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# Spatial and Temporal Enhancement of Colour Development in Apples Subjected to Reflective Material in the Southern Hemisphere

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**Abstract:** (1) *Background:* Climate change associated with a warm autumn often hampers the development of colouration of many fruits including late ripening apple varieties in New Zealand. (2) *Objective:* This study will provide detailed information on the possibility of enhancing colouration of apples under the diffuse light conditions in autumn in the southern hemisphere (SH). The aim is to obtain a larger proportion of fruit meeting the (red) colour market specifications, especially within the first picks, and to identify both the side of the fruit and its position within the tall trees canopy (3.5 m) as affected by reflective mulch on the ground spread at and over different times. (3) *Material and methods:* Reflective white textile mulch (Extenday®) was spread in the grassed alleyways 4 weeks or 2 weeks before the anticipated harvest in April on cv. Fuji and Pacific Rose apple trees without hail nets in the Northern Part of the South Island (41° S) of NZ. Fruit colour (blush) was determined by scoring and colourimeter during fruit maturation and at harvest, and fruit quality was determined at harvest by standard methods. (4) *Results:* (a) In cv. Pacific Rose apple, the reflective mulch increased the scored blush value from 1.5 (<50% blush) to 3.9 (ca. 75% blush) before the first pick, whereas the control fruit (without Extenday$^R$) reached a final score value of only 3.0. (b) Fruit colour improved after one week of exposure to reflective mulch in the SH. (c) The scored blush on fruit near the trunk with reflective mulch doubled (Pacific Rose) or tripled (Fuji) at harvest in comparison with trees with grass alleyways (control). (d) Two and four weeks of reflective mulch enhanced colouration of the down facing side for fruit of both cultivars, especially for fruit from the inside of the canopy near the tree trunk. However, reflective mulch significantly improved blush by 20% on fruit from the periphery of the canopies of the tall trees in both cultivars without significantly affecting fruit firmness, soluble solids, starch breakdown or ripeness. (5) *Conclusions:* The results from ca. 2000 colour measurements showed that the short exposure of at least two weeks of reflective mulch was sufficient for enhancing colouration for outside, inside and down facing sides of the fruit of both cultivars. As a result of this surprisingly short and efficient exposure time for these tall trees (3.5 m), the reflective mulch increased the portion of fruit harvested in the first pick by 8% (Fuji) and by 27% (Pacific Rose) with improved fruit storability or export quality and thereby increased financial returns to the grower in the SH.

**Keywords:** apple (*Malus domestica* Borkh.); anthocyanin; colouration; Envy, Extenday®; fruit quality; Fuji; Jazz; light reflection; PAL—Phenylalanine-amminia-lyase; reflective mulch; shading



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## 1. Introduction

For the consumer, fruit colour is one of the predominant incentives for purchasing a fruit. From apricot to persimmon and from apple to grape, the red colour is associated with ripeness, good taste and sweetness (Hamadziripi et al., 2014) [1]. Therefore, colour management is an important issue for fruit production around the world. New Zealand's apple industry provides markets all over the world with a wide range of red coloured apple varieties, such as Gala, Braeburn, Jazz, Envy and Fuji, during the Northern hemisphere

(NH) spring and summer before local fruit in the NH become available. The formation of anthocyanin pigments in the fruit skin, which are responsible for the red colouration of fruits, including of the apple, depends mainly on environmental factors such as light quality (PAR, UV) and quantity and temperature (cool night), which are sensed by the MYB 10 gene (Wang et al., 2011) [2]. Fruit colouration i.e., blush can also be influenced to some extent by cultural practices such as pruning, thinning, fertilization, biostimulants and plant growth regulators (Andris and Crisoto, 1996) [3].

New Zealand exhibits record apple yields of 100–120 t/ha compared with 60–80 t/ha in Bonn, Germany. In New Zealand, late ripening apple cultivars, especially Fuji, are commonly grown on tall trees of 3.5 m height on semi-vigorous rootstocks and can fail to form red colour. This is due to the mutual shading, shorter autumn day length (photoperiod), decreasing light intensity (PAR and UV), decreasing solar angle (Meinhold et al., 2010a) [4] and the occurrence of warm autumns with warm nights. Reflective mulches, either metallised polyethylene or white woven polypropylene plastic, placed between tree rows on the ground, have been used in a number of NH countries to improve light distribution within the canopy and thus to enhance colouration of ripening fruits. In trials carried out on cv. Fuji apples under the high light conditions in California, the percentage area of skin red colour was increased by up to 65% (Andris and Crisosto, 1996) [3]; more fruit from the white reflective mulch treatment were packed in the well-coloured premium marketing categories "Fancy" and "Extra Fancy" than the control. Referring to Standard Fruit Specifications for apple cv. Fuji (T&G Specifications Manual, 2018) [5], high Grade fruits must have predominant pink or red colour $\geq$ 75% of the fruit surface area and Standard Grade fruit must have $\geq$ 50%. Therefore, using reflective mulches in New Zealand's Fuji orchards, with overcast autumn weather conditions and a large portion of diffuse light, could increase the export packout due to better colouration and would justify the cost of the material, which can be repeatedly used. First, we need to understand the underlying mechanisms and identify the target fruit within the canopy. With insufficient blush and colour (°hue) development of attached fruit in different positions on the tree, the aim of this study was to evaluate the ways in which reflective mulch influences fruit quality and colour on large and vigorous trees in New Zealand (NZ) at 41° S latitude in the Southern Hemisphere (SH), also with future hail nets to come in mind. A white woven reflective mulch was used 4 or 2 weeks before the predicted harvest date in mid-April to evaluate the necessary timeframe for sufficient colour development (anthocyanin synthesis) of these late-ripening cv. Fuji and Pacific Rose apples at Motueka (NZ). To identify how the position of the fruit on the tree was affected by light reflectance, the colour development on marked attached fruits from the inside and outer periphery of the tree canopy was monitored at regular intervals and fruit analysed for quality after harvest. This study was conducted to provide detailed information on the possibility of enhancing colouration of apples to obtain a larger proportion of fruit meeting the colour market specifications and therefore to increase the portion of the desired first pick. Additionally, the aim is to identify, which side of the fruit and its position within the tree are affected by reflective mulch. This could therefore lead to a better financial return for the fruit while satisfying both trader and consumer and providing not only more attractive, but also healthier apple fruit (Overbeck et al., 2013) [6] (Smrke et al., 2019) [7].

