The effects of reflective ground film application on fruit quality, skin texture, bud break, return bloom and fruit formation of ‘Hayward’ kiwifruit

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Abstract

Light plays a fundamental role in plants in many ways, including plant growth, development and productivity. In kiwifruit, vines can often produce a dense canopy that results in low light levels in the fruiting zone at the lowest portion of the canopy. Therefore, to improve the light environment by changing the distribution of light throughout the canopy, reflective ground films can be applied in orchard. These films have now begun to see routine use in horticultural production in New Zealand, particularly within the pipfruit industry for fruit colour finishing. However, there are arguably extremely limited studies to date describing the reflective covers application in kiwifruit. In our study, the Ultramat white UV woven reflective ground cover was tested in a 22 year-old 'Hayward' kiwifruit orchard applied with T-bar in Plant Growth Unit of Massey University, New Zealand in Season 2011/2012. The aims of this study are to investigate the effects of the use of reflective films on the light environment in a kiwifruit orchard; on regulating fruit quality i.e. fruit fresh weight, fruit skin colour, fruit dry matter percentage and compounds such as phenolics in fruit skin as well as on enhancing bud break, return bloom and fruitset.

From our results, films had positive effects on fruit quality parameters, such as fruit fresh weight, firmness, soluble solids content and dry matter percentage, especially in fruit lower canopy. Besides the enhancements of individual fruit quality, films also showed a tendency to promote fruit quality consistency in fruit fresh weight and dry matter percentage. The application of reflective films may also appear to have an enhancement of bud break, return bloom and fruitset in the following season. However, there are still several aspects unknown in this study such as the relationship between reflective ground covers and kiwifruit skin phenolics content, and many of the differences described here were not statistically significant. Thus, to fully understand the effects of reflective ground covers in the future, more experiments are needed, and moreover, sample fruits should be measured based on storage time to further understand the effects of reflective ground covers on kiwifruit storage life.

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1 Introduction and literature review

1.1 Introduction:

1.1.1 Overview of New Zealand kiwifruit industry

Kiwifruit, which is the edible berry of a woody vine in the genus *Actinidia,* is the most important commercial crop in New Zealand. It has a fibrous, dull brown-green skin and bright green or golden flesh with rows of tiny, black, edible seeds. The fruit has a soft texture and a sweet but unique flavor, containing a rich source of vitamin C. Moreover, kiwifruit is a low fat natural source of vitamin E, which is good for heart health protection. There are also many antioxidants and other potential-beneficial phytochemicals in kiwifruit. All these factors make kiwifruit the most important commercial crop in New Zealand.

Originally, the kiwifruit is from China, because of the gooseberry like flavor, it was called as Chinese gooseberry. And the vines which account for much of our commercial production are from the cultivar ‘Hayward’, which was the descendant of seeds of *Actinidia deliciosa* var. deliciosa imported into New Zealand in 1904. In 1925, Hayward Wright, a New Zealand horticulturalist, produced the well-known green kiwifruit which came to be known as the Hayward variety (Zespri, 2007). Initially there was only private production and consumption. The ‘Hayward’ kiwifruit has a typical greenish brown skin covered with hairs (Ferguson, 1997), which usually weighs up to about 120g, and the light green flesh has a tart-sweet taste (Jaeger *et al*., 2003).

Kiwifruit have been grown in New Zealand since the early 1900s, but became an important export crop only after the Second World War (Jaeger *et al*., 2003). As recently as 1970s, the industry boomed because the volume of kiwifruit exports rose rapidly at that time. By 1976, the exported crop exceeded local consumption for the first time. Nevertheless, during the period between late 1980s and early 1990s, when competing countries entered the market, the New Zealand industry crashed (Jaeger *et al*., 2003). However, with improved production techniques and close attention to environmental issues, along with aggressive marketing, New Zealand’s kiwifruit industry has bounced back (Jaeger *et al*., 2003).

In the late 1970s, research was undertaken to develop new varieties of kiwifruit. Progress was slow but there was some success with the Zespri Gold production moving from limited trials to exports commencing in 1998. Zespri® Gold was launched in 1999 after years of development, and has been hugely successful globally. The industry had evolved from a one-fruit to a two-fruit industry. In the last decade, no other horticultural marketer has successfully launched a new variety with the success of Zespri® Gold. Also, there were three new kiwifruit varieties released for commercial production In June 2010. Under the release 614 hectares of the three varieties – early gold (Gold3), long-storing gold (Gold9) and a new, sweet variety of green (Green14) – were grafted by growers. In June 2011, a further 200 hectares of Gold3 and 200 hectares of Green14 were made available to growers. In February 2012 more hectares of Gold9 and Gold3 may be released, subject to 2011 storage trial outcomes (Zespri annual report, 2011).

Kiwifruit is now the second most important horticultural export in New Zealand after wine (Figure 1-1). In the last three years, the number of kiwifruit which were exported from New Zealand was 361,066 metric tons in 2009, 360,000 metric tons in 2010 and 400,000 metric tons in 2011, with 80% of the exports represented by the ‘Hayward’ cultivar (Belrose Inc., 2011).

However, kiwifruit exports will likely fall back to ‘normal’ levels after a record 2011 season, because the confirmation of ‘Psa’ had arrived in New Zealand in November 2010 was a blow to New Zealand kiwifruit industry. Plant symptoms were discovered that suggested that Psa or "*Pseudomonas syringae* pv. actinidiae " a variant of the bacterium *Pseudomonas syringae* (an airborne transmittable bacteria) were present in a Bay of Plenty kiwifruit orchard in the North Island. The destructive potential of Psa is clear from the experience in Italy. Yet, little was known about how and when the disease arrived in New Zealand, how widespread it was, how it would behave and the appropriate management response for New Zealand conditions (Zespri group annual report, 2011). Provisions of the Biosecurity Act 1993 have been used to limit its spread. These measures were continued in 2011, but were largely unsuccessful with most orchards in the Bay of Plenty displaying some level of infection by November 2011. Zespri alongside with Kiwifruit Vine Health Incorporated (KVH) which is a special purpose, not for profit industry body to co-ordinate the ongoing response to Psa, are now working together to achieve what is best for the industry.

Figure 1-1: Horticultural products exports in New Zealand in 2011. (Plant and Food Research, 2011). Kiwifruit is the second most important horticultural export in New Zealand after wine.

The value of the exports represented almost NZ$1 billion in 2011, with the main destinations being Japan and the European Union (Plant and Food Research, 2011). The current average yield is over 30 metric tons/ha, the highest in the world, and there are more than 12,500 planted hectares. New Zealand's ZESPRI is the leading world marketer of kiwifruit, representing 30% of the global trade (Zespri Group annual report, 2011).

1.1.2 Kiwifruit production cycle

For growing kiwifruit, the ideal climate should meet the conditions of plentiful sunshine, rain and just the right amount of chill in the winter. Free draining, fertile soils with pH levels between 5 and 6.8 also help to create an ideal environment for kiwifruit. A typical annual growth cycle of kiwifruit is shown in Figure 1-2.

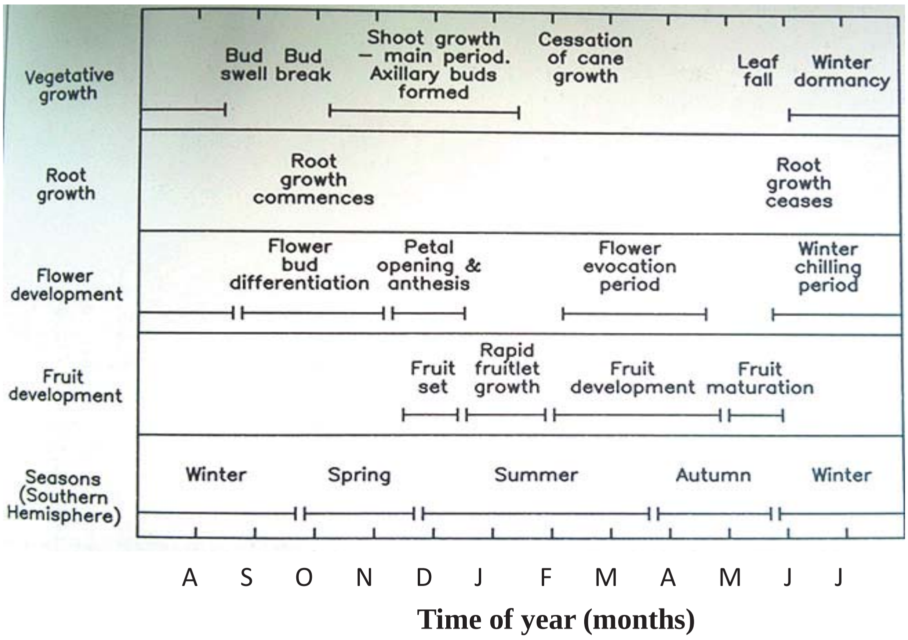

Figure 1-2: The annual growth cycle for kiwifruit cv. 'Hayward' growing in the Te Puke district, Bay of Plenty. (Taken From Kiwifruit: science and management, 1990, edited by I.J. Warrington and G.C. Weston for the New Zealand Society for Horticultural Science).

In New Zealand, a typical annual growth cycle of kiwifruit is up to 240 days a year. With vine pruning in winter (June), the New Zealand season begins, which immediately follows the previous year's harvest. The vines lay dormant during the winter months (June to August), when the growers are allowed to have the opportunity to remove last season's fruiting canes and to select and tie down new leaders which form the foundations for new growth (Zespri production cycle, 2012). Usually, bud swell is the first sign of growth after winter in late August, followed by bud break in the early Spring (late September to early October) , after which the kiwifruit vines begin to grow again. The root extension also begins in the early spring time. New shoots appear on the leaders and develop into canes rapidly with the development and enlargement of flower bud occurring during the same period. Usually 2 months after bud break, in late November to early December (late spring to early summer), the flower buds open. These kiwifruit flowers are pollinated with the help of bees. The vines then begin to fruit with the pollinated flowers transforming themselves into small berries which grow very quickly during the summer months (December to February). At the same time, kiwifruit vines undergo tremendous growth (the canes can sometimes reach up to 5 - 6 metres in length during the growing process), therefore, growers frequently prune the vines so that the growth of the canopy could be directed and managed (Zespri production cycle, 2012). In about mid to late January, the rate of main cane growth declines mainly because the competition of shoots with a heavy load of fruit becomes more marked; the decreased cane growth accompanying with high rates of fruit growth. As the weather cools in the New Zealand Autumn (March to May) harvest time approaches. By early May, a satisfactory harvesting stage is coming since fruit matures. Usually it is approximately 150 days after flowering. The kiwifruit are tested for ripeness and when they pass a certain criteria for quality and grade, the kiwifruit are carefully picked by a huge team of workers. Once the kiwifruit have been picked, they are transported to the packhouse to be packed and stored ready for shipping and export. As the winter approaches, the leaves fall from the vines, signalling the end of another growing year. The vines move towards a dormant state, the dormant phase of the vine generally lasts from leaf fall through until late August and await the coming of spring, when swelling of buds indicates the beginning of the new season (Kiwifruit: science and management, 1990).

1.1.3 Kiwifruit postharvest physiology and storage life

Consumers always prefer kiwifruit with better quality i.e. more flavor, higher aroma and heavier weight. To get more flavor and higher aroma in kiwifruit, at harvest, one of the most important quality parameters is the concentration of soluble solids, which, by turning into sugar during storage, will give fruit flavor and aroma. In New Zealand, kiwifruit industry is quite advanced, which has made a certain standard that kiwifruit will not be picked until Brix levels reach 6.2 °, which is a measure of harvest maturity. The reason 6.2° has been adopted as a standard is because fruits harvested with Brix <6.2° usually exhibit poor sensory quality, and low aroma intensity after a period of storage (Harman, 1981; Mitchell, 1990). Most of the kiwifruit produced by New Zealand are exported to foreign markets such as Japan, Europe. So it is important to make sure that during the transportation time these fruit will ripen and maintain in good quality conditions.

Since kiwifruit is one of the most important commercial crops in New Zealand, further developing technologies to produce kiwifruit with enhanced fruit qualities of which consumers will be in favor is important. Also, based on the understanding of the development processes of kiwifruit, we will introduce one of the most important environmental factors, light, which is thought to have the largest influence on yield quality of many tree crops, such as apple, grape and kiwifruit. So, providing a better light environment in kiwifruit orchard could be an effective way to produce better quality kiwifruit.

1.1.4 Relationship between light and fruit quality

Light plays a fundamental role in plants in many ways, including plant growth, development and productivity (Montanaro *et al*., 2006). There are three aspects of light: the quality, intensity and duration, which directly impact plant growth. The color or wavelength reaching the surface of plant is referred as light quality. From all different colour sunlight has, red and blue have the greatest impact on plant growth, by combining with each other, these two colours of light enhance flowering. To the contrary, green light is least effective. Both light duration and light intensity play an important role in plant development and productivity. For light duration referring to the amount of time that a plant exposed to sunlight, can have a great effect on flowering response. Meanwhile light intensity is much to do with the primary metabolism such as photosynthesis. The more sunlight a plant receives, to some extent, the higher photosynthesis rate will be. The most effective photosynthesis wavelength range is from 400nm to 700nm. However, although light is essential to photosynthesis, excess light has a negative effect on photosynthesis, which could lead to photoinhibition defining as light-dependent down-regulation of the quantum yield of photosynthesis (Lang *et al.*, 1994). Lang *et al.*, (1994) found that at low light intensity (< 100μmol quanta m^{-2} s^{-1}), more than 80% of the absorbed quanta would be utilized for photosynthesis. However, when the responses to around 50% of 'full' sunlight levels were examined (~1000μmol quanta m^{-2} s^{-1}), only 25% of the absorbed quanta were used in photosynthesis.

Besides the primary metabolism which is relevant to light intensity, such as photosynthesis, light also plays a role in plants secondary metabolism. Secondary metabolism plays a role in keeping all the of plants' systems working properly in several ways, such as photoprotection, stress response and others. Although researchers know that this trait is common in many plants, it is still difficult to determine the precise role each secondary metabolite plays. Light can enhance secondary metabolism such as phenolics metabolism. In a study of kiwifruit, Montanaro *et al.,* (2007) pointed out that compared with fruits which were artificially shaded while growing on mature vines, fruits were exposed to natural light had more phenolic compounds, which indicated that light significantly increased the accumulation of phenolic content, the same result was also found in apple cv. *Fuji* (Hao et al., 2004). In tomato, Luthria *et al.,* (2006) reported that UV radiation from 290 nm-400 nm can significantly increase the phenolics content by 20%, compared with tomato under no-UV treatment.

Light is reported to have effects on fruit development in kiwifruit. Biasi and Altamura (1996) reported that light enhances the differentiation of the vascular system, especially the xylar component in the berry of kiwifruit *(Actinidia deliciosa)*. Via the enhancement of differentiation of the xylem, kiwifruit quality is improved. Also, in a study of Montenaro *et al.,*(2006), light was reported to play a role in influencing transpiration and calcium accumulation in kiwifruit. Orchard production is directly related to the amount of light intercepted by the orchard. Light interception refers to the total amount of available sunlight that is captured by the orchard canopy. In apple, Barrit *et al*., (1987) have shown that per acre production is positively correlated with light interception. In a study of cucumber, artificial lighting was provided by high pressure sodium (HPS) lamps, interlighting increased first class yield and decreased unmarketable yield, also had an effect on improving the fruit skin chlorophyll concentration, but had only a minor effect on the fruit dry matter concentration (Hovi-Pekkanen, 2008). Thus, to secure enhancement in fruit qualities, many orchards have attempted to optimize canopy light interception (Whiting *et al*., 2008).

However, light interception is not the only factor in light environment to influence the fruit quality. The other factor, which is far more important, is the distribution of light throughout the canopy (Whiting *et al*., 2008). Light distribution can be thought of as sunlight penetration into the orchard canopy. Very often, although the overall canopy light interception was high, fruit didn't get better quality due to the poor distribution of light throughout the canopy. Because insufficient light to the interior and lower regions of the canopy can lead to poor floral bud initiation and poor canopy net photosynthesis, and thus result in poor fruit quality (Faust, 1989; Jackson, 1980).

In kiwifruit, vines can often produce a dense canopy that results in low light levels in the fruiting zone at the lowest of the canopy, which tends to produce fruit with poor quality at harvest. Also, under poor light conditions, the fruits tend to need more time to reach the commercial harvest maturity of 6.2 °Brix. And usually they are small in size and pale in colour, have low aroma and less flesh firmness, which results in poor fruit quality after storage. Therefore, to improve the light environment by changing the distribution of light throughout the canopy, reflective ground films are applied in orchard. Some of the reflective ground films have been already commercialized.

