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Plant morphology is affected by light quality selective plastic films and alternating day and night temperature

Der Effekt von lichtqualitätsselektiven Plastikfilmen und alternierenden Tag-Nachttemperaturen auf die Morphologie der Pflanze

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Summary

Plant morphology is affected by light quality and temperature. The present work aimed to test and compare the effect of light quality selective plastic films and their interacting effects with those of daily alternating temperature in two cultivars of *Petunia* x *hybrida* ('Ultra Blue' and 'Silvana Purpur'), *Fuchsia* x *hybrida* 'Beacon' and *Pisum sativum*. The plants were grown under three different day (DT) and night temperature (NT) regimes (DT/NT 21/13 °C, 17/17 °C and 13/21 °C) and in combination with three coloured plastic covers (SCE-4: $R_{600\text{-}700}/FR_{700\text{-}800}$-ratio of 0.75, control film: R/FR-ratio of 1.06 and YCE-1: R/FR-ratio of 1.57). Shoot length was shorter under YCE-1 (high in R) compared with SCE-4 (high in FR) in all species but *P. sativum*, with a successive decreasing effect from *P.* 'Ultra Blue', *P.* 'Silvana Purpur' to *F.* 'Beacon'. Compared to a high DT, a high NT reduced shoot length in all species but more strongly in *P. sativum* than in *F.* 'Beacon' and *P.* 'Ultra Blue' and least in *P.* 'Silvana Purpur'. Further, temperature alternations affected shoot length slightly more under a high than a low R/FR-ratio, while the effect of changing R/FR-ratio was more prominent under high NT than high DT conditions. Light quality selective plastic films may serve as a non-chemically growth regulating tool for plant production in greenhouses under circumstances with high outdoor temperatures and irradiance where application of thermoperiodic responses meet limitations.

Zusammenfassung

Die Morphologie der Pflanze wird von der Lichtqualität und der Temperatur beeinflußt. Die hier vorgestellte Arbeit hatte zum Ziel, den Einfluß von lichtqualitätsselektiven Filmen und deren Zusammenspiel mit alternierenden Tag- und Nachttemperaturen zu untersuchen. Versuchspflanzen waren zwei Sorten von *Petunia* x *hybrida* ('Ultra Blue' und 'Silvana Purpur'), *Fuchsia* x *hybrida* 'Beacon' und *Pisum sativum*. Die Pflanzen wurden bei drei unterschiedlichen Tag (DT)- und Nacht (NT)-Temperaturbedingungen gehalten (DT/NT 21/13 °C, 17/17 °C und 13/21 °C), kombiniert mit drei verschiedenfarbigen Plastikdeckmaterialien (SCE-4: $R_{600\text{-}700}/FR_{700\text{-}800}$-Verhältnis von 0.75, Kontrollfilm: R/FR-Verhältnis von 1.06 und YCE-1: R/FR-Verhältnis von 1.57). Die Haupttriebe waren kürzer unter YCE-1 (mit hohem R-Wert) verglichen mit SCE-4-Folie (mit hohem FR-Wert) mit einem abbnehmenden Effekt von *P.* 'Ultra Blue' über *P.* 'Silvana Purpur' bis zu *F.* 'Beacon'. Dieser Effekt galt jedoch nicht für *P. Sativum*. Bei einer hohen DT-Behandlung führten hohe NT zu einer verminderten Trieblänge bei allen untersuchten Arten, jedoch stärker ausgeprägt bei *P. sativum* als bei *F.* 'Beacon' und *P.* 'Ultra Blue' und am schwächsten bei *P.* 'Silvana Purpur'. Weiterhin beeinflußten die untersuchten Temperaturbedingungen die Haupttrieblängen geringfügig stärker unter hohen (verglichen mit geringeren) R/FR-Verhältnissen, während der Effekt des unterschiedlichen R/FR-Verhältnisses sich mehr bei hohen NT (verglichen mit hohen DT) hervorhob. Lichtqualitätsselektive Plastikfilme können daher möglicherweise als nicht-chemische Wachstumsregulatoren in der Pflanzenproduktion im Gewächshaus eine Rolle spielen, insbesondere unter hohen Außentemperatur- und Strahlungsbedingungen, wo Anwendungen von thermoperiodischen Methoden ihre Grenzen erreichen.

