives, fruit materials and the environment to be evaluated dictate the methods to follow. These procedures are either non-destructive and involve techniques that allow us to track the course of sunburn development and related environmental parameters, or destructive and involve the removal of fruit from the tree for field/laboratory measurements.

Techniques employed can be used for presymptomatic monitoring or describing the symptoms already present. Some current techniques allow presymptomatic observations of changes in the physiological state of fruit, i.e. stress observations before fruits display visible symptoms. In this respect thermal, reflectance and fluorescence imaging have proved their potential by detecting stress-related changes in the pattern of light emission (*Chaerle & van der Straeten*, 2000). Using such techniques would allow us to alleviate solar injury stress at an early stage, so avoiding irreversible damage and thus substantially reducing yield loss. While descriptive methods (e.g. pigment analyses, electron microscopy imaging) help to better understand the underlying mechanisms of sunburn formation. All assessing techniques described here have their pros and cons as well as their specific applicability; therefore any of those cannot be favored to use exclusively to assess sunburn incidence. The combination of the following techniques will be the best choice to meet a given research objective perfectly. The principles behind the measurements and their usefulness for sunburn assessments will be discussed here.

1. Thermal measurements

First measurements related to sunburn on apples were done by *Overholser* et al. (1923) who made comparisons between temperatures of apple fruits located in the shaded and exposed sides of the canopy. *Harvey* (1923, 1925) compared ambient air temperature and surface temperatures of the sunny and shaded sides of various fruits including apples. Records were taken with inserted thermocouples.

Similarly, *Brooks & Fisher* (1926) compared air temperature to fruit surface temperature (FST) of 10 apple cultivars. Although their method of pushing the sensory bulb of a thermometer beneath the skin was imprecise, results were still very informative and allowed comparisons among cultivars. Comparative fruit surface temperatures were measured by *Meyer* (1932) as well, however, his results cannot be considered to be decisive as he used detached apples exposed to natural sunlight in his experiment. Since then, similar methods were employed by several researchers to monitor FSTs of apples susceptible to sunburn (*Unrath*, 1972; *Thorpe*, 1974; *Bergh* et al., 1980; *Kotzé* et al., 1988; *Parchomchuk & Meheriuk*, 1996; *Glenn* et al., 2002; *Adams & Valdés*, 2002; *Evans*, 2004; *Gindaba & Wand*, 2005; *Saudreau* et al., 2007; *Schrader*, 2009).

Such measurements characterize temperature changes very well and with fruit-inserted thermocouples connected to data logger with automated data recording make this procedure easy. However, they have some disadvantages including that the insertion of thermocouples wounds the fruit (*Prohens* et al., 2004) and makes the measurements on the same fruit unrepeatable in later times (thermocouples are usually used in a fruit for up to 24-h for FST measurements) (*Ferguson* et al., 1998). Small variations in the depth of insertion of the thermocouple can also significantly affect the results and cause abnormal pigmentation or fruit development. To solve these problems, *Felicetti* (2003), *Schrader* et al. (2003), *Felicetti & Schrader* (2008b) and *Seo* et al. (2008) used thermocouples placed on the fruit surface, instead of insertion, and held in place by a small fabric adhesive bandage. This tape method was preferred for long term measurements, as the thermocouples could be moved as fruit changed position and peel was not damaged to allow entry of pathogens. The main aim of these measurements with thermocouples was to monitor FST throughout the season and examine daily whether sunburn had occurred. If so, the date of event was recorded and FST for several days preceding incidence of sunburn was reviewed to determine the highest temperature that had occurred prior to the sunburn event. This was recorded as the threshold temperature of naturally occurring sunburn of a given cultivar (*Schrader* et al., 2001). The disadvantage of this method is that sudden weather changes can cause FST to increase markedly above what it had been previously. Sunburn occurs, but may cause us to overestimate the threshold temperature for sunburn. This explains why the threshold temperatures established with this FST-tracking method are generally higher than for experimental induction methods.