Recently, reflective ground films have started to be routinely applied in horticultural production in New Zealand, particularly within the pipfruit industry (Figure 1-3A). Some orchards are applied reflective ground films for apple colour finishing. (Figure 1-3B).

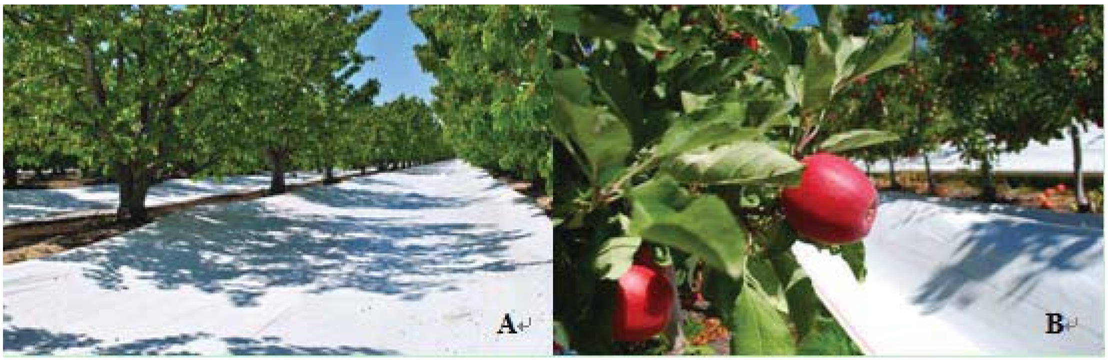

Figure 1-3: A. Photograph of Extenday (reflective film) applied in apple orchard. B. photograph of Extenday applied for fruit colour finishing. (www.extenday.com)

The full understanding of the properties of the now varied films on the market, film shelf-life, and the full extension of that understanding to provide an exploitative framework for industry, is still unclear. In this review, a summary of the current state of knowledge of the films application is presented including an introduction of reflective ground films and the effects of the ground reflective films in different fruit. The aim of this review is to find out the relationship between reflective ground films and fruit quality.

1.2 What is reflective ground film?

Reflective ground film is a shiny bright white/silver plastic cover for improving canopy light relations, which are made to improve fruit quality including fruit coloration and sugar content, thus improving fruit yield and quality. It is developed to cover the entire orchard floor and not just the area immediately below the trees, which maximizes the amount of light that can be reflected back into the trees (Meinhold *et al*., 2010). It has been widely applied in different fruits including apples, pears and strawberries. Usually it is applied prior to the harvest time, because light also has an effect on fruit shelf life (Meinhold *et al*., 2010).

1.2.1 Effects on changing light environment

Reflective ground film has a significant improvement in light environment, especially in enhancing light distribution. There are several kinds of reflective ground films which are made of different materials including paper, aluminium foil, composite and polypropylene. In a study of Meinhold *et al*., (2010), they examined the reflection of four representative objects: Extenday, Uniset O, Mylar, Svensson ILS Alu, to find out the most effective reflective film in enhancing fruit quality, especially in fruit colouration. The main physical properties of the four different materials are given in Table 1.

The spectral reflection (280-800nm) of these objects was recorded in a laboratory over a range of angles of reflectance (5-120° from the ground) as dependent on a range of angles of incidence (30-60° from the normal) to identify the magnitude of reflection as dependent on wavelength (UV-VIS) and any major reflection angles. The results, which can also be found in table 1,were that Svensson ILS Alu, Extenday and Mylar reflected evenly over the whole visible/PAR and UV spectrum, whereas the Uniset O reflected less UV than visible light. While three materials (Svensson ILS Alu, Extenday and Uniset O) had suitable angles of reflection for use as ground cover to improve colouration of fruits ca. 1 m above, Mylar appears as a regular reflector.

Table 1-1: Physical properties of the materials employed in the present study for reflection. (Taken From: Meinhold *et al*., 2010)

Tradename	Extenday80™	Uniset O	Mylar	Svensson ILS Alu
Weight	80g m^{-2}	70g m^{-2}	40g m^{-2}	140g m^{-2}
Material	Woven plastic polypropylene	Coated paper	Aluminium foil	Plastic with woven aluminium strips
Surface properties	Woven textile	Smooth surface	Smooth surface	Textile
Disposal	Re-usable	Bio-degradable	Single use	Re-usable
Properties	Double-sided	Single-sided	Single-sided	Re-usable
Colour	Bright white	White	Silver	Silver
Key findings:	- Reflected evenly over the whole visible/PAR and UV spectrum - Had suitable angles of reflection as ground cover for fruit colouration	- Reflected less UV than visible light. - Had suitable angles of reflection as ground cover for fruit colouration	- Reflected evenly over the whole visible/PAR and UV spectrum - A regular reflector	- Reflected evenly over the whole visible/PAR and UV spectrum - Had suitable angles of reflection as ground cover for fruit colouration

It can be seen from Vangdal *et al*., (2007)'s study, light measurements showed that the light regime in the trees was changed significantly by the reflective ground film, in this study, it was Extenday™ which was applied. A 3-meter wide reflective mulch was applied in the paths which were between two tree rows (in below refer as alleyways); attached to the trees on both sides with elastic bands. Under different weather conditions, light measurements were recorded as μmol/m^2/s in the orchard using a quantum sensor type QS (Delta-T Devices, Cambridge, UK). In the alleyways, compared with the light above the reflective ground film, the light above the grass, which was without film, was 20-40% lower. Within the tree canopy, the reflected light was five times higher in trees grown with a reflective ground film than the control trees without reflective films. In the alleyways, light reflection was 10 times higher from the plastic mulch compared with the grass (Vangdal *et al*., 2007)

1.3 Reflective ground film application in different fruit

1.3.1 Apples

For competitive markets and consumers, one of the standards to measure apple fruit quality is skin color, because it plays an important role in consumer appeal. It has been shown previously that there is a relationship between fruit color and light exposure in apples. (Lancaster, 1992; Saure, 1990). Fruit that face outward (and are thus exposed) show much greater potential to accumulate anthocyanins, which is the main factor causing red skin color in apples, than did those in shaded parts of the canopy (Reay and Lancaster, 2001).

To solve this problem and improve fruit quality, the reflective ground film is applied to change the light environment thus has an improvement on fruit colouration. For coloration, these films are applied a few weeks before the harvest, which is usually in late summer or early fall depending on cultivars. For a cultivar like Royal Gala, it would be better to apply the reflective films in late summer, while for a cultivar like Fuji, application in early fall is suggested. Usually the colour response is quite rapid with noticeable results within a few days after application.

1.3.1.1 Effects on fruit quality

Several studies have shown that reflective ground covers improve red colouration in apples. Sometimes due to climatic characteristics, hail nets are used, because the hail injury on leaves decrease photosynthesis and also cause damage on fruits during the growing season (Tartachnyk & Blanke, 2002; Stampar *et al*., 1999). However, since many of the hail nets are black, the incident solar light will be reduced and thus results in a negative impact on the development of fruit on its final colour (Jakopic *et al.,* 2007). Guerrero *et al.,* (2002) reported that, in 'Redchief Delicious' apples, three different treatments consisted of fruit under black and white hail nets and controls without nets were applied. Fruit colour was measured after harvest. Skin color of fruit in control group had a better colouration compared with those applied hail nets, which indicated that there was a reduction of both, incident solar light and final fruit color due to either black or white hail nets over the trees (Table 1-2).

Table 1-2: Fruit colour value under different hail net treatments (L* represents brightness; h* represents hue angle whose low value represents more red colouration, while high value means more yellow colouration).

Treatments:	**L***	**h***
Control	44.1	38.8
Black hail net	48.4	53
White hail net	44.8	41

Meinhold *et al*.,(2011) reported that when measured as hue color angle (Fig. 1-4) of the outer, sun-exposed, light-saturated side of the apple fruit, no effect of any of the reflective ground covers under black hail net on fruit (red) coloration was observed, as expected. However, the ground covers improved the coloration of the inner, shaded side of the apple fruit, albeit without statistical difference. It can be seen from the figure 1, the lower side of the apple fruit showed the most significant effect of the reflective materials under the black hailnet. Because of these improvements of colouration of the lower side of the apple fruit, well-coloured apple fruit have been produced in this experiment.

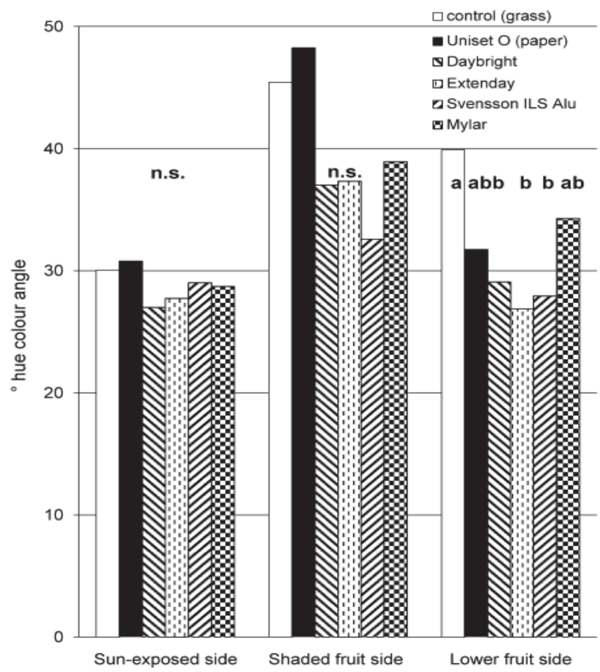

Figure 1-4: Compared with control group (without reflective materials), effect of 5 different reflective materials including: Uniset O (paper), Daybright, Extenday, Svensson ILS Alu, Mylar, under hailnet on coloration of cv. ‘Gala Mondial apple fruit, expressed as hue color angle (lower values represent more red coloration) (Meinhold *et al*., 2011)

Similar results were also found by Vangdal *et al*., (2007), where fruits from the upper part of the control trees had significantly more surface colour than fruits from the lower part. However, in trees grown with reflective films no such difference was found, which suggested that the reflective mulch helps fruits of lower part of canopy in improving fruit colouration. Also, the results indicated that fewer picks will be needed in reflective mulch treated apple orchards.

Apart from improving fruit colouration, increasing levels of intercepted light also has the potential to improve internal fruit quality, for instance, Vangdal *et al*., (2007) mentioned that in apples, fruits from trees grown with reflective mulch were larger with a higher content of soluble solids compared with fruit from trees grown without reflective mulch. In addition, it has been reported by Vangdal *et al*., (2007) that apples from the trees grown with reflective mulch had significantly higher soluble solids content, which is referred to as the degree Brix, suggesting that apples grown with reflective mulch had higher Brix.

As it has been discussed above, reflective ground films seem to provide an efficient technology in horticulture to improve fruit quality in apples particularly in fruit colouration, which is the prime external quality parameter for consumer preference and fruit trade, as well as in fruit size and inner quality such as soluble solids content. However, there might be some disadvantages in application of reflective ground covers. Bertelsen (2005) reported that in application of ‘Extenday’, the grass sward was weakened in the first season of its coverage and disappeared during the second season. This could be a problem in areas subjected to erosion. As table 1 showed, some of the reflective ground covers are re-usable, but some of them are single use or bio-degradable. Therefore, the shelf life of the film really depends on which type of film is applied. Some of these films might last several years, while others just last two months. The costs of purchasing these reflective films depend on the size and material of these films.

1.3.2 Pears

Besides apples, the reflective ground covers have been also applied on pears. As it was mentioned in the former part of this review, it has been reported that some reflective ground covers, such as ‘Extenday’, having improvements on red colored fruit especially in the lower part of the trees. (Gillot *et al.*, 2002; Funke & Blanke, 2003). However, since pears have green colored fruit, this is not an issue. The issues here are if the reflective ground covers have any other effects on fruit. Bertelsen (2005) found that the reflective ground covers also have a significant effect on flower bud formation (cv ‘clara frijs’), as flower bud counts in the spring in 2002 showed an average of 44 flower buds per tree on the control trees (without covers) compared to 96 flower buds on the trees with reflective covers ($P<0.01$) and resulted in a 60% increase in yield on the trees with covers, while the yield went down to less than 7kg/tree on the control trees. Positive effects of reflective ground covers have also been shown in experiments in Denmark, scientists found that pears trees which were applied reflective ground covers were larger compared with those from control trees (Vangdal *et al*., 2007).

1.3.3 Sweet cherries

Reflective ground covers are applied in sweet cherry fruit as well. Whiting *et al*., (2008) found that there was an increase in shoot growth rates in trees treated with reflective ground cover. Thus, the final shoot length of trees with mulch was 32% higher than that of trees without mulch. Also compared with untreated trees, more flower bud formation was found with treated trees, possibly due to improved light levels in the canopy interior from increased reflection of radiation by reflective mulch.

In terms of fruit quality, based on comparisons of fruit weight, color, firmness and soluble solids, fruit treated with reflective ground cover reached optimum commercial maturity about 5 days sooner than those untreated (Whiting *et al*., 2008). In the Swiss study, sweet cherry fruits from reflective mulch treated plots had a higher content of soluble solids compared to controls (Vangdal *et al*., 2004).

1.3.4 Kiwifruit

1.3.4.1 Influence of light exposure on storage life of kiwifruit

It is found that under poor light conditions, for example, some kiwifruit were treated with mesh bags to restrict the amount of light reaching, under this kind of condition, the kiwifruit need more time to reach the commercial harvest maturity of 6.20° Brix, they are small in size and pale in colour, have less flesh firmness, low carbohydrates concentration, and poor sensory characteristics (Davison, 1977; Snelgar & Hopkirk, 1988; Lawes, 1989). Also, there is no doubt that kiwifruit storage life is influenced by the fruit characteristics such as soluble solids, flesh firmness and colour. To find out what kind role of light plays in quality and storage life of kiwifruit, Tombesi *et al*., (1993) studied ‘Hayward’ cultivar in an 8-year-old kiwifruit commercial orchard.

Fruits were divided into three groups:

1) fruits from the external part of the canopy and grown at levels of photosynthetically active radiation (PAR) of 300-600 μmol/m^2 per sec;
2) fruits of internal part of the canopy and grown at levels of PAR < 50 μmol/m^2 per sec;
3) fruits of external and internal part of the canopy artificially shaded, with aluminium foil packet covering the fruit from 3 weeks after full bloom until harvest.

At harvest the fruits grown in high light intensity have a high quality and can be stored for a long time; after 25 weeks of cool storage they have a soluble solids concentration > 14° Brix and a flesh firmness of c. 10 N. Fruits from shaded positions of the canopy showed significantly lower mean fresh weight and chlorophyll content (-35%); at harvest and during storage they were slightly but consistently less firm and had lower soluble solids concentration than exposed fruits. Artificial shading of individual fruit for most of the growing season significantly reduced chlorophyll content in the mesocarp (-77%), starch and alcohol soluble sugars concentration, flesh firmness, soluble content and dry matter, whereas the titratable acidity was significantly increased. At the end of storage, fruit loss because of Botrytis cinerea and other diseases was small for external fruits and moderate for the internal ones, whereas on the shaded fruits, just after 18 weeks, 30% of fruits were damaged; at the end of storage the losses were 40%, which suggested that the storage life of artificially shaded fruits was significantly reduced in comparison with exposed fruits. Thus it is possible to indicate that during fruit growth, light exposure could exert a significant influence on the standard of quality and storage life. This result was also confirmed by Meinhold *et al*., (2010).

1.3.4.2 Studies of reflective ground covers applying in kiwifruit

There are not so many studies which have investigated reflective ground covers application in kiwifruit. Thorp *et al*., (2001) suggested that the reflective ground covers had a major effect on fruit size and vine yield in kiwifruit. The average fruit size of 'Hayward' kiwifruit which was applied reflective covers showed a 7% increment and total yield increased by 13%, compared with the untreated kiwifruit vines.