Abbreviations: DIF – difference between day and night temperature, DT – day temperature, FR – far-red light, NT – night temperature, R – red light.

Introduction

An increasing concern about the use of chemicals in plant production has initiated a large number of experiments aiming to control plant height in greenhouse crops without such chemicals (HENDRIKS and UEBER 1995, MYSTER and MOE 1997). The morphology of plants is highly influenced by the growing conditions and there is a focus on how plant physiological responses can be utilised instead of growth retardants, chemicals which mainly affect gibberellin biosynthesis (RADEMACHER 1995).

Growers throughout Europe, North America and Japan are now using temperature manipulations to induce thermoperiodic responses, which was first discovered by WENT (1944) and refined for practical purposes from the mid-seventies (MOE 1983, ERWIN and HEINS 1985). The day temperature (DT) is kept at the same level or lower than the night temperature (NT) since the shoot and internode elongation are decreas-

ing with a decreased difference (DIF=DT–NT) between DT and NT (decrease in DIF) (ERWIN et al. 1989a). Some plant species, and in particular *Euphorbia pulcherrima* (MOE et al. 1992, UEBER and HENDRIKS 1992) and *Lilium longiflorum* (ERWIN et al. 1989b), even grow shorter under a short temporary decrease in temperature in the morning (temperature-drop) compared to constant temperature. However, these temperature strategies are not effective in all species (MYSTER and MOE 1995), and the application of negative DIF is difficult during times of the year with high DT as a result of high solar irradiation.

The spectral distribution of light has a strong impact on the morphology of plants (SMITH 1994). In particular, a high amount of R compared to FR light (high R/FR-ratio) will decrease stem length, while FR-enriched light conditions (low R/FR-ratio) will enhance elongation. Addition of $CuSO_4$ to water filters has been proven to decrease stem length in a wide range of species (MORTENSEN and STRØMME 1987, RAJAPAKSE and KELLY 1992, 1995, KAMBALAPALLY and RAJAPAKSE 1998). In addition to establishing a high R/FR-ratio the $CuSO_4$ filters also transmit most of the wavelengths in the blue and near-blue region. These wavelengths also contribute to a more compact plant shape (COSGROVE 1981, MORTENSEN and STRØMME 1987).

Recently, the technology for producing coloured plastic film has been improved and effects on plant growth have been documented (MURAKAMI et al. 1997, OYAERT et al. 1997, 1999). The selectivity of the dye for specific wavelengths of light is important and there is a preference for incorporating dyes that transmit all wavelengths but FR (MURAKAMI et al. 1996, 1997). The light quality of light applied during the night period is affecting the relative response to daily temperature alternations (MOE et al. 1991). The plastic films provide an opportunity to study the interaction between temperature and the R/FR-ratio in the photoperiod, a relationship that to our knowledge never has been studied before. Therefore, in addition to compare the effect on morphology of two photoselective plastic films, we took the opportunity to study the interaction between the R/FR-ratio in the photoperiod and DT/NT alternations in order to gain more knowledge on the physiological basis of thermoperiodism.

Materials and Methods

The experiment was carried out at the Agricultural University of Norway (60 °N) from June to mid September without any additional artificial light.

Plant material and pre-treatment

Seeds of *Petunia* x *hybrida* Vilm 'Ultra Blue' and *Pisum sativum* L. 'Torsdag', and vegetatively propagated *Petunia* x *hybrida* Vilm 'Silvana Purpur' (basket petunia) and *Fuchsia* x *hybrida* Voss 'Beacon' were used in the experiment. The plants were raised under short-day (SD) conditions (10 h photoperiod) at 22 °C NT and a slightly higher DT depending on outdoor temperature and irradiance (daily average temperature: 23.5 °C). Eleven cm plastic pots, limed and fertilised peat (Floralux, Nittedal Torvindistrier, Norway) were used, and after establishment the plants were watered daily throughout the whole experiment with a complete nutrient solution.

