Green Office Vrije Universiteit Amsterdam

Science for Sustainability Journal
Green Office VU

Influence of UV absorbing films on yield, quality and pest activity of protected strawberry crops

Inder Kumar[1]
[1]University of Reading, Reading, UK

*Corresponding author: Inder Kumar
E-mail: inderkumarpannu@yahoo.in
Orcid: https://orcid.org/0000-0001-9358-9616

ABSTRACT

The cultivated strawberry (*Fragaria x ananassa* Duch.) is a highly valuable and economically crucial soft fruit crop. Strawberries are famous due to their particular flavour, colour, quality, and appearance, as well as their nutritional value. They are one of the top ten crops cultivated and consumed in the UK. However, due to the limited season for cultivation but all year demand, there is still a high level of imported fresh produce from other prominent strawberry producing countries both in Europe and worldwide. There is a potential to develop new horticultural films with in-creased UV absorption to reduce pest and disease incidence, improve the yield of strawberries grown under protection and extend the strawberry season in the UK further; this is because insect visualisation and host recognition are influenced by UV radiation, and the life cycle of many fun-gal diseases relies on UV light. Therefore, an experiment was set-up to study the effect of four newly developed UV absorbing horticultural films (ranging from complete UV transmission to complete UV blocking) on strawberry plant growth, yield and fruit quality, as well as pest infestation. Overall, plant growth and fruit quality were largely unaffected by UV absorbance. Still, the yield was enhanced, and the thrips population significantly reduced, which are beneficial outcomes for the strawberry industry. The partially UV absorbing film (UV 370) performed considerably better than other films regarding fruit quality and yield. The completely UV blocking film (UV 400) was serving better initially but degraded after the second peak harvest resulted in reduced performance later. If the UV 400 film could be stabilised to prevent degradation, there is the potential to improve strawberry fruit yield and quality.

1. Introduction and Literature Review

1.1 The Strawberry

The garden strawberry (Fragaria x ananassa Duch.) is a highly valuable, non-woody, and herbaceous soft fruit crop. From historical times, strawberries are a part of different cultures and cuisines; serving fresh strawberries with sour cream to a newlywed couple as a morning break-fast is a tradition in the western world. Berries are consumed both in raw and cooked forms and can be used as dressing on desserts, processed into jams, and dried leaves are used as tea. Strawberries are one of the most domestically and commercially cropped soft fruits due to their appealing flavour, colour, quality and appearance (Bruhn et al., 1991).

1.1.1 Health Benefits of Strawberries

Strawberries are a good source of Vitamin C and Vitamin K, and they are rich in fibre, folic acid, manganese and potassium as well as being low in fat; a 100 g serving of strawberries contains 32 Calories, 0.3 g fat, 7.7 g of carbohydrate, and 2 g fibre. The anthocyanin pigments which give the strawberry its red flesh contain antioxidants that protect against inflammation and heart diseases. Strawberries are also rich in fructose sugar and help maintain blood sugar levels which means they are recommended to diabetic patients (Lewin, 2016).

1.1.2 Strawberry Consumption in the UK

Strawberries are highly consumed in the UK and are the 8^{th} most cultivated crop in the UK. The UK ranks 14^{th} for global strawberry production (FAOSTAT, 2017), with cultivation from May to October. For the year around availability of strawberries in supermarkets and to support domestic consumption out of season, the UK import strawberries from Morocco, Spain, Israel, and Egypt, which are significant producers and exporter of strawberries globally (FAOSTAT, 2017).

1.1.3 Strawberry Consumption in India

In India, strawberries are a symbol of luxury and are consumed only occasionally due to low availability and high price. There is limited opportunity for strawberry cultivation due to the tropical climate and issues including low production levels, soil-borne diseases, pest infestation, lack of modern cultivation technologies and a high market price. At present, scientific research in India is limited, and there is uncertainty in the strawberry supply chain at the commercial level (Pramanick et al., 2013).

1.1.4 Technology adoption in India

The adoption of technology, including cultivation under protection (polytunnels) and soil use-fewer media (coir), such as that used in the UK, has massive potential to improve strawberry cultivation in India. The cultivation of strawberries is limited to risk-bearing progressive farmers only. Long summers, cheap labour for picking coupled with polytunnels and soilless media could potentially reduce the risk of strawberry cultivation, increase productivity, increase the overall area under cultivation, decrease cost price ratio, and ultimately provide an opportunity to reach ordinary man's daily diet.

History of Domestication

The cultivated strawberry (*Fragaria x ananassa* Duch.) is a hybrid of F. virginiana and F. chiloensis and belongs to Family Rosaceae, Sub-Family Rosoideae and Genus *Fragaria* (Darrow, 1966). The first hybridisation occurred in the 18th century in France. It marked the beginning of the domestication and commercialisation of strawberry as the resulting hybrid *Fragaria x ananassa* produced fruit, which was larger and had a better flavour, aroma and earlier/longer fruiting period than the native species (Wilhelm, 1974).

1.1.5 Morphology of Strawberry Plant

Strawberry is a non-woody perennial plant made up of the crown, leaves, inflorescences, runners and root system (Figure 1).

Crown and Stolons

According to Darrow (1966), the crown is the shortened stem from which the primary roots arise. Runners (stolons) also elongate from the mother plant to produce daughter plants.

Inflorescence and Flower Type

A cluster of flowers is formed and arranged in a dichasial cyme during blooming. The inflorescence is a modified stem having terminal blossoms consisting of primary, secondary, and tertiary flowers, creating a cluster of terminal flowers. The flowers are hermaphroditic with six sepals, six petals, 20-35 stamen, hundreds of pistils (Darrow, 1966).

Fruit Type

Strawberry fruit is aggregated, achenes are the 'true fruits' and the fruit's edible part is a fleshy receptacle. Strawberry is both self-pollinated and cross-pollinated; the wind is the primary source of pollination, with insects promoting pollination.

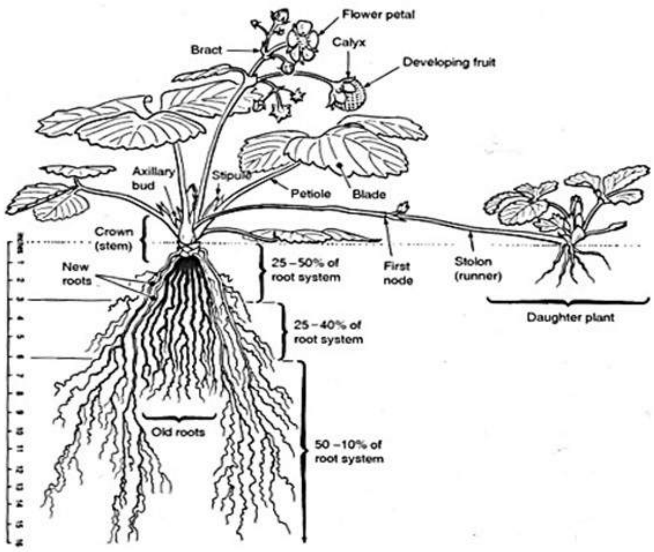

Figure 1: Morphology of the strawberry plant (Darrow, 1966).

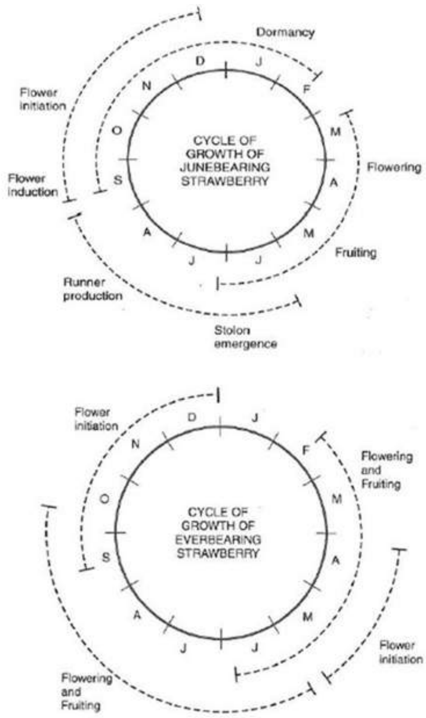

Figure 2: Lifecycle of Junebearer strawberry plant type (left) and Everbearer strawberry plant type strawberry (right) (Durner, 1984)

1.1.6 Strawberry Plant Types: Junebearers and Everbearers

According to Durner, Barden, Himelrick, and Poling (1984), the strawberry plant can be one of two types: Junebearer or Everbearer. Junebearer plants are short-day plants; flowering is initiated in autumn when temperatures are low, and photoperiods are short. Blooming take place in the following spring, and the first fruits are harvested from mid-May to mid-July (Figure 2). In Everbearer plants, fruiting typically occurs with two cropping peaks, the first bloom occurs in spring from the flower buds initiated in autumn (as in Junebearer plants), but a second bloom takes place in late-summer from flowers undertaken in spring, meaning that Everbearers can be harvest until early-October (Figure 2).

1.1.7 Strawberry Production

The world's top five strawberry producers are China (38.7% of global production), the USA (17.5%), Mexico (4.9%), Turkey (4.8%) and Spain (4.0%) (FAOSTAT, 2017).

UK Statistics

UK strawberry production is ranked 14^{th} globally, with 101,411 tonnes harvested in 2014 (FAOSTAT, 2017) and a production value of $128,090,490. Presently, strawberry cultivation occurs across 5400 Ha, primarily in Kent, Herefordshire, and Norfolk (DEFRA, 2017). Cultivation in polytunnels under horticultural films started in the 1990s, whereby previously stagnant production levels increased significantly despite a gradual reduction in the country's crop area. Commercial strawberry cultivation in soil-less media using hydroponics started in Europe in the 1970s. It was developed in The Netherlands and Belgium to reduce soil-borne diseases, including root diseases and nematode diseases, and reduce pest damage on fruits and vegetables (Lieten, 2013). Cropping under protection using horticultural films provided a new avenue for the British strawberry season. It enabled the season to be extended from 6-8 weeks in June and July to 6-7 months from April to October. Moreover, high-quality fruit is being produced to meet the commercial standards and consumer demand.

India Statistics

Strawberries are a lavish soft fruit for the Indian market, and only 1610 tonnes were produced in 2014 (FAOSTAT, 2017). Cultivation occurs in specific regions such as Mahableshwer in Maharashtra province with marginal production in Northern India such as Srinagar, Shimla, Haryana and Punjab primarily to meet the commercial demand of deluxe hotels and restaurants in metropolitan cities. Presently cultivation is in the soil on approximately 30-35 raised beds/acre and 1000 plants/bed with plastic mulch and drip irrigation. Planting occurs in October, with harvest in January; Farmers typically intercrop garlic, chilli, and onion in February to provide shade in May and allow for late harvesting until mid-May (IndiaAgronet, 2017).

Relevance of Technology Adoption in India

Due to disease infestation such as grey mould (*Botrytis cinerea*), powdery mildew, nematodes and pests such as red ants and aphids, research at the institutional level is being carried out to cultivate strawberry in soil-less media of cocopeat + perlite + vermicomposting (3:1:1) with drip irrigation system (Pramanick et al., 2013). Soilless media cultivation via peat is less sustainable due to environmental hazards. Coir (coconut husk) is more environmentally friendly and can enhance the soft fruit industry's quality and quantity (Asaduzzaman et al., 2015). The main aim of India's research is to promote cost-effective cultivation at a mass level and reduce production and consumption price ratio. Cultivating strawberries on tabletop systems with coir bags and drip irrigation provides the opportunity to produce strawberries in media free from soil-borne fungal diseases, root diseases, nematode infestation, and insect attack grower complete control over the water and nutrient supply to the plants.