## 2. Materials and Methods

### *2.1. Apple Trees, Orchard Location, Management and Experimental Design*

For the experiments, two orchards near Motueka were chosen. This Northern part of the South Island (latitude 40–42° S) is one of the major pipfruit growing areas of New Zealand. The treatments were carried out on Fuji/MM 106 apple trees without hail nets in a commercial orchard owned by Michael Moss and on Pacific Rose/MM 106 trees at HortResearch, Nelson Research Centre at Motueka. Due to the semi-vigorous rootstock, trees were ca. 3.5 m in height, and the spacing of the trees was relatively wide with 5 m $\times$ 3 m for Fuji and 4 $\times$ 2.5 m for Pacific Rose (Figure 1), respectively. Twelve apple trees per variety were employed in each location in one (Fuji) or two rows (Pacific Rose). Trees planted in N–S-oriented rows were selected on the basis of uniform crop load and vigour. The girth measurements 20 cm above the graft union ranged from 39 cm to 51 cm for Fuji and 30 cm to 42 cm for Pacific Rose respectively. The design of the experiment was a randomized block with 4 replicates. Each block consisted of one tree per treatment (0, 2, 4 weeks) being separated by at least one border tree leaving at least 6 m between exposed and control trees (Figure 1). A new batch of reflective mulch (Extenday$^{TM}$, Extenday New Zealand Limited, Auckland) was placed in the alleyways on both sides of a tree 4 weeks (Fuji 2 March, Pacific Rose 7 March) or 2 weeks (Fuji 16 March, Pacific Rose 21 March) before the anticipated harvest in April in both locations. Trees with uncovered grass strips served as control (Figure 1).

(**a**) (**b**)

**Figure 1.** Apple trees of cv. Pacific Rose on MM 106 (**a**) without (left) and (**b**) with reflective mulch (right) at HortResearch, Motueka (NZ).

### *2.2. Colour Scores (Blush) during Fruit Maturation*

For each of the four replicates of the three durations, i.e., reflective mulch for 0, 2, 4 weeks prior to harvest, ten attached apple fruit from the inside the tree canopy close to the tree trunk and ten apple fruit from the outer periphery of the tree canopy were tagged. Blush development was visually classified every other day on the same 480 attached fruits in five groups (0 = no blush; 1 = 1–25% blush; 2 = 25–50% blush; 3 = 50–75% and 4 = 75–100% blush). Blush development on 240 tagged cv. Fuji apple fruit was scored ten times starting 6 March and ending 29 March, six days before the first pick. Similarly, 240 tagged Pacific Rose fruit were scored nine times starting 8 March and ending 30 March, 11 days before the first pick.

### *2.3. Colour Measurement during Fruit Maturation*

Colour development was measured on half (five) of the already tagged fruit for blush scoring. Colour was measured on the same 240 fruit (120 fruit per variety) in situ non-destructively three times at weekly intervals prior to the predicted harvest date. Colour was measured on three spots on opposite sides on the fruit equator, i.e., the side of the fruit facing the trunk ("green side") and the side of the fruit facing the outside ("red side"), with a Minolta Chroma Meter CR-200 (Minolta Co., Osaka, Japan) based on CIE (1976; L*, a*, b*) colour space. Colour was described by the parameters chroma and hue angle according to McGuire (1992) [8].

### 2.4. Fruit Quality and Colour Assessment at Harvest

To examine the effect of the reflective mulch on fruit quality and colour, eight fruit from the inside and outside of the tree canopy and 4 fruit from the top of the canopy were sampled for each treatment and replicated at each pick. Apples, representative of each treatment, were assessed for fruit weight, soluble solids (by refractometry), starch breakdown (after staining with potassium iodine), background colour, percentage blush on the peel and flesh firmness (with a penetrometer using standard methodology) (Meinhold et al., 2010a) [4] (Overbeck et al., 2013) [6]. Streif-Index was calculated by fruit firmness/(soluble solids x starch breakdown). This resulted in 720 fruit quality values for cv. Fuji (480 for cv. Pacific Rose).

At harvest, colour was measured as described above again on two opposite sides of the fruit ("red" and "green" side) and additionally on the down facing side of the fruit marked while on the tree before harvest.

### 2.5. Yield and Fruit Grading

For apple cv. Fuji (Pacific Rose), the harvest in Motueka, New Zealand, started with the first pick on 5 April (11 April) and the second pick on 17 April (no second pick for Pacific Rose). The initial start date of the first pick was selected according to NZ industry standards based on the internal quality of the fruit, i.e., the starch breakdown. The first pick was selective and based on blush and colour (area and brightness), whereas the last pick on 30 April (23 April) was a strip pick to remove all leftover fruit.

An automated Lynx Grader (LYNX Horticultural Systems, Auckland, New Zealand) was used to assess yield, fruit weight and fruit number for each pick.

### 2.6. Statistics

The experiment comprised 24 apple trees, i.e., 12 trees for each of the two varieties. Each treatment consisted of one tree plus border trees and was repeated four times in a randomised design. Twenty fruits from each tree were scored for blush development ten times (Fuji) or nine times (Pacific Rose) prior to harvest, so that 2400 score values could be obtained. Fruit quality and colour measurements at harvest were done on 20 fruit per tree per pick and variety.

Colour angle (° hue) and blush scores during fruit maturation were analysed by ANOVA separately for each side of the fruit and date and the two positions within the tree canopy for the effects of the treatments.

Percentage blush, colour angle (° hue) and fruit quality parameters at harvest were analysed by ANOVA separately by pick and the two positions within the tree canopy for the effects of the treatments.

Yield data were analysed by two-factorial analysis of variance (ANOVA) (treatment x pick). If there was no significant interaction, the data were analysed for the main effects of treatment and pick.

Overall, the yield of 24 apple trees, 4800 score values and 720 colour measurements during maturation as well as 1200 fruit quality assessments and 3600 colour measurements at harvest were statistically processed by analysis of variance (ANOVA) and post-hoc Tukey test at the 5% error level using SPSS Statistics package 26 (IBM, Michigan, USA).

## 3. Results

### 3.1. Temperature Course in March and April

Figure 2 shows the temperature course during the experiment and probable start of the induction of anthocyanin synthesis from 28 March with a $T_{min}$ and $\Delta T$ of 1.7 °C and 17.5 °C on 31 March.