Experimental design

The experiment was started 14 days (*P.* 'Sylvana Purpur' and *P. sativum*) and 21 days (*P.* 'Ultra blue' and *F. hybrida*) after propagation time. *P.* 'Silvana Purpur' were pinched above the sixth leaf and *F. hybrida* above the third leaf pair and all plants were moved to air conditioned greenhouse compartments. A 12-h „day period" was defined as the period lasting from 06.00 h until 18.00 h, while the „night period" consisted of the remaining 12 h. Three different temperature (DIF) treatments were used, one in each of 3 compartments: Positive DIF, DT/NT 21/13 °C; zero DIF or constant temperature, DT/NT 17/17 °C; negative DIF, DT/NT 13/21 °C. The actual DT or NT was measured at plant level and varied ±0.4 °C, while the water vapour deficit was kept at 0.38 kPa with a variation of ±0.03 between the compartments and day and night periods. Within each compartment and temperature treatment plants were placed on trolleys (area: 1 m×2 m) which were covered by 3 different plastic films produced by Mitsui Chemicals, Inc., Tokyo, Japan: SCE-4 (low $R_{600\text{-}700}/FR_{700\text{-}800}$-ratio: 0.75), control film (R/FR: 1.06) and YCE-1 (R/FR 1.57). The plastic was wrapped around the trolleys so that it covered incoming light from the top and sides to 5 cm below the bottom of the pots. To allow air circulation and secure proper temperature and humidity control light was not filtered from below. Spectral distribution of the transmitted radiation and further description are given in Fig. 1.

Six plants of each species were used per treatment and the plants were spaced so that their leaves did not touch each other. The experiment was repeated once and the recordings were analysed according to a split-plot model (ANOVA procedure) with replications as blocks, temperature regime as main plots and plastic cover as sub-plots based on mean values in each replication and treatment. The plastic films were randomised with the temperature treatments, but it should be noted that the temperature treatments therefore were not randomised within the blocks as normally required in a split-plot model. Tukey studentized range test is applied where the response to the treatments are significant different.

Results

Morphology

The plant species tested in this experiment responded differently to the change in R/FR-ratio established by the plastic covers applied. The film giving rise to a high R/FR-ratio (YCE-1) reduced the length of the main shoot in *P.* 'Ultra Blue' with 30 % and 44 % compared to the daylight control or a plastic cover establishing a low R/FR-ratio (SCE-4), respectively (Tab. 1). The longest side shoot was less affected by the different light conditions (23 % from low to high R/FR-ratio) than the main shoot, and, as a consequence, since the