1.4 Relationship of solar radiation and fruit cuticle properties

Since light playing an important role in fruit quality, solar radiation, accompanying with changing light environment should be discussed. It is well known that UV radiation induces different effects in plants, most of which are known to be deleterious (Caldwell, 1981). Fruits suffer severe damage when they are exposure to excessive solar radiation, such as, sun-scald in apples. Also, light and temperature can work together to make fruit suffer another damage called sun burn. Among all parts of fruits, the cuticle is the first structure to interact with solar radiation (Solovchenko & Merzlyak, 2003). The photoprotective capacity of the cuticle is related to its ability to moderate the wavelengths of light that penetrate into the tissues, which is reducing UV-B penetration either by reflection, or absorption by flavonoids localized in the waxy layer, or through ferulic acid co-polymerized with cutin (Krauss *et al*., 1997). It is easy to investigate photoadaptation and protection in fruit since it represents a useful natural system, which exhibits only one (sun facing) side of a fruit usually being affected by direct solar radiation. Therefore paired comparison of optical properties and pigment content within a single sample is allowed (Solovchenko & Merzlyak, 2003). Compared to the shaded side, the sun facing side of fruit generally have a considerably higher content of flavonoids in the peel (Merzlyak *et al*., 2002). It also has been found that, in apple fruit, cuticles containing phenolics could be involved in UV protection (Ju & Bramlage, 1999). These findings indicated that phenolics contained in fruit cuticles might be one of the key factors which can help fruit protect self from UV light, which means the industry could produce better quality fruit. All industry could do is to find out what kind of means could increase the amount of phenolics in fruit cuticles.

Solovchenko &Merzlyak (2003) in their apple fruit study, which studied the optical properties of isolated cuticle and detached peel of apple fruit (*Malus domestica* Borkh., cv. Antonovka), concluded that a massive build-up of flavonoids in the peel cells located just below the cuticle, resulting in trapping of radiation in a broad spectral range, plays a dominant role in the long term adaptation of apple fruit to elevated levels of solar radiation. However, there are limited relative studies about properties of kiwifruit cuticles under solar radiation at present, indicating that there is a lack of understanding in relationship between solar radiation and kiwifruit skin.

1.5 Summary and Project aims

1.5.1 Summary

To summarize, reflective ground covers may offer some potential to regulate fruit quality in apples, pears, sweet cherries and kiwifruit, especially in fruit coloration by changing the light environment of the canopy. However, there are few studies to date and although there is at least one study describing the reflective covers application in kiwifruit, we may hypothesize that these reflective ground covers have a large potential to improve the fruit quality and storage life in kiwifruit. Therefore, it is expected that more studies should be conducted to find more information about it including varying time and duration of applications to target specific stages of fruit growth and maturation and also to find whether there is an effect on fruit firmness at harvest. Such information could lead to the development of a rigorous model for the use of reflective films within kiwifruit production in the future.

1.5.2 Project aims

My project, which were studied in a kiwifruit orchard using T-bar system, has three main aims: 1) To investigate the effects of the use of reflective ground covers on the light environment in a kiwifruit orchard; 2) To investigate the effects of the application of reflective ground covers on regulating kiwifruit quality including fruit fresh weight, fruit skin colour, fruit dry matter percentage and UV compounds in fruit skin and to discuss how the application works; 3) To investigate the effect of the use of reflective ground covers on enhancing bud break, flower bud formation and fruitset in the season following initial film application.

2 Materials and Methods

The study was carried out in an experimental 22 year-old 'Hayward' kiwifruit orchard using T-bar system in Plant Growth Unit of Massey University, New Zealand. The selected reflective film was Ultramat white UV woven reflective ground cover, Cosio Industries, Auckland, New Zealand. The reflected film was laid within and under kiwifruit vines at a spacing of length of film was 15 m and the length from the central leader to edge of the film was 4.15 m, and was placed down on 20 December 2011 (Season 2011/2012), and maintained in position, with frequently cleaning, and removal of trash, until harvest (11th May 2012). At the same time, we also segregated vines which were not laid with film to act as our controls. All the data of light environment, fruit quality and bud break as well as flower bud and fruitset monitoring were taken in season 2011/2012.

2.1 Quantification of light environment

To quantify the light environment, we used an Optronics OL756 spectroradiometer, complete with OLIS-270 2-inch integrating sphere (both Optronics Laboratories, Florida, USA). Our system was calibrated using an Optronics OL752-10E plug-in tungsten standard of spectral irradiance, which itself was calibrated with direct comparison to a NIST traceable source (Optronics Laboratories, Florida, USA). Our scans were taken at four locations within the vine (i.e. almost entirely underneath the canopy, bar our 'exterior' scans); (1) 'uppermost interior of canopy', at a distance of 0.6 m from the vine trunk, and a height of 1.5 m from the ground (at the edge of the film's location), (2) 'mid-interior', at a distance of 1 m from the vine trunk, and a height of 1 m from the ground, (3) 'lower canopy', at a distance of 1 m from the vine trunk, and a height of 0.7 m from the ground, and (4) 'exterior', at a distance of 1.5 m from the vine trunk (beyond the reach of any elements of the vine canopy, therefore a 'naked' scan), and a height of 0.7 m from the ground (Figure 2-1). For all scans the integrating sphere was facing downwards, incident to the ground/film itself. Two scanning campaigns have taken place to date; we aimed to capture relatively clear skies on both scanning occasions, but it should be noted that some patchy cloud was apparent during both sampling time points. The light scanning equipment was deployed in the field using a modified trolley system (Figure 2-2).

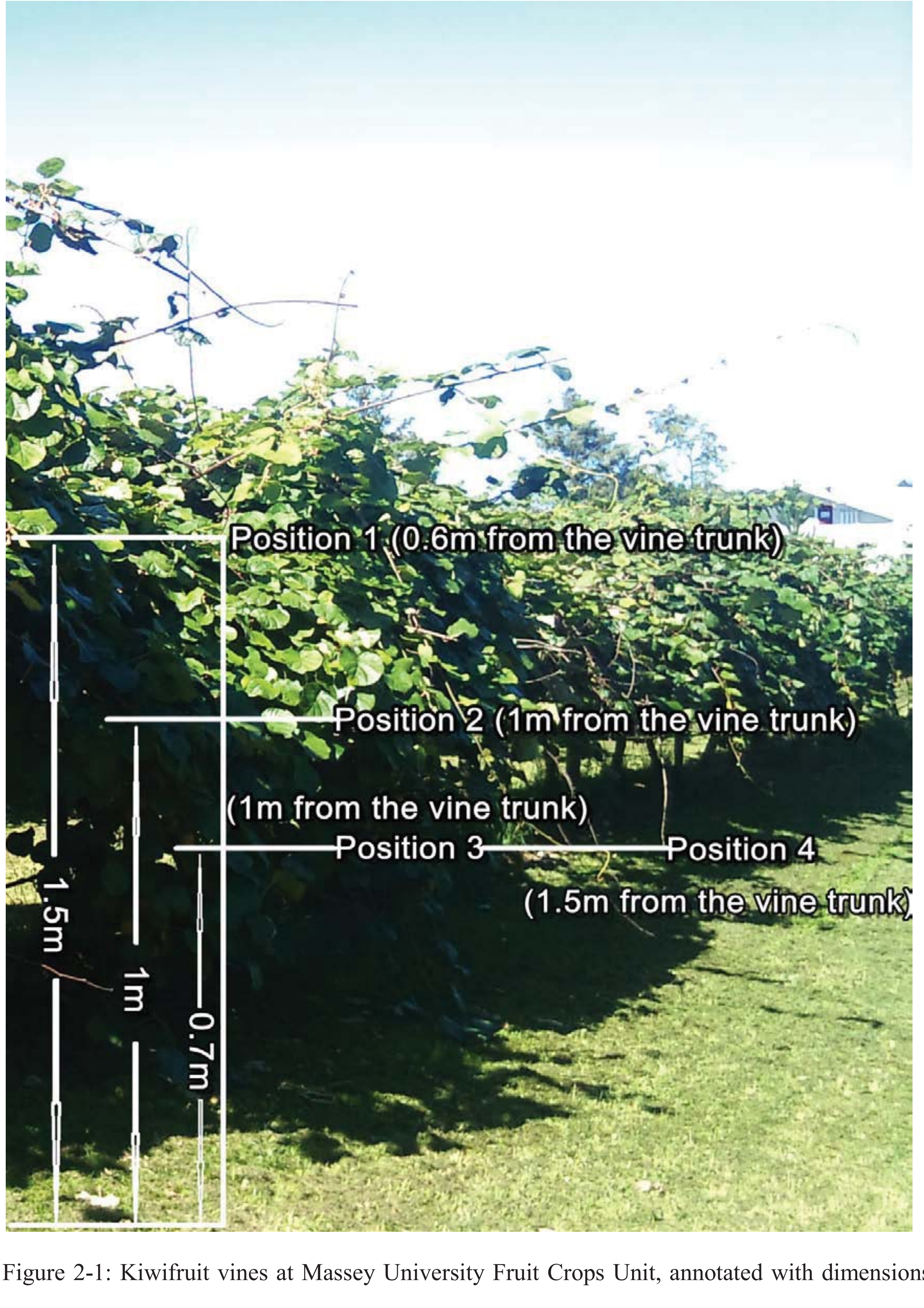

Figure 2-1: Kiwifruit vines at Massey University Fruit Crops Unit, annotated with dimensions and locations of spectroradiometric scanning positions.

Figure 2-2: A photo taken in the kiwifruit orchard when we were doing the scan of lower canopy on 6 March 2012. The spectroradiometer was under the lap-top with the battery attached between the wheels. The sensor was bound with the arm to go through the canopy taking the scans.

2.2 Kiwifruit quality measurements

2.2.1 Harvest

All the kiwifruit which were used in quality measurements were harvested on 11th May 2012. The canopy of both treatments has been divided into three different positions as linked to scan zones mentioned in previous part: 1) Position 1: 'uppermost canopy', at a height of 1.5 m from the ground; 2) Position 2: 'mid canopy', at a height of 1 m from the ground; 3) Position 3: 'lower canopy', at a height of 0.7 m from the ground. 15 fruit samples were taken from each position per treatment. Thus, there were total 90 fruits taken from both treatments. When fruits were picked, they were labeled by a three-part code, e.g. f (film)/n (no film)-P1/P2/P3(positions)-1(the number of fruit sample). All of the fruits were put in a 0 ℃ cool store room and were taken from cool store at ambient temperature the night before 24th May 2012 when the quality measurements were about to start.

2.2.2 Fresh weight and skin colour measurement

On 24th May 2012, these fruits were weighed and colouration was measured on a Minolta Spectrometer (CM-2600d, Minolta, Japan) on 15 kiwifruit per position/per treatment, used in L* a* b* h* c* colour mode .

2.2.3 Firmness, Soluble solids and kiwifruit skin peel taken

Skin peel was taken from all 90 samples by a peeling instrument. Those skin peels were peeled from halfway down on the sun-facing side of each fruit. The peels were thin but occasionally there were some flesh remaining on the peel. According to canopy positions and different treatments, those skin peels were labeled with individual fruit codes and grouped into batches of 3 per position per treatment, i.e. 5 fruit peels = 1 replicate sample for freezing in liquid nitrogen for each position and treatment. After being frozen in liquid nitrogen, peels were put into pre-labeled sterile bags and stored in the -30℃ freezer for future measurement of UV absorbing compounds.

After finishing the peeling process, fruit firmness were measured by a QALink Penetrometer (Willowbank Electronics Ltd., Napier, New Zealand). Then the top and bottom of each fruit was cut off to take juice for fruit soluble solids of all 15 fruits of each position per treatment. The Brix value was measured by a digital pocket refractometer (PAL-1, Atago, Japan).

When these measurements could not be finished in one day, this measuring process was done in a 'block' approach, which means all the measurements were finished in the following sequence one by one: first, peel taken; second, firmness; third, Brix of fruit No.1 from every position and treatment, then measure fruit No.2 from every position and treatment, and so on.

2.2.4 UV absorbing compounds

The replicate samples of peels were ground in liquid nitrogen, and were then weighed to 0.3 g. After that those powder were homogenized in medium containing methanol:HCl: H_2O (79:1:20), centrifuged at 10000×g for 10 minutes. After finishing centrifuging, supernatant liquid was taken. When UV absorbing compounds were measured, these supernatant liquid were made a 3 in 1 dilution in medium containing methanol:HCl: H_2O (79:1:20). The absorption of diluted solution were measured in the region 240-400nm. The solution which was not diluted was measured in the region 400-800nm.

2.2.5 Light transmission of kiwifruit peels

10 Kiwifruit peels were taken from (+ film) treatment and (-film) treatment respectively after 125-day cold storage for measuring light transmission from wavelength 280nm to 800nm. To measure the transmission of kiwifruit peels, we used an Optronics OL756 spectroradiometer, complete with OLIS-270 2-inch integrating sphere (both Optronics Laboratories, Florida, USA). Our system was calibrated using an Optronics OL752-10E plug-in tungsten standard of spectral irradiance, which itself was calibrated with direct comparison to a NIST traceable source (Optronics Laboratories, Florida, USA). First of all, the sensor tested the incandescent light transmission directly, next step a peel was put on the sensor under the incandescent lamp to detect the transmission of it from wavelength 280nm to 800nm. Then we calculated irradiance of peels of (+film) treatment and those of (-film) treatment as percentage of no peels transmission.

2.2.6 Outer suberised layers thickness

Another 10 Kiwifruit peels were taken from (+film) treatment and (-film) treatment respectively after 125-day cold storage to measure outer suberised layers thickness. Peels were taken as it was mentioned above, and then the flesh were scraped until the inside layer was reached. The outer suberised layers thickness was measured by a digital caliper (0-150mm, Mitutoyo Corporation, Japan). The measurements were taken from three positions on each peel, and then averaged the measurements per peel as one measurement. So the actual average was calculated on the peels per treatment.

2.2.7 Phenolics content determination

10 more fruit peels were taken from 10 different fruit per treatment to measure skin pigments after 150-day cold storage. These peels were stored in -80℃ freezer for a couple of days before the extraction. Each peel was ground into powder with liquid nitrogen. Put the powder into pre-labeled tube. Acidified methanol (methonal:HCl:H_2O=79:1:20) is chosen as the solvent. So 0.5g frozen ground tissue plus either 1 ml solvent. These samples were vortex well, then centrifuged in a microfuger ca. 10,000g for 10 mins at 8℃. After centrifuging, these samples were syringed and filtered. During the extraction, all the samples at each step were kept chilled (on an ice bath). All the samples were extracted and put in the high-performance liquid chromatography (HPLC) machine on the same day. Afterwards, all the samples were analysed using a Shimadzu Prominence HPLC with a prominence solvent delivery module (LC-20AT), prominence auto-sampler (SIL-20AC), prominence UV/VIS photodiode array detector (SPD-M20A), column oven (CTP-20A) and prominence degasser (DGU-20A5) fitted with a Phenomenex Luna 5µ C18(2) 100A 150 x 4.6mm column with a C18 4 x 32.0mm security guard column attached. These samples were run in a 'block' approach, which means these samples were put in the machine in a special order: the first sample of film treatment and the first sample of no-film treatment; then the second sample of film treatment and the second sample of no-film treatment until all the measurements were taken, in case the HPLC doesn't provide steady data. The mobile phases were (A) acetonitrile +0.1% formic acid and (B) acetonitrile/water/formic acid (5:92:3). The content of Solvent B was 100% at 0 min and decreased linearly to 90% at 20 min, 80% at 30 min, 70% at 36 min, 50% at 38.5 min, held at 5%

between 42 and 45 min. The flow rate was 1mL min^{-1}. Two wavelengths (280nm, 350nm) were used. An aliquot of 40μl was injected into HPLC. An external standard (chlorogenic acid) was used as separated injections to aid the identification of polyphenols. The concentrations of chlorogenic acid which were injected were 0μg/ml, 1μg/ml, 5μg/ml, 10μg/ml and 50μg/ml respectively. A standard curve of chlorogenic acid was drawn by the results of HPLC.

2.2.8 Bud break counting

To test how the reflected film treatment has effect on bud break in spring, we did the broken bud counting once a week, which started on 13th Sep 2012 and stopped when the bud burst percentage became steady. 8 vines (4 vines for film treatment, 4 vines for control treatment), which grows in the same row, were chosen. The total buds (including both burst buds and un-burst buds) as well as the number of burst buds were counted on 5 canes per vine, which were calculated as bud burst percentage per week. The counting stopped on 25th Sep 2012.

2.2.9 Flower bud and fruitset monitor

Flowers were monitored on 19th Oct 2012. 8 vines (4 vines for film treatment, 4 vines for control), which grows in the same row, were chosen. The number of flower buds of 5 randomly chosen canes in each vine was counted. On 17th Dec 2012, the number of fruitset per vine was counted.

2.3 Statistical analyses

The obtained results were analysed using two-factor ANOVA and one-way ANOVA (Microsoft Excel 2007), followed by post hoc tests according to the Tukey test using SPSS v19 (SPSS Inc., Chicago, IL). Data of HPLC were analysed by Principle component analysis using Minitab 15 (Minitab Inc., Pennsylvania).