Such FST-tracking point measurements can be used for screening purposes only, they cannot reveal spatial heterogeneity in FST (the angle of the sun is gradually changing during the day causing the highest temperature point is gradually shifted on the fruit surface). Therefore, it seemed to the use of other temperature measuring procedures need to be employed for a more accurate observation of FST. Infrared thermometry (e.g. Raytek Corp. – Raynger series; Heimann Corp. – KT models) and thermography (e.g. FLIR Systems – ThermaCAM series, AGEMA Systems – Theromovision series) allowed non-destructive and remote determination of FSTs by detecting long wave infrared radiation (8–14 μm) emitted from the fruit (*Chaerle & van der Straeten*, 2000). Thermometry seemed to be a very useful tool in apple FST measurements (*Thorpe*, 1974). In case of thermography, computer software transforms radiation data into thermal images in which temperature levels are indicated by a false-color gradient. Modifications in the FST caused by adverse solar radiation lead to changes in physiological and biochemical procedures of the fruit as a result of active natural protective mechanisms (e.g. induction of HSPs genes). The associated changes in patterns of heat balance of the fruit surface can be monitored instantly and remotely by thermographic imaging. These technologies, therefore, seemed to be more useful when studying the course of sunburn development or detect temperature differences on the fruit surface in apples (*Glenn* et al., 2002; *Evans*, 2004; *Gindaba & Wand*, 2005, 2008; *van den Dool*, 2006; *Wand* et al., 2006), tomatoes (*Adams & Valdés*, 2002) and pepino fruits (*Prohens* et al., 2004).

2. Visual assessments

As colors of sunburn symptoms are readily visible and distinguishable from the non-affected fruit surface, it seems practical to determine the degree of change in color. Color changes in apples associated with sunburn damage have been determined using various objective charts (e.g. Deciduous Fruit Board chart series in South Africa) (*Wand* et al., 2006; *Gindaba & Wand*, 2008) and with the use of colorimeter (e.g. Minolta – CR-series, Gardner types) (*Lurie* et al., 1991). *Felicetti & Schrader* (2008a, 2009a, b) used the most common technique to compare peel colors of undamaged and various stages of sunburned fruit. They determined the CIE $L^*a^*b^*$ (L^*, lightness coordinate; a^*, red/green coordinate; b^*, yellow/blue coordinate) color space and calculated hue angle and chroma values.

The use of chlorophyll fluorescence *in vivo* to visually detect photoinhibitory damage has been described by *Critchley & Smillie* (1981). Hence, by measuring the yield of chlorophyll fluorescence, information about changes in the efficiency of photochemistry and heat dissipation can be gained (*Maxwell & Johnson*, 2000). Although fluorescence measurements may sometimes provide a useful measure of the photosynthetic performance of plants, its real strength lies in its ability to give information that is not readily available in other ways. In particular, fluorescence can give insights into the ability of a plant to tolerate environmental stresses and into the extent to which those stresses have damaged the photosynthetic apparatus (*Maxwell & Johnson*, 2000; *Song* et al., 2001; *Willits & Peet*, 2001). *Smillie & Hetherington* (1983) proved that it can be used to assess effects of irradiating apples with UV light under laboratory conditions and to follow photobleaching resulting from sunburn of apples in the orchard. While these measurements on sunburned apples do not identify the primary cause of the injury they do provide a means of measuring its effect. Identification of the actual injurious wave length bands or combination of these contributing to sunburn should be amenable to study by chlorophyll fluorescence techniques and it should also be possible to detect early stress injuries, e.g. photoinhibition, which precede the loss of chlorophyll. As in the case of UV radiation of apples, the decline in log F_R was linearly related to the time of irradiation and it seems feasible to use fluorescence *in vivo* to screen for resistance and adaptation to UV light, and also to intense visible light (*Smillie & Hetherington*, 1983). *Seo* et al. (2008) used a portable modulated flourometer (OS5-FM type, Opti-Sciences) to detect heat stress-induced changes in chlorophyll fluorescence and relate heat stress indicators to the physical symptoms of sunburn on 'Fuji' apple fruit. *Ma & Cheng* (2003) and later *Chen & Cheng* (2007) used a custom-made pulse-modulated flourometer (FMS2 type, Hansatech) to compare chlorophyll fluorescence of sunny and shaded sides of 'Gala' and 'Smoothee' apple fruits.