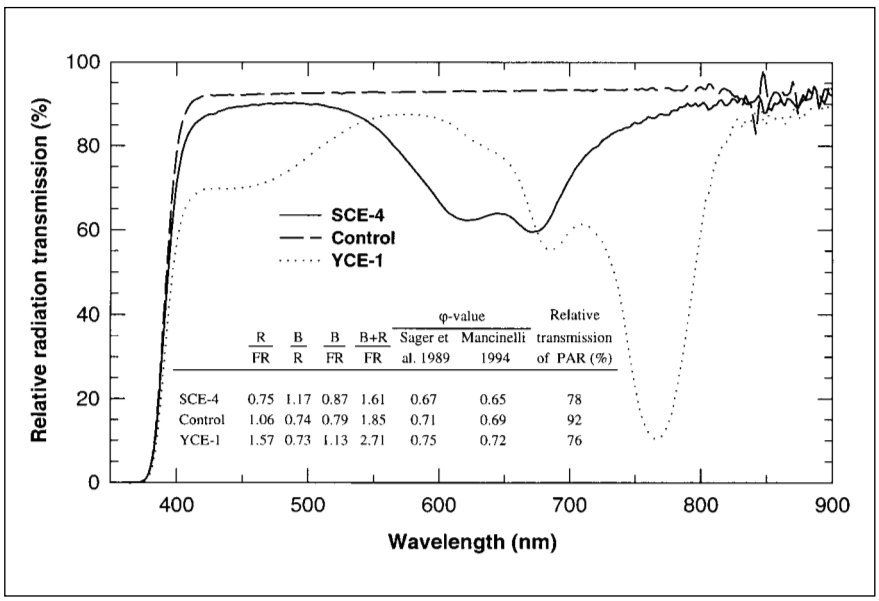


Fig. 1. Relative transmission of light (CIE standard illuminant D65) through SCE-4, control film and YCE-1 and ratios between blue (B: 400–500 nm), red (R: 600–700 nm) and far-red (FR: 700–800 nm) established under the films. The light spectre was measured with a spectroradiometer (LI-COR 1800) and φ-values calculated after SAGER et al. (1988) and MANCINELLI (1994).
Relativer Lichtdurchgang (CIE Standard Lichtquelle D65) durch SCE-4, Kontrollfilm und YCE-1 und Verhältnisse zwischen blau (B: 400–500 nm), rot (R: 600–700 nm) und dunkelrot (FR: 700–800 nm), etabliert unter den Filmen. Das Lichtspektrum wurde mit einem Spektroradiometer (LI-COR 1800) gemessen und die φ-Werte wurden nach SAGER et al. (1988) und MANCINELLI (1994) berechnet.

Table 1. The effect of different DIF treatments and light quality selective plastic films on plant morphology in *Petunia* x *hybrida* 'Ultra Blue'. Statistical significance are given for each parameter, ns: Not significant, different letters indicates differences according to Tukey stundentized range test at 5 % level.
Der Effekt von verschiedenen DIF-Behandlungen und lichtqualitätsselektiven Plastikfilmen auf die Morphologie von Petunia x hybrida 'Ultra Blue'. Statistische Signifikanzen sind für alle Parameter angegeben, ns: nicht signifikant, unterschiedliche Buchstaben bei signifikanten Unterschieden, nach Tukey Studenttest, 5 %-Niveau.

		Plant height (cm)	Plant height / diameter	Length of main shoot (cm)	Internode length on main shoot (mm)	Length of longest side shoot (cm)	Internode length on longest side shoot (mm)
DIF	Positive	21.7	0.72	18.7	8.8 a	25.3	15.4 a
	Zero	20.2	0.68	16.8	8.2 ab	23.3	14.6 ab
	Negative	17.9	0.63	13.7	6.3 b	20.1	12.0 b
Plastic film	SCE-4	23.0 a	0.78 a	20.7 a	9.8 a	25.6 a	15.8 a
	Control	20.2 a	0.69 b	16.6 b	7.8 b	23.1 a	14.1 b
	YCE-1	16.5 b	0.56 c	11.6 c	5.5 c	19.8 b	12.1 c
Statistical differences							
DIF		ns	ns	ns	0.033	ns	0.038
Plastic film		0.003	≤0.001	≤0.001	≤0.001	0.004	≤0.001
DIF × Plastic film		ns	ns	ns	ns	ns	ns

side shoot was longer than the main shoot, this also became true for the final plant height (28 % reduction). The reduction in shoot length caused a remarkable decrease in the ratio between plant height and diameter (Tab. 1). The average length of shoots emerging after pinching in *P.* 'Sylvania Purpur' decreased by 19 % under a high compared to a low R/FR-ratio (Tab. 2), while the reduction under YCE-1 compared to SCE-4 in plant height and the length of the shoot developed at the second node below the pinching point in *F. hybrida* was 10 and 13 %, respectively (Tab. 3). The effect of the plastic cover on shoot length of *P. sativum* was small and without any practical application (Fig. 2).