3 Results

3.1 Changes in canopy light environment

When comparing our film and no film treatments in the external scanning position (Fig. 3-1), we see a clear increase in light reflected across all wavelengths from 290 nm (the lower limit of sunlight) to 750 nm, indicating the nature of light being potentially provided to the interior of the canopy. For the interior of uppermost canopy (Fig. 3-2), both figure 3-2A and figure 3-2B showed that there was a higher irradiance in (+ film) treatment than the one in (-film) treatment, especially in the wavelength range from 400nm to 700nm. The second sampling time has a much higher irradiance than the first sampling time in both the canopy with and without film, because the weather was sunnier at the second sampling time.

When considering the resultant changes in light quality and quantity reflected into the canopy itself, one analysis approach is that of reflected irradiance as a percentage of our no film/grass treatment (Fig. 3-3). Here, we can see that there are marked % increases in reflected light across the entire spectrum as indicated above, and that there are interesting differences according to canopy position also. Key increases in reflected light include the UV region (290-400 nm), the blue region (450-490 nm), and the red/far-red region (630-740 nm) (Fig. 3-3A). Interestingly, there is an indication that the uppermost canopy position is receiving the least reflected amount of red light, and the lowest portion of the canopy is receiving the most, i.e. in figure 3-3A, equivalent to an almost 5.5 fold increase in reflected ‘red’ light for the uppermost canopy interior position as compared to a 13 fold increase in the red region generally for the lowest canopy interior position. Moreover, in figure 3-3B, the lowest canopy is receiving the most reflected amount equivalent to an almost 8 fold increase in all range of wavelength.

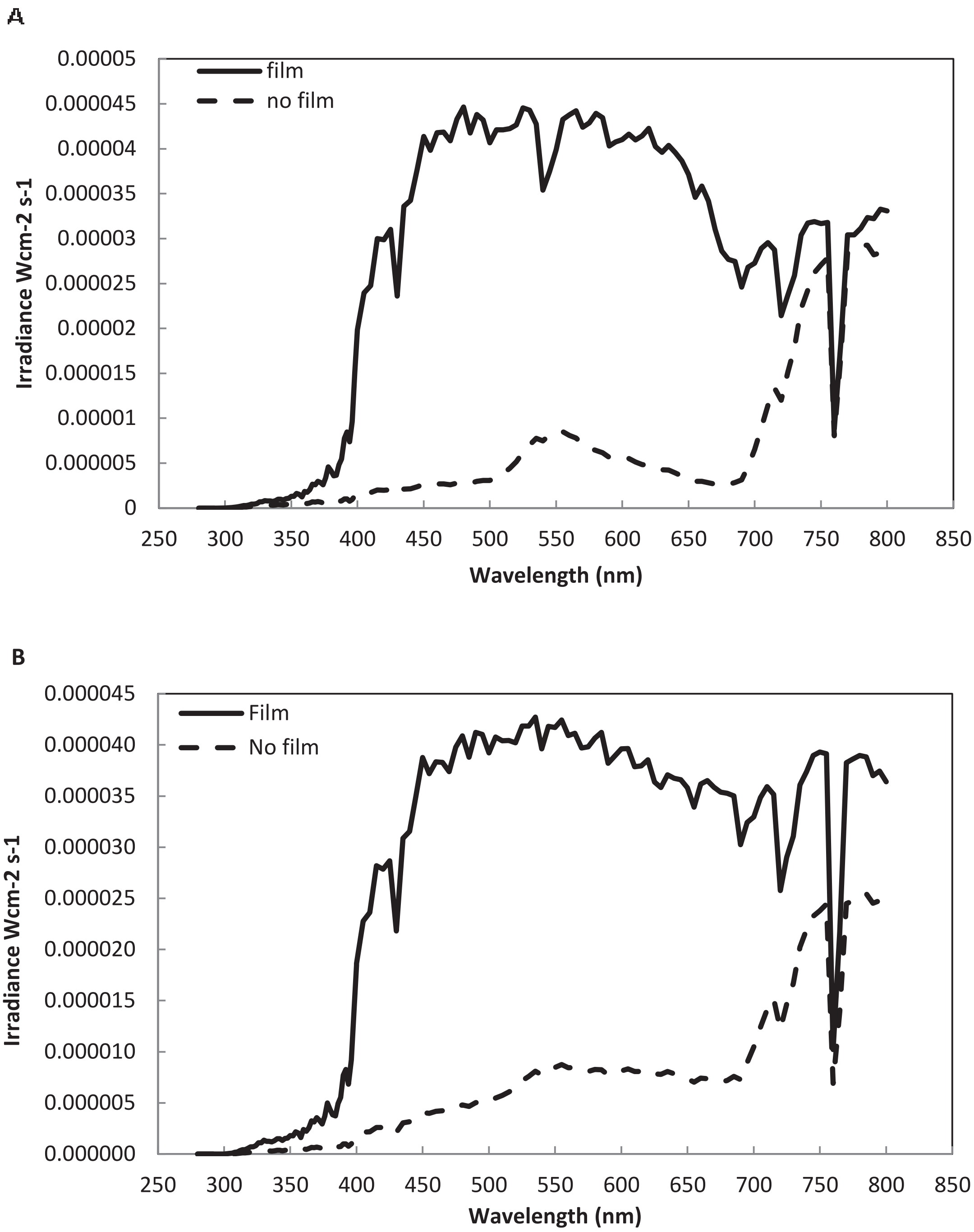

Figure 3-1：Irradiance of light reflected in the presence of reflective ground-covering film (+film) or naked ground (no film) according to wavelength at a height of 0.7 m from the ground: A) Scans were taken on 6/3/2012; B) scans were taken on 30/3/2012. No dash: irradiance reflected from film covered ground, dash: irradiance reflected from naked ground. Both Figure 1A and Figure 1B shows that there was a higher irradiance under the film treatment than the one under naked ground, especially within the wavelength range from 400nm to 700nm.

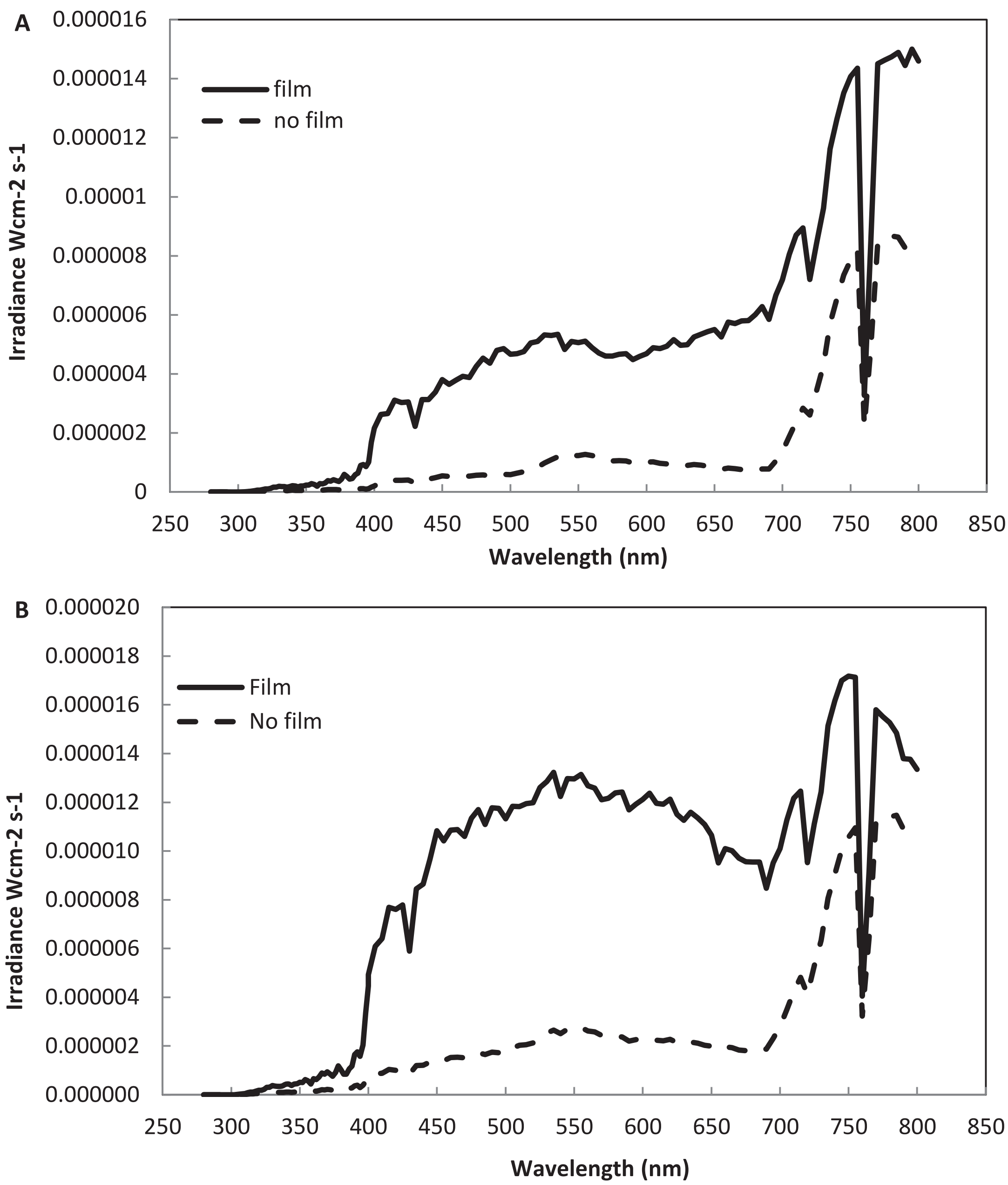

Figure 3-2: Irradiance of light reflected in the uppermost interior canopy in the presence of reflective ground-covering film (+film) or naked ground (no film) according to wavelength: A) Scans were taken on 6/3/2012; B) scans were taken on 30/3/2012. No dash: irradiance reflected from film covered ground, dash: irradiance reflected from naked ground. Both Figure 2A and Figure 2B shows that there was a higher irradiance under the film treatment than under naked ground, especially in the wavelength range from 400nm to 700nm. The second sampling time displayed a much higher irradiance than the first sampling time in both the canopy with film and without film, probably due to sunnier sky conditions at the second sampling time.

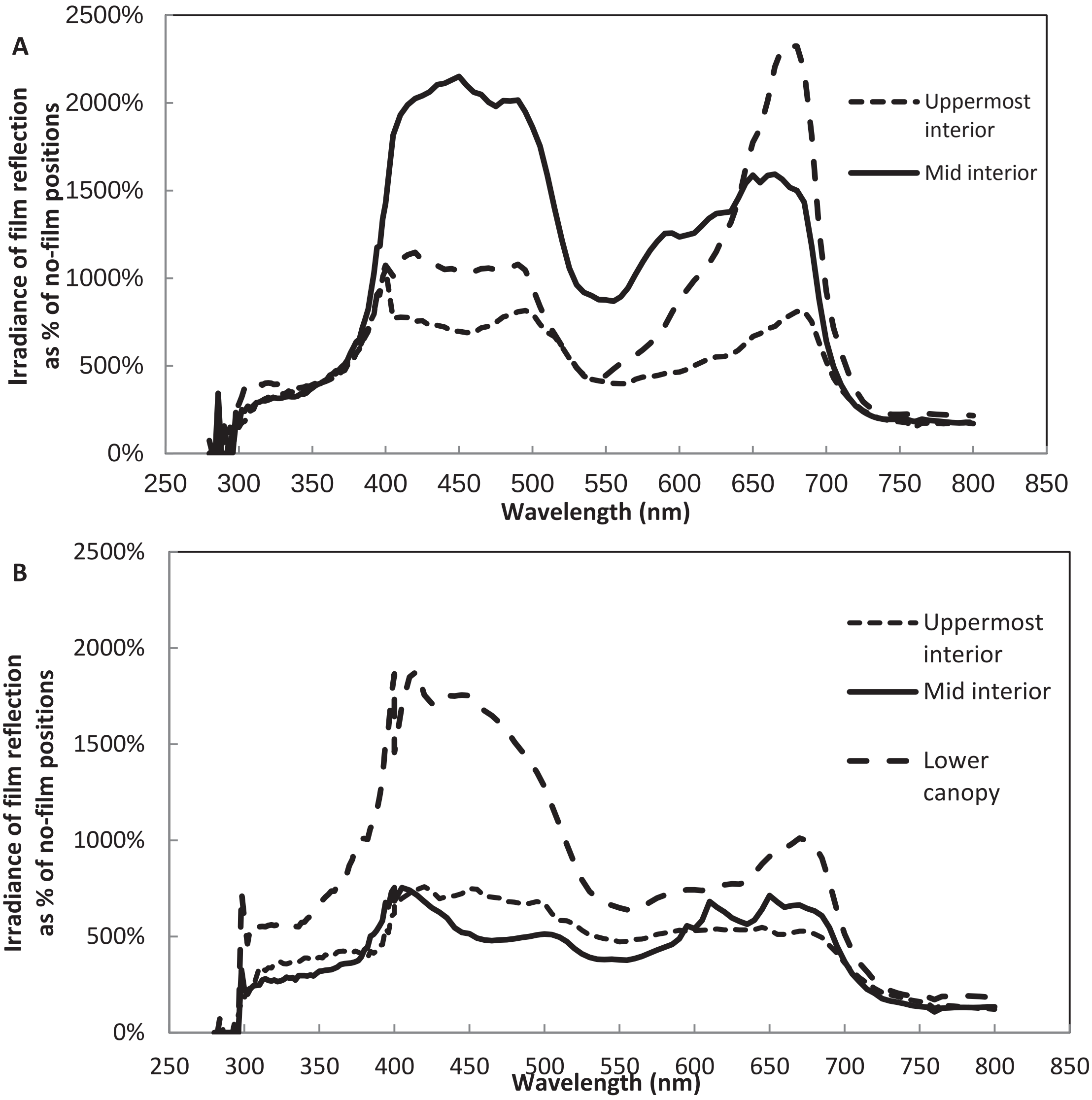

Figure 3-3: Irradiance of light reflected from reflective ground-covering film according to wavelength represented as a percentage of naked ground (no film) scans taken from identical canopy positions. A) Scans were taken on 6/3/2012; B) scans were taken on 30/3/2012. Long dash: lower interior canopy, no dash: mid-interior canopy, short dash: uppermost interior canopy. In both Figure 3A and 3B, there is an indication that the uppermost canopy position is receiving the least reflected amount of red light (630-740nm), and the lowest portion of the canopy is receiving the most, i.e. in Figure 3A, equivalent to an almost 5.5 fold increase in reflected 'red' light for the uppermost canopy interior position as compared to a 13 fold increase in the red region generally for the lowest canopy interior position. Moreover, in Figure 3B, the lowest canopy is receiving the most reflected amount equivalent to an almost 8 fold increase in all range of wavelength.

3.2 Fruit fresh weight

According to Figure 3-4, the average fruit fresh weight in uppermost canopy, middle canopy and lower canopy in (+film) treatment was 93.6g, 93.2g and 90.6g respectively; while the average fruit fresh weight in (-film) treatment was 89.7g, 86.9g and 81.1g respectively. Two-factor ANOVA showed that there was a significant difference between (+film) treatment and (-film) treatment ($P<0.05$), although there were no significant differences of each positions. Also there were no interactions. The trend was for lower canopy to produce the lightest fruit. When results expressed as percentage difference (Figure 3-5), the fresh weight of fruit grown under reflective ground covers was 120% of the weight of fruit grown under (-film) treatment in the lower canopy. The difference in fresh weight was significant with kiwifruit between these two treatments regardless of canopy position ($P<0.05$). However, there were no significant differences in fruit fresh weight across different positions in both treatments. Both Figure 3-4 and Figure 3-5 illustrate that reflective ground film did have an effect on increasing fresh weight, with a tendency for the biggest impact on the lower canopy fruit. Also the variance of fresh weight in (+film) treatment is 147.04 while the variance in (-film) treatment is 242.72, which indicate that, under reflective ground covers treatment, fruit from all positions were of similar fresh weight. These results suggest that reflective ground film not only can enhance the fresh weight of fruit in lower canopy, but also has an effect on promoting the consistency of fruit quality in fresh weight.