The determination of the radiation reflection spectra is also a useful tool in the visual assessments related to sunburn damage on apples. Knowing the specific conditions (radiance) of the formation of each type of sunburn symptoms, it can help to estimate the absolute efficiency of sprayable sunburn protectants such as Surround. For this purpose, spectrometer (PP Sytems, Unysis type) was used and the reflected radiation (195–400 nm) was measured by *Glenn* et al. (2002). They expressed the radiation reflection as a percentage of the control reflection spectrum. Whole fruit reflectance spectra in 400–800 nm range were recorded by *Merzlyak* et al. (1998, 2002) with a Hitachi spectrophotometer. In latter case, they compared the reflection spectra of the sunny and shaded sides of apple fruits for four cultivars ('Antonovka obyknovennaya', 'Zhigulevskoye', 'Renet Simirenko' and 'Granny Smith'). Between the reflectance of apple fruit peel of sunny and shaded sides, *Ma & Cheng* (2003) and later *Chen & Cheng* (2007) made comparisons using a spectroradiometer (Li-type, LI-COR Systems). *Ding & Fuchigami* (2004) also confirmed the applicability of the reflectance spectroscopy (FOSS NIR system) in early detection of sunburn in 'Fuji' apples.

For visual characterization of sunburn damage on apple fruit, scanning electron microscopy imaging technique was used by *Andrews & Johnson* (1996, 1997). They were able to characterize alterations in the wax cuticle and in structural organizations in the sunburned peel and detected intercellular damage prior to the appearance of the visual symptoms of sunburn. Later, *Hao & Huang* (2004) used scanning electron microscopy for similar purposes. *Felicetti* (2003) and *Felicetti & Schrader* (2008b) employed the same technique for characterizing photooxidative sunburn symptoms in transverse sections of the apple skin.

3. Fruit quality measurements

Probably, *Tustin* et al. (1993) were the first who assessed quality of 'Braeburn' apple fruits with various extent of blush area (<40%, 40–70% and >70%) on the surface including a group of fruits with "marginal sunburn discoloration". Quality and maturity indices used were starch pattern index, firmness and soluble solids concentration. Later, *Curry* (1994) used 'Granny Smith' and 'Red Delicious' cultivars and sorted fruits into six categories based on the extent of sunburn damage; none, "light", "bleached", "bronzed", "buckskin", and "cracked". Each fruit was subdivided into exposed and shaded halves and each half was evaluated for firmness, soluble solids and acidity. Tissue samples were analyzed for sugars, total nitrogen, and mineral content. Later, *Racskó* et al. (2005b) pointed out the alterations in fruit quality parameters within the sunburned surface of 'Idared' apple fruit. Besides skin color and the depth of tissue damage, they evaluated the changes in firmess and soluble solids with various distances from the center of the sunburned spot. Although, this study provided many details on sunburn effect on fruit qualities, authors did not indicate which type of sunburn was studied. Based on the description, it seems likely that *Racskó* et al. (2005b) studied sunburn necrosis as they did indicate that plant cells, suffering from sunburn, died.

Recently, *Schrader* et al. (2008) and *Schrader & Kahn* (2009) have determined internal fruit quality traits of apples at various stages of sunburn browning. They extended the firmness and soluble solids measurements on flesh tissues beneath the sunburned area with the determination of titratable acidity and water content. They studied 'Fuji' at monthly intervals from harvest to 6 months for regular atmosphere (RA) cold storage and five cultivars at harvest and after 3 and 6 months of RA cold storage. As severity of sunburn browning increased from S-1 to S-4, firmness and soluble solids increased whereas titratable acidity declined as time as time in cold storage increased. This study provided useful practical information on postharvest life of apple fruits with sunburn browning. More recently, *Schrader* et al. (2009) compared these fruit quality traits on the sun-exposed side, the shaded side and the shoulder between the two to ascertain the changes in fruit quality in the various sides of fruit with different degrees of sunburn. These findings are extremely important because apples with moderate sunburn browning are generally marketed.

