Possibilities of Increasing Production and Quality of Strawberry Fruits and Several Flowers by New Blue Fluorescent Greenhouse Films

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Abstract

Within the framework of the project SPECTRAFOIL funded by the EU and Grafe Color Batch (Germany), together with the industrial partners Palrig (Israel), Sunsaver (Spain) and several growers and research partners in Israel, Cyprus, Spain and The Netherlands, new fluorescent greenhouse films for several climates and several horticultural production systems were developed.

One of the results of SPECTRAFOIL was the development of new blue fluorescent greenhouse films. Technical aspects were investigated, such as spectral light transmission, fluorescent effect, stability of pigments and films. The effect of different fluorescent films on the production and quality of strawberry fruits was investigated at A&F, Wageningen. In these experiments, strawberry plants were grown in small tunnels covered with films containing blue fluorescent pigments in different concentrations, which increased total light transmission and influenced light quality (more blue light) during the years 2002 and 2003. Both fruit production (number of fruits, fruit weight) and fruit quality (color, size, shape, dry matter, freedom from physiological disorders and diseases, balance between sugars and acids) were determined. Blue fluorescent films caused strawberry plants to produce a higher yield, a higher number of fruits and a slightly higher mean fruit size. Differences in fruit quality were small.

Moreover, the effects of blue fluorescent films on different shrubs, perennials and annuals were tested at two growers in The Netherlands. Blue fluorescent films gave a 4 days earlier yield to *Alchemilla* and a 2 days earlier yield to *Virburnum*. Flower quality of *Alchemilla* was improved. This was probably due to higher day temperatures and lower humidity caused by a higher light transmission of the film. The same film caused a 5 days earlier yield to *Celosia*, at the same time improving flower quality.

Blue fluorescent films have potentials to increase the yield of strawberry and force the flowering of perennials.

INTRODUCTION

Natural light is an important factor in horticultural production. Light provides energy for photosynthesis, the process by which plants produce carbohydrates and oxygen from carbon dioxide and water. For photosynthesis light with the wavelengths from 400-700nm is necessary. This part of the global radiation is called photosynthetically active radiation (PAR) (CIE 106/8 1993). Light also acts as an informational medium for plants such as identifying surrounding environmental conditions. Photoreceptors inside the plant function as light sensors providing information on changes in light composition in the growing environment, so the plant can react with a photomorphogenetical response. Photomorphogenesis is the process that determines the form, colour and flowering of plants, wavelengths from 300-800nm are important (CIE 106/5 1993) for this process.

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Since the optimum light intensity and light spectrum are essential for optimum plant growth and development, much effort is focussed on the development of transparent greenhouse covering material with better optical properties (Fletcher et al., 2003; González et al., 2001; Hemming et al., 2004; Hoffmann, 1999; Kittas and Baille, 1998; Murakami et al., 1997; Pearson et al., 1995; Rajapakse et al., 2000; Sonneveld et al., 2002). Within the framework of the project SPECTRAFOIL funded by the EU and Grafe Color Batch (Germany), together with the industrial partners Palrig (Israel), Sunsaver (Spain) and several growers in Israel, Cyprus, Spain and The Netherlands, new greenhouse films for several climates and several horticultural production systems were developed. Several research partners were involved in this development, such as Wageningen UR - Agrotechnology and Food Innovations in The Netherlands (WUR-A&F), Agricultural Research Institute in Cyprus (ARI) and Agricultural Research Organization in Israel (ARO).

The aim of SPECTRAFOIL was to develop optimized photoselective greenhouse films according to the needs of vegetables and ornamentals under different climatic conditions. SPECTRAFOIL focussed on three different problems:

1. Development of greenhouse films containing fluorescent pigments to increase light transmission and to change its spectral composition mainly for Northern European climates (Fluorescent films). This will be presented in this paper.
2. Development of greenhouse films containing near infrared absorbing pigments to decrease greenhouse temperature mainly in regions with high irradiation in Southern European climates (NIR-blocking films).
3. Development of greenhouse films containing pigments blocking out ultraviolet radiation to reduce pest and diseases in greenhouses (UV-blocking films).