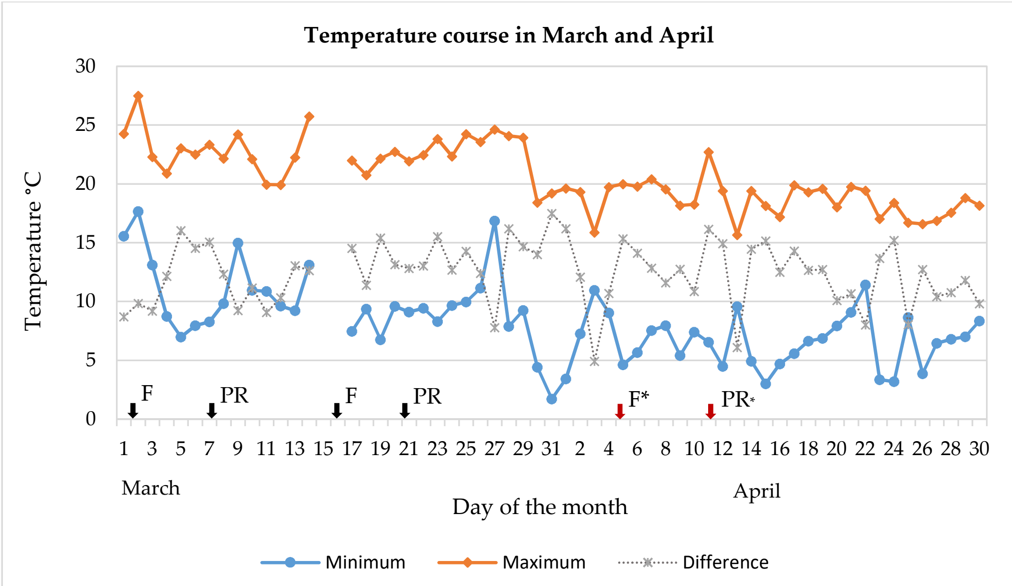


**Figure 2.** Temperature curve in March and April at HortResearch, Motueka, New Zealand, during the experiment- black arrows indicate the dates of laying the reflective material for Fuji (F) and Pacific Rose (PR) and the red arrows for the begin of the harvest (asterisks).

### *3.2. Increase in the Portion of the First Pick*

In both apple cvs., Fuji and Pacific Rose, the reflective mulch increased the portion of fruit harvested in the first pick, which is relevant for storage and export quality as only the first pick goes into storage and is exported. This portion of the first pick of the late and difficult to colour cv. Fuji increased from 30% in the control to 38% with reflective mulch 4 weeks prior to harvest (Figure 3). This desired effect was more pronounced for the other later ripening cv., Pacific Rose, with an increase from 40% in the control to 62% with reflective mulch 2 weeks prior to harvest and, significantly, to 67% 4 weeks prior to harvest (Figure 4). For untreated trees, there was a significant difference of the percentage yield between the second and the third pick. There was no significant difference in mean fruit weight between the picks (result not shown), ensuring full-sized fruit in the first pick. Reflective mulches did not significantly affect overall fruit yield in either cvs., Fuji and Pacific Rose (Figures 3 and 4), thereby preventing any interference with the effects of the reflective mulch.

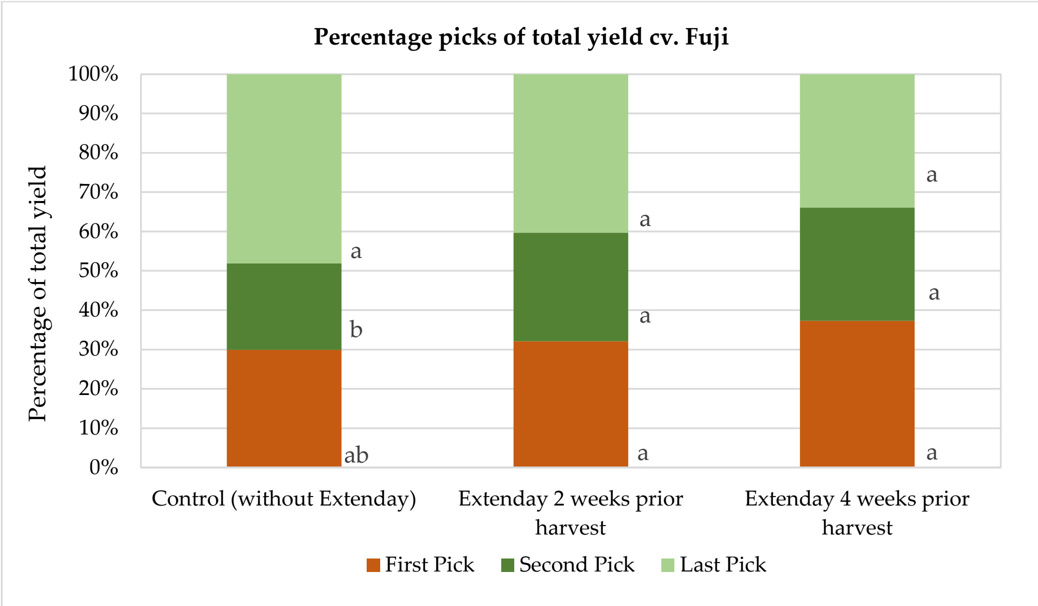


**Figure 3.** Summation of yield in each pick of cv. Fuji as dependent on the timing of reflective mulch in Motueka, New Zealand, (41° S). (Picks with different letter for the same treatment are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position)).

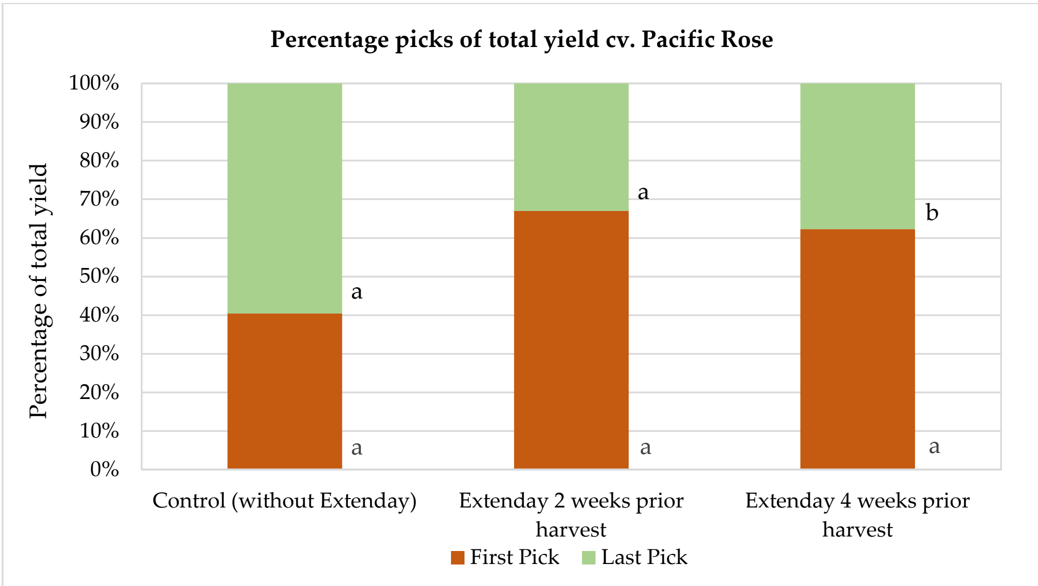


**Figure 4.** Summation of yield in each pick of cv. Pacific Rose as dependent on the timing of reflective mulch in Motueka, New Zealand, (41° S). (Picks with different letter for the same treatment are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position)).