4. Measurements of physiological and biochemical alterations

In the early 1900s, *Brooks & Fisher* (1926) made comparisons in sap concentrations, i.e. osmotic pressures of the sunny and shaded sides of 'Winter Banana' apples. They used this procedure to point out the role of sap concentration in heat resistance found in adjacent tissues subjected to different degrees of exposure.

Electrolyte leakage of fruit cells which is correlated with the integrity of cell membranes, provides an objective measurement of the effect of excessive irradiation. When fruit tissue is injured by high temperature, membrane permeability is increased, and electrolytes diffuse out of the cells. This allows the assessment of relative heat damage by measuring the amount of electrolyte leakage (*Chen* et al., 1982). Even if this method is destructive, it is very useful to estimate the relative thermostability of fruit cell membranes. Several authors employed this technique using electrolyte conductivity meters (*Inaba & Crandall*, 1988; *Schrader* et al., 2001; *Felicetti*, 2003; *Prohens* et al., 2004; *Felicetti & Schrader*, 2008b). Even with a sigmoidal response curve fitted to the electrolyte leakage data across various treatment temperatures makes it possible to predict critical high temperatures at which sunburn symptoms occur (*Inaba & Crandall*, 1988).

First, *Le Grange* et al. (2002) and later *Gindaba & Wand* (2007a, b) measured gas exchange attributes (photosynthetic light-response and CO_2-response, stomatal conductance) of apple leaves when comparing various sunburn control measures (evaporative cooling, kaolin particle film application and shade net). They used these techniques aiming to identify a technology that effectively reduces sunburn with minimum negative effects on tree physiological processes. This investigation extended earlier studies on comparison of midday gas exchange by the application of shade net and kaolin particle film technology (*Glenn* et al., 2003; *Jifon & Syvertsen*, 2003). Later, *Chen & Cheng* (2007) and *Chen* et al. (2009) were able to measure dark respiration and photosynthetic O_2 evolution rates of heat treated apple peel discs with a ChloroLab-2 liquid-phase oxygen electrode system (Hansatech Instruments). This technique of measuring fruit peel gas exchange responses to environmental conditions related to sunburn damage provides new insights into fruit physiology. *Glenn* et al. (2008) used CIRAS-2 gas analyzer (PP Systems) to measure fruit surface respiration of UV-irradiated and heat treated apple peel disks. They extracted small pieces of peel and flesh cores from apple fruits and placed them on glass slide, where the base and exposed edges of fruit samples were coated with silicone grease to prevent gas exchange from surfaces other than the peel. With this technique they were able to predict possible adaptation strategies (e.g. UV repair mechanisms) by examining both the maximum quantum efficiency of photosystem II and dark respiration.

Excessive radiation causes significant changes in the pigment composition of apple fruits. Most often chlorophyll degradation occurs accompanied with the increase of other pigments actively involved in photoprotective mechanisms of the fruit (e.g. flavonoids can serve as radical scavengers). Therefore, it is a frequent practice to evaluate sunburn damage with measuring the amounts and relative ratios of various pigments. Chlorophyll *a* and *b*, and total carotenoids and phenolics are usually determined spectrophotometrically in methanol or mixed extracts (*Merzlyak* et al., 1998, 2002; *Yuri* et al., 2000b; *Reay & Lancaster*, 2001; *Solovchenko* et al., 2001; *Hao* et al., 2004; *van den Dool*, 2006; *Chen & Cheng*, 2007; *Chen* et al., 2009; *Iamsub* et al., 2009) rather than separate them by HPLC which is both costly in time and materials and often difficult to correct for measurements at a single wavelength and for losses during the extract manipulations (*Wellburn*, 1994). However, HPLC technique is essential for quantification of individual pigments (*Awad* et al., 2000, 2001; *Ma & Cheng*, 2003; *Solovchenko & Schmitz-Eiberger*, 2003; *Ding & Fuchigami*, 2004; *Hao* et al., 2004; *Takos* et al., 2006; *Wand* et al., 2006). *Felicetti & Schrader* (2008a, 2009a, b) used HPLC technique for the determination of â-carotene, lutein, idaen, violaxanthin, zeaxanthin, antheraxanthin, quercetin and individual quercetin glycosides (quercetin 3-arabinofuranoside, quercetin 3-arabinopyranoside, quercetin 3-galactoside, quercetin 3-glucoside + quercetin 3-rutinoside, quercetin 3-xyloside, quercetin 3-rhamnoside), chlorogenic acid and epicatechin associated with sunburn browning.