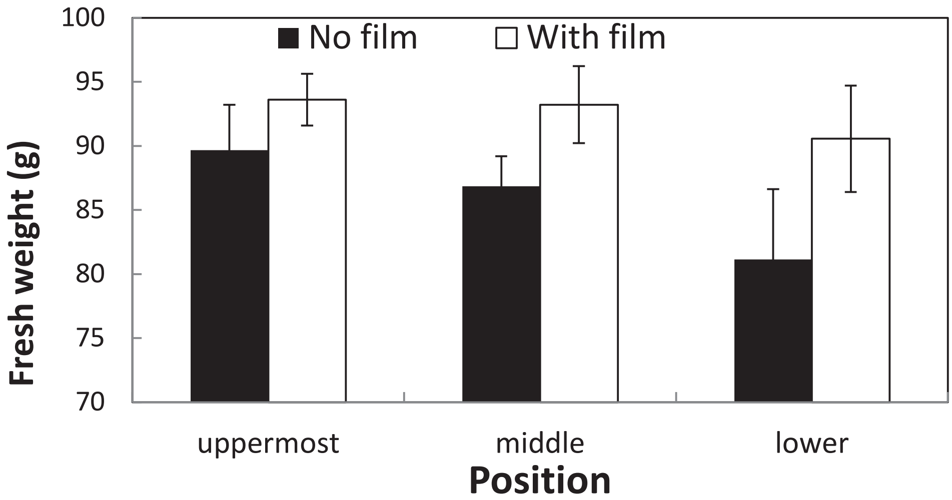

Figure 3-4: Fresh whole fruit weight in Hayward kiwifruit according to canopy position in the presence of reflective ground-covering film (+film) or naked ground (no film). Three different canopy positions were: uppermost interior canopy; middle interior canopy; lower canopy. Each separate position is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 15 replicate fruits per position.

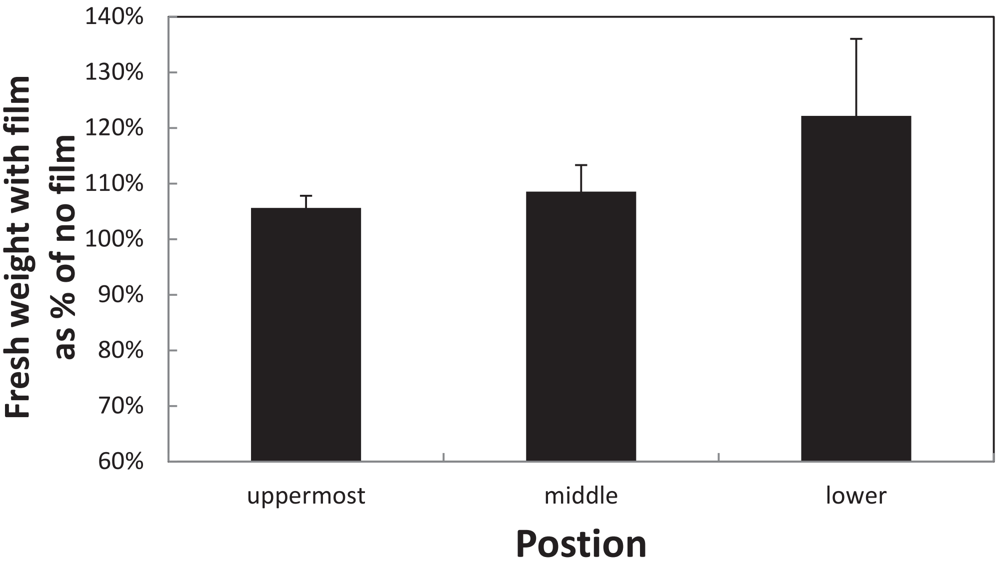

Figure 3-5: Fresh whole fruit weight in Hayward kiwifruit according to canopy positions in the presence of reflective ground-covering film (+film) represented as a percentage of the fresh weight of naked ground (no film) fruit taken from identical canopy positions. Three different canopy positions were: uppermost interior canopy; middle interior canopy; lower canopy.

3.3 Fruit firmness

There were significant differences in fruit firmness one month after harvesting between kiwifruit grown under two different treatments ($P<0.01$ in all cases: Fig. 3-6). In comparison with fruits grown without reflective film in each canopy positions, fruits grown with film were much firmer ($P<0.01$ in all canopy positions). Meanwhile, across different positions in both treatments, there were significant differences in fruit firmness, $P<0.05$ in (+film) treatment while $P<0.001$ in no film treatment. Fruit grown in lower canopy regardless of treatments were the firmest fruit across all the positions. However under (+film) treatment, compared with (-film) treatment, firmness of fruits grown in upper and middle canopy significantly increased by almost 0.7 units maximum. These results indicate that the use of film did have an effect on increasing fruit firmness; however, the presence of reflective film cannot absolutely reduce variability in fruit firmness according to canopy position of fruit, as observed in the absence of film.

3.4 Fruit soluble solids

After one-month of storage, fruit soluble solids as Brix value in both (+film) treatment and (-film) treatment were measured (Fig. 3-7). For fruit in our no film treatment, the lower the canopy position is, the lower the Brix value is. Two-factor ANOVA showed that there were no significant differences between fruit cultivated under (+film) treatment and (-film) treatment. However, in (+film) treatment, fruit in lower canopy showed the highest Brix value among all three positions. There were no significant differences fruit of uppermost and middle canopy between both (+film) treatment and (-film) treatment. However, Brix value of fruit of lower canopy in film treatment was significantly higher than those in no film treatment ($P<0.05$). There were significant differences in Brix value across different positions in (+film) treatment ($P<0.05$); while no significant differences in no film treatment. These results mentioned above indicate that in terms of Brix value, the presence of reflective ground films may only help a lot in increasing the value in lower canopy position, and thereby avoiding risk of fruit with low sweetness after long term storage.

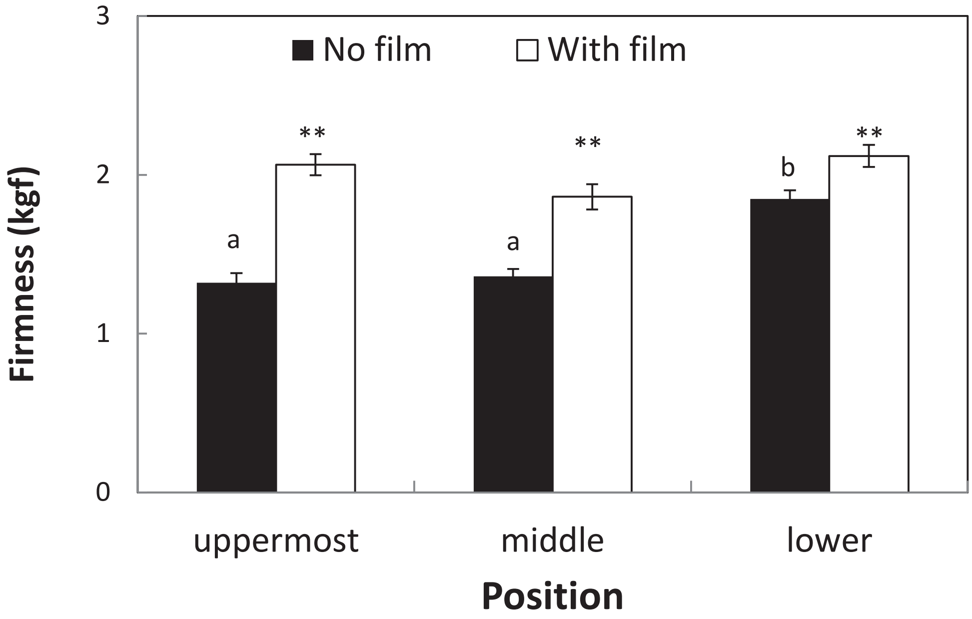

Figure 3-6: Firmness tested after 1 month storage after harvest in Hayward kiwifruit with in the presence of reflective ground-covering film (+film) or naked ground (no film). Fruit were stored in trays at 0°C after harvest. Three different canopy positions were: uppermost interior canopy; middle interior canopy; lower canopy. Each separate position is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 15 replicate fruits per position, and asterisks indicate significant differences between treatments for each canopy position at $P<0.01$. And columns that do not share the same letter are significantly different at $P<0.05$. Compared with (-film) treatments, fruit cultivated in (+film) treatments exhibited firmer fruit regardless of canopy position ($P<0.01$). There were significant differences in fruit firmness across different positions in both treatments, $P<0.05$ in (+film) treatment while $P<0.001$ in no film treatment. These results indicate that the use of film increases fruit firmness, and but cannot absolutely reduce variability in fruit firmness according to canopy position of fruit, as observed in the absence of film.

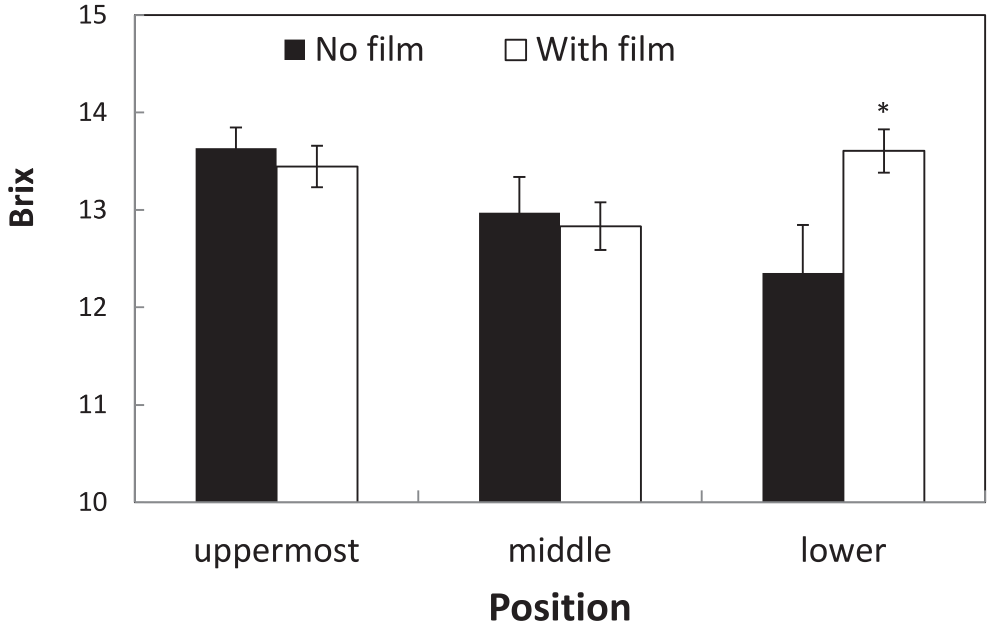

Figure 3-7: Brix value in Hayward kiwifruit measured 1 month after harvest with in the presence of reflective ground-covering film (+film) or naked ground (no film). Fruit were stored in trays at 0°C after harvest. Three different canopy positions were: uppermost interior canopy; middle interior canopy; lower canopy. Each separate position is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 15 replicate fruits per position, and the column with an asterisk indicates significant differences between treatments for lower position at P<0.05. Compared with (-film) treatments, most of fruit cultivated in (+film) treatments did not exhibit higher Brix value regardless of canopy position. There were significant differences in Brix value across different positions in (+film) treatment (P<0.05); while no significant differences in no film treatment.

3.5 Fruit dry matter percentage

Fruit dry matter percentage value of both treatments after one month storage was illustrated in Figure 3-8. In no film treatment, the lower the canopy position is, the lower the dry matter percentage is. The dry matter percentage in fruit of uppermost, middle, lower canopy under no film treatment were 15.1%, 14.3% and 13.3% respectively. However, in (+film) treatment, fruit from all canopy position showed almost same dry matter percentage value which was around 16.5%. Dry matter percentage values in fruit cultivated under film treatment were higher than those cultivated under no film treatment across all canopy position. There were significant differences in fruit dry matter percentage between kiwifruit cultivated under two different treatments ($P<0.001$ regardless of canopy positions). There were no significant differences in fruit dry matter percentage across different positions in either (+film) treatment or in (-film) treatment. For each canopy position, there were significant differences between (+film) and (-film) treatments. All results mentioned above indicate that the presence of reflective film increases fruit dry matter dramatically. Also the variance of dry matter percentage in (+film) treatment is 5.91 while the variance in (-film) treatment is 7.26, which indicate that, under reflective ground covers treatment, fruit from all positions were of similar fruit dry matter percentage. These results suggest that the presence of reflective film not only increases fruit dry matter dramatically, but also enhanced the consistency of fruit quality in dry matter percentage.

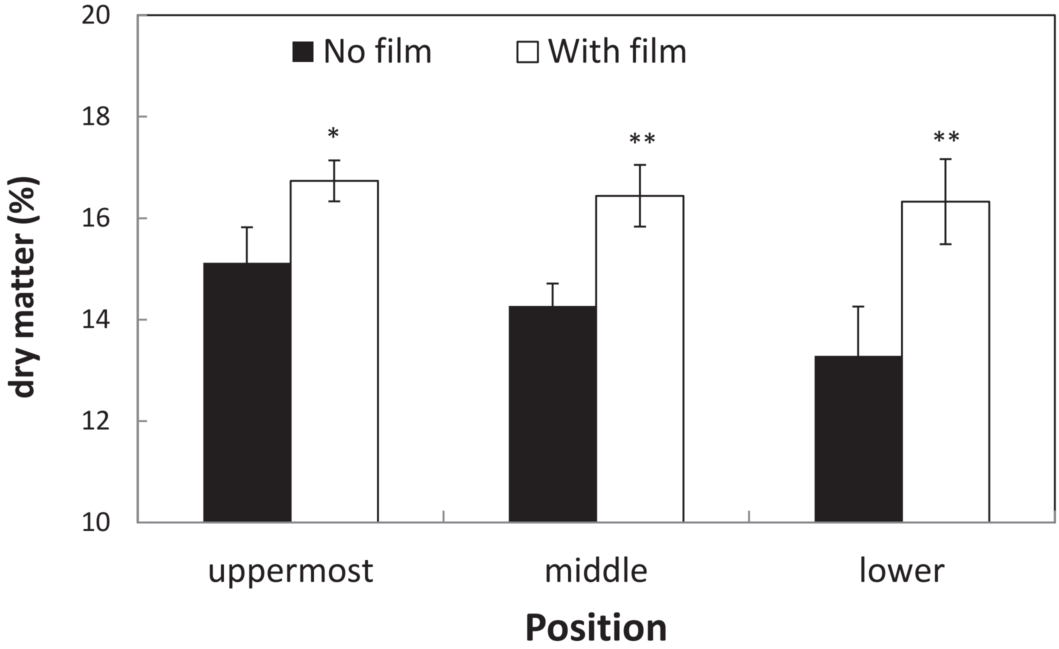

Figure 3-8: Dry matter weight in Hayward kiwifruit measured 1 month after harvest with in the presence of reflective ground-covering film (+film) or naked ground (no film). Fruit were stored in trays at 0°C after harvest. Three different canopy positions were: uppermost interior canopy; middle interior canopy; lower canopy. Each separate position is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 15 replicate fruits per position, asterisks indicate significant differences between treatments for each canopy position (* means $P<0.05$;** means $P<0.01$). Compared with (no film) treatments, fruit cultivated in (+film) treatments exhibited much higher fruit dry matter percentage regardless of canopy position ($P <0.005$). There were no significant differences in fruit dry matter percentage across different positions in both treatments. These results indicate that the use of film increases fruit dry matter dramatically.

3.6 Fruit colouration

Fruit coloration, which was expressed as L* (brightness), c* (chroma), h* (hue angle), was measured at harvest (Fig. 3-9). For kiwifruit, when the value of hue angle is low, the fruit skin illustrates redder colouration, while high value means more yellow colouration. According to Figure 3-9A, regardless of the canopy positions, compared with (no film) treatments, fruit cultivated in (+film) treatments exhibited significantly brighter skin colour (higher L*, $P<0.001$), especially in uppermost and middle canopy. However, there were no significant differences in lower canopy. This pattern could also be found in hue angle (Fig. 3-9C), with significant differences in fruit of uppermost and middle canopy while no significant differences in fruit of lower canopy. Nevertheless, there were no significant differences between fruit cultivated in (+film) treatment and (-film) treatment regardless of canopy positions in hue angle. These results indicate that in uppermost and middle canopy, fruit treated with film exhibited brighter and redder skin colour; while film did not have effects on fruit from lower canopy. For chroma (Fig. 3-9B), there were no significant differences between fruit under (+film) treatment and (-film) treatment regardless of canopy positions. However, film treated middle canopy fruits were significantly different from those under (-film) treatment. All these results mentioned above indicated that reflective film can enhance fruit skin brightness, but have no effects on other colour parameters. There was a position effect in fruit from middle canopy, which suggested that film treated fruit in middle canopy were significantly different from those under (-film) treatment. Kiwifruit surfaces are dead at maturity. Suberized cells form brown layer on epidermis. In this experiment, colour of skin cells was not significantly changed by (+film) treatment.