### *3.3. Colour Scores (Blush) during Fruit Maturation and at Harvest*

When applied four weeks before the anticipated harvest in the late and poorly colouring cv. Fuji, the reflective mulch improved blush development of the fruit significantly compared to untreated fruit by at least one score value on a 1 to 4 colour viz., blush scale, as soon as one week after the material had been laid (Figure 5).

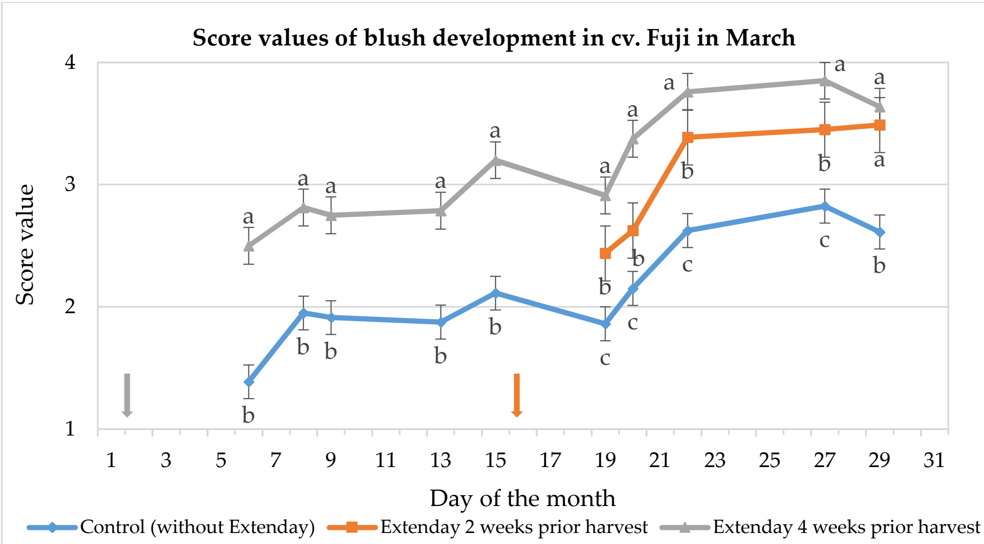


**Figure 5.** Score values of blush development in cv. Fuji in March as dependent on the timing of reflective mulch (average of fruit from the inside and outside of the tree canopy). (plus SEs; Different letters denote statistical differences within the same date at the $p = 0.05$ level (n = 80 fruit per treatment per pick.) Arrow indicates day of laying the mulch.

***When reflective mulch was applied only two weeks before the anticipated cv. Fuji harvest, colour improvement could already be observed after one week,*** which has not been reported before to our knowledge. The score value of cv. Fuji fruit increased significantly from 1.5 to 3.9 before the first pick, whereas the control fruit (without mulch) reached a score value of only 3.0 (Figure 5).

In the difficult to colour cv. ***Pacific Rose, the blush development also started one week after the material had been laid out*** at score values 1.5 for both the control group (without Extenday$^{TM}$) and the "Extenday 4 weeks prior to harvest" group (Figure 6).

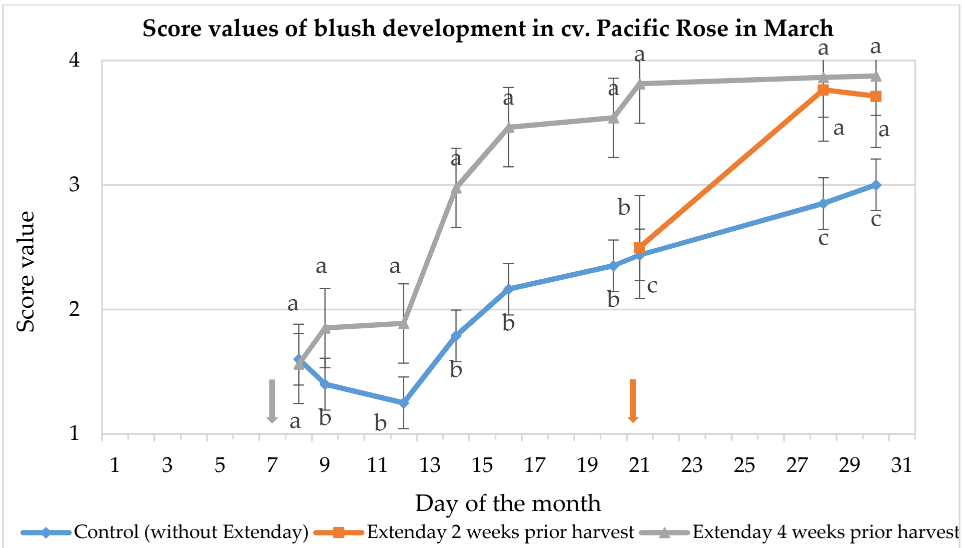


**Figure 6.** Score values of blush development in cv. Pacific Rose in March as dependent on the timing of reflective mulch (average of fruit from the inside and outside of the tree canopy) at Motueka (NZ). (plus SEs; Different letters denote statistical differences within the same date at the $p = 0.05$ level (n = 80 fruit per treatment per pick.) Arrow indicates day of laying the mulch.

Both exposure times for Fuji and Pacific Rose resulted in the same score values at harvest (Figures 5 and 6) being significantly different to values from fruit without reflective material.

In addition to the scored colour values recorded repeatedly on the same marked attached fruit (Figures 5 and 6), blush was also finally measured at harvest, from fruit from each of the two (Pacific Rose) or three picks (Fuji). The marked effect of the reflective mulch was on fruit at harvest of both cultivars (Fuji and Pacific Rose) from the otherwise partially shaded inside of the tree canopy (Tables 1 and 2).

**Table 1.** Percentage blush of cv. Fuji apple at each pick dependent on fruit position within the canopy.

| | Fruit Position within the Tree Canopy | | | | | |
|---|---|---|---|---|---|---|
| **Pick and Treatment** | **Inside** | | **Periphery** | | **Top** | |
| **First pick** | | | | | | |
| Control (without Extenday) | 18.4 | b | 65.8 | b | 71.9 | b |
| Extenday 2 weeks prior to harvest | 62.0 | a | 78.1 | a | 74.1 | b |
| Extenday 4 weeks prior to harvest | 68.6 | a | 79.7 | a | 84.4 | a |
| **Second pick** | | | | | | |
| Control (without Extenday) | 43.9 | b | 66.4 | b | 82.5 | a |
| Extenday 2 weeks prior to harvest | 77.5 | a | 77.0 | a | 72.2 | a |
| Extenday 4 weeks prior to harvest | 78.0 | a | 77.3 | a | 79.7 | a |
| **Last pick** | | | | | | |
| Control (without Extenday) | 37.2 | b | 63.1 | b | 73.4 | a |
| Extenday 2 weeks prior to harvest | 80.5 | a | 74.4 | a | 76.9 | a |
| Extenday 4 weeks prior to harvest | 75.8 | a | 77.2 | a | 76.9 | a |

Different letters denote statistical differences within the same fruit position within the apple tree and pick at the $p = 0.05$ level (n = 80 fruit per treatment per pick). Background colours highlight / visualise significant differences in blush.

