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The effect of high UV-B dosage on apple fruit photosystems at different fruit maturity stages

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ABSTRACT

Apple fruits (*Malus domestica* Borkh) of the cultivars Granny Smith, Fuji, Cripp's Pink, Braeburn, Golden Delicious and Topred were harvested at three stages during fruit growth. Previously sun-exposed peels of the apple fruits were exposed to a high ultraviolet radiation-B (UV-B) dosage for 150 min at each stage. In a second experiment mature 'Granny Smith', 'Fuji' and 'Cripps' Pink' fruits previously sun or shade exposed were also exposed to the UV-B stress. The effect of UV-B stress on fruits photosystem components was assessed by measuring the change in maximum light use efficiency and light reflection of fruit peels. UV-B induced pigment changes were analysed for 'Braeburn', 'Fuji' and 'Cripps' Pink'. The UV-B stress did not cause photoinhibition to any of the cultivars during fruit growth. However, UV-B stress did cause photoinhibition to previously shaded mature 'Granny Smith' and 'Fuji' fruits. Previously shaded 'Cripps' Pink' fruits were conversely as insensitive to UV-B stress as the previously sun exposed fruits. 'Braeburn' showed no major pigment response to UV-B stress throughout the season. However, in 'Fuji' and 'Cripps' Pink' fruits, total phenolic content increased at mid-season and maturity, while decreasing at the juvenile stage. All cultivars appear to have a stronger light reflection response to UV-B stress at the juvenile stage than later in the season. Photosystem II (PS II) units (as indicated by the F_m values) and the oxygen evolving complex activity (as indicated by the F_v values) in all the cultivars decreased with fruit maturity. Shaded 'Cripps' Pink' fruits seemed to use the xanthophyll cycle as a photoprotective mechanism after UV-B stress. Photosynthetic systems in sun-exposed, therefore acclimatised, apple fruit peel are possibly not sensitive to UV-B stress in isolation. The fruits are probably well screened against UV light. Conversely, shaded peel may be less adapted and therefore more sensitive to high UV-B exposure. The light reflection response to UV-B stress at the juvenile stage could be due to the reduced phenolic content after stress and the presence of more PS II units at this stage compared to the mature stage.

1. Introduction

Fruit appearance is an important quality parameter for marketing horticultural produce. The export of apple fruits (*Malus domestica* Borkh) to the fresh market is of high economic value for South Africa. This export accounted for an average of 41.9% of total apple production from 2002 to 2012 (Hortgro, 2013). Sunburn reduces the percentage packout and total income from apple fruits. Sunburn damage can affect up to 18% of total production (Gindaba and Wand, 2005). The major sunburn type, sunburn browning, occurs in fruit production areas around the world and manifests as a yellow–bronze discoloration on apple fruit peels. Sunburn browning is caused by light (UV and visible) and heat at temperatures between 46 and 49 °C (Schrader et al., 2001; Schrader et al., 2003; Schrader et al., 2008). Solomakhin and Blanke (2010) found that the transpirational cooling of 'Fuji' apple leaves was 0.3–0.6 °C on a clear sunny day. However, fruit temperatures can be 10–15 °C higher than air temperature (Parchomchuk and Meheriuk, 1996; Ferguson et al., 1998).

Sunburn develops as a result of direct damage to the photosynthetic apparatus or to the photoprotection mechanism of fruit peel photosystems caused by heat and light stress (Chen et al., 2008). Excluding UV-B reduced the occurrence of sunburn on attached apple fruits thereby implicating UV-B in the development of fruit

Abbreviations: TBP, thylakoid bound pigments; APX, ascorbate peroxidise; EPS, epoxidation state; AVI, apple violaxanthin index; OEC, Oxygen evolving complex.

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sunburn (Schrader et al., 2001; Schrader et al., 2003). UV-B causes damage to plant photosystems by damaging the reaction centres of photosystem II (PSII) (Iwanzik et al., 1983). It also leads to the degradation of the D1 and D2 proteins, which form the core of the reactions centres of PSII (Jansen et al., 1996). The D1 and D2 proteins degrade much quicker under UV-B combined with photosynthetic active radiation (PAR) than with either one of these stresses alone (Babu et al., 1999). Babu et al. (1999) also found that D1 and D2 degradation in plant leaves by UV-B or PAR alone is not coupled to the redox state of PSII while degradation under combined UV-B and PAR is. UV-B also has a negative effect on the enzymes of the Calvin cycle leading to reduced CO_2 uptake in plant leaves (Krause et al., 1999; Surabhi et al., 2009).

Fruit producers use different sunburn protection mechanisms, including spraying UV-B protective substances, overhead evaporative cooling and shade netting. It is important to determine the maturity stage at which fruit become sensitive to sunburn inducing factors during fruit development of different cultivars. This can help producers to correctly time their sunburn prevention mechanisms which can reduce waste and minimise operational costs. There is no literature available regarding the sunburn susceptibility of different apple cultivars produced in South Africa. Based on personal observation, we would range the following apple cultivars from high to low sunburn susceptibility: Granny Smith, Braeburn, Cripps' Pink, Golden Delicious, Fuji, Topred. The seasonal response of apple fruits and the response of apples fruits with different UV-B exposure histories to UV-B stress have not been studied before.