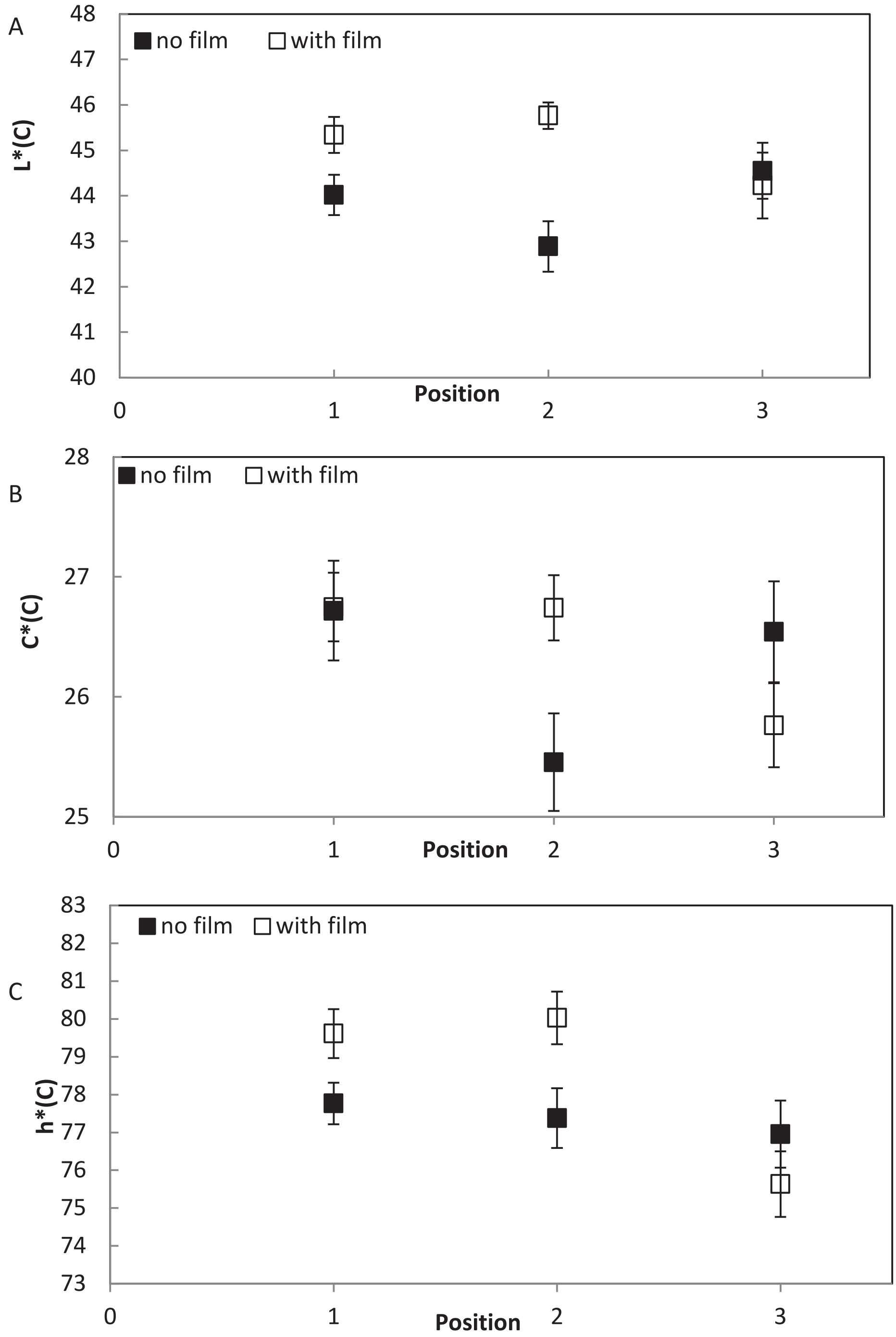

Figure 3-9: Colouration in Hayward kiwifruit with in the presence of reflective ground-covering film (+film) or naked ground (no film). Colouration was expressed as L* which is brightness (A); c* which is chroma (B); h* represents hue angle whose low value represents more red colouration, while high value means more yellow colouration (C). Position 1, position 2 and position 3 represent three different canopy positions which were uppermost interior canopy; middle interior canopy and lower canopy respectively. In all 3 figures, film treated fruit in middle canopy were significantly different from those under (-film) treatment.

3.7 Fruit peel texture

3.7.1 UV absorbing compounds

UV absorbing compounds in kiwifruit peels were measured from 240-400nm (Fig. 3-10). Peels of fruit from uppermost and middle canopy cultivated under (no film) treatment exhibited more UV absorbing compounds ($P<0.05$). However, peels of fruit from lower canopy in (+film) treatment has a similar concentration of UV absorbing compounds than those in fruit cultivated under (no film) treatment (Fig. 3-10A). Regardless of canopy position, peels of fruit under (no film) treatment may exhibit more UV absorbing compounds than those under (+film) treatment from wavelength 240nm to 400nm, however, statistical analyses did not show significant differences between two treatments (Fig. 3-10B). In both treatments, peels of fruit from lower canopy exhibited the highest levels of UV absorbing compounds among all three canopy positions. There were no significant differences in UV absorbing compounds across different positions where film was not present, while fruits with film show a significant difference at $P<0.05$. These results indicate that the use of film increases concentration of UV-absorbing compounds in lower canopy, and can increase variability in concentration of UV-absorbing compounds of different canopy position of fruit, as observed in the absence of film.

3.7.2 Kiwifruit peels transmission

Kiwifruit peels in both (+film) treatment and (-film) treatment, which were taken after 125-day cold storage, were measured for light transmission from wavelength 280nm to 800nm. Since there were no differences from wavelength 280nm to 358nm, only irradiance through (+film) treated peels and (-film) treated peels to pass as percentage of no peels transmission were calculated (Fig.3-11). Compared with (no film) treatments, peels of fruit cultivated in (+ film) treatment did not allow as much irradiance as percentage of no peels transmission, which indicates that peels of fruit cultivated with film absorbed more light. Also, he irradiance through both (+film) and (-film) peels below 358nm was about 0 (data not shown). The small irradiance detected below 358nm in both (+film) and (-film) peels indicates that most of UV light was absorbed by kiwifruit skin peels.

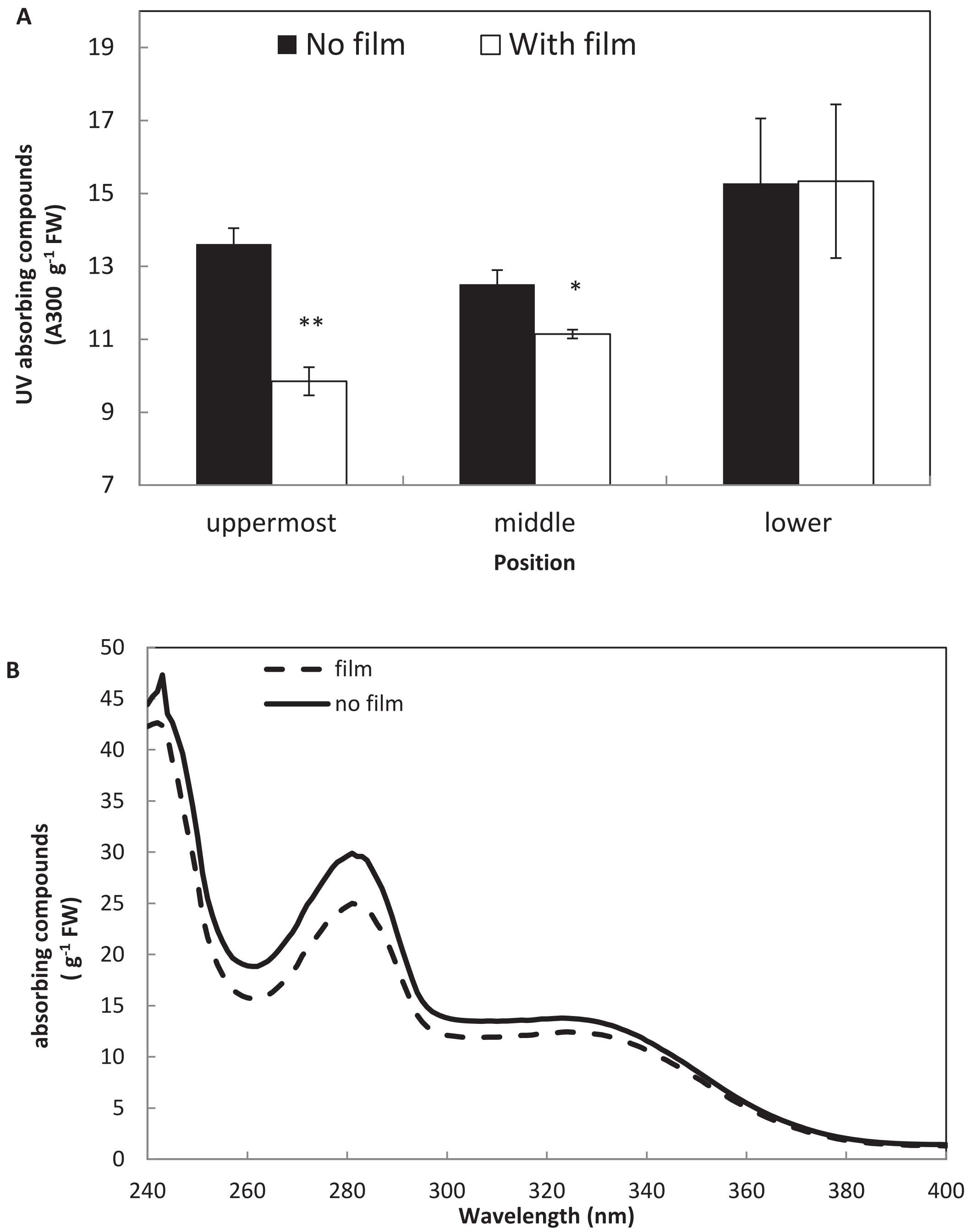

Figure 3-10: Concentration of UV-absorbing compounds A) measured as 300nm in Hayward kiwifruit with in the presence of reflective ground-covering film (+film) or naked ground (no film). B) measured from wavelength 240nm to 400nm regardless of canopy position. A) Three different canopy positions were: uppermost interior canopy; middle interior canopy; lower canopy. Each separate position is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 15 replicate fruits per position, three asterisks and two asterisks indicate significant differences between treatments for uppermost and middle canopy position at P<0.01 and P<0.05 respectively. Compared with (no film) treatments, peels of fruit cultivated in (+ film)

treatment did not exhibit more UV absorbing compounds regardless of canopy position (P=0.09). There were no significant differences in UV absorbing compounds across different positions where film wasn't present, while fruits with film show a significant different at P<0.05. These results indicate that the use of film increases concentration of UV-absorbing compounds in lower canopy, and can increase variability in concentration of UV-absorbing compounds to canopy position of fruit, as observed in the absence of film. Also the presence of reflective ground film has effects on increasing UV absorbing compounds in fruit peels from lower canopy.

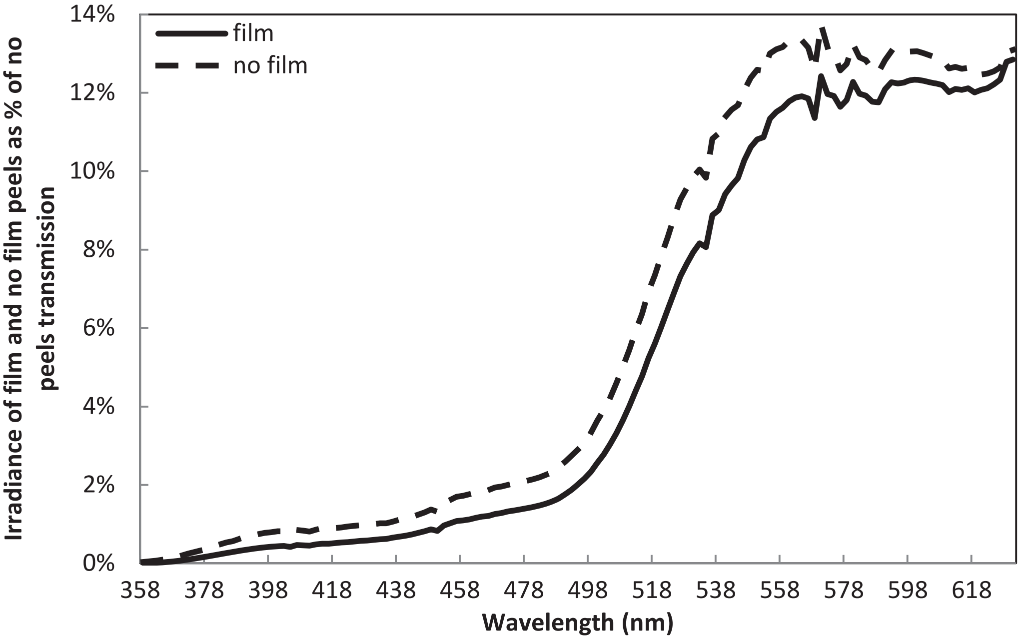

Figure 3-11: Irradiance of fruit peels measured from wavelength 358nm to 618nm in Hayward kiwifruit with in the presence of reflective ground-covering film (+film) or naked ground (no film). Compared with (no film) treatments, peels of fruit cultivated in (+ film) treatment didn't exhibit more irradiance as percentage of no peels transmission, which indicates that peels of fruit cultivated with film absorbed more light.

3.7.3 Kiwifruit outer suberised layers thickness

Kiwifruit peels in both (+film) treatment and (-film) treatment, which were taken after 150-day cold storage, were measured for outer suberised layers thickness (Fig. 3-12). There were significant differences between fruit of (+film) treatment and those of (no film) treatment at P<0.01. Compared with (no film) treatments, fruit cultivated in (+film) treatments exhibited much thicker outer suberised layers. These results indicate that the presence of film increases fruit cuticle thickness dramatically.

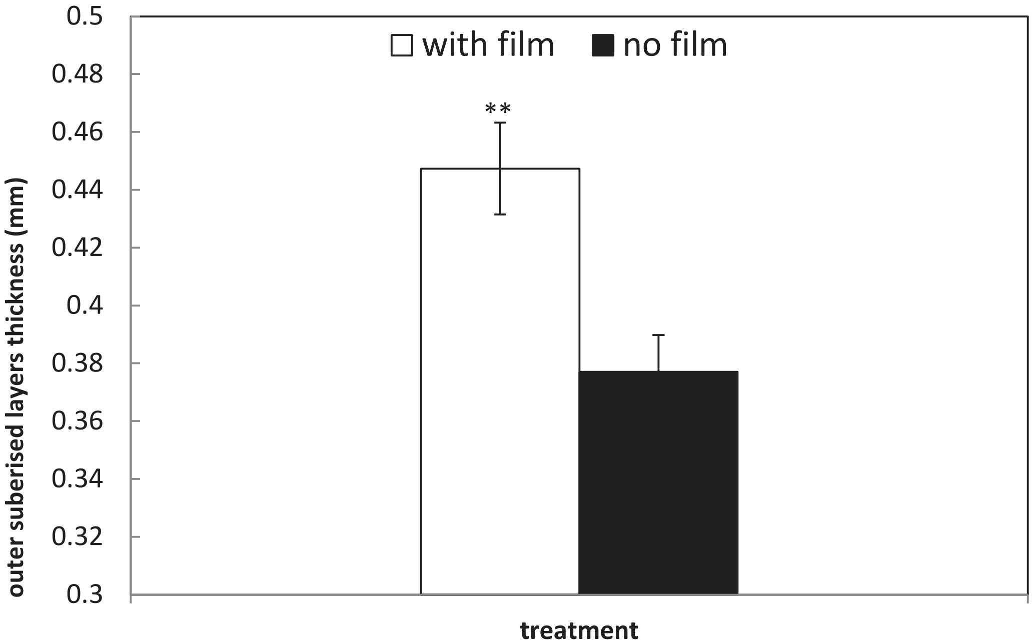

Figure 3-12: Cuticle thickness in Hayward kiwifruit with in the presence of reflective ground-covering film (+film) or naked ground (no film). Each treatment is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 10 replicate fruits per treatment, asterisks indicate between fruit of (+film) treatment and those of (no film) treatment at P<0.01. Compared with (no film) treatments, fruit cultivated in (+film) treatments exhibited thicker cuticles. These results indicate that the presence of film increases fruit cuticle thickness dramatically.