**Table 2.** Percentage blush of cv. Pacific Rose apple at each pick dependent on fruit position within the canopy.

| | Fruit Position within the Tree Canopy | | | | | |
|---|---|---|---|---|---|---|
| **Pick and Treatment** | **Inside** | | **Periphery** | | **Top** | |
| **First pick** | | | | | | |
| Control (without Extenday) | 39.4 | b | 74.8 | b | 90.0 | a |
| Extenday 2 weeks prior to harvest | 86.3 | a | 89.4 | a | 95.3 | a |
| Extenday 4 weeks prior to harvest | 92.3 | a | 91.1 | a | 90.3 | a |
| **Last pick** | | | | | | |
| Control (without Extenday) | 67.0 | b | 74.7 | b | 80.0 | a |
| Extenday 2 weeks prior to harvest | 84.1 | a | 79.1 | ab | 86.2 | a |
| Extenday 4 weeks prior to harvest | 89.5 | a | 89.7 | a | 88.3 | a |

Different letters denote statistical differences within the same fruit position within the apple tree and pick at the $p = 0.05$ level (n = 80 fruit per treatment per pick). Background colour highlights significant differences in blush.

The percentage of blush on inside fruit tripled (Fuji) or doubled (Pacific Rose) at the first pick with reflective mulch in comparison with the untreated control, i.e., grass alleyways. Similarly, reflective mulch significantly improved blush by 20% on fruit from the tree periphery for all picks in cv. Fuji and for the first pick in cv. Pacific Rose (Tables 1 and 2).

The significantly improved colouration (blush) of fruit closer to the tree trunk within the tree canopy is due to diffuse light reflection from the mulch in the alleyways into the tree canopy (Meinhold et al., 2010a) [4]. This effect was absent on fruit from the upper part and periphery of the canopy (Tables 1 and 2) due to the larger distance (3 m) from the reflective mulch and sufficient solar radiation under NZ autumn weather conditions.

*3.4. Colour Development of the Apple Fruit during Maturation*

Reflective mulch 2 or 4 weeks before harvest improved fruit colouration significantly during maturation of the Fuji apples, as measured by decreased hue colour angle both on the inner side of fruit (green side) inside the tree canopy (110 °hue to 75 °hue) and those in the outer tree periphery (100 °hue to 60 °hue) (Figure 7).

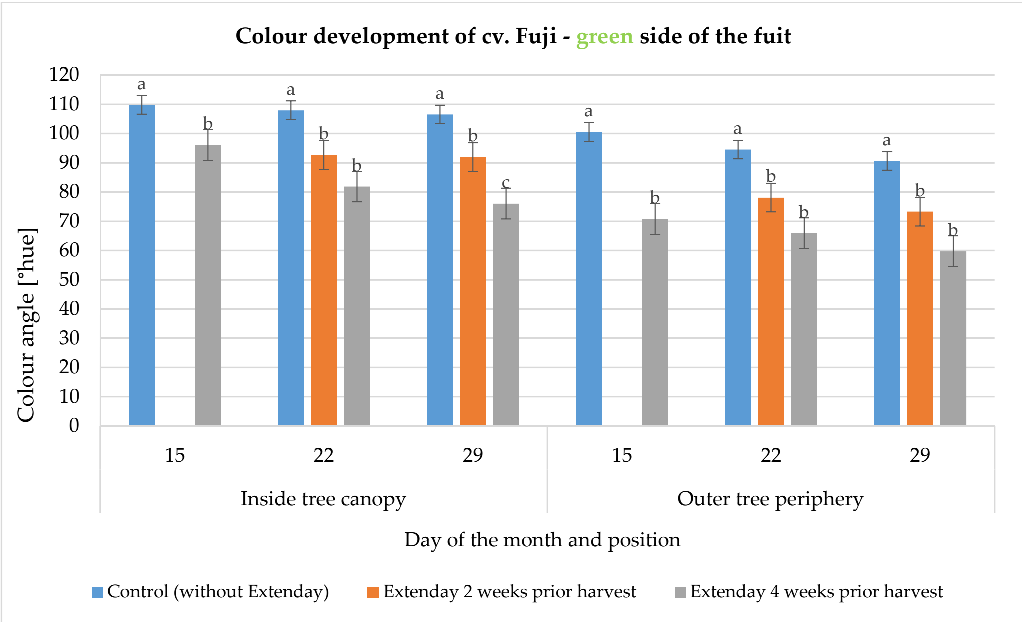


**Figure 7.** Colour development dependent on fruit position within the tree of cv. Fuji as measured on 15, 22 and 29 March on the inner green side of the fruit as affected by reflective mulch. (Treatments with different letter for the same position of the fruit within the same day are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position)).

In contrast to the pronounced significant effect of the reflective mulch on the trunk-oriented green side of the cv. Fuji fruit (Figure 7), the colour effects of the reflective mulch were lesser on the red side of the fruit. Reflective mulches significantly improved hue colour angle of the red side of the fruit from the inside the tree canopy, irrespective of the time. By contrast, the red side of the cv. Fuji fruit in the periphery was already well coloured with colour angles of ca. 35° hue (Figure 8), so that the application of Extenday$^{TM}$ had no significant effect.

Similarly, the effect of reflective mulch on colour development on the green inner, trunk-oriented side of the fruit was significant. Larger colour angles of 100–110 °hue in untreated fruit of cv. Pacific Rose, especially fruit from the inside of the tree canopy (Figure 9), meant greener apple fruit. Spreading Extenday$^{TM}$ two weeks prior to harvest was sufficient under NZ weather conditions (SH at 41° S) to significantly enhance fruit colouration. On the trunk-oriented inner green side of the fruit two weeks prior to harvest, reflective mulch improved fruit colour viz., decreased the green side from 105° hue to 80° hue, whereas it remained at 100° hue in the control group. Both treatments of reflective mulch significantly enhanced colouration on the red side of the fruit in cv. Pacific Rose (Figure 10), even on the outer tree periphery (Figure 13). Overall, the effect on the green side inside the tree canopies of both varieties was more pronounced than on the red side of the fruit.