On the contrary, a change from positive (DT/NT 21/13 °C) to negative DIF (13/21 °C) reduced shoot length 36 % in *P. sativum*, slightly less in *F. hybrida* (30 %) and *P.* 'Ultra Blue' (28 %), while the reduction by negative DIF was only 15 % in *P.* 'Silvana Purpur' (Fig. 2, Tab. 1, 2 and 3). In *P. sativum* the shoot length was almost the same under positive and zero DIF while a strong inhibition was observed under negative DIF (Fig. 2), which was seen already shortly after the start of the experiment. In the other species tested there was a successive decrease in elongation from positive to zero and negative DIF (Tab. 1, 2, and 3). Even though not statistical significant, the effect on elongation of changing the R/FR-ratio by covering the plants with plastic film was slightly stronger under negative than positive DIF in *P.* 'Ultra Blue' and 'Silvana Purpur' and *F. hybrida* (Tab. 4). Contrary, in the same species the effect of altering the temperature regime was stronger under a high than low R/FR-ratio. Since there was no systematic effect of light quality on stem elongation in *P. sativum,* there was no interaction with the effect of temperature.

The number of leaves developed on the shoots was the same irrespective of the light conditions and only reduced by 5 to 7 % under negative compared to posi-

Table 2. The effect of different DIF treatments and light quality selective plastic films on plant morphology in *Petunia* x *hybrida* 'Silvana Purpur'. Statistical significances are given for each parameter, ns: Not significant, different letters indicates differences according to Tukey stundentized range test at 5 % level.
Der Effekt von verschiedenen DIF-Behandlungen und lichtqualitätsselektiven Plastikfilmen auf die Morphologie von Petunia x hybrida 'Silvana Purpur'. Statistische Signifikanzen sind für alle Parameter angegeben, ns: nicht signifikant, unterschiedliche Buchstaben bei signifikanten Unterschieden, nach Tukey Studenttest, 5 %-Niveau.

		Average shoot length (cm)	Average internode length (cm)	Number of days to first visible flower bud	Number of days to first open flower
DIF	Positive	21.9	10.0	29.7	36.6
	Zero	20.6	10.3	29.8	38.0
	Negative	18.3	8.7	31.6	40.8
Plastic film	SCE-4	22.4 a	10.5 a	30.3	38.3
	Control	20.7 b	9.8 b	29.5	37.1
	YCE-1	17.8 c	8.6 c	31.3	39.9
Statistical differences					
DIF		ns	ns	ns	0.039
Plastic film		0.001	0.001	ns	ns
DIF × Plastic film		ns	ns	ns	ns

Table 3. The effect of different DIF treatments and light quality selective plastic films on plant morphology in *Fuchsia* x *hybrida* 'Beacon'. Statistical significance are given for each parameter, ns: Not significant, different letters indicates differences according to Tukey stundentized range test at 5 % level.
Der Effekt von verschiedenen DIF-Behandlungen und lichtqualitätsselektiven Plastikfilmen auf die Morphologie von Fuchsia x hybrida 'Beacon'. Statistische Signifikanzen sind für alle Parameter angegeben, ns: nicht signifikant, unterschiedliche Buchstaben bei signifikanten Unterschieden, nach Tukey Studenttest, 5 %-Niveau.

		Plant height (cm)	Length of main shoot (cm)	Internode length on main shoot (mm)	Number of side shoots >3 cm	Dry weight (g)	Percent dry weight (%)
DIF	Positive	37.9 a	36.0 a	3.85 a	4.89	15.5 a	12.5
	Zero	34.9 a	32.6 a	3.57 b	3.95	14.9 a	11.9
	Negative	26.7 b	25.4 b	2.90 c	3.83	11.5 b	11.0
Plastic film	SCE-4	35.8 a	33.6 a	3.66 a	3.78	13.5 ab	11.5 b
	Control	32.4 b	30.1 b	3.36 b	4.39	15.0 a	12.6 a
	YCE-1	31.3 b	30.3 b	3.31 b	3.78	13.4 b	11.4 b
Statistical differences							
DIF		0.009	0.015	0.001	ns	0.009	0.057
Plastic film		0.003	0.026	0.007	ns	0.033	0.010
DIF × Plastic film		ns	ns	ns	ns	ns	ns

Table 4. Percent decrease in length of main stem from low (plastic film SCE-4) to high R/FR-ratio (YCE-1) under different day and night temperature combinations and from positive (DT/NT 21/13 °C) to negative DIF (DT/NT 13/21 °C) under different plastic films (R/FR-ratio).
Prozentuale Abnahme der Länge des Haupttriebes bei niedrigem (Plastikfilm SCE-4) und hohem R/FR-Verhältnis (YCE-1), bei unterschiedlichen Tag- und Nachttemperatur-kombinationen und bei positiven (DT/NT 21/13 °C) und negativen DIF (DT/NT 13/21 °C) unter unterschiedlichen Plastikfilmen (R/FR-Verhältnis).