In a comparison of sunny and shaded sides of apple fruits, *Ma & Cheng* (2003) and *Chen & Cheng* (2007) determined the activity of various enzymes (superoxide dismutase, ascorbate peroxidase, catalase, monodehydroascorbate reductase, dehydroascorbate reducatse, gluthation reductase, NADP-glyceraldehyde-3-phosphate dhydrogenase, phosphoribulokinase, stomatal fructose-1,6-biphosphatase, sucrose phosphate synthase) involved in natural protective mechanisms against excessive solar radiation. With these methods, they were able to point out differences in the photosynthetic capacity and thermotolerance in the sunny and shaded sides of apple fruits. *Zhang* et al. (2007) measured 5'-nucleotidase activity to study sunburn-related membrane functions under high temperature and relative humidity stress. By determining PPO activity, *Zhang* et al. (2008) pointed out a causal relationship between the browning process of sunburned fruit and PPO activity. Several other chemical compounds were also analyzed from sunburned fruit peels and compared to unaffected samples in order to track the changes caused by excessive solar radiation; ascorbic acid (*Lurie* et al., 1991; *Iamsub* et al., 2009), amino acids (*Lurie* et al., 1991), malonaldehyde (*Lurie* et al., 1991), malondialdehyde (*Iamsub* et al., 2009) and reducing sugars (*Lurie* et al., 1991). Besides the mass of data reported on various compounds in several papers, authors were not always able to exactly explain the physiological role of the measured compounds related to sunburn damage.

Lately, several newer techniques are also available to study plant response to excessive environmental conditions at a cellular level. Such tool is to track the gene expression of heat shock proteins (HSPs) as HSPs synthesis is a typical response of fruits when subjected to high temperatures (*Lurie & Klein*, 1990; *Ferguson* et al., 1994; *Woolf* et al., 1995). However, most studies of high temperature response have been done on laboratory materials such as cultured cells, micro-organisms or laboratory-grown plants. The experimental material was often subjected to a rapid, large increase in temperature and this has led to a perception that high temperature responses are induced by abnormal conditions. However, plants in the field can encounter HSPs-inducing temperatures during normal diurnal temperature cycles in the warmer seasons. This was confirmed by *Ferguson* et al. (1998) who used Northern analysis in field conditions. They studied the expression of HSP70 and smHSP genes associated with high daily flesh temperatures of 'Braeburn' apples. The major advantage of such analysis is to help determine how fruit acclimate to survive conditions of high temperature and solar irradiation. Later, *Ritenour* et al. (1998, 2001) used Western immunoblot analyses to measure the differences in large HSP and smHSP between apple fruits grown in the shade or under the direct sun. To point out the genetic impact on heat shock response of apple fruit, they used cultivars characterized with various susceptibilities to sunburn ('Fuji', 'Jonagold', 'Criterion', 'Gala' and 'Red Delicious').