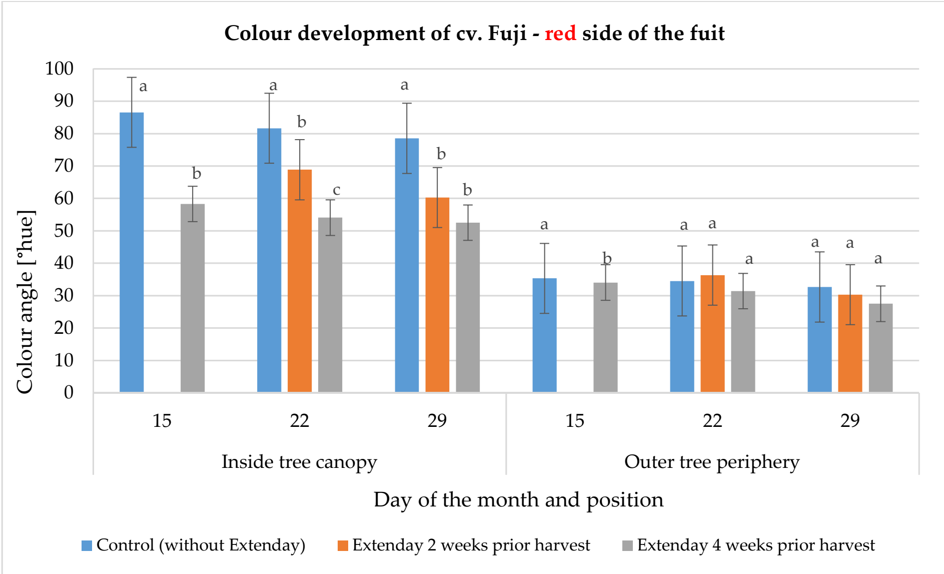


**Figure 8.** Colour development dependent on fruit position within the tree of cv. Fuji as measured on 15, 22 and 29 March on the red side of the fruit as affected by reflective mulch. (Treatments with different letter for the same position of the fruit within the same day are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position).

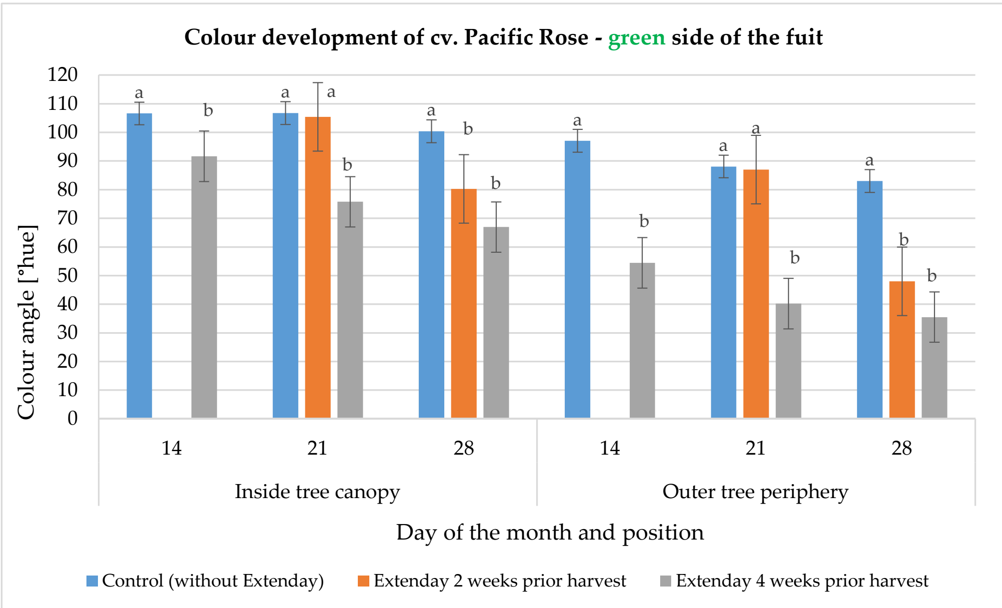


**Figure 9.** Colour development dependent on fruit position within the tree of cv. Pacific Rose as measured on 14, 21 and 28 March on the green side of the fruit as affected by reflective mulch spread 4 or 2 weeks prior to anticipated harvest. (Treatments with different letter for the same position of the fruit within the same day are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position).

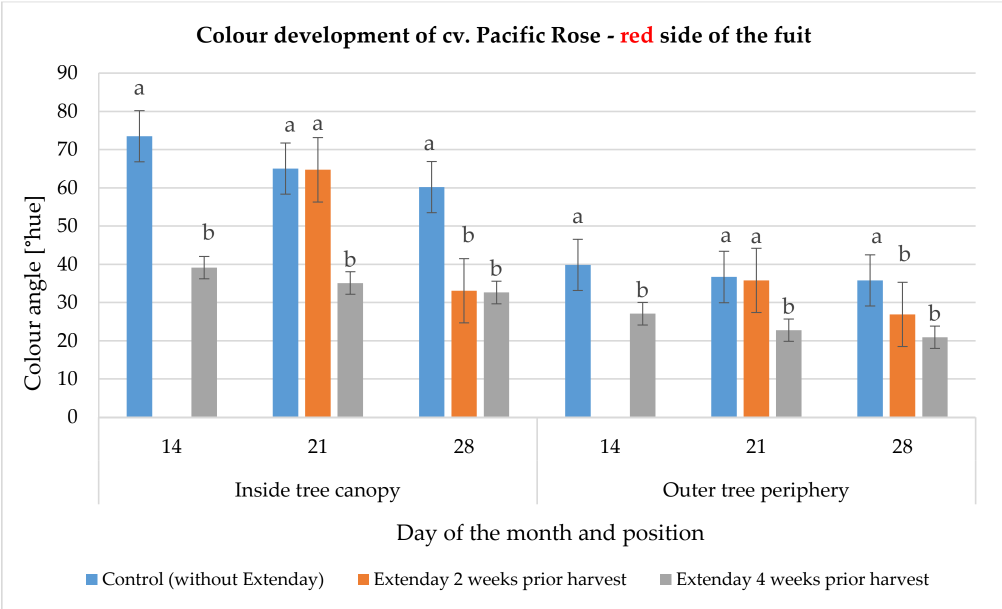


**Figure 10.** Colour development dependent on fruit position within the tree of cv. Pacific Rose as measured on 14, 21 and 28 March on the red side of the fruit as affected by reflective mulch. (Treatments with different letter for the same position of the fruit within the same day are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position).

### *3.5. Colour of Apple Fruit at Harvest*

Figures 11 and 12 show that two weeks of reflective mulch is sufficient for enhancing colouration of the down facing side in cv. Fuji and cv. Pacific Rose, especially for apple fruit from the inside of the canopy near the tree trunk. For Pacific Rose, these values were massively decreased from 88 °hue to 18 °hue in both cases of 2 and 4 weeks reflective mulch prior to harvest (Figure 11).