		Plant species/cultivar			
		Petunia 'Ultra Blue'	*Petunia* 'Silvana Purpur'	*Fuchsia* 'Beacon'	*Pisum sativum*
Decrease (%) from low to high R/FR-ratio					
	Positive DIF	43	14	4	9
	Zero DIF	43	20	11	0
	Negative DIF	48	24	16	9
Decrease (%) from positive to negative DIF					
	Low R/FR-ratio (SCE-4)	24	12	24	34
	Control	29	12	32	41
	High R/FR-ratio (YCE-1)	31	22	34	34

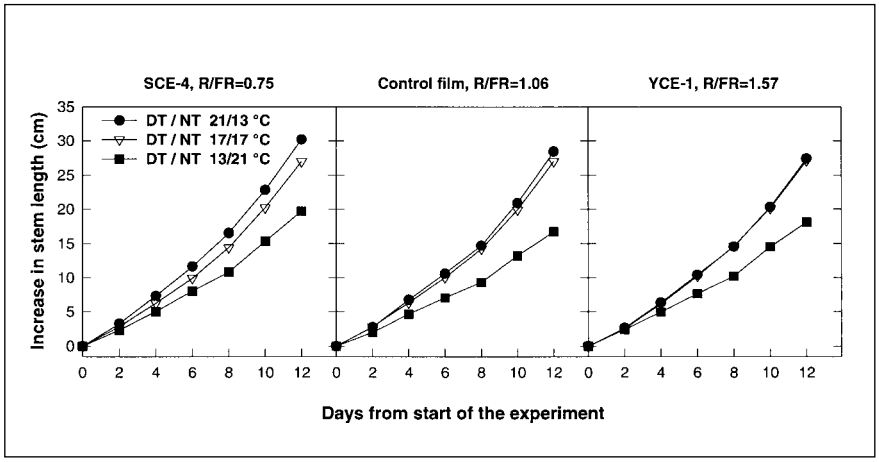


Fig. 2. The effect of different DT and NT (T) and light quality selective plastic films (P) on increase in stem length in *Pisum sativum* 'Torsdag'. Statistical significance: T - P=0.008; P and T × P – not significant.
Der Einfluß von verschiedenen DT und NT (T) und lichtqualitätsselektiven Plastikfilmen (P) auf die Zunahme der Haupttrieblänge von Pisum sativum 'Torsdag'. Statistische Signifikanz: T - P=0.008; P und T×P – nicht signifikant.

tive DIF in *F. hybrida* and *P. sativum*. In all species tested, a decreasing internode length from a low to a high R/FR-ratio and from positive to negative DIF was therefore mainly causing the reduction in final shoot and side shoot length (Tab. 1, 2, and 3). The light and temperature conditions had no effect on the number of shoots emerging after pinching in *P.* 'Sylvana Purpur' and *F. hybrida*. The number of side shoots on the main stem was slightly increased under YCE-1 compared to SCE-4 (10 %) and the control (3 %) in *P.* 'Ultra Blue', and in *F. hybrida* a positive interacting effect (not statistical significant) of negative DIF and YCE-1 (high R/FR-ratio) on the number of side shoots was observed.

Flowering

In *P.* 'Sylvana Purpur', there was an average increase of 1.9 and 4.2 days under negative compared to positive DIF in the time to visible flower bud and first open flower, respectively, while the light quality had even less effect (Tab. 2). The same response was observed in *P.* 'Ultra Blue', while time to visible flower bud was hardly affected in *F. hybrida*. The only divergent effect of the treatments on number of flower and flower buds was an increased number under the control film in *P.* 'Sylvana Purpur' and *F. hybrida*.

