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THE INFLUENCE OF LIGHT QUALITY ON THE PHOTOPERIODIC RESPONSE OF SALVIA OCCIDENTALIS

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INTRODUCTION

In both short-day and long-day plants a long-day effect can be obtained by lengthening a relatively short light period of a high intensity (main light period) with a supplemental irradiation of low light intensity. The same effect can be obtained when instead of this supplemental light period the long dark period is interrupted by a short irradiation of high light intensity (night-break).

In almost all plant species the maximum of activity has been found in the red part of the spectrum for both the