The objectives of the study were to: (1) determine whether there is a specific development stage at which fruits become more sensitive to UV-B stress, and (2) study the effect of sun light exposure history on UV-B sensitivity. The maximum light use efficiency of photosystem II (F_v/F_m) and related parameters were used to measure stress induced damage to the fruit photosystem.

2. Materials and methods

2.1. Plant material and experimental design

Apple fruits were collected from farms in the Grabouw area (34°9′10.55′′S; 19°1′47.62′′E) of the Mediterranean-type climate Western Cape Province of South Africa. Two experiments were conducted: Experiment 1 analysed the response of apple fruits to UV-B stress at different maturity stages; Experiment 2 analysed the response of apple fruits with different sunlight exposure histories to UV-B stress at maturity.

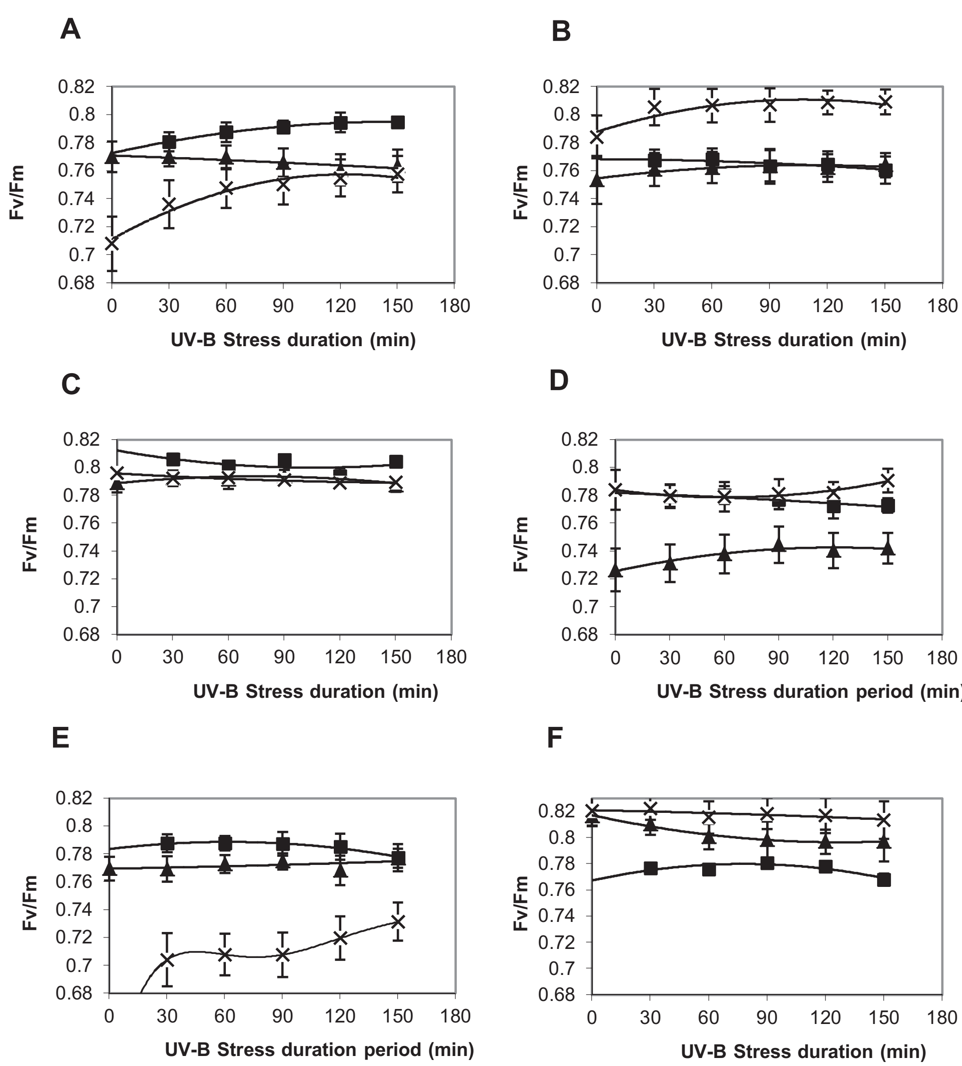

Fig. 1. Changes in the maximum light use efficiency (F_v/F_m) of sun-exposed apple fruit peel during UV-B treatment. Harvest 1 = juvenile stage (■), Harvest 2 = mid-season (▲), Harvest 3 = mature stage (X). A = 'Granny Smith'; B = 'Braeburn'; C = 'Fuji'; D = 'Golden Delicious'; E = 'Cripps' Pink'; F = 'Topred'. Means and standard errors are indicated.