Shoot dry weight

Dry matter accumulation of the shoot was recorded in *P.* 'Ultra Blue', *P.* 'Silvana Purpur' and *F. hybrida*. In the latter one the shoot dry weight decreased dramatically by negative as compared to zero and positive DIF (26 %), while there was hardly any difference between plants grown under SCE-4 and YCE-1 (Tab. 3). In the two *Petunia* cultivars a smaller decrease in dry matter was observed under negative compared to positive DIF (≤ 12 %) and under YCE-1 compared to SCE-4 (≤ 10 %). In all species a high amount of dry matter was found in plants grown under the control film as it transmitted more light (Fig. 1). In general, an equal or less pronounced effect of the plastic films and DIF was found on percent dry matter of the fresh weight than on the shoot dry weight (Tab. 3).

Discussion

The change in day light spectral distribution (R/FR-ratio: 1.06) under the light quality selective plastic films to a low (SCE-4, R/FR-ratio: 0.75) or a high R/FR-ratio (YCE-1, R/FR-ratio:1.57) affected plant height and elongation of internodes in the two cultivars of *Petunia* and *F. hybrida* tested in this experiment. Our results are consistent with earlier reports on plastic films with a similar dye transmitting relatively more R than FR (high R/FR-ratio) under which stem length in *Lycopersicon esculentum*, *Cucumis sativus* (MURAKAMI et al. 1997) and *Capsicum annuum* (CERNY et al. 1999) has been reduced and with the opposite enhancing effect of the film giving rise to a low R/FR-ratio.

The fourth species, *P. sativum*, was hardly affected by the different plastic covers. In experiments with similar films we found no significant effect on stem elongation in *Begonia* x *hiemalis* and *Kalanchoe blossfeldiana* (unpublished results). MORTENSEN (1990) found neither any effect of $CuSO_4$ filters in *B. hiemalis* even with a R/FR-ratio of 4. MORGAN and SMITH (1979) have nicely described a variation among plant species in their responses to changes in the R/FR-ratio and they related this to an adaptation to the species different habitats. A low R/FR-ratio will enhance elongation, while internodes become shorter under a high R/FR-ratio in „shade-avoiding" species (adapted to open canopies). There are also species that hardly respond to changes in R/FR-ratio („shade-tolerant") or with a weak response as reported here for the cultivar 'Torsdag' in *P. sativum*. WELLER and REID (1993) have earlier found a 10 % decrease in shoot length of *P. sativum* by an increase in R/FR-ratio from 0.9 to 1.6, while an increase to R/FR-ratio to 4.8 was needed to gain a reduction of 25 %.

B light is also found to reduce stem elongation as demonstrated by the strong effect of B on hypocotyl elongation in *Cucumis sativum* (COSGROVE 1981, SHINKLE and JONES 1988) and the lack of inhibition in the *hy4* mutant of *Arabidopsis* despite of normal levels of phytochrome and responses to the R/FR-ratio (KOORNEEF et al. 1980). The B light may act through a B light receptor or through phytochrome since both pigments absorb light in the B region, but a coaction

between pigment systems is also described (MOHR 1994). It is clear from Fig. 1 that YCE-1 used in the present study has a decreased level of B light even though it gave rise to compact plants. However, there is a corresponding reduction in R, while the decrease is much stronger in FR than B light. It is therefore likely to assume that the main reducing effect on shoot length under this plastic film was caused by the change in R/FR-ratio.

The reduced stem and internode elongation under negative compared to positive DIF observed in the present experiment confirmed earlier reports in upright cultivars of *P. hybrida* (KACZPERSKI et al. 1991), *F. hybrida* (TANGERÅS 1979, ERWIN et al. 1991) and *P. sativum* (GRINDAL et al. 1998). However, there are also reports on *P. sativum* (ERWIN et al. 1993) and *P. hybrida* cultivars (VOGELEZANG et al. 1992) with a poor response to DIF. To our knowledge thermoperiodic responses have never been tested earlier in basket petunia (*P. hybrida 'Silvana Purpur'*) and we categorise this cultivar to have a moderate response to DIF.