3.7.4 HPLC

Phenolic concentration in kiwifruit epidermal peels was determined by high-performance liquid chromatography (HPLC) at two different wavelengths (280 nm, 350 nm) (Table 3-1). The two largest peaks were at retention times 8.4 and 13.4 min. A standard solution of chlorogenic acid was run separately and its retention time was 10.5 min. Data are reported only for the peak wavelength for each compound; i.e. 280 nm for peaks at 10.5 and 13.4 min, and 350 nm for peak at 8.4 min.

Peels from the no film treatment exhibited higher peak areas than those of (+film) treatment for all three selected retention times (Table 3-1). However, there were no significant differences between (+film) treatment and (-film) treatment. The concentration of chlorogenic acid was higher in (-film) treated epidermal peels than those in (+film) treated peels (Table 3-2). These results indicate that while kiwifruit grown under the film treatment may appear to have a lower concentration than no film-treated kiwifruit for all three compounds; the statistical analyses confirmed that there were no significant differences between these two treatments.

To test whether there were any significant patterns of difference between the compounds present in film and no-film kiwifruit peels, ten 280 nm peaks and two 350 nm peaks were chosen to do Principal component analysis (PCA). The score plot of PCA is illustrated in Figure 3-13, there is minimal separation between our two treatments. These results indicated that there were no gross differences between the composition of film-treated and not-treated kiwifruit peel composition in these 12 peaks. Also there were no indications that extracts from no film peels had significantly higher concentrations of metabolites.

UV light protection may be provided more strongly by compounds absorbing at 280 nm (the wavelength which is most damaging for DNA). To check if there was a clearer difference just within 280 nm peaks alone, two 350nm peaks were excluded, and the PCA was run again with the ten 280nm peaks (Fig. 3-14). However, again there was no sign of a clear separation between the two treatments (with and without film). These results indicated that there were no significant differences in compounds, such as phenolics, of kiwifruit skin peels between film treatment and no film treatment.

Table 3-1: Mean concentrations of major phenolic compounds, measured by HPLC at 280 nm and 350 nm. Results are mean of seven samples. Significance (Sig.) measured by ANOVA. NS means No significance between film and no film treatment ($P>0.05$).

Wavelength	**Ret. Time**	**Treatment**	**Peak area**	**Area adjusted for weight**	**Std er**	**Significance**	**% of no film**
280 nm	10.5	no film	354070	938311	187198.1	NS	81.73%
		film	339381	766918	136015.9		
280 nm	13.4	no film	2007424	5715817	1479340	NS	66.88%
		film	1718547	3822825	663948.5		
350 nm	8.4	no film	2840755	7130787	1952769	NS	76.45%
		film	2521906	5451542	886935		

Table 3-2: Mean concentrations of chlorogenic acid calculated by a standard curve which came from the results of separated chlorogenic acid injections of HPLC (Mentioned in previous chapter). Results are mean of seven samples. Significance (Sig.) measured by ANOVA. NS=No significance between film and no film treatment ($P>0.05$).

Wavelength	**Treatment**	**Average concentration (µg/g)**	**Std er**	**Significance**	**% of no film**
280nm	no film	13.71241	1.074386	NS	81.47%
	film	11.17197	0.939362		

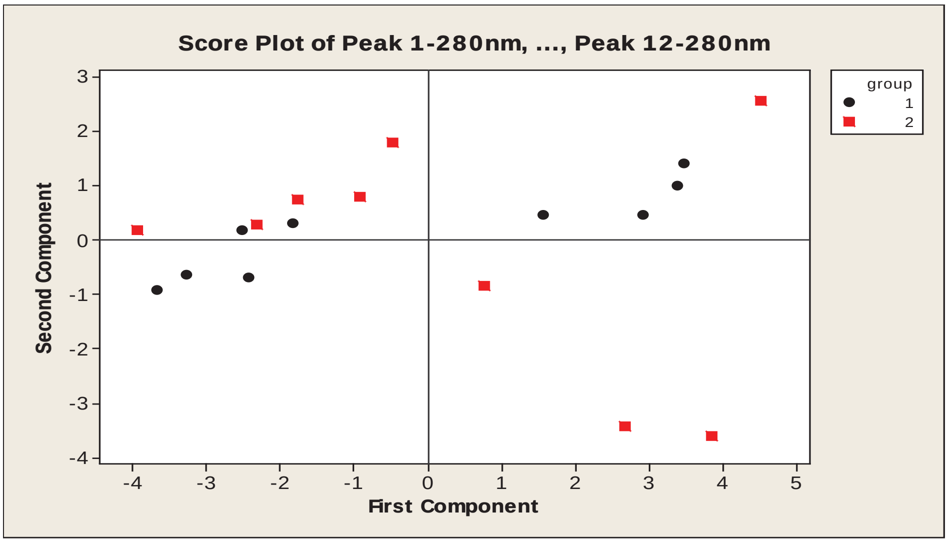

Figure 3-13: A PCA score plot of twelve peaks (including both 280 nm and 350 nm) of (+film) and no film treatment measured by Minitab 15. Group 1 = (+film) treatment; Group 2 = no film treatment. According to the figure, there is minimal separation between our two treatments indicating that there were no significant differences between (+film) treatment and no film treatment in phenolics of kiwifruit skin peels within both 280 nm and 350 nm.

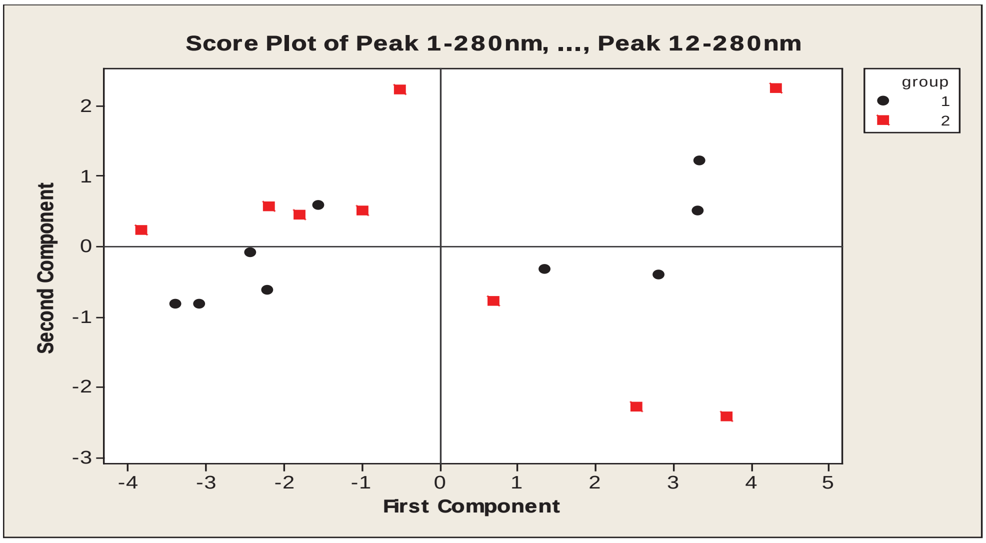

Figure 3-14: A PCA score plot of ten 280nm peaks of (+film) and no film treatment measured by Minitab 15. Group 1 = (+film) treatment; Group 2 = no film treatment. According to the figure, there is minimal separation between our two treatments indicating that there were no significant differences between (+film) treatment and no film treatment in phenolics of kiwifruit skin peels within 280 nm.

3.8 Changes in bud burst and fruitset

To find out whether and how the presence of reflective ground film would change kiwifruit bud burst percentage, leaf buds and burst buds number were counted on 40 canes (20 canes per treatment) on 13/9/12, 19/9/12 and 25/9/12 respectively and converted to bud burst percentage (Fig. 3-15). Although there were no significant differences between (+film) and (no film) treatment, according to Figure 3-15, bud burst percentage in (+film) treatment was consistently higher than that in (no film) treatment. These results indicate that the presence of reflective ground film may accelerate bud burst in the following season, before film is laid again.

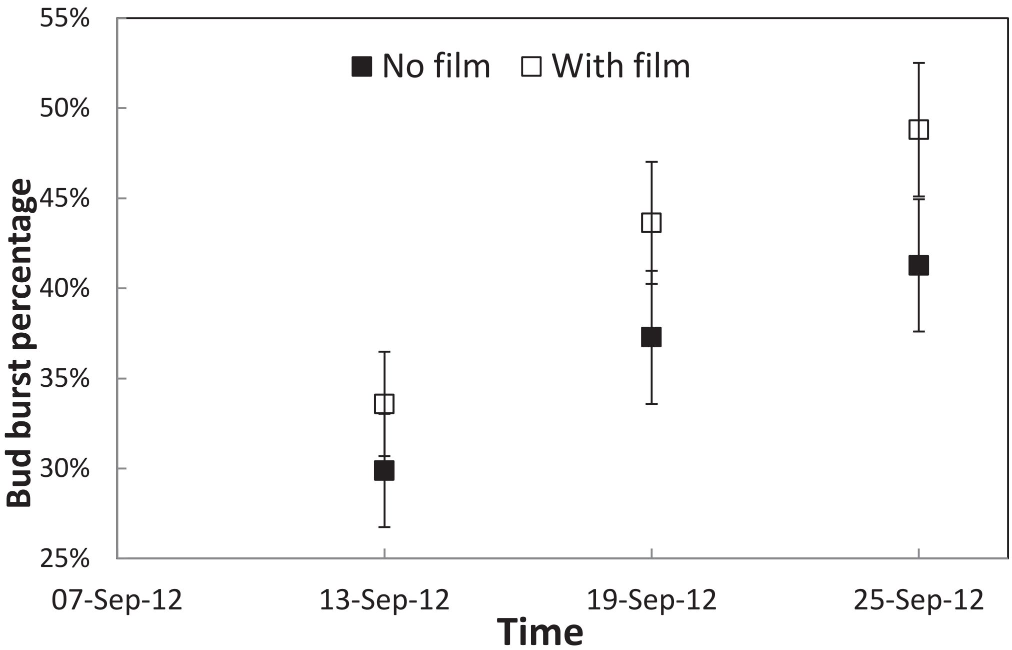

Figure 3-15: Bud burst percentage in Hayward kiwifruit with the presence of reflective ground-covering film (+film) or naked ground (no film), as a percentage of total buds. Data were collected on 13/9/12, 19/9/12 and 25/9/12. Each treatment is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 20 replicate canes per treatment. Compared with (no film) treatments, fruit cultivated in (+film) treatments exhibited much higher bud burst percentage. These results indicate that the use of film may appear to increase bud burst, the statistical analyses confirmed that there were no significant difference between these two treatments.

The results of fruitset percentage according to flower bud formation with and without film were presented in Figure 3-16. Data of flower bud number and fruitset number were collected in October and December respectively. Compared with (-film) treatment, vines treated with (+film) appeared to have a higher fruitset. However, both treatments illustrated low fruitset percentage, which could perhaps be due to poor pollination in the orchard. These results indicate that the presence of film may increase the percentage of fruitset, however, the statistical analyses confirmed that there were no significant difference between these two treatments.

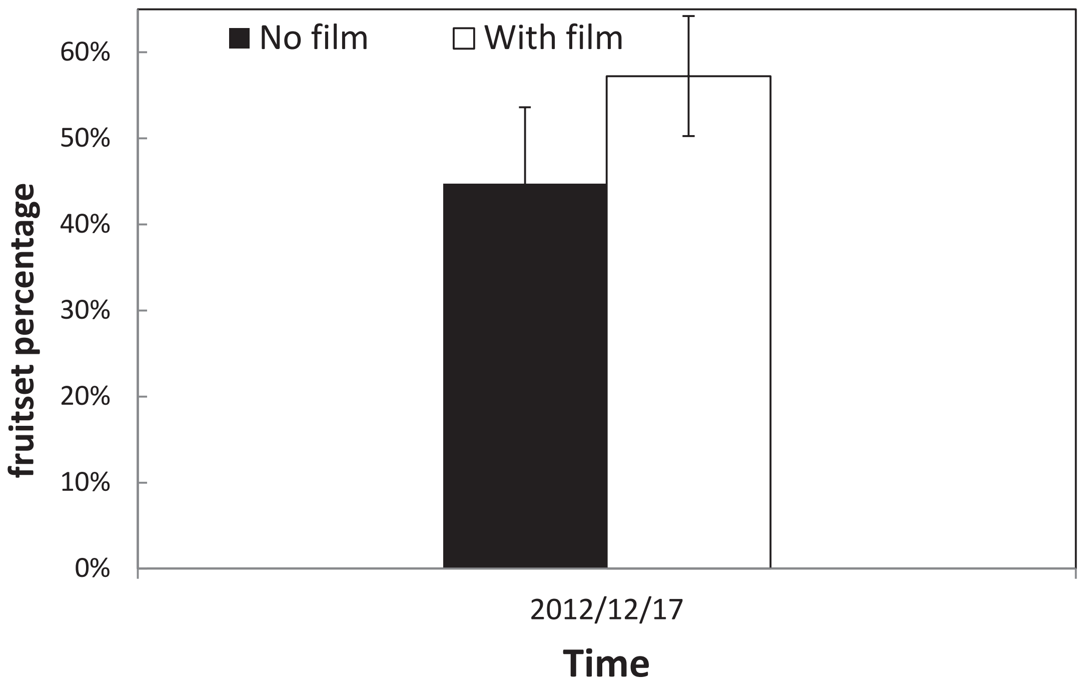

Figure 3-16: Fruitset percentage in Hayward kiwifruit according to flower bud number and fruitset number with the presence of reflective ground-covering film (+film) or naked ground (no film). Data of flower bud number and fruitset number were collected on 10/19 and 12/17 respectively. Each treatment is treated as a replicate in one-way ANOVA. Data presented are means ±1 SE of 20 replicate canes per treatment. Compared with (no film) treatments, canes treated with (+film) treatments exhibited much more fruitset. These results indicate that while the presence of film may appear to somehow increase fruitset percentage, the statistical analyses confirmed that there were no significant differences between these two treatments.

4 Discussion

4.1 Fruit quality measurements

The fruit size, soluble solids and fruit firmness, as well as dry matter of kiwifruit are important quality parameters. After harvest, fruit will lose firmness, turn soluble solids into sugar and those fruit displaying high dry matter at harvest will likely yield high quality (better flavor and thus consumer acceptability) after storage. The reduction of soluble solids concentration causes starch decrease during ripening, which influences flesh firmness, thus considerably reduces the storage life of kiwifruit (Tombesi *et al.,* 1993). For kiwifruit industry, the storage life of kiwifruit is a major concern because the majority of fruit will be exported to foreign markets. All these quality parameters mentioned above are largely influenced by light, which is a major factor of enhancing fruit primary metabolism such as photosynthesis. Photosynthesis is a process used by plants and other organisms to convert the light energy captured from the sun into chemical energy that can be used to fuel the organism's activities then converting CO_2 into carbohydrates, which is quite relevant to fruit quality parameters such as soluble solids. Liu X *et al.,* (2007) reported that in cv. Dangshan Su pear, when sunlight can be fully utilized and the fruit tree is properly trimmed, fruit canopy can increase light intensity to get better photosynthesis which contributes to a better inner physiological system, and thus the fruit quality will be improved. In this study, the light intensity enhanced the soluble solids content of cv. Dangshan Su pear.

In our experiment, it is clear that the presence of our reflective film has significant consequences for the light environment of our study vines, both in terms of spatial and spectral variation. In kiwifruit orchards, T-bar system and pergola system are two main vine support structure applied. It has to be noticed that our study vines are grown in an orchard applied T-bar vine support structure. The differences of the orientation of kiwifruit canes during growth in summer and during fruiting following year between T-bar and Pergola vine support structure are shown in Figure 4-1. A pergola provides a single plane of canopy, which is quite different from what T-bar system provides (Fig. 4-1). The differences of architecture indicate that the application of reflective ground films will have different effects on different kiwifruit vine support structure. These results obtained from this experiment are valuable for a T-bar using kiwifruit orchard, while they could possibly also be useful in pergola system because in our experiment the uppermost canopy with reflective film still got 5 fold higher light intensity than that the (-film) treated uppermost canopy got.