5. Practical evaluation of sunburn damage

The degree of sunburn can be evaluated by different procedures. Many of the scientists used measures based on the percentage of the total fruit surface area affected by sunburn (*Gaus & Rogoyski*, 1992; *Melgarejo* et al., 2004; *Wünsche* et al., 2004a; *Racskó* et al., 2005a). The accuracy of such estimates of the visible surface area depends on the clarity of sunburn symptoms on the fruit surface which is sometimes difficult as sunburn may have different levels of visibility depending on the color of the skin, the cultivar susceptibility, the environmental conditions, etc. In some cases fruit may even appear to be unaffected, when in fact sunburn damage exists but in the subepidermal tissues. This is the typical case of "sunburn scald" in 'Granny Smith' apples where symptoms appear postharvest during cold storage (*Hall & Scott*, 1989; *Contreras*, 1999). In normal cases, the symptoms are generally easily recognizable for photooxidative sunburn, however, there is often an intermediately or differently colored ring, called "halo" area (*Felicetti & Schrader*, 2009a, b), between the unaffected fruit surface and the sunburn spot of sunburn browning and sunburn necrosis that makes the evaluation difficult.

Others expressed the percentage of the total number of fruits on the tree damaged (*Bergh* et al., 1980; *Miller*, 1982; *Kotzé* et al., 1988; *Rogoyski* et al., 1993; *Contreras*, 1999; *Schupp* et al., 2002a, b, 2004; *Stampar* et al., 2002; *Palmer* et al., 2003; *Kreuzwieser & Kelderer*, 2004; *Raffo & Iglesias*, 2004; *Blanco*, 2005; *Gindaba & Wand*, 2005, 2008; *Benegas* et al., 2006; *Dos Santos & Wamser*, 2006; *Benegas & Rodríguez*, 2007; *Do Amarante* et al., 2007; *Araya*, 2008; *Iamsub* et al., 2008, 2009; *Racskó* et al., 2008, 2009; *Tapia*, 2008). These evaluation methods seemed to be very useful from practical point of view (e.g. comparing cultivar susceptibility), however, they did not inform about which type of sunburn (sunburn necrosis, sunburn browning or photooxidative sunburn) was observed, i.e. what environmental factor(s) caused the symptoms observed. Without knowing of the existence of various sunburn types, *Warrington* et al. (1996) already recorded the incidence of two types; photooxidative sunburn and sunburn browning as whitening and red/orange blush respectively.

Others characterized sunburn damage based on the severity of the symptoms, i.e. the degree of discoloration on the exposed fruit surface (*Allmendinger* et al., 1943; *Lurie* et al., 1991; *Curry*, 1994; *Parchomchuk & Meheriuk*, 1996; *Fallahi* et al., 1998; *Contreras*, 1999; *Yuri* et al., 2000a; *Yuri*, 2001; *Glenn* et al., 2002; *Middleton* et al., 2002; *Wünsche* et al., 2001, 2004b; *Hao & Huang*, 2004; *Prohens* et al., 2004; *Raffo & Iglesias*, 2004; *Blanco*, 2005; *Gindaba & Wand*, 2005; *Wand* et al., 2006; *O'Connell & Goodwin*, 2007). This method gives a picture of the severity of sunburn and is quite useful, for instance, to evaluate the effectiveness of various protecting methods/chemicals. However, the problem with such estimating technique is that it is too subjective; the scoring value greatly depends on the evaluator's own judgement, and therefore the results of different researchers are not comparable. From the descriptions of the methods used, it seems likely that above authors used a scale of various numbers (2 to 5, or even to 10) of stages of sunburn development from mild bleaching or mild sunburn browning to severe sunburn necrosis. This classification is based on skin color changes mostly, representing a defective view, that is, sunburn necrosis exclusively forms from sunburn browning or from photooxidative sunburn through sunburn browning on a direct way. However, sunburn browning is not a necessary precondition of the formation of sunburn necrosis. Sunburn necrosis or necrotic symptoms can, however, develop in other ways as well, i.e. from sunburn browning or photooxidative sunburn depending on the environmental conditions. On the other hand, photooxidative sunburn ? sunburn browning ? sunburn necrosis is not the pathway of sunburn development, i.e. the increasing extent of damage, even if the color of the symptoms (white ? yellow/mild brown ? dark brown, respectively) would assume it. Again, we stress here that color changes on the exposed fruit surface are not closely correlated with the degree of sunburn damage, therefore cannot be used as an accurate descriptor.

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