The objective of the research described here is to develop new fluorescent greenhouse covering materials containing different fluorescent pigments, which shift ultraviolet radiation into blue light, so that light intensity in the greenhouse is increased. The optimum pigment concentration had to be found. Technical aspects of fluorescent films were investigated, such as spectral light transmission, fluorescent effect and stability. It was investigated whether it is possible to increase PAR transmission of the films and simultaneously improve the light spectrum meeting the needs of the plants produced under these films.

MATERIALS AND METHODS

Plastic Films and Experimental Greenhouses

For the experiment, 6 greenhouse tunnels of 4 m by 5 m with a height of 2.10 m were placed in two rows of 3 greenhouses with a space of 4 m between the greenhouses and the rows. The tunnels were covered with different experimental plastic films containing a blue fluorescent pigment. Plastic films were arranged on the experimental greenhouses by coincidence. The fluorescent pigment absorbed ultraviolet radiation and transformed it into blue radiation. With this pigment experimental plastic films were produced. They contained the blue pigment in three different concentrations here coded as "a", "b" and "c". Experiments were carried out in 2002 and 2003. During the first year low, pigment concentrations were used in the plastic films advised by the pigment producer (a and b). Since fluorescent effects were low higher concentrations were used in second year trials (c).

The spectral transmission of the films with wavelengths of 300 to 800 nm was measured with an "Ulbricht integrating sphere" at A&F, Wageningen. This "Ulbricht integrating sphere" contains a diodearray spectrophotometer measuring the spectral lighttranmission for the wavelength of 300 nm $< \lambda <$ 1100 nm. The internal diameter of the sphere is 0.75 m. The inner surface of the sphere is coated with $BaSO_4$ (KODAK). Standard materials were used for calibration purposes.

Plant Material and Analysis of Strawberry

The effect of the new developed films on strawberry 'Elsanta' was investigated in two experimental periods in 2002 and 2003. Experiments were carried out at Wageningen UR – A&F. For the experiment small greenhouse tunnels of 4 m by 5 m with a height of 2.10 m were used. The greenhouses were covered with the experimental films described above. Strawberry plants were defrosted and potted in Libra containers filled with potting soil, especially developed for strawberries and fertilized with slow release Osmocote (16-11-11 NPK). Potting took place on 8th of May 2002 and on 7th of April 2003. In each tunnel 15 containers with 10 plants each were placed, of which 9 containers contain examination plants, the rest contain border plants. The plant density is 9.5 plants m^{-2}. Water was supplied by drippers with a drain of 25%. For pollination, a beehive was placed between the tunnels. Bees could freely pass in and out the tunnels.

Plants were harvested 2-3 times a week. For each container of each tunnel, the harvested fruits were separated into three size classes (> 40 mm, 26-40 mm, < 26 mm) according to the rules of the Dutch auction. For each class, total weight and number of fruits were recorded, as well as the number of deformed and diseased fruits.

Strawberry fruit color was determined by recording images with an image acquisition system consisting of a color CCD-camera mounted on top of a closed white illumination box. A special color segmentation algorithm was used to segment the fruits from the blue background in the image (Fig. 1.). Per single fruit the mean color value was recorded.

Furthermore, dry matter and ash content of the fruits were determined, as well as the electric conductivity (EC) and sucrose concentration in the fruit sap. Fruits were homogenised with a home-mixer. Dry matter was measured after 24 h drying at 105 °C and ash content subsequently after 4 h at 550 °C. Acidity (pH) and conductivity (EC) of each mixed sample were determined. Refraction index (Brix index) of fruit sap was determined with a refractometer using juice clarified by centrifugation (4500 rpm for 5 min). The refraction index was recalculated to the percentage sucrose in the strawberry fruits.