1.1.8 Strawberry Production under Polythene

According to Krizek, Clark, and Mirecki (2005), in the past few decades, research on the development of UV absorbing and UV transmitting films intensified due to an expected potential to increase the quality and yield of fresh produce. A study was conducted by Krizek et al. (2005) with UV absorbing and UV transmitting films to guide researchers and growers to cultivate high-value crops; results stated that films absorbing radiation up to 380 nm showed better results of quality and yield. Another study on lettuce showed that the concentration of antioxidants and phenolic compounds were significantly greater in UV blocking films than UV forthcoming films, and overall yield was also increased (García-Macías et al., 2007). An experiment conducted by Tsormpatsidis et al. (2008) also showed that lettuce plants grown under UV blocking films (UV 400 nm) had a greater dry weight (2.2 times) compared to those grown under UV transmitting films. Still, anthocyanin content was eight times lower when UV radiation was blocked, negatively affecting the product's quality.

For pest and disease control, Diaz and Fereres (2007) stated that UV blocking films interfere with the vision of pests and vectors inside polytunnels and thus reduce pest and disease infestation. Doukas and Payne (2007) experiment with studying the effect of UV films on insects and found there were 5.8 and 23.4 times more aphids caught in a light trap inside UV transparent films and complete UV blocking films (up to 400 nm), respectively, as compared with films blocking UV up to 385 nm.

1.2 Experimental Aim

Standard horticultural films contain UV absorbing compounds that protect the film from UV breakdown and absorb UV up to a wavelength of 350 nm. There is a potential to develop new horticultural films with increased UV absorption to reduce pest and disease incidence and improve the yield of strawberries grown under protection; this is because insect visualisation and host recognition influence UV radiation. Alongside learning about protective strawberry cultivation in the UK and how this technology could be adopted in India, the research aims to study how UV radiation affects strawberry plant growth, yield, quality and behaviour, or some of the significant strawberry pests.

1.3 Experimental Objectives

- To experiment with horticultural films with four different levels of UV absorbance ranging from complete UV transmission to complete UV blocking on time to flowering and fruiting, yield, berry number, average berry weight, fruit quality characteristics including sweetness, Vitamin C, titratable acid, fruit firmness and shelf life and insect behaviour including the response of Western Flower Thrips (WFT) and Spotted Winged Drosophila (SWD).
- To experiment on the two different plant types of strawberries (Junebearers and Everbearers).

1.3.1 Cultivars Studied

Malling Centenary (MC), originally MallingTM Centenary, is a Junebearer cultivar bred by the East Malling Research Strawberry Breeding Club. It was selected in 2006 and commercially released for all-around production in the UK in 2008. Malling Centenary is a popular Junebearer, an early-main season cultivar with high fruit quality (flavour, Brix, and shelf life). It has a large berry size with over 90% Class 1 yield and can maximise picking efficiency and reduce waste and harvest costs. Malling Centenary has tolerance to powdery mildew, but as it has hairy leaves and petioles petiole, it tends to hold moisture-prone to grey mould (NIAB EMR, 2017).

Amesti (AM), originally Driscoll©Amesti™, is an Everbearer cultivar released by Driscoll's breeding programme and is famous for its large berry size with bright red flesh. Characteristics such as good shelf life, long harvest period, appearance and tolerance for powdery mildew make it a popular cultivar.

2. Material and Methods

Based on research objectives, there were two parts of the experiment; for the first part, an experiment was set-up at the University of Reading's Sonning Farm designed to examine the effect of a range of horticultural films ranging from complete UV transmission to complete UV block-ing on strawberry yield, quality, and plant growth. The second part of the experiment was set-up at NIAB-EMR, East Malling, Kent, to study the behaviour of strawberry pests on the same set of films.

2.1 Experimental Design

2.1.1 Sonning Farm, the University of Reading, Berkshire

Plant Material and Experimental Design

The experiment was performed using two strawberry cultivars, the Junebearer cultivar Malling Centenary and the Everbearer cultivar Amesti. The experiment was set-up in 16 mini polytun-nels, each with a dimension of 3 m x 8 m x 2.5 m (W x L x H). The cultivars were planted in coir filled bags on the tabletop system (Figure 3).

The experimental design was a complete randomised block design, with four blocks and one replication per block (Figure 4). There were six bags of each cultivar in each mini-tunnel, each containing eight plants planted on 21st March 2017, giving a total of 96 plants per tunnel. Four different types of UV films were used for the experimental treatments; two of the firms partially blocked UV radiation up to the following wavelengths: 350 nm (UV 350) and 370 nm (UV 370), whilst the other two films completely blocked UV radiation (UV 400) and wholly transmitted UV radiation (UV Open).

Figure 3: The 16 mini-tunnels at the University of Reading's Sonning Farm (left) and inside view of a mini-tunnel showing the table top system with coir bags and drip irrigation system (right)

Plant Husbandry and Environmental Monitoring

A drip irrigation system provided fertigation in each tunnel; four drippers per bag provided water and nutrients to the plants at a rate of 2.2 L / hr. Plants received four irrigation events per day with an interval of 3 hours. The feed tanks, dosatron injectors and water supply are shown in Figure 5. Two different feeds were used to varying cropping stages; the first was a starter feed (Strawberry Starter, Solufeed Ltd, Bognor Regis, UK) used until 50% flowering. The second feed, a fruiting feed (Strawberry Special, Solufeed Ltd, Bognor Regis, UK), was used for the remainder of crop-ping (Table 1). The pH of the water supplied to the tunnels was reduced to 5.5 pH using dilute nitric acid.

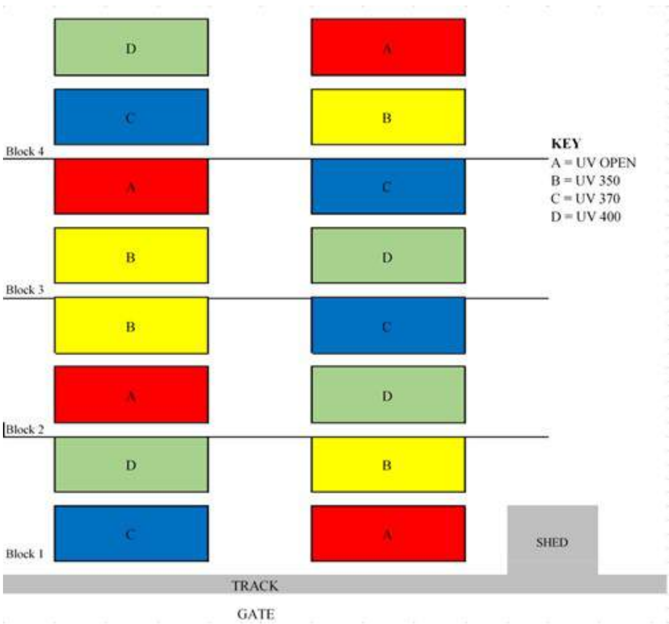

Figure 4: Arrangement blocks and treatments for the 16 mini polytunnels at the University of Reading's Sonning Farm. Code 'A' stands for UV film transmitting UV radiation (UV Open), code 'B' and 'C' stand for the films partially blocking UV radiation up to 350 nm (UV 370) and 370 nm (UV 370) and code 'D' stands for the film blocking UV radiation up to 400 nm (UV 400)

To reduce pest and disease infestation, beneficial species for the biological control of several pests were introduced, which included: predatory mites for thrips (Amblyline cu, *Amblyseius cucumeris* / *Neoseiulus cucumeris*) and red-spider mites (Phytoline p, *Phytoseiulus persimilis*) and parasitic wasps for aphids (Aphiline c, *Aphidius colemani* and Aphiline e, *Aphidius ervi*) and whitefly (Encarline f, *Encarsia formosa*). All biological control agents were provided by Syngenta Bioline, Clacton-on-Sea, UK and applied every two weeks throughout cropping. Fungicides were sprayed to reduce powdery mildew and botrytis in the tunnels. Weeds and dead leaves were removed by hand at weekly intervals, and both the front and back doors of the mini-tunnels were kept open for the circulation of fresh air.

A temperature sensor (PT 100 Solar Sensor, Omega Engineering Limited, Manchester, UK) and solarimeter (Tube Solarimeter, Delta-T Devices, Cambridge, UK) were placed in each tunnel (Figure 7), and temperature (°C) and irradiance (kW/m^2) was measured in each tunnel (Figure 6). Data was logged every 20 minutes using a data logger (DT 500 Data Taker, National Instruments Corporation LTD, Newbury, UK), set up inside a shed next to the mini-tunnels with a live feed available to view on a PC monitor. The temperature sensor was placed inside an aspirated box. A picture of the sensors and data logger is shown in Figure 6.

Figure 5: Irrigation system consisting of A) calcium feed tank B) starter feed tank C) fruiting feed tank D) dosatrons (1:64 injection) and E) pre-acidified water supply (pH 5.5)

2.1.2 NIAB-EMR, East Malling, Kent

Plant Material and Experimental Design

The experiment was performed using the Everbearer strawberry cultivar Amesti only. The experiment was set-up in 12 Polytunnels, each 12 m x 2 m x 1.5 m (L x H x W). All tunnels were sealed using insect-proof mesh (Figure 8). The same four films used for the mini-tunnels at the University of Reading were used for the experimental treatments. The experimental design was a complete randomised block design, with three blocks and one repli-

Nutrient	Strawberry Starter (%)	Strawberry Special (%)
Total nitrogen (N)	14.9	2.2
– NO3-N	11.1	1.6
– NH4-N	3.8	0.6
Phosphorus pentoxide (P2O5)	6.9 (P:3.0)	9.2 (P:4)
Potassium oxide (K2O)	29.9 (K:25)	29.0 (K:24)
Magnesium oxide (MgO)	2.8 (Mg: 1.8)	8.9 (Mg:5.6)
Boron (B)	0.01	0.03
Copper (Cu) (as EDTA)	0.002	0.03
Iron (Fe) (as EDTA)	0.1	0.3
Manganese (Mn) (as EDTA)	0.1	0.17
Molybdenum (Mo)	0.001	0.008
Zinc (Zn) (as EDTA)	0.002	0.14
Calculated EC at 1 g / L	1.44 Ms	1.23 Ms

Table 1: Composition of Solufeed Strawberry Starter and Strawberry Special

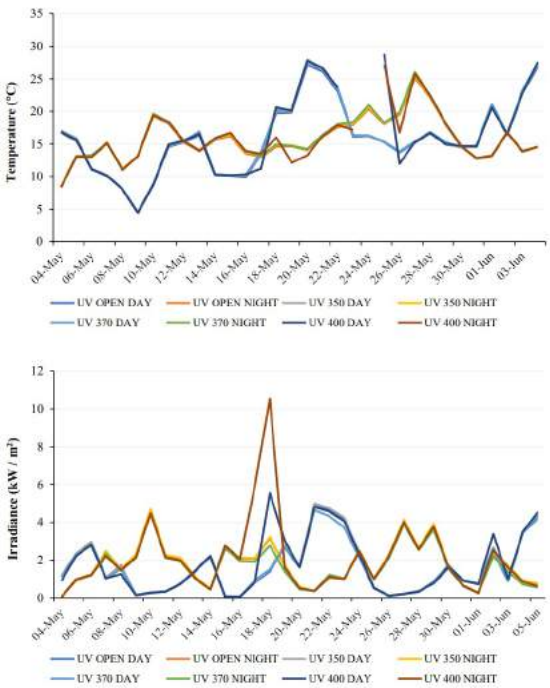

Figure 6: Average temperature (top) and solar irradiance (bottom) logged for each treatment in the mini- tunnels at the University of Reading's Sonning Farm

cation per block (Figure 9). Inside each mini-tunnel, nine bags containing ten plants give 90 strawberries plant per tunnel.