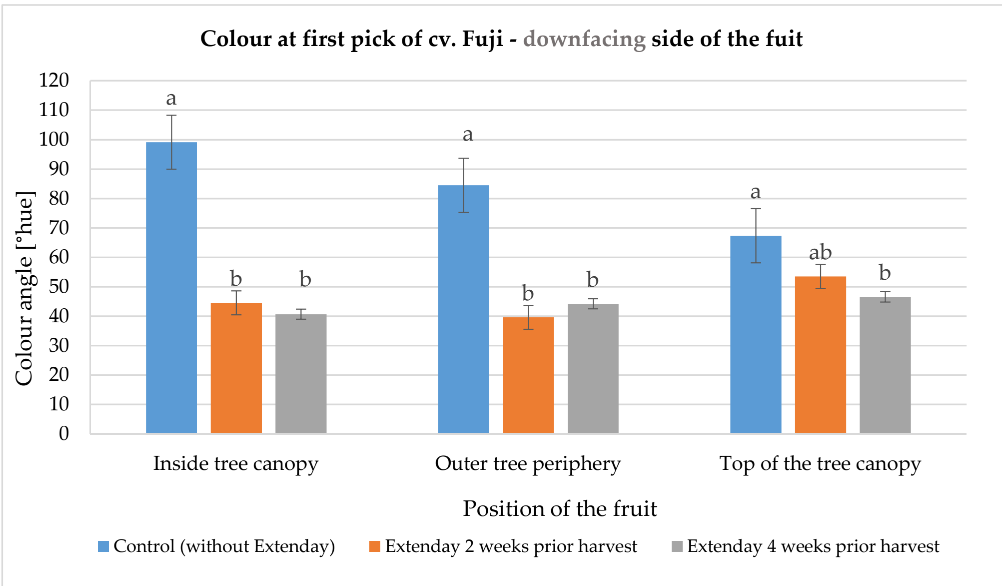


**Figure 11.** Colour of the down facing side of the cv. Fuji fruit at first pick as affected by the timing of reflective mulch. (Treatments with different letter for the same position of the fruit within the same pick are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position).

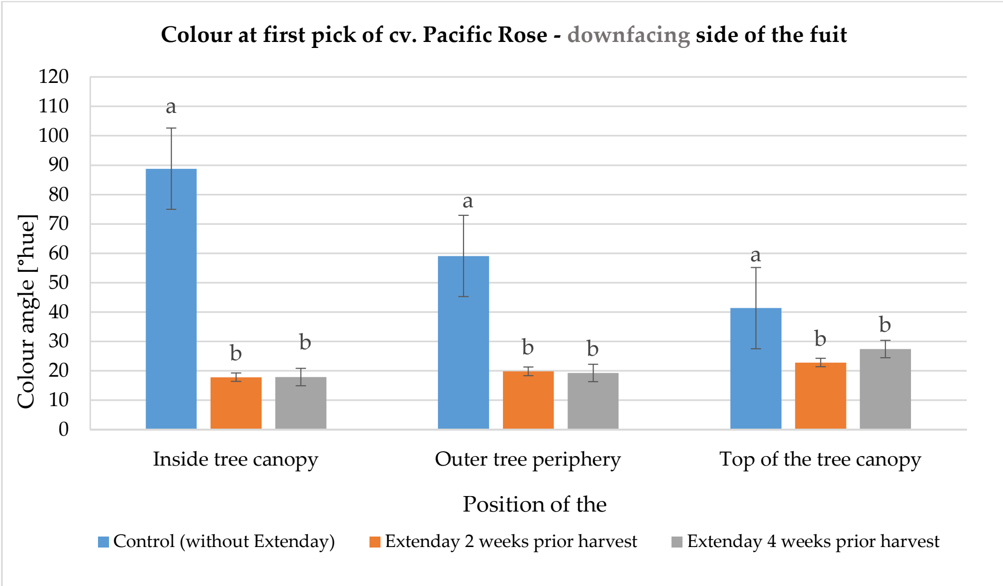


**Figure 12.** Colour of the down facing side of the cv. Pacific Rose fruit at first pick as affected by the timing of reflective mulch. (Treatments with different letter for the same position of the fruit within the same pick are statistically different ($p < 0.05$) (n = 60 fruit per treatment per position).

In cv. Fuji, the colour of the down facing side of the fruit was similarly reduced from nearly 100 °hue to 40–44 °hue (Figure 12). Interestingly, the down facing side of the fruit from the top of the tall trees (3.5 m) was already sufficiently coloured with 68 °hue in cv. Fuji and 40 °hue in cv. Pacific Rose (Figure 13).


**Figure 13.** Effect of reflective mulch on fruit colouration of cv. Pacific Rose at harvest- most conspicuous on the (down-facing) apex side of the apple fruit.

### *3.6. Effect of Reflective Mulches on Fruit Quality at Harvest*

Fuji fruit from the periphery of the tree canopy in the first pick and fruit from the inside for the second pick showed significantly higher Streif index (Table 3). The accelerated ripeness is mainly caused by differences in starch breakdown (data not shown). These findings for apple trees with Extenday® showed a tendency to enhance starch breakdown as described by Meinhold et al. [9]. There was no significant effect on ripening (Streif index) for apple fruit in cv. Pacific Rose (Table 4).

**Table 3.** Quality parameter (Streif index) and ripening of cv. Fuji apple at each pick dependent on fruit position within the tree canopy.

| | Fruit Position Within the Tree Canopy | | | | | |
|---|---|---|---|---|---|---|
| **Pick and Treatment** | **Inside** | | **Periphery** | | **Top** | |
| **First pick** | | | | | | |
| Control (without Extenday) | 0.19 | a | 0.15 | b | 0.21 | a |
| Extenday 2 weeks prior to harvest | 0.21 | a | 0.19 | a | 0.25 | a |
| Extenday 4 weeks prior to harvest | 0.20 | a | 0.19 | a | 0.24 | a |
| **Second pick** | | | | | | |
| Control (without Extenday) | 0.13 | b | 0.12 | a | 0.14 | a |
| Extenday 2 weeks prior to harvest | 0.16 | a | 0.13 | a | 0.17 | a |
| Extenday 4 weeks prior to harvest | 0.16 | a | 0.14 | a | 0.13 | a |
| **Last pick** | | | | | | |
| Control (without Extenday) | 0.11 | a | 0.10 | a | 0.11 | a |
| Extenday 2 weeks prior to harvest | 0.11 | a | 0.10 | a | 0.12 | a |
| Extenday 4 weeks prior to harvest | 0.11 | a | 0.10 | a | 0.10 | a |

Different letters denote statistical differences within the same fruit position within the apple tree and pick at the $p = 0.05$ level (n = 80 fruit per treatment per pick). Background colours highlight significant differences in fruit maturity (Streif index) between control (grassed alleyway) and reflective mulch (Extenday™).