Plant Material of Flower Crops

The effect of the new developed fluorescent films on the earliness of *Viburnum* and *Alchemilla* was investigated at two Dutch commercial growers. For these crops early flowering is important to get a higher price at the market. Therefore plastic tunnels were placed above ten-year-old shrubs *Viburnum* plants on February, 28th, 2003. Either the blue fluorescent films with pigment concentration "c" or the reference film were used. For *Alchemilla* the greenhouse was erected at March, 6th, 2003. The plastic covering remained about 7 weeks on the crops before harvesting could start. The date of harvesting was registered by the grower.

The effect of the newly developed fluorescent films on the growth of the annual crop *Celosia* was also tested. Without a greenhouse this crop will not come to flower with an adequate quality in The Netherlands. *Celosia* was sown the greenhouse tunnels on July, 4th, 2003 using the same films. Production time under the plastic film greenhouses was 11-12 weeks. All crops were treated as usual concerning water and nutrient management and pesticide application.

RESULTS

The Production of Strawberry Fruits

The spectral transmission of the new developed blue fluorescent greenhouse film averaged over the PAR region (photosynthetically active radiation) of 400-700 nm is given in

Fig. 2 compared to the reference film. Absorption of the pigment takes place around 365 nm, the pigment shows fluorescence between 410-480 nm. The pigment slightly increased PAR radiation under the film and at the same time it also increased the amount of blue radiation with ca. 1-3% depending on the pigment concentration.

Cumulative fruit weight, cumulative number of fruits and mean fruit weight of strawberry 'Elsanta' is given in Table 1. The blue fluorescent films with the higher pigment concentrations b and c increased the cumulative fruit weight with about 10%. The higher strawberry production under the blue fluorescent films is due to a higher number of fruits produced. Mean fruit weight was comparable between the reference and the fluorescent film. Fruit weight was higher in 2003 than in 2002 due to a higher temperature sum and a higher irradiation sum (data not shown).

No significant differences in fruit colour could be observed by fruits grown under the different fluorescent greenhouse films. In tendency, fruits grown under blue fluorescent films are slightly brighter but more saturated than fruits grown under the reference film, which are darker but paler. No significant differences could be detected in fruit quality parameters measured as dry matter, ash content, sucrose concentration, electric conductivity and pH of fruit sap. In tendency, fruits grown under the blue fluorescent films were found to be slightly more acid (lower pH) than fruits grown under the reference film. Since the sweetness to sourness ratio can be used as quality index that fairly correlates with the taste quality, it can be concluded that fruits grown under the blue fluorescent films taste less sweet than fruits grown under the reference film.

The Production of Flowers

Ten-year-old shrubs *Viburnum* plants were covered with the blue fluorescent film and a reference film. At the beginning of the experiments the shrubs had no leaves. First flowers could be harvested under the blue fluorescent film on April, 14th, 2003. Under the reference film the crop could be harvested 2 days later. Growth was satisfactorily under both films. The difference with outside cultivation was obvious (Fig. 3.).

Alchemilla plants were covered with the blue fluorescent film and a reference film, when there was no growth yet. At the end of April a difference in growth could be observed. Under the blue fluorescent film flowers were more developed and already stretching at April, 29th. Under the reference film the crop was still more compact, no stretching. At the same time the crop growing outside showed no flowers or buds (Fig. 4). Growth of *Alchemilla* under the blue fluorescent film was very satisfactory for the grower. The time difference in yield was four days.

Growth of the annual crop *Celosia* took place satisfactorily. First yield under the test film was at September, 10th 2003, while under the reference film first yield was at September, 15th 2003. Under the blue fluorescent film flower spikes were more regular with less side branches and, consequently, a better quality, than under the reference film.

DISCUSSION

The Production of Strawberry Fruits

In the experiments as described in this report, the effects of fluorescent films on fruit production and quality of *Fragaria × ananassa* 'Elsanta' were determined. In the past several fluorescent films were developed. Some fluorescence pigments absorb parts of the green radiation and emit it again in the form of red radiation (Zarka and Zarka, 1985; Pearson et al., 1995; Kittas and Baille, 1998). Though some vegetables and some cut flowers showed a 5-10% increase of yield under the high light intensity in Israel (Zarka and Zarka, 1985), the transmission of PAR of those films is reduced compared to standard polyethylene films. Recently films are developed, which absorb parts of the ultraviolet, blue and green region of the spectrum. González et al. (2003) and Pearson et al. (1995) investigated such films and again found a reduction in PAR transmission.