Extended stem length as a result of low R/FR-ratios in dense canopies is thought to be mediated by phytochrome B (SMITH 1994) in coaction with other light stable phytochromes (MOHR 1994). The present study is the first one aiming to test if DIF is interacting with the R/FR-ratio in the photoperiod. In the species responding to light quality, *Fuchsia* and *Petunia*, the effect of DIF was relatively stronger under a plastic film with a high (YCE-1) compared with the one with a low ratio (SCE-4). Correspondingly, the plants were more responsive to changes in light quality under negative than positive DIF. In contrast to these experiments, we have recently tested the interaction between DIF and light quality selective plastic films in *Cucumis sativum* and found that the effects of the films are stronger under positive than negative DIF (GRINDAL et al., unpublished data).

The lack of a consistent interacting response pattern among these species between DIF and the R/FR-ratio are therefore arguing against a specific role of phytochrome in thermoperiodic stem elongation. On the other hand, no effect of DIF is found in the phytochrome B deficient *Cucumis sativum* mutant *lh* (GRINDAL 1997) indicating the importance of this receptor for the DIF response. A decreased response to DIF was also observed in wild type plants of *Cucumis sativum* when they were exposed to a short end-of-day FR treatment (GRINDAL 1997), a light response that also is thought to be perceived by light stable phytochromes (SMITH and WHITELAM 1997).

In the present experiment the effect of the plastic film on stem elongation may also be reduced as light was filtered through the plant canopy. Since the individual plants were placed so that they did not toughing each other, such a filtering effect should therefore be most pronounced within the individual plant, especially for *P.* 'Ultra Blue' and *F. hybrida* since many side shoots and branches are present. This might explain why there was less effect of the films on the side shoots of *P.* 'Ultra Blue' than on the main shoot, even though side shoots quite often grow more vigorous than the main shoots. We have also observed a slightly stronger effect of the plastic films in pinched plants of *Campanula isophylla* with only 2 shoots than in non-pinched plants (BØHNSDALEN et al., unpublished results). Similarly, a likely reason why the plastic films affected the elongation the most under negative DIF is that plants become compact under such temperature conditions and less filtering within the plant itself may occur. The opposite interacting effect between DIF and the plastic films observed in *Cucumis sativum* (GRINDAL et al., unpublished results) is in conflict with this assumption, but the plants of *Cucumis sativum* were also highly responsive to changes in both light quality and temperature.

The rate of flowering is quite often increased under shade and low R/FR-ratios (SMITH 1994). There was hardly observed any effect of the plastic films in the present experiment, while plastic films with same light quality selective properties are found to affect flowering time by 2–3 days in cucumber and tomato (MURAKAMI et al. 1997).

There was a maximum difference of 10 % in dry matter accumulation in the shoot under high (YCE-1) and low R/FR-ratio (SCE-4). Leaf area was not recorded in this experiment, which makes it difficult to justify if a reduced area under YCE-1 could have resulted in less shoot dry weight than under SCE-1. On the other hand, light intensity influenced plant development in the present experiment. A 14–16 % higher amount of light (400–700 nm) under the control film than SCE-1 and YCE-4, decreased time to flowering and increased number of flowers and shoot dry weight slightly. The reason there was no dividing response pattern on shoot elongation due to higher light transmission by the control than the coloured films might be that the experiments were carried out during summer time with excess of light.

Most plant species normally develop less shoot dry weight under negative than positive DIF (ERWIN and HEINS 1995). However, less elongation normally counteracts this effect, and in case of *Fuchsia* reported here there was no difference in shoot dry matter per stem unit in response to DIF, although there was a 26 % reduction in total shoot dry matter from positive to negative DIF.

Conclusion

The tested light quality selective plastic films may be beneficial for non-chemical control of plant height in some species. The effect may be modified by the growing conditions such as DIF, and since the films transmit only about 75 % of the incoming light they may also serve as a shading material. Plastic films reflecting or absorbing FR and heat waves may therefore meet the request for alternative methods for growth control in periods with high temperature and excess of light when temperature strategies are difficult to apply and the effect of chemical growth retardants may be weak (UEBER 1998). Long term and large scale tests remain to answer these questions.

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