**Table 4.** Quality parameter (Streif index) of cv. Pacific Rose apple at each pick dependent on fruit position within the tree canopy.

| | Fruit Position Within the Tree Canopy | | | | | |
|---|---|---|---|---|---|---|
| **Pick and Treatment** | **Inside** | | **Periphery** | | **Top** | |
| **First pick** | | | | | | |
| Control (without Extenday) | 0.44 | a | 0.19 | a | 0.40 | a |
| Extenday 2 weeks prior to harvest | 0.37 | a | 0.26 | a | 0.28 | a |
| Extenday 4 weeks prior to harvest | 0.38 | a | 0.29 | a | 0.32 | a |
| **Last pick** | | | | | | |
| Control (without Extenday) | 0.39 | a | 0.26 | a | 0.20 | a |
| Extenday 2 weeks prior to harvest | 0.33 | a | 0.25 | a | 0.19 | a |
| Extenday 4 weeks prior to harvest | 0.35 | a | 0.21 | a | 0.24 | a |

In both cultivars, there was no significant effect of the reflective mulch on fruit weight (result not shown), as expected, given the short time of environmental microclimate modification in the orchard.

## 4. Discussion

The objective of the present work was to study the influence of a reflective white textile mulch (Extenday®) on colouration of fruit at various positions within the canopy of the tall trees on three sides of the fruit (inside, outside, down-facing) and quality in two late maturing apple cultivars under Southern hemisphere conditions in New Zealand at 41°S depending on the time of spreading the ground cover.

### *4.1. Fruit Colouration*

In fruit grading, export quality (class I) depends on the overall percentage colouration of the fruit surface. The down facing side is usually the part of the apple fruit least exposed to light [10] and least coloured, and therefore, any improvement in its colouration is relevant for grading and pricing of the fruit.

Satisfactory colour of apple fruit requires a certain amount of available sunlight. Therefore, fruit or fruit parts grown in shade will not turn red during ripening due to a lack of anthocyanin synthesis, particularly under hail nets [11,12].

This may be due to providing a longer exposure to light during the time, when anthocyanin synthesis, PAL activity and MYB 1 and MYB 10 gene expression in the apple peel starts ca. 4–5 weeks prior to harvest (Lancaster, 1992, Wang et al., 2011) [2,13]. The results show the strong effects of reflective mulch on red colouring, as expressed by an increase in blush development (Figures 5 and 6) or the decline in colour angle [°hue] (Figures 9 and 10). Both effects can be shown throughout the last weeks before harvest and were more pronounced on fruit from the inside than from the outside of the canopy (Figures 7 and 8). This will result in more fruit archiving even red colouring and therefore being chosen for consumption.

Overall, the most pronounced effects of the reflective mulch on late-ripening apple cultivars were on

(a) Fruit from the inner part of the tree (in comparison with the tree periphery),
(b) The inner side of fruit in the tree (as compared with the outer side of these fruit),
(c) The down-facing side of fruit in the tree canopy (as compared to the outer side of the fruit),

which has not been studied in such detail neither in the NH nor the SH.

### *4.2. Fruit Picks*

Fruit in the first pick are mostly from the outer and upper periphery of the tree canopy. Because the main influence of the reflective mulches can be observed and explained on fruit from the inner part of the tree canopy [12], their portion enhances in the first pick. Sometimes fewer picks have to be carried out to retrieve all fruit from a tree. Any increase of the portion of fruit in the first pick, such as 8% in cv. Fuji and 27% in cv. Pacific Rose (Figures 2 and 3), improves labour efficiency; exclusively fruit from the first pick are suitable for long term storage or export with superior financial returns. Therefore, the use of reflective mulch can be cost effective, as expensive and scarce labour is saved.

### *4.3. Fruit Quality*

The results in Tables 3 and 4 are in line with findings in Europe, where the weather at 50° N at Bonn is less beneficial with a shortage of autumn radiation. Positive mulching effects have been shown on soluble solids and starch breakdown in cv. Elstar and Jonagold on small trees (2.8 m) on dwarfing M9 rootstock (Funke and Blanke 2011) [14].

The amount/ intensity of reflected light decreases with the square of the distance to the reflective mulch and hence hardly influences fruit in the upper part of the tree canopy.

### *4.4. Tree Training Size/Rootstock and Colouration*

The use of semi-vigorous rootstocks such as MM106, as used in this trial, are common throughout NZ and some of the SH but can hardly be found on the European continent. The larger trees of MM106 provide a larger distance of the target fruit from the reflective mulch. Therefore, the influence of reflective mulch on fruit colouration shows a more profound effect on small trees such as Braeburn and Elstar and Jonagold all on M9 rootstock (Funke and Blanke 2005, 2011) [10,14] than on large trees (Table 5).

**Table 5.** Influence of latitude and tree size on minimum exposure time of reflective mulches.

| Location | Latitude | Tree Height | Weeks | Yield | Time |
|---|---|---|---|---|---|
| **Southern hemisphere** | | | | | |
| Nelson, Southland, New Zealand | 39–41° S | 3.5 m | 2+ | 90–120 t/ha | March–April |
| **Northern hemisphere–North America-USA** | | | | | |
| Washington State, Pacific Northwest, USA | 46–47° N | 3.5 m | 3–4 | 60–90 t/ha | September |
| Geneva, New York, East Coast, USA | 46° N | 3.5 m | 3–4 | 60–90 t/ha | September |
| **Northern hemisphere -Europe** | | | | | |
| South Tyrol, Italy | 45–46.5° N | 3.5m | 2+ | 60–90t/ha | Aug.–Sept. |
| Lake Constance, Germany | 47.4° N | 3.5 m | 3+ | 60–80 t/ha | Aug.–Sept. |
| Bonn/Belgium/Holland/Poland/ Somerset, East Malling, Kent, UK | 50–51° N | 2.8 m | 4+ | 40–60 t/ha | September |

## 5. Conclusions

Four weeks use of reflective mulch appeared only slightly more beneficial than 2 weeks use in the present experiment (Figures 4 and 5), which is in line with NH results with tall apple trees from South Tyrol (46°), but considerably shorter than the 4 to 6 weeks even with smaller trees (2.8 m) at 50° N in the "apple belt" along the 50–51° N, e.g., at Bonn, Belgium, Kent and Somerset etc. (Table 5). The positive results of 2 weeks less of spreading enables duplicate use in the same year starting with early ripening apple varieties such as cv. Gala and subsequent use in late ripening varieties such as cv. Fuji, Envy or Jazz and may extend the overall period of reflective mulch in the orchard. Such repeated use of these materials, textile or other, makes their use more sustainable and more economic, since the material is already out in the field and just needs to be pulled onto another plot.

Usually prices are higher in the beginning of the season with better returns for first picked fruit; long-term storage is restricted to first pick fruit. In both apple cvs Fuji and Pacific Rose, the reflective mulch increased the portion of fruit harvested in the first pick, which is the relevant portion for storage and export quality and, to our knowledge, has not been reported so far for these varieties on such large trees in the southern hemisphere (SH).

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## Abbreviations

| | |
|---|---|
| NH | Northern hemisphere (NH) |
| PAL | Phenylalanine-ammonia-lyase |
| PAR | Photosynthetically active radiation |
| SH | Southern hemisphere |

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