It has to be considered that the increase in PAR is dependent on the amount of pigment in the polymer and the amount of UV in global radiation. In winter on average <1 W*m^{-2} UV-B and ca.7 W*m^{-2} UV-A are available in Middle European Countries by an average global radiation of ca. 100 W*m^{-2}. In summer the average amount of UV radiation rises up to 2 W*m^{-2} UV-B and ca. 40 W*m^{-2} UV-A by an average global radiation of 600 W*m^{-2} (CIE 85 1989). So the potential of fluorescent effects is limited. Fluorescent effects are enlarged by increased pigment concentrations. We can conclude from our measurements and experiments that total PAR transmission can be increased by blue fluorescent pigments by 1 to 3%.

In our experiments blue fluorescent films with higher pigment concentrations resulting in a higher PAR transmission increased the number of strawberry fruits produced. Apparently a high PAR transmission and a blue enriched environment increased strawberry yield. Also Fletcher et al. (2002) found strawberry yield to be highest under plastic films with high light transmission. They found cumulative fruit number and fruit fresh weight to be increased with increased PAR transmission of the films. Plants grown under lower light transmission films produced the lowest fruit fresh weight per plant (Fletcher et al., 2002). Awang and Atherton (1995) additionally found a reduction in marketable fruit of strawberries under low light conditions.

Fruit quality is determined by appearance (colour, size, shape, freedom from physiological disorders and decay), flavour, firmness, texture, dry matter and organoleptic properties (balance between sweetness (sugars) and sourness (acids) (Dorais et al., 2001; Montero et al., 1996). In the strawberry experiments described here, some of these quality traits were determined. In general, sweetness to sourness ratio is used as a quality index (Montero et al., 1996). Alavoine and Crochon (1989) showed that the refractrometric index seems to fairly correlate with the taste quality. Given that sucrose concentrations hardly differed, the acidity results indicate that fruits grown under the blue fluorescent films tasted less sweet than fruits grown under the reference film.

The Production of Flowers

The effect of blue fluorescent films on different shrubs, perennials and annuals was tested at two growers in The Netherlands. The 4 days earlier yield of the perennial *Alchemilla* was probably due to higher day temperatures and lower relative humidity caused by a higher light transmission of the blue fluorescent film. *Alchemilla* always flowers around Mother's Day (early May), a very important moment for flower growers. All flowers harvested before that time reach a good price. However, only a 2 days difference in earliness of *Virburnum* was not big enough for the grower. Since the shrub *Virburnum* already induces its flowers in autumn the year before, it can be assumed than growing conditions in autumn are more important for bud development than the relatively short time under the plastic tunnel resulting in less differences in earliness.

The improvement of flower quality of *Celosia* can be explained by the more uniform climate under the blue fluorescent film compared to the reference film. Under the reference film there was a higher relative humidity. Hot sunny days with a low relative humidity were alternated with dull days with a high humidity. Humidity was higher under the reference, sometimes too high for the *Celosia* flowers. Young flower buds under the reference film could not withstand these alternations and died. Consequently, there was more space, less competition, to grow for the remaining flower buds, giving them an irregular spike.

CONCLUSIONS

Blue fluorescent films seem to be favorable for strawberry fruit production. Whether this is due to the higher PAR transmission of the films or to a light quality effect cannot be concluded from the experiments. Blue fluorescent films caused 10% higher strawberry yields, mainly because of an increased fruit number. From these investigations it can be concluded that the new developed greenhouse films containing blue fluorescent pigments have good potentials to affect growth and development of strawberry 'Elsanta' positively.