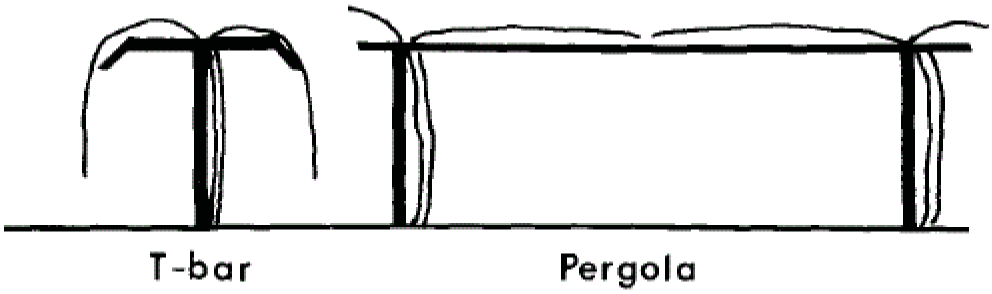

Figure 4-1: A diagram showing the orientation of kiwifruit canes during growth in both T-bar and Pergola vine support structures (Hopping *et al.,* 1993).

Compared with no film treatment, we found reflective ground cover had positive effects on fruit quality parameters such as fresh weight, firmness and dry matter percentage. Especially for fruit in lower canopy (a height of 0.7 m from the ground), they had the biggest increment in fresh weight and soluble solids (Brix value) as well as dry matter percentage by film application. The increment of soluble solids could have a positive effect on avoiding risk of fruit with low sweetness after long term storage. The possible reason of this big increment is that when we measured light environment inside the canopy, we found film helped the lowest canopy get the most irradiance at 400-700nm, which is in the range of best wavelength for photosynthesis, among all the canopy positions, thus increasing the light intensity which enhanced photosynthesis. However, under (+film) treatment, the middle canopy get the least irradiance among all the canopy positions, which possibly caused that those fruit in middle canopy were the softest fruit among three positions in film treatment. Nevertheless, these fruit were still firmer than those in no film treatment. These results indicate that reflective ground cover could enhance fruit quality by increasing the amount of light within the canopy available for photosynthesis, especially in the lower tree canopies. Despite the fact that we did not measure photosynthetic rate of any canopy leaves in our study, even small increases in net photosynthesis could affect fruit size and dry matter content, particularly if leaves proximal to fruit received non-limiting additional PAR. Hanrahan *et al.,* (2011) has already pointed out that in apple, reflective ground covers made of white woven mulch cloth have been shown to increase photosynthetically active radiation (PAR) within the canopy, especially in the lower parts of the canopy. Thus, without advancing maturity, reflective ground cover are reported to increase yield, fruit size, sugar content of apples (Grout *et al.,* 2004; Solornakin and Blanke, 2007), pears (Bertelsen, 2005) and kiwifruit (Thorp et al., 2001). Also in a study of kiwifruit, Costa G *et al.,* (2003) pointed out that reflective mulch had a positive effect on promoting photosynthesis during the day and the yield and average fruit weight were positively affected by the mulch. Besides the enhancements of individual fruit quality (such as lower canopy fruit), reflective ground covers also showed a tendency to promote fruit quality consistency in fruit fresh weight and dry matter percentage, which indicate that reflective ground covers are desirable for kiwifruit industry because they could help to remove poor performing fruit from population.

Although light can enhance photosynthesis, if the fruit canopy is exposed to excessive light (e.g. above 1000μmol quanta m^{-2} s^{-1}), there could be a risk of photoinhibition, as was discussed in the Introduction. In our experiment, the highest reflected irradiance we observed was 520μmol quanta m^{-2} s^{-1}, detected in the lower canopy (a height of 0.7 m from the ground), which is much less than 1000μmol quanta m^{-2} s^{-1}, a value which has been noted by some authors to place leaves at risk of photoinhibition. So it remains possible that reflective ground covers can positively affect fruit quality by increasing light intensity, thus promoting photosynthesis without having any negative effects.

Although both my data and unpublished data obtained from Thamarath Pranamomkith from the same project indicated that fruit had better retention of firmness in film-treated fruit among all the treatments after 1 month storage, unpublished data obtained from Thamarath Pranamomkith suggested that kiwifruit retained good firmness at the first five months of cool storage at 0°C, however, approximately 33% of the film treated fruit softened dramatically at 150 d of storage after taken the fruit out from the cold room and placed them at 20°C overnight (Fig. 4-2). This kind of disorder associated with symptoms like extreme softening of the fruit often happens when fruits were stored for too long at very low temperatures, which called as chilling injury (Bauchot *et al.,* 1999) or known as low temperature breakdown. These results gave us an insight that it is quite complicated in a process from pre-harvest studies to post-harvest studies; in this case, reflective ground cover has many positive contributions, nevertheless it may have an increased susceptibility to low temperature breakdown. In a study of kiwifruit 'Hayward' (Lallu, 1997), 'Hayward' kiwifruit were placed into temperature cabinets set at –0.5, 0.0, 0.5, 1 or 2.5℃ for 24 weeks. Low temperature breakdown symptoms were significantly lower in fruit stored at temperature above 1℃ than in fruit stored at or below 0℃. So to avoid low temperature breakdown in fruit applied reflective mulch, storage temperature could be an important factor.

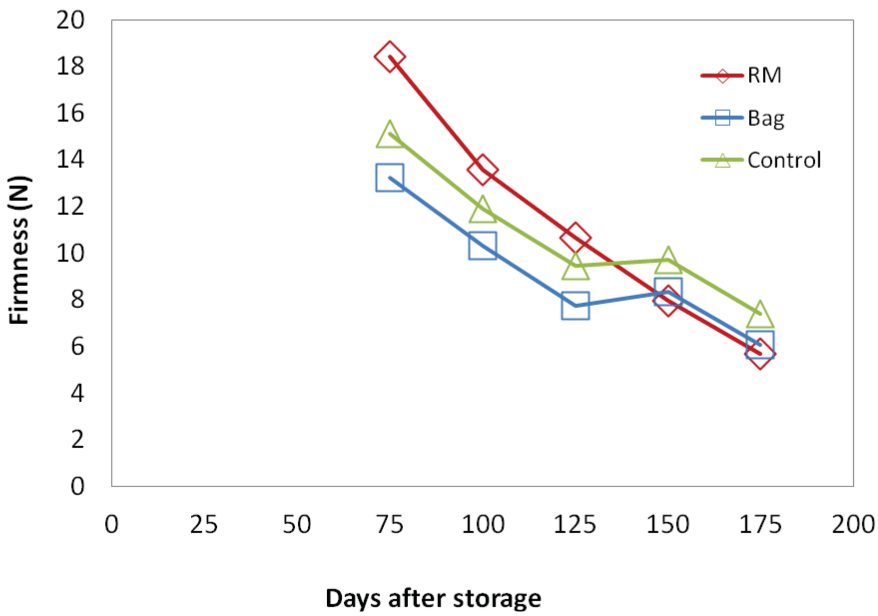

Figure 4-2: Firmness in Hayward kiwifruit with in the presence of reflective ground-covering film (RM), bag treatment and naked ground (Control). There is a sharp reduction of fruit firmness of the RM treatment after 125 d of storage. (Unpublished data obtained from Thamarath Pranamornkith) *NB: at each sampling point contain 4 replications, each rep has 23 fruit, except at 175 d (only 1 rep left).*

In terms of fruit skin colouration, reflective ground covers have been reported to enhance fruit colouration in several different crops, such as apples (Grout *et al.,* 2004; Solornakin and Blanke, 2007), pears (Bertelsen, 2005) and kiwifruit (Thorp et al., 2001). Also in the same project, data obtained from Thamarath Pranamornkith suggested that regardless of canopy positions, there were significant skin colour differences between film and no film treatment (Table 4-1), which indicated that reflective ground cover had effects on changing kiwifruit skin colour. These colour differences between treatments emerged fairly soon after film laying (data not shown), which suggests that the differences may relate to colour development in living skin, before it became dead at maturity.

Table 4-1: Skin colouration measured as L* - brightness, c* - chroma, h*- hue angle in Hayward kiwifruit with in the presence of reflective ground-covering film or naked ground (no film) at harvest (Data obtained from Thamarath Pranamornkith)

Colour	L*	c*	h*
Bagged	51.95 a	32.43a	83.77a
no film	46.60 b	27.43b	78.00b
film	45.40 c	26.06c	75.48c
$LSD_{0.05}$	0.55	0.59	0.8
n	105	105	105

However, in my experiment, reflective ground covers did not exhibit a strong inclination on changing fruit skin colour. There were no significant differences in fruit skin parameters measured as c* -chroma and h* -hue angle between film and no film treatment regardless of canopy positions. Fruit under (+film) treatment were significantly brighter (higher L*-brightness) than fruit cultivated in (-film) treatment. Fruit from middle canopy under (+film) treatment were significantly different from fruit treated without film. It is difficult to tell whether the presence of reflective ground film has effects on changing kiwifruit skin colour because of too many factors involved in this parameter. The sample number of Pranamomkith's project for each treatment was 105, which was far more than my 45 sample fruits for each treatment. So it is possible that due to the limitation of my fruit sample number, there were no significant differences between film and no film treatment in my experiment.

As it is mentioned in introduction chapter, light is also relevant to plant secondary metabolism. The elevations of light (including UV light) can elevated fruit phenolics content. However, in our experiment, we did not find that reflective ground cover has any positive effects on plant secondary metabolism, which in our case, was the relationship between film and phenolics content of kiwifruit skin. There was a study in wine grapes (Coventry *et al.,* 2005) which reported that reflective ground cover enhanced total phenolics in berries by increasing light intensity. Nevertheless, when we measured phenolics of peels by HPLC, there were no significant differences in phenolics of peels between (+film) treatment and no film treatment, and in some major peaks, peels of no film treatment had more phenolics. In a study of kiwifruit skin, Hallett and Sutherland (2005) mentioned that the skin of Hayward kiwifruit has a complex structure comprising a thick layer of dead, radially compressed cells with suberised cell walls over the hypodermis, which means the thicker the skin, the more the dead cells. As we mentioned in the results chapter, fruit of (+film) treatment had higher fresh weight and thicker outer suberised layers, which means if the same peeler was used to peel fruit from both (+film) treatment and (-film) treatment, the thickness of the fruit peel was same which was approximately 1mm. And the peel was always attached with some flesh. So in our phenolics experiment, the thicker the peel, the less flesh attached (Figure 4-3). Those fleshes were not scrapped out when these peels were extracted. Therefore, it is possible that there were more dead cells on cuticles from (+film) treatment than those from no film treatment, which could explain the reason why there were not more phenolics in those peels in the (+film) treatment.

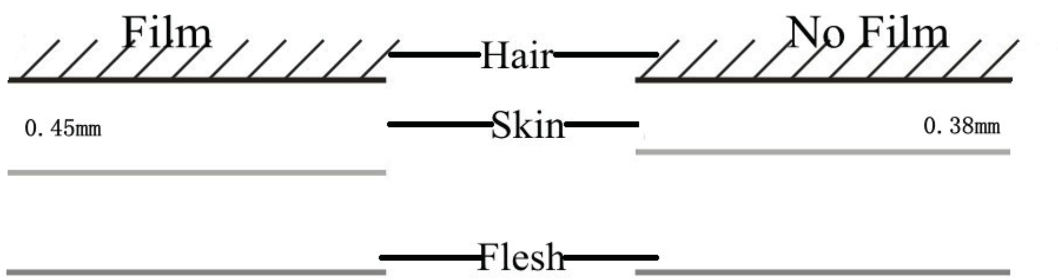

Figure 4-3: A simple diagram of kiwifruit peel. Both peels contain outer epidermal layers ('skin') and attached flesh from (+film) treatment and no film treatment have same thickness (approximately 1mm). Based on the results of outer suberised layer thickness, the (+film) peel has thicker skin (0.45mm), with less flesh attached; while the peel from no film treatment attaches more flesh, thinner skin (0.38mm).

For UV absorbing compounds, compared with (no film) treatments, peels of fruit cultivated in (+film) treatment did not exhibit more UV absorbing compounds regardless of canopy positions as well as that there were no significant differences between (+film) and (-film) treatment. UV absorbing compounds are normally considered as sun-screen of fruit. As reflective ground cover enhanced irradiance in kiwifruit canopy as well as that in the transmission experiment indicated that peels under film treatment absorbed more light, which suggests they may be expected to have produced more UV absorbing compounds. In fact, our results are quite opposite of our expectation: it is the peel from no film treatment that exhibited more UV absorbing compounds. From the results of transmission experiment, it seems that most of the UV light was absorbed by peels from both (+film) and (-film) treatment. Browning of caused by the progressive death of epidermal cell layers progressed during fruit expansion. It is possible that all the UV light was absorbed by these outer suberised layers, which means living cells at harvest were well shielded from external UV light. And since there were more dead cells (thicker outer suberised layer) in (+film) peels (Figure 4-3), this may possibly result in less UV absorbing compounds in (+film) peels. Another possible reason to explain this result could be that although the application of reflective ground cover may enhance light irradiance in kiwifruit canopy, but the enhancement is probably not enough to change the second metabolism which in our case is to increase the amount of UV absorbing compounds.

4.2 Bud break, return bloom and fruitset

Light always plays essential roles in regulating induction and release of bud dormancy. From the results, although statistical analyses confirmed that there were no significant differences between (+film) treatment and (-film) treatment, it could be seen that (+film) treatment appear to have a positive effect on bud break, return bloom as well as fruitset, which has also been reported in a study of apple (Hanrahan *et al.*, 2011), when the reflective ground covers were applied in a full season, there is an increase in return bloom and therefore potential crop load in the second season. This is due to the enhanced light conditions in the previous season giving rise to more carbohydrates which store in plants, thus produce more fruitful wood, especially in the lower canopy which is usually more shaded without reflective ground cover. Faster budbreak is desirable in kiwifruit industry, because some international markets, such as

European market, require early fruit.

It is obvious, in kiwifruit, on vines in the field that those grown under heavy shade flower poorly the following (‘return bloom’) season in comparison with those that grow in well-exposed situations (Kiwifruit: science and management, 1990). Also it has been reported in a study of pears cv. ‘Clara Frjis’ that the application of reflective ground covers had positive effects on pears flower formation (Bertelsen, 2005). In terms of fruitset, Grant and Ryugo (1984) found that in kiwifruit, buds on exposed shoots gave rise to shoots which were over three times more fruitful than buds on shaded shoots by using manipulated vines in the field. It is possible that the enhancement of light in the previous season promoting the bud break in kiwifruit. These results indicate that reflective ground film may appear to have a positive effect on bud break and flower bloom as well as fruitset in the following season by enhancing light intensity in the previous season.

5 Conclusions

It is clear that the application of reflective ground films from 20th December 2011 until harvest (11th May 2012) had some positive effects on fruit quality at harvest such as fruit fresh weight, fruit firmness, soluble solids content and fruit dry matter percentage by changing light intensity, which probably thus enhanced the photosynthesis, especially in fruit of lower canopy. Besides the enhancements of individual fruit quality, reflective ground films also showed a tendency to promote fruit quality consistency in fruit fresh weight and dry matter percentage, which indicate that reflective ground films are desirable for kiwifruit industry because they could help to remove poor performing fruit from population. The application of reflective ground films may also appear to have an enhancement of the bud break, return bloom and fruitset in the following season. However, as it was mentioned before, the orchard where our experiment was conducted is using T-bar to grow kiwifruit. Nowadays, T-bar and pergola systems are the most popular systems applied in the commercial orchards to grow kiwifruit. These results obtained from this experiment are valuable for a T-bar using kiwifruit orchard, while they also could possibly be useful in pergola system because in our experiment the uppermost canopy with reflective film still got 5 fold higher light intensity than that the uppermost canopy without film got. So it is possible that reflective ground covers will be the best choice to an orchard which is a high density, well-managed orchard where trees are already highly efficient and the availability of light is the major limiting factor for any further increases in productivity.

However, there are still several aspects unknown in this study which need to be studied carefully in the future. For example, although now we think the positive effects of reflective ground films on fruit quality are owing to the enhancement of photosynthesis, but the photosynthetic capacity of leaf was not measured in this project. Also although the results indicate that reflective ground films have positive effects on several fruit quality parameters at harvest, from the unpublished data mentioned in discussion chapter, it seems that reflective ground cover may have an increased susceptibility to recognized storage disorder, which means the film-treated fruit may have to be sold early or we could try to prevent low temperature breakdown by changing storage temperature. Meanwhile, the relationship between reflective ground covers and kiwifruit skin phenolics content are remaining unclear. Many of the differences described here were not statistically significant, to see these subtle effects may require much larger experiments. Thus, to fully understand the effects of reflective ground covers in the future, more experiments which involve larger sample number are needed, and moreover, sample fruits should be measured based on storage time to further understand the effects of reflective ground covers on kiwifruit storage life.

6 References

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