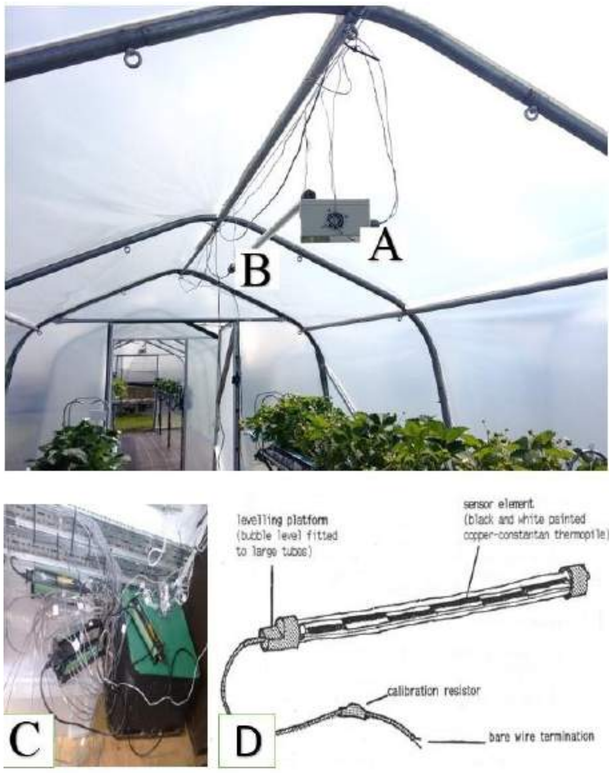

Figure 7: Environmental monitoring at the University of Reading's Sonning Farm. A) temperature sensor in-side an aspirated box hanging inside one of the mini-tunnels B) tube solar emitter hanging inside one of the mini-tunnels C) data logger D) diagrammatic view of tube solarimeter showing working principle

Plant Husbandry and Environmental Monitoring

Fertigation inside tunnels was supplied by drip irrigation to provide water and fertiliser, similar to the University of Reading's Sonning Farm set-up. No insecticide or fungicides were applied. Hand weeding was carried out inside tunnels once a week to prevent insects' alternate hosts. Data loggers were installed inside each tunnel to monitor temperature and humidity; data was logged every 30 minutes (Figure 10).

2.2 Data Collection

2.2.1 Sonning Farm, University of Reading, Berkshire

Flowering and Fruiting Time

The date at which 50% of the plants in each tunnel's bag has at least one open flower and then one ripe fruit was recorded, and the average number of days from planting calculated for each cultivar and treatment.

Cropping Performance

Fruits and runners were picked once every week and twice weekly at peak harvest, with data combined to weekly. Each harvest yield, berry number and runner number per bag were recorded. Yield and berry number were divided into marketable, unmarketable (less than 10 g, otherwise acceptable) and rejected (less than 10 g, non-uniform colour, diseased or pest damage).

At the end of fruiting, the following were calculated:

- **Total Marketable Berry Number:** The total number of marketable berries.
- **Total Marketable Yield:** The total weight of the marketable berries.
- **Total Un-Marketable Berry Number:** The total number of un-marketable berries.
- **Total Un-Marketable Yield:** The total weight of the un-marketable berries.
- **Total Rejected Berry Number:** The total number of rejected berries.
- **Total Rejected Berries Weight:** The total weight of the rejected berries.
- **Total Berry Number:** The total number of berries.
- **Total Berry Weight:** The total weight of all berries.
- **Average Marketable Fruit Weight:** calculated (marketable yield / marketable berry number).
- **Percentage Class 1 Yield:** calculated as (marketable yield / total yield) X 100

Figure 8: Outside view of the mini-tunnels at NIAB EMR (left) and inside view of mini-tunnels showing the Amesti plants in substrate bags and irrigation supply (right)

Figure 9: Arrangement of blocks and treatments for the 12 polytunnels at NIAB EMR. Code 'A' stands for UV film transmitting UV radiation (UV Open), code 'B' and 'C' stand for the films partially blocking UV radiation up to 350 nm (UV 370) and 370 nm (UV 370) and code 'D' stands for the film blocking UV radiation up to 400 nm (UV 400)

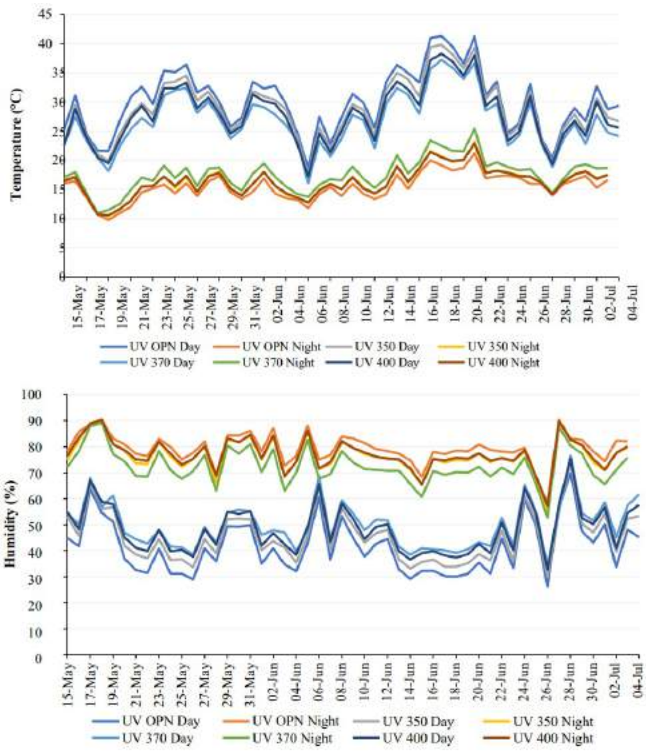

Figure 10: Average temperature (top) and humidity (bottom) logged for each treatment in the mini-tunnels at NIAB-EMR

Fruit Quality

Fruit Grading: Berries were graded according to diameter using sizing rings. Three punnets of 500 g of berries were collected per treatment per cultivar on 5^{th}, 12^{th}, and 19^{th} June 2017. The number of berries with a diameter (broadest part berry shoulder) of 40+ mm, 38 mm, 35 mm, 32 mm, 30 mm, 28 mm, 26 mm and 24 mm were recorded. 500 g was chosen as this is the typical weight of a container sold in the UK during the peak strawberry season.

- **Fruit Dry Weight:** Three batches of approximately 100 g batches of fruit was collected from each cultivar and treatment on 5^{th}, 12^{th}, and 19^{th} June 2017 (the actual fresh weight was recorded). The berries were placed in a foil tray lined with greaseproof paper and dried in a ventilated oven at 70°C for 72 hrs, and then the weight of the fruit was recorded. Dry weight was calculated as (dry weight / fresh weight) X 100.
- **Total Soluble Solids (TSS):** Three batches of 250 g berries per cultivar per treatment were collected on 5^{th}, 12^{th}, and 19^{th} June 2017. Each berry's calyx was removed, and each 250 g sample was blended using a hand blender for one minute. 1 ml from each batch was dropped onto the refractometer's surface using the pipette. The Brix was recorded using a digital refractometer (PAL-1 Pocket Refractometer, ATAGO, Minato-ku, Tokyo, Japan). This was repeated three times for each batch, and an average per batch calculated. Different pipettes were used for each batch and treatment, and the refractometer was calibrated routinely using distilled water.
- **Fruit Firmness:** Three batches of 12 berries (total 36 berries) of a uniform size, shape, and ripeness were collected from each cultivar and treatment on 5^{th}, 12^{th}, 19^{th} June 2017. Fruit firmness was calculated as the force (N) required pushing 3.5 mm probe 2 mm deep into the shoulder of the berry using a penetrometer (Fruit Hardness Tester, Omega Engineering Limited, Manchester, UK). Each berry was tested once, and an average of the 12 berries was calculated.
- **Shelf Life:** Three batches of 12 berries (total 36 berries) of a uniform size, shape, and ripeness were collected for each cultivar and treatment on 5^{th} and 1^{th} June 2017. The berries were placed in 12-cell clear plastic egg boxes (1 berry per cell) and stored at 4±2°C. Berries were checked every two days, and the number of spoiled berries counted as re-moved. Shelf life was calculated as the number of days from picking to reach 100% spoilage.
- **Titrations:** Vitamin C and titratable acid (TA) were calculated by titration using the methods described in Appendix 2 and Appendix 3, respectively. The titrations were carried out using freeze-dried strawberries; 250g of fresh berries per treatment were collected on 8^{th} June and freeze-dried for one week, and then powdered using a hand blender. This powder was then reconstituted with water to prepare a 5 ml sample for each titration.
- **Sugar-Acid Ratio:** Total soluble solids (TSS) and titratable acid (TA) results were used to calculate the sugar-acid ratio as (TSS / TA).

Plant Growth

Three randomly selected plants per cultivar per tunnel (a total of 12 plants per treatment) were harvested at the end of the experiment, and the following data collected:

- **Leaf Number:** the total number of trifoliate leaves per plant, including the folded leaves. All leaves were removed from the plants using a sharp scissor by cutting just below the leaf base.
- **Crown Number:** the total number of crowns per plant were counted, including the central crown and branch crowns. Crowns developed from runners were not counted.
- **Crown Diameter (mm):** crown diameter was measured across the crown's widest part using a digital calliper to the nearest 0.1 mm. The diameter included the central crown and branch crowns.
- **Inflorescence Number:** the inflorescences were removed from the crown's base to collect all entire inflorescence. The total number of inflorescences per plant were counted.
- **Petiole Length (cm):** the petioles were cut from the top of the stipule to the leaves' base and measured using a 30-cm ruler. An average of three petioles was calculated per plant.
- **Runner Number:** all the runners were cut from the crown's base, and a total number of runners per plant were counted.
- **Dry Weights (g / plant):** the leaves, crowns, petioles, and inflorescences collected from destructive harvest were packed in separate labelled paper bags and dried in a ventilated oven at 70°C for 72 hrs. The dry weight of individual parts was recorded and a total plant dry weight calculated by summing up these parts.

2.2.2 NIAB-EMR, East Malling Research, Kent

Western Flower Thrips (WFT)

A culture of WFT was kept at NIAB-EMR, and both adults and larvae were introduced into each tunnel at a flowering time using 12 infested chrysanthemum plants. Each of the 12 tunnels received one flower to obtain an equal number of Thrips in each tunnel. Inoculation was performed on 25^{th} May, 2^{nd}, 9^{th} and 20^{th} June 2017 and data was collected on 1st, 8th, 19th and 26th June 2017. One flower from each plant was retained, and the Thrips were extracted to estimate numbers in each inoculum. Data was collected on the number of Thrips larvae in old flowers and adults in mid-aged flowers in each treatment. Data was collected two weeks after inoculation, with ten flowers per tunnel collected in 70% ethanol so the Thrips could be extracted and counted.

2.3 Statistical Analysis

Statistical analysis was performed by using software GenStat 16th Edition. Two-way and three-way Analysis of Variance (ANOVA) were the statistical tests used. Where $P \leq 0.05$ was considered a significant result. Statistically significant differences between cultivars and treatments were checked using the least significant difference (LSD).

3. Results

3.1 Sonning Farm, The University of Reading, Berkshire

3.1.1 Flowering and Fruiting Time

Flowering time differed significantly between cultivars (P=0.002) with Amesti flowering earlier than Malling Centenary by 5 days. Fruiting time also differed significantly between cultivars (P<0.001) with Amesti fruiting earlier than Malling Centenary by 10 days. There was no significant difference in flowering or fruiting time between the UV treatments and no significant interactions found (Figure 11).

3.1.2 Cropping Results

Yield

There was a significant difference in marketable yield between cultivars (P<0.001), with Malling Centenary having a greater yield than Amesti by 110 g / plant. However, Amesti had a significantly lower un-marketable yield (P<0.001) and rejected yield (P<0.001) compared to Malling Centenary by 7 g / plant and 6 g / plant, respectively.

There was a significant interaction between the cultivars and UV treatments for the marketable yield (P=0.001, Figure 12); for Amesti, the marketable yield was significantly higher in UV 370 than UV 400 (14% less than UV 370) and for Malling Centenary, the marketable yield was substantially higher in UV 370 than UV 350 (15% less than UV 370).

There was also a significant interaction between cultivars and UV treatments for the un-marketable yield (P=0.008, Figure 12). For Amesti, UV 370 had a significantly lower un-marketable yield than UV 350 (41% lower than UV 350). For Malling Centenary, UV 400 had a considerably lower un-marketable yield than UV Open (40% lower than UV Open).

The treatments' effect on rejected yield differed between the cultivars, resulting in a significant interaction (P<0.001, Figure 12). For Amesti, UV 370 had a significantly lower rejected yield than UV Open (40% lower than UV Open). Malling Centenary also had a considerably lower rejected yield in UV 370 than UV Open but to a greater extent than Amesti (72% lower than UV open).

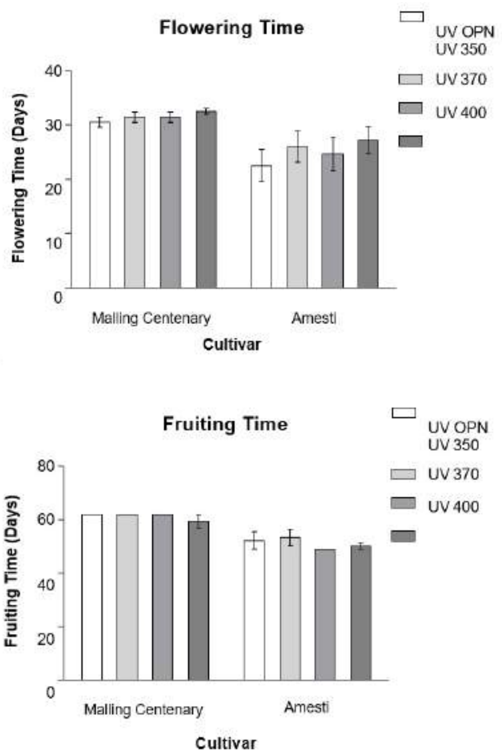

Figure 11: Treatment effects on flowering time (top) and fruiting time (bottom) for cultivars Malling Centenary and Amesti (n=4). Flowering time and fruiting time was when 50% of the plants had at least one open flower and one ripe fruit

Berry Number

Overall, Malling Centenary had a significantly higher marketable berry number than Amesti by seven berries/-plant (P<0.001). There was also a significant interaction between the cultivars and treatments (P<0.001, Figure 12); for Amesti, UV 350 had a significantly higher number of Marketable berries than UV Open (11% less than UV 350) whereas for Malling Centenary, UV 400 a had significantly higher number of berries than UV 350 (14% less than UV 400).

There was only a significant difference in the unmarketable berry number between cultivars, where Amesti had a significantly lower number of unmarketable berry number than Malling Centenary by 1.3 berries/plant ($P<0.001$, Figure 12).

For the rejected berry number, Amesti also had a lower number of rejected berries than Malling Centenary by 0.5 berries/plant ($P<0.001$). There was also a significant interaction between culti-vars and UV treatments ($P<0.001$, Figure 12); for Amesti, UV 370 had a significantly lower rejected berry number than UV Open (36% lower than UV Open). Malling Centenary also had a considerably lower rejected berry number in UV 370 than UV Open but to a greater extent than Amesti (89% lower than UV Open).

Average Marketable Berry Weight

Amesti had a significantly higher average marketable berry weight than Malling Centenary by 7.15g ($P<0.05$). There was no significant interaction between the cultivars and treatments. Still, the treatment's main effect was substantial ($P=0.007$, Figure 12). It showed that UV 370 had a significantly higher average marketable berry weight than all other treatments, and UV Open had the lowest (7.5% less than UV 370).

Percentage Class 1

Amesti had a significantly higher percentage of Class 1 than Malling Centenary by 3% ($P<0.001$). There was also a significant interaction between the treatments and cultivars ($P=0.039$); for Amesti percentage, Class 1 was highest in UV 370 and lowest in UV Open (2.3% lower than UV 370). For Malling Centenary, the percentage Class 1 was highest in UV 400 and was lowest in UV Open (5% lower than UV 400).

Berry Size Grading

Berries were graded over three harvests, and the results are shown in Figure 13. On the first harvest (5th June, Figure 13A), the highest number of berries were in the 40+ mm grade and the least in grade 22 mm. There was a significant difference between the cultivars ($P<0.001$); for Amesti, grade 40+ mm had the highest number of berries, whereas, for Malling, Centenary had smaller fruit with grade 32 mm and grade 22 mm the least for both cultivars. There was also a significant difference between each cultivar's treatments ($P=0.048$). For Amesti, UV Open, UV 350, UV 370 and UV 400 all had the highest number of fruits in grade 40+ mm and 22 mm the least. For Malling Centenary, in UV Open, grade 35 mm and grade 32 mm had the highest berry number. In UV 350, grade 32 mm had the highest number of berries, whereas UV 370 and UV 400 grade 35 mm had the highest number of berries than other grades.

For the second harvest (12th June, Figure 13B), grade 40+ mm had a significantly higher number of berries than other grades, and grade 22 mm had the most minor. There was a significant difference between cultivars for the total number of berries per grade ($P<0.001$). Amesti and Malling Centenary 40+ mm had the higher number of berries, and 22 mm had the least number of berries. There was no significant difference in the number of berries per grade between either cultivar treatments. For the final harvest (19th June, Figure 13C), berry size had reduced, with grade 35 mm having the highest number of berries for both cultivars and grade 22 mm had the least. There was a significant difference between treatments for each cultivar ($P<0.001$). For Amesti in UV Open, grade 35mm had the highest number of berries, whilst in UV 350, UV 370 and UV 400, grade 40+ mm had the highest. For Malling Centenary, in UV Open grade 35 mm had the highest number of berries whereas in UV 350 and UV 370, grade 32 mm the highest number of berries, and UV 400, grade 38 mm had the highest berry number. In general, grade 22 mm had the least number of berries in both cultivars.

3.1.3 Cropping Profile

For the first three harvests (1st May, 8th May and 165th May), Amesti had a significantly higher yield than Malling Centenary by 5, 46 and 16 g / plant, respectively ($P<0.001$, Figure 14). For the next four harvests harvest (22nd May to 12th June), Malling Centenary had a significantly higher yield than Amesti by 39, 37, 126 and 53 g / plant, respectively ($P<0.001$, Figure 14). There was no significant difference in yield between cultivars on the 19th June or 26th June. Still, in the final week (3rd July), Amesti had a significantly higher yield than Malling centenary by 12 g / plant ($P=0.002$, Figure 14).

The effect of the treatment on yield each week for Amesti and Malling Centenary is shown in Figure 14. For the first harvest (8th May), there was a significant difference in yield between treatments, but only for Amesti ($P=0.030$), where UV 370 had a significantly higher yield than UV Open (34& less than UV 370). The second highest yield was in UV 400 (30& less than UV 370) and then UV 350 (31& less than UV 370). On the 22nd of May, there was a significant difference in yield between treatments, but only for Malling Centenary ($P=0.008$), where UV Open had a higher yield than UV 350 (22& less than UV Open). In the following week (29th May), there was also a significant interaction between the cultivars and treatments ($P<0.001$); for Amesti, UV Open had a significantly higher yield than

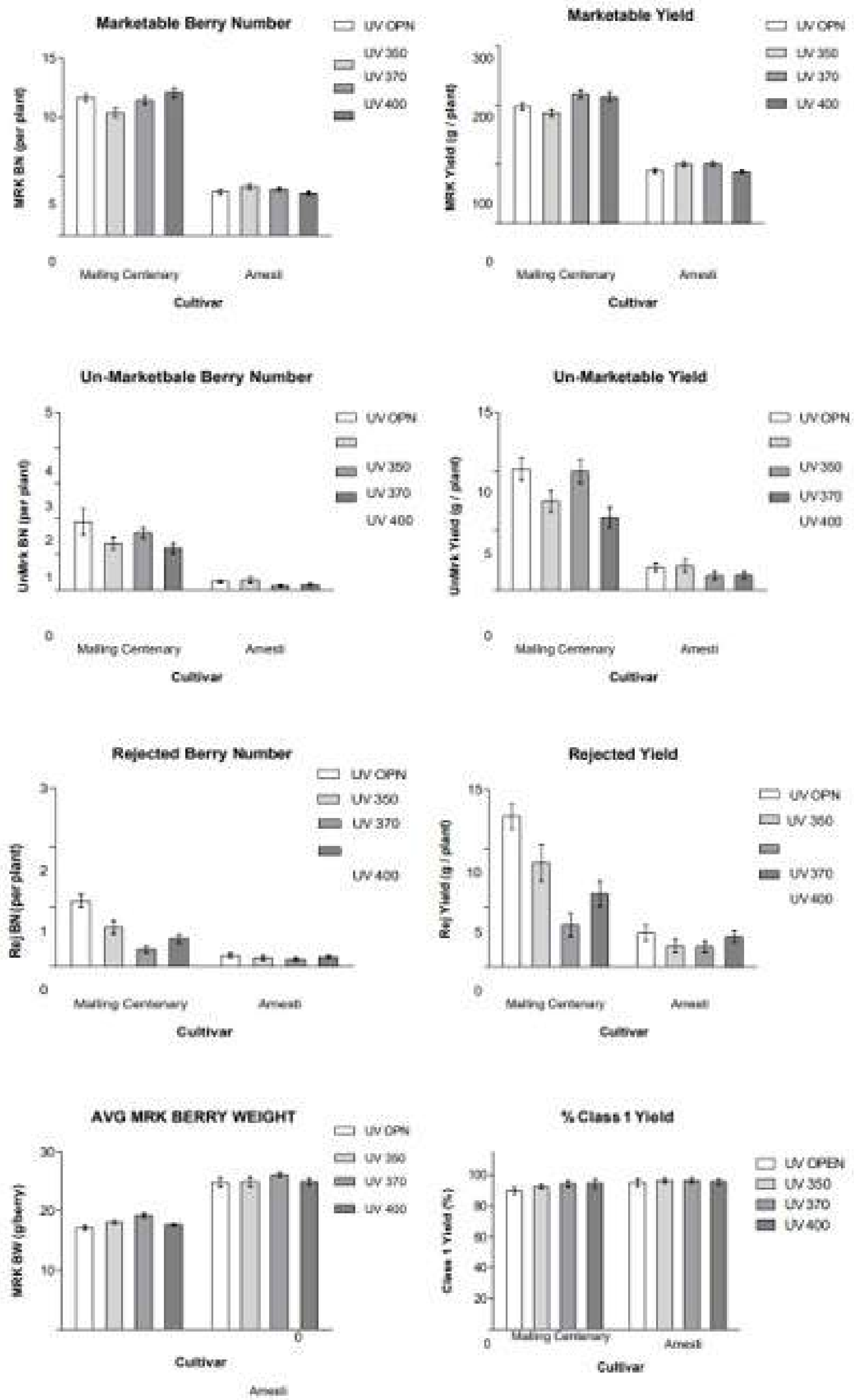

Figure 12: Cropping results for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=4)

UV 370 (60& less than UV Open), and for Malling Centenary, UV 350 had significantly higher yield than UV Open (32& less than UV 350). On the next harvest (5th June) for Amesti, UV 350 had a significantly higher yield than UV Open (17& less than UV 350) and for Malling Centenary, UV 370 had a significantly higher yield than UV Open (17& less than UV 370) (P=0.010). On 12th June, there was also a significant interaction between the cultivars and UV treatments (P<0.001); for Amesti, UV 350 had a

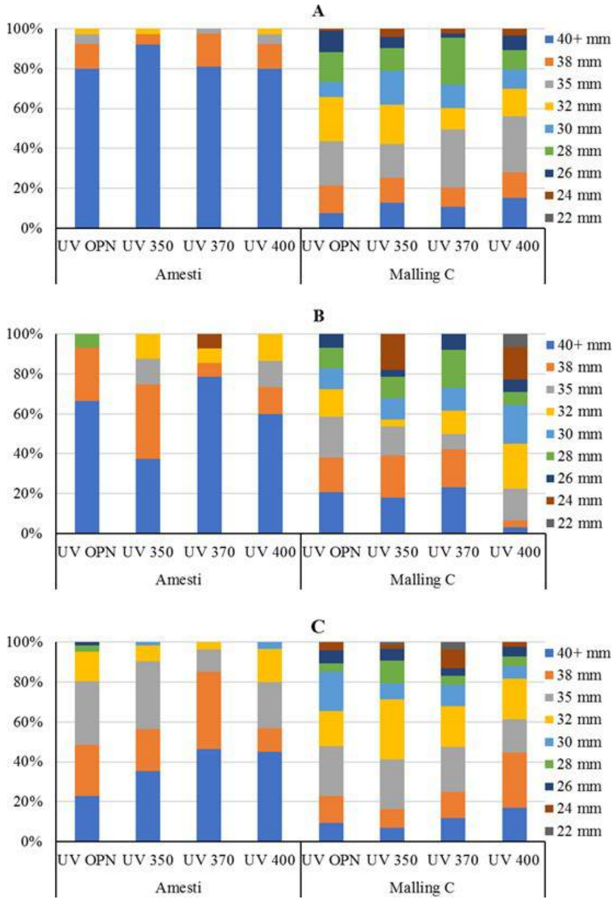

Figure 13: Grading results for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=3). Grading was carried out for three harvests: 5th June (A), 12th June (B) and 19th June (C)

significantly higher yield than UV Open (40& less than UV 350), and for Malling Centenary, UV 370 had significantly higher yield than UV 350 (30& less than UV 370).

On 19^{th} July, there were no significant differences in yield between cultivars or treatments. In the following week (26^{th} June), there was only a significant difference between treatments (P=0.012) and yield was significantly higher yield in UV 400 than UV Open (37& less than UV400). In the final harvest (3^{rd} July) there were no significant differences in yield between treatments for either cultivar.

3.1.4 Fruit Quality

Fruit Dry Weight

The percentage fruit dry weight for each cultivar and treatment was calculated for three harvests; the results are shown in Figure 15. For all three harvests, Malling Centenary fruit had a significantly (P<0.001) higher percentage dry weight than Amesti, by 10%, 14% and 16% for 5^{th}June, 12^{th}June 19^{th}June respectively. There was no significant difference in percentage dry weight between treatments for any harvest, and no significant interactions between the cultivars and treatments were found.

Total Soluble Solids (TSS)

Total soluble solids content (TSS) was calculated for three harvests, and the results are shown in Figure 16. On the first test (5^{th}June, Figure 16A), there was only a significant difference be-tween cultivars (P<0.001) where Malling centenary has significantly higher TSS than Amesti.

For the second test (12^{th}June, Figure 16B), the effect of the treatment differed for each cultivar resulting in a significant interaction (P<0.001); for Amesti, there was a reduction in TSS with increasing UV absorption, with TSS highest in UV Open and lowest in UV 400 (11% less than UV Open). There was a significant difference in TSS be-tween the UV Open and UV 370 treatments and UV Open and UV 400 (0.9 and 1.0°Bx respectively); all other differences be-tween treatments were not significant. For Malling Centenary, there was no clear trend and no significant differences in TSS between treatments; TSS was highest in UV 400 and was lowest in UV 350 (6.5% less than UV 400).

In the final test (19^{th}June, Figure 16A), TSS was significantly higher in Malling Centenary than Amesti by 1.0°Bx (P<0.001). There was also a significant difference in TSS between UV treatments (P=0.014); TSS was highest in UV 400 and UV Open and significantly greater in both than UV 370 by 0.5°Bx. All other differences between treatments were not significant.

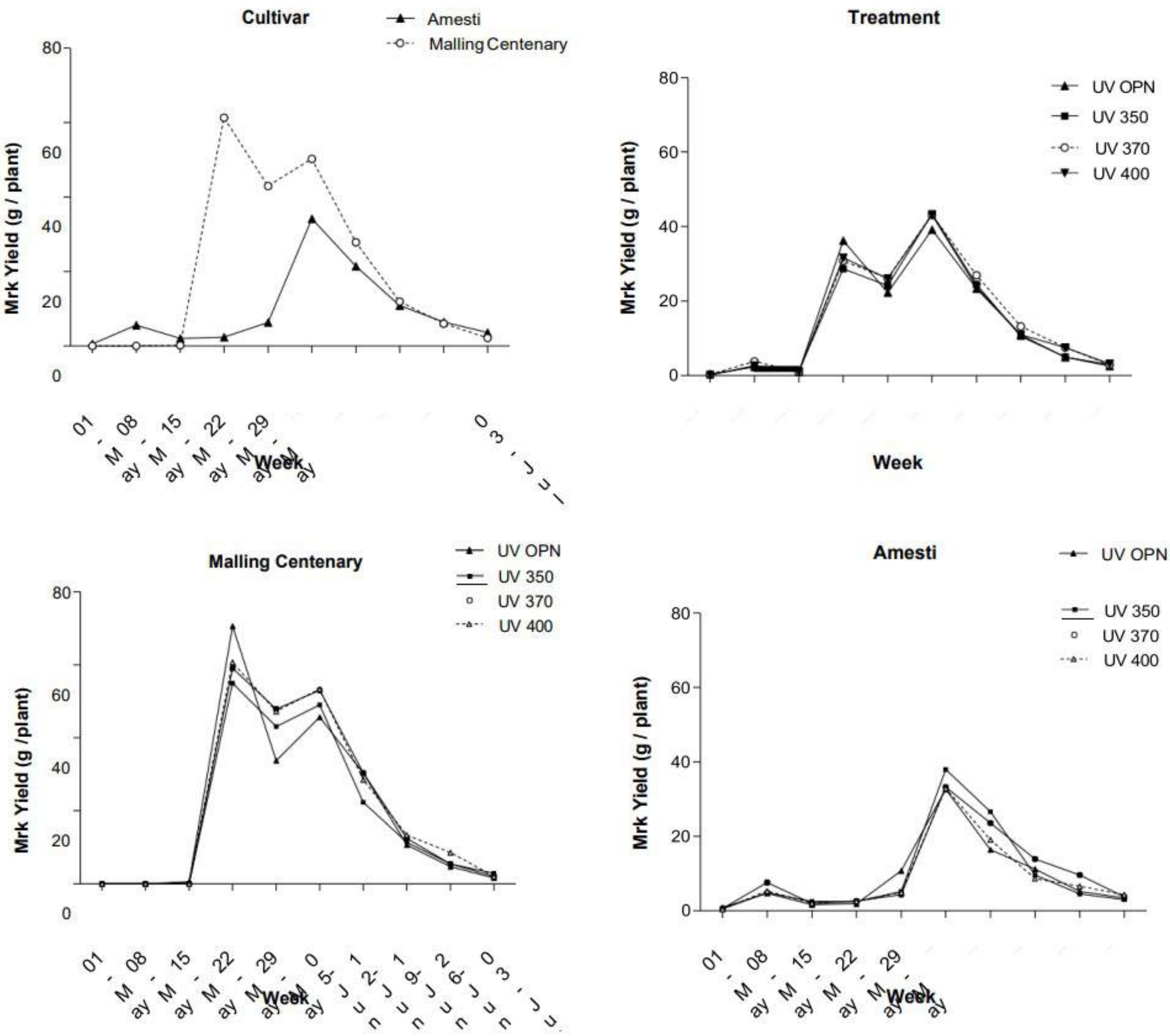

Figure 14: Cropping profiles of Malling Centenary and Amesti cultivated under four different levels of UV absorbing films. The main effect of cultivar (n=16), treatment (n=8), and the interaction between the cultivars and treatments (n=4) are shown

Fruit Firmness

Fruit firmness was calculated for each cultivar and treatment for three harvests, and the results are presented in Figure 17. For the first harvest (5^{th} June, Figure 17A), the effect of the treatments on fruit firmness differed for each cultivar resulting in a significant interaction ($P<0.001$); for Amesti, fruit firmness was generally greater in the more UV absorbing films. Fruit firmness was significantly greater in UV 400 and UV 370 compared to UV 350 (by 16% and 5.47%, respectively) and in UV 370 compared to UV Open (6.09%). All other differences between treatments for Amesti were not significant. There was no clear trend for Malling Centenary be-tween treatments; fruit firmness was highest in UV Open and was lowest in UV 370 (17.5% less than UV Open).

In the second harvest (12^{th} June, Figure 17B), Malling Centenary had a significantly ($P<0.001$) higher fruit firmness than Amesti by 4.6 N. The was no significant difference in fruit firmness between UV treatments and no significant interaction between the cultivars and treatments found.

In the final harvest (19^{th} June, Figure 17C), Malling centenary also had significantly higher fruit firmness than Amesti by 3.1 N ($P<0.001$), and there was a significant difference between the treatments ($P=0.003$). However, there was no clear trend; fruit firmness was highest in UV Open and was lowest in UV 350 (10% less than UV Open).

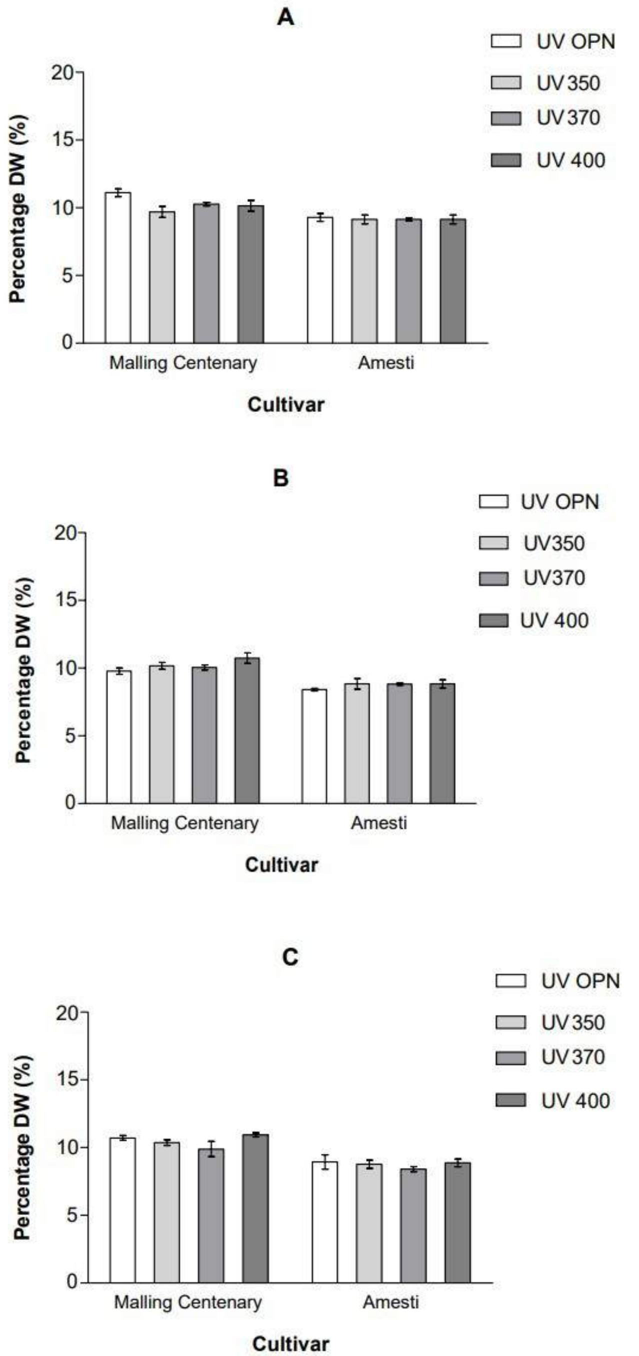

Figure 15: Percentage fruit dry weight for Malling Centenary and Amesti cultivated under four different lev-els of UV absorbing films (n=3). Percentage fruit dry weight was calculated for three harvests: 5th June (A), 12th June (B) and 19th June (C)

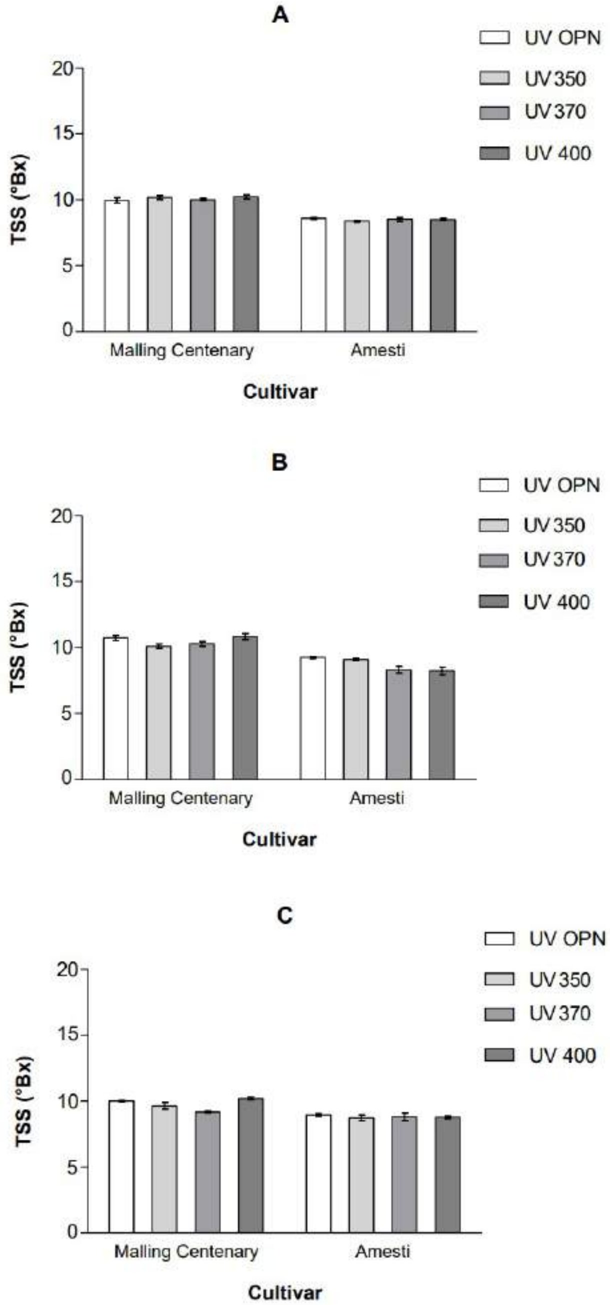

Figure 16: Total soluble solids (TSS) for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=3). TSS was calculated for three harvests: 5th June (A), 12th June (B) and 19th June (C)

Shelf Life

Shelf life for each cultivar and treatment was calculated for two harvests, and the results are shown in Figure 18. There were no significant differences between cultivars or treatments for either test or no significant interactions between the cultivars and treatments were found. The average number of shelf life days was 14 days.

Vitamin C

Vitamin C content was calculated using berries harvested on 8th June and freeze-dried. There were no significant differences in Vitamin C content between the culti-

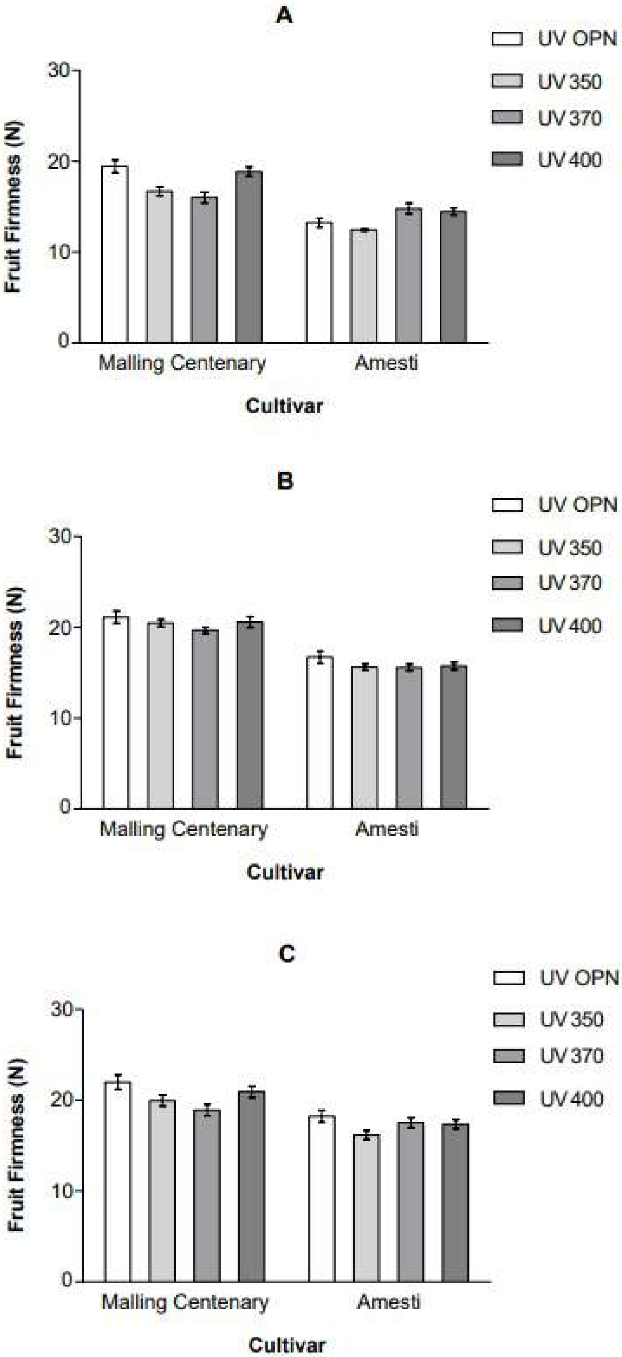

Figure 17: Fruit firmness for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=3). Fruit firmness was tested for three harvests: 5th June (A), 12th June (B) and 19th June (C)

vars or treatments, and no significant interaction was found (Figure 20). The average Vitamin C content was 63.34 mg / 100 g fresh fruit.

Titratable Acid (TA)

Titratable acid (TA) was calculated using berries harvested on 8th June and freeze-dried. Results are shown in Figure 20. Overall, Amesti had significantly higher TA than Malling Centenary (24% less than Amesti) ($P<0.001$).

There was also a significant interaction between the cultivars and treatments ($P<0.001$); for Amesti, UV 370 had significantly higher TA than all other treatments, followed by UV Open (4% lower than UV 370) than UV 400 (6% less than UV 370) and UV 350 (8.5% lower than UV 370). For Malling Centenary, UV Open had significantly higher TA than other treatments, followed by UV 370 (2.5% less than UV Open), then UV 400 (18% less than UV Open) and finally UV 350 (37% less than UV Open).

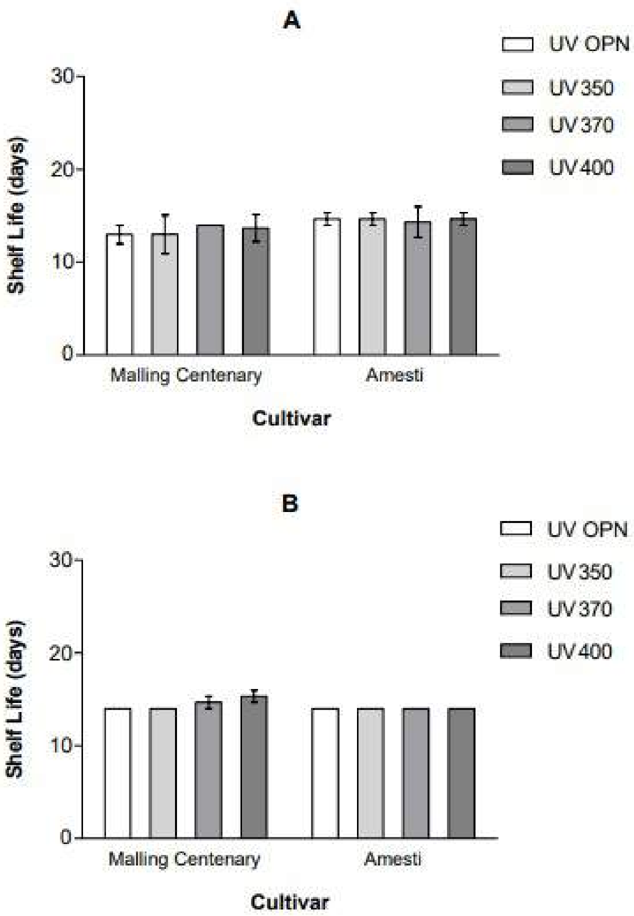

Figure 18: Shelf life for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=3). Shelf life was calculated for two harvests: 5th June (A) and 19th June (B)

Sugar Acid Ratio

There were no significant differences in the sugar-acid ratio between the cultivars or treatments, and no significant interactions were found (Figure 20). The average sugar-acid ratio was 31.28.

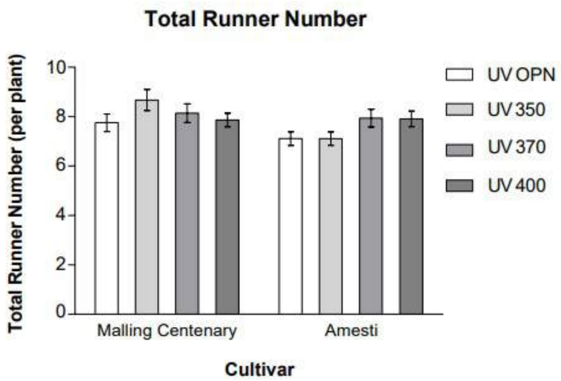

Figure 19: Shelf life for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=3). Shelf life was calculated for two harvests: 5th June (A) and 19th June (B)

3.1.5 Destructive Harvest

Runner Number

The total number of runners per plant for each cultivar and treatment is shown in Figure 19. There was only a significant difference between cultivars (P=0.010) where Malling Centenary had significantly more number of runners than Amesti by 0.6 runners / plant.

Crown Number, Crown Diameter and Crown Dry Weight

Treatment effects on crown number, diameter and dry weight for cultivars Malling Centenary and Amesti are shown in Table 2. Overall there were no significant differences in crown measurements between treatments or cultivars, and no significant interactions were found. Average crown number was 3.7 per plant, average crown diameter was 4.8 cm and average crown dry weight was 6.2 g / plant.

Petiole Length and Petiole Dry Weight

Petiole length and dry weight for each cultivar and treatment are shown in Table 2. There were no significant differences between cultivars or treatments for petiole length or dry weight, and no significant interactions were found. Average petiole length was 19.8 cm and average petiole dry weight was 9.4 g / plant.

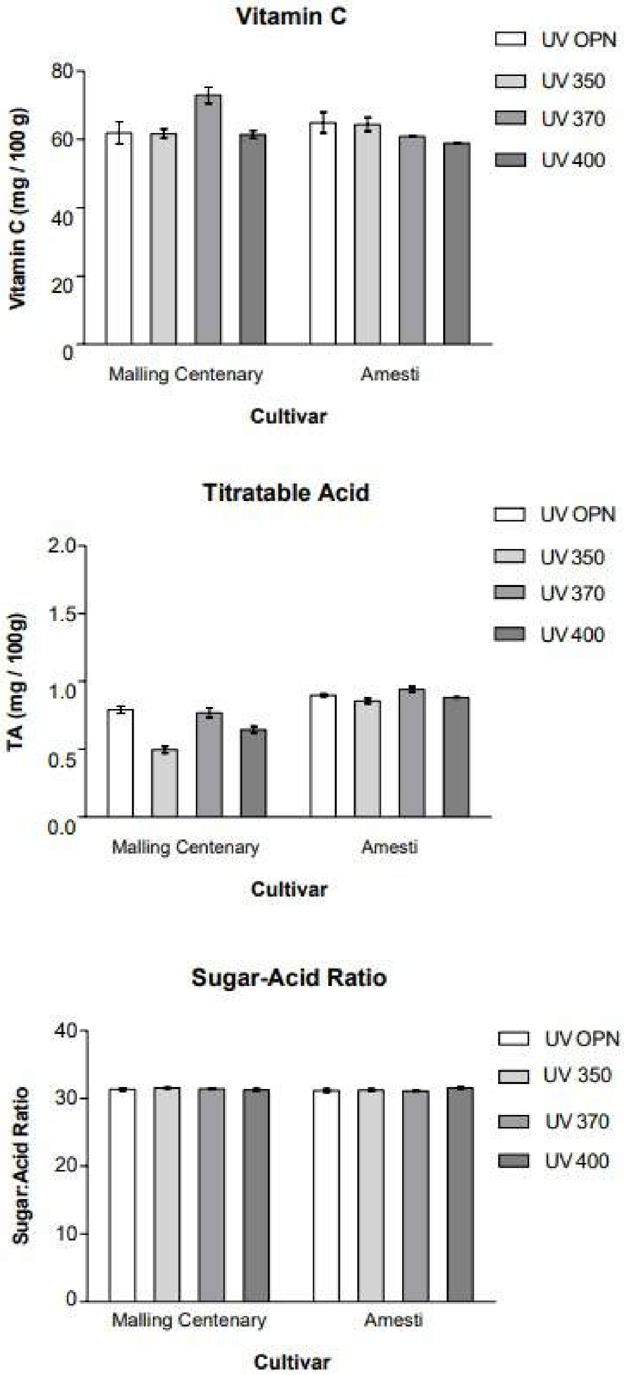

Figure 20: Vitamin C (Top), titratable acid (Middle) and sugar:acid ratio (bottom) for Malling Centenary and Amesti cultivated under four different levels of UV absorbing films (n=3)

Inflorescence Number and Inflorescence Dry Weight

Inflorescence number and inflorescence dry weight for each cultivar and treatment are shown in Table 2. There was a significant difference in inflorescence number and dry weight between cultivars (P<0.001 for both); Amesti had a significantly higher number of inflorescences per plant and inflorescence dry weight than Malling Centenary by 2.1 per plant and 4.1 g / plant respectively. There were no significant differences between treatments for either inflorescence number or dry weight, and no significant interactions were found.

Leaf Number and Leaf Dry Weight

Treatment effects on leaf number and leaf dry weight for each cultivar are shown in Table 2. There was no significant difference between treatments for either leaf number or leaf dry weight. Leaf number did not significantly differ between cultivars, but Malling Centenary had a significantly higher leaf dry weight than Amesti by 4.5 g / plant (P=0.006).

Total Dry Weight

Total dry weight of plant is shown in Table 2, there was no significant difference in total plant dry weight between cultivars or treatments, and there was no significant interaction found. Average total plant dry weight was 50.4 g / plant.

3.2 NIAB-EMR, East Malling Research, Kent

3.2.1 Western Flower Thrips (WFT)

There was a significance effect of UV treatment on total thrips population (P=0.030, Figure 21). Total thrips population reduced with increasing UV absorption. Compared to the UV open film, thrips populations were 21%, 8% and 60% reduced in the UV 350, UV 370 and UV 400 films respectively. However, only the difference between the UV Open and the UV 400 film was significant.

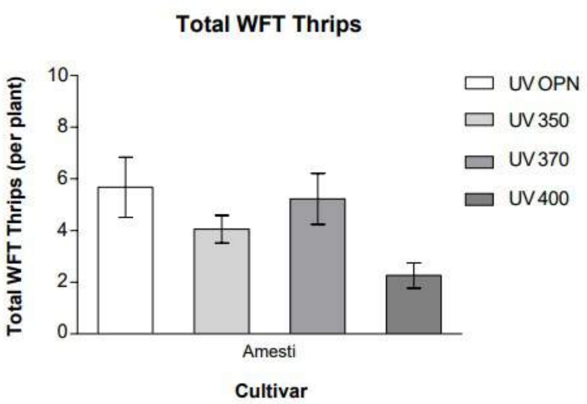

Figure 21: Total western flower thrips (WFT) population for Amesti cultivated under four different levels of UV absorbing films (n=3)

4. Discussion

Strawberries are one of the most consumed soft fruits in the UK and worldwide; they are a soft fruit with a high nutritional value and are an essential part of the human diet. In the late 1990s, there was a drastic reduction in overall land under cultivation for strawberries in the UK but an increase in per hectare productivity; this was due to the introduction of polytunnels clad in horticultural films, which increased the Class 1 percentage to over 90% and allowed for the extension of the season from 4-6 weeks in June and July to 4-6 months from March-August (DEFRA, 2017). There are still issues with strawberries being a seasoned crop, meaning there is a heavy reliance on imported fruit to support strawberries' all-around availability in supermarkets. How-ever, this provides excellent research opportunities in improving strawberry cultivation and further season extension. Further technological development of horticultural films, soil-less media and drip irrigation systems can further support the strawberry season and improve yield and fruit quality in the UK. It has a massive potential to support India's technology adoption, where marginal strawberry cultivation in the tropical environment is primarily for the supply to luxury hotels. Due to the high cost of fruit, strawberries in India can also be a part of the ordinary per-son's diet. At present, strawberry cultivation in India is in soil. It faces challenges including soil and air borne disease, pest infestation, low land productivity, high post-harvest yield loss, and high processing costs. Strawberry cultivation using polytunnels clad with horticultural films and soil-less media and drip irrigation can potentially reduce these challenges and enhance the quality and quantity of strawberry produce.

UV absorbing horticultural films have been proven to increase the quality and quantity of produce such as lettuce, tomato and cucumber (Papaioannou, Katsoulas, Maletsika, Siomos, & Kittas, 2012; Raviv & Antignus, 2004; Diaz & Fereres, 2007) due to a reduction of pest and disease infestation. This technolgy has potential to reduce the total price of cultivation due to reduced insecticide and pesticide sprays, reduced costs of picking and increased returns due to an increase in Class 1 quality berries for strawberry. Therefore, an experiment was conducted in two parts: first at The University of Reading's Sonning Farm to study the effect of UV absorbing films on the quality and quantity of strawberries for two plant types (the Junebearer cultivar Malling Centenary and the Everbearer cultivar Amesti) and second at NIABEMR to study the effect of the same films on two essential pest species in strawberry: western flower thrips (WFT) and spotted wing drosophila (SWD) for the Everbearer Amesti. In both locations, four films were studied; one film was entirely open for UV radiation,

Cultivar	Treatment	Crown No (per plant)	Crown Diameter (cm)	Crown DW (g / plant)	Petiole Length (cm)	Petiole DW (g / plant)	Infl. No (per plant)	Infl. DW (g / Plant)	Leaf No (per plant)	Leaf DW (g / plant)	Total Plant DW (g / plant)
Amesti	UV OPN	3.75	4.39	5.53	19.3	7.73	4.75	6.82	26.67	25.67	45.75
	UV 350	4	4.93	6.73	19.61	8.55	5.67	7.36	30.92	30.92	53.56
	UV 370	4	4.47	6.15	19.72	9.48	5.58	7.71	28.92	28.92	52.26
	UV 400	3.58	5.08	6.48	19.3	9.82	4.5	6.63	29.25	29.25	52.18
Malling Centenary	UV OPN	3.42	4.84	5.73	19.71	8.61	3.42	3.4	28	28	45.74
	UV 350	3.33	5.24	6.39	20.4	10.33	2.75	2.39	27.75	27.75	46.86
	UV 370	3.92	5.01	6.51	20.47	10.87	3.17	3.32	30.17	30.17	50.87
	UV 400	3.5	4.7	6.18	19.56	9.98	2.58	3.08	26.33	26.33	45.57
P. Value											
Cultivar		0.139	0.136	0.964	0.063	0.12	<0.001	<0.001	0.471	0.006	0.577
Treatment		0.433	0.165	0.435	0.262	0.164	0.395	0.709	0.481	0.007	0.144
C * T		0.683	0.149	0.866	0.9	0.845	0.415	0.579	0.365	0.873	0.953

Table 2: Treatment effects on destructive harvest results for cultivars Malling Centenary and Amesti (n=12). Infl = inflorescence, DW= dry weight and No = number. P. values for the main effects of the cultivars, treatments and interaction between the cultivars and treatments are shown

two were partially blocking at 350 nm and 370 nm and one blocking UV completely by up to 400 nm. Results obtained and their implications are discussed in this chapter.

4.1 Effect of UV absorbing films on strawberry yield and yield components

The main components of strawberry yield are berry number and berry size (Hancock, Sjulin, & Lobos, 2008). At the start of the season, both cultivars produced large-sized berries, and there was a significantly higher number of berries graded as 40+ mm. Later in the season, at peak harvest, both cultivars had smaller sized berries than those from initial picking, and most berries were grade 35 mm. This was likely due to the increasing crop load, resulting in smaller berry production. Overall, Malling Centenary produced a more significant number of berries than Amesti by seven berries/plant. However, Amesti had a larger fruit size by 7 g / berry. Despite the lower berry weight and size, the increased berry number led to a significantly higher marketable yield in Malling Centenary than Amesti by 110 g / plant. The average yield per plant was greater in Malling Centenary, most likely due to the difference in plant type between the cultivars. Malling Centenary is a Junebearer; fruit is produced from autumn-initiated flowers only. These plant types produce a profuse number of fruits with a picking peak for 4-5 weeks in summer. However, this is dependent on weather conditions. Whereas, Amesti is an Everbearer that produce fruits from autumn blossom in the spring and early summer and in from spring blossom in late-summer and

Early autumn (Durner et al., 1984). Amesti produced flowers, whereas the Junebearer Malling Centenary had a more concentrated harvest resulting in a higher yield. Still, it had run out of flowers and fruits by the end of the experiment. Amesti also had a significantly lower un-marketable yield and rejected yield than Malling Centenary, which is likely due to the lower total yield and berry number of Amesti compared to Malling Centenary and agrees with the more significant percentage Class 1 percentage found for Amesti, which was 3.5% greater than Malling Centenary.

For protected strawberry production using polytunnels clad with horticultural films, there is a much lower yield loss due to disease than strawberry cultivation in open fields (Diaz & Fereres, 2007; Tsormpatsidis et al., 2011). There is the potential to further reduce disease in protected strawberry crops by using UV absorbing films which interfere with the life cycle of many fungal disease and visions systems of pests. Papaioannou et al. (2012) found no significant effect of UV absorbing films on total marketable yield and berry number of tomato. In this experiment, a significant effect of UV absorbing films on strawberry was found. There was a substantial difference between Malling Centenary and Amesti between treatments for marketable yield, which was most significant in UV 370 for both cultivars and lowest in UV 350 for Malling Centenary and UV 400 Amesti. According to Raviv and Antignus (2004) , manipulation of UV spectral properties interfere with different fungi' life cycle prevents yield loss due to fungal diseases such as Botrytis cinerea. Diaz and Fereres (2007) found a potential reduction of Botrytis cinerea sporulation in tomato and cucumber plants with UV absorbing horticultural films. Rejected berry number and yield accounted for diseased berries in this experiment; the result obtained are in agreement with these previous findings as a lower un-marketable yield and rejected yield was found with UV absorbance as the UV 370, and UV 400 treatments had the lowest un-marketable yield for Amesti and Malling Centenary respectively. UV 370 had a significantly lower rejected yield for both cultivars.

4.2 Effect of UV absorbing films on strawberry fruit quality

The taste and flavour of strawberries are essential, but as antioxidant-rich berries, they are also famous for their health-promoting factors (Mahmood, Anwar, Abbas, Boyce, & Saari, 2012). Junebearer strawberries are generally considered of better quality than Everbearer cultivars (Scott, Lawrence, & Draper, 1979), although there has been improved Everbearer quality through breeding programmes in recent years. Supermarket demand is higher for Junebearer than Everbearer berries, with Everbearers primarily to extend the season. Total sugar, acid, fibres and other nutrients are the essential characteristics that define the flavour and nutritional value of strawberries and firmness and shelf life. Once picked, the berries follow several processing and packaging stages. So, firmness and shelf life are also crucial for the industry to provide an efficient stock of strawberries in supermarkets while fulfilling flavour standards. Therefore, this study aimed to examine the effect of UV absorbing films on fruit.

Flavour

During the ripening of fruits, plant produce volatile compounds, and the composition of sugars and organic acid changes, which can alter the quality and flavour of the berries (Mahmood et al., 2012). Therefore, UV absorbing films on the sugar: the acid ratio was examined. The sugar: the acid ratio was calculated from the total soluble solids (TSS) and titratable acids (TA) results. Overall, Malling Centenary had significantly higher TSS than Amesti throughout the season whilst Amesti had significantly higher TA than Malling Centenary by 25%. This is likely because Malling Centenary is a Junebearer cultivar that generally has higher quality than Everbearer cultivars. It could also be because Amesti produced much larger berries than Malling Centenary (7 g / berry greater than Malling Centenary). Nevertheless, no significant difference in the sugar: the acid ratio was found between cultivars.

Kwon et al. (2017) found no significant difference in TSS in UV blocking horticultural films for tomato and cucumber, and results from Papaioannou et al. (2012) were in agreement, also finding.

No significant effect of UV absorbing films on TSS in tomato. Also, Keller and Torres-Martinez (2002) found no significant impact on SSC in grape wine production with a 2% reduction in UV radiation. At the start of the season, this experiment's results agreed, as no significant differences in TSS be-tween treatments were found. However, further into cropping (12th June), a reduction in TSS with an increase in UV absorption was found for Amesti. A week later (19th June), TSS was highest in UV Open and UV 400 and significantly greater in both than UV 370. Samples of the film were sent to the chemistry department at the University of Reading. By 15th June, the UV 400 film was found to have degraded, perhaps explaining why the TSS had increased to be on a similar level to that of the UV Open film by 19th June.

According to Papaioannou et al. (2012), there was no significant effect of UV absorbing films on TA in tomatoes. In this experiment, Amesti, UV 370 had significantly higher TA than UV 350, whereas, for Malling Centenary, UV Open had a significantly higher yield than UV 350. There was no significant difference in sugar-acid ratio between the treatments for either cultivar, meaning UV absorbance had no significant effect on the berries' flavour for either cultivar.

Nutritional Content

Strawberries are rich in antioxidants, and ascorbic acid (Vitamin C) is among them. Due to the health benefits of antioxidants, such as reducing blood cholesterol level and eliminating toxic sub-stances from the body, strawberries are recommended to patients with heart problems (Lewin, 2016). It was, therefore, essential to study the effect of the UV absorbing films on the nutrient content of the fruit. Overall, there were no significant Vitamin C content differences between the cultivars or treatments. The average Vitamin C content was 63.34 mg / 100 g fresh fruit. Results obtained agreed with Josuttis et al. (2010), who found no significant effect of UV absorbing films on anthocyanin and antioxidants for strawberries.

Firmness and Shelf Life

Firmness and shelf life are important quality characteristics for the industry as strawberries have to be processed and packed once they are picked before they reach the supermarket shelves. According to Ordidge et al. (2012), a small but significant decrease in fruit firmness of the cultivar Elsanta cropped under UV absorbing films compared to UV open films. However, this experiment's results disagreed, finding that during initial picking (5th June), for Amesti, fruit firmness was generally more significant in the more UV absorbing films, whereas, for Malling Centenary, there was no apparent effect of UV treatment on fruit firmness. During later pickings (12th and 15th June), there was no difference in fruit firmness between treatments for either cultivar.

The disagreement of results obtained with Ordidge et al. (2012) may be due to various reasons such as different horticultural films, cultivars feed, and different climate regimes in each experiment.

Overall, the average shelf life during the season was 14 days. At the start of the season (5th June), Amesti had a significantly higher shelf life than Malling Centenary by two days; however, by 19th June, there was no difference between cultivars. There was also no significant effect of UV absorption on shelf life. Amesti may have had a higher shelf life in the early season than Malling Centenary due to a large berry size. With further seasonal picking, a reduction in berry size of Amesti resulted in similar shelf life to Malling Centenary. These results agree with Ordidge et al. (2012), who found no significant effect of UV absorbing films on shelf life for the cultivar Elsanta.

4.3 Effect of UV absorbing films on strawberry plant growth

Vegetative growth is an important phase of the plant life cycle; potential changes in plant growth and development phase can respond negatively to farm budget as excessive vegetative growth is prone to pest and disease infestation, increasing pesticide consumption insecticides. In contrast, a decrease in plant vegetative growth will affect reproductive development.

Can potentially reduce yield (Went, 1957). No significant effect of UV absorbance on plant size was found. The average plant dry weight was 50.4 g / plant. Only a significant difference in in-florescence number between cultivars was found, with Amesti having a significantly higher number of inflorescences compared to Malling Centenary by 2.1% and dry weight 4.1g, which was because Amesti being an Everbearer continued to flower when Malling Centenary had finished.

4.4 Effect of UV absorbing films on strawberry pests

Western flower thrips (WFT) (*Frankliniella occidentalis* Perg.) is the most invasive species among all thrips in the glasshouses and greenhouses and is a potential threat for plants during the flowering stage (Brunner & Frey, 2010). WFT threat is a global issue at present that affects the farm budget. UV absorbing films have the potential to reduce thrips population drastically. In this experiment, the total thrips population per plant reduced with increasing UV absorption; compared to the UV open film, thrips populations were 21%, 8%, and 60% reduced in the UV 350, UV 370 and UV 400 films, respectively. However, only the difference between the UV Open and the UV 400 film was significant. Papaioannou et al. (2012) also found a significant reduction in thrips population with UV absorbing film in tomato where a 53% and 59% reduction in thrips population in the first year and the second year was found when UV absorbing films were compared with UV Open films.

5. Study Limitations

- The experiment was designed for an eight-week strawberry crop. Malling Centenary being a Junebearer, finished fruiting by the end of the experimental period. However, Amesti being an Everbearer, still had inflorescences with flower buds, flowers and fruits. Therefore, data collection for Amesti remains unconcluded.
- Three shelf-life tests were planned. However, the third test could not be completed, as Malling Centenary had run out of fruit. Starting the shelf life tests earlier would be beneficial if this experiment were repeated.
- Tests for phenolic, flavonoid and anthocyanin content were not able to be performed before submitting this work. However, freeze-dried samples for each cultivar and treatment have been kept for this analysis.
- White fruits were tagged for colour assessments, but a high-temperature event turned these berries red within a 24-hr period. Therefore, tests for colour development could not be performed.
- Due to the results' commercial sensitivity, the SWD data was not released by NIABEMR and could not be incorporated into this work.

6. Conclusion

Overall, plant growth and fruit quality were largely unaffected by UV absorbance. Still, the yield was enhanced, and the thrips population significantly reduced are beneficial outcomes for the strawberry industry. Overall, the partially UV absorbing film (UV 370) performed significantly better than other films regarding fruit quality and yield. The completely UV blocking film (UV400) performed better initially but degraded after second peak harvest resulted in reduced performance later in the season. If the UV 400 film could be stabilised to prevent degradation, there is the potential to improve strawberry fruit yield and quality.

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