Moreover, blue fluorescent films seem to have a good potential to give earlier flowering to perennial flowers, such as *Alchemilla.* Flower quality of *Alchemilla* and *Celosia* were improved. From practical grower tests it can be concluded that the new developed blue fluorescent greenhouse films have good potentials to produce early flowers of perennials in spring and to improve flower quality positively under the Dutch climate.

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Tables

Table 1 Effect of fluorescent films on the total cumulative total fruit weight (g), total fruit number and mean fruit weight (g) of *Fragaria* × *ananassa* 'Elsanta' in 2002 and in 2003 (± standard deviation).

Pigment	Total fruit weight (g)	Total fruit number	Mean fruit weight (g)
Reference 2002	22332±325	2361±26	9.4±0.4
Blue -a	22848±226	2414±25	9.5±0.4
Blue -b	25390±281	2569±35	9.9±0.6
Reference 2003	28820±316	2188±32	13.2±0.6
Blue -c	31940±195	2447±15	13.4±1.0

Figures

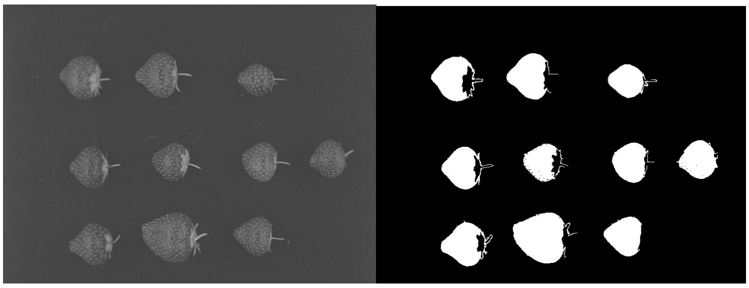

Fig. 1. Colour measurement of strawberry fruits grown under the new fluorescent films (left) and image segmentation by a special algorithm (right).

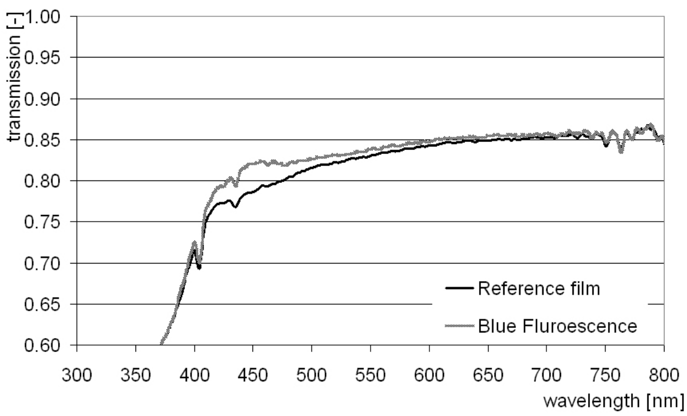

Fig. 2. Spectral transmission of a new developed blue fluorescent greenhouse film and a reference film tested by Wageningen UR - A&F, The Netherlands.

Fig. 3. *Viburnum* grown under new fluorescent greenhouse films (left) and at the same time outside (right).

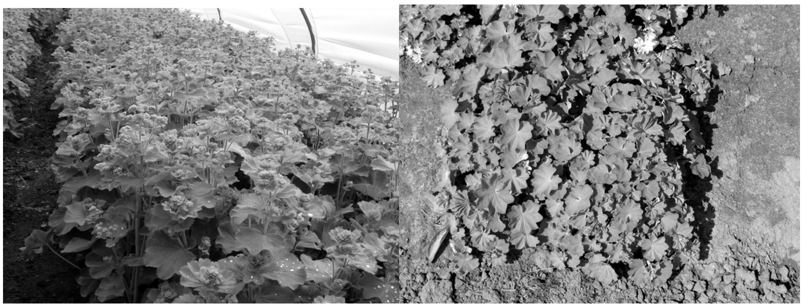

Fig. 4. *Alchemilla* grown under new fluorescent greenhouse films (left) and at the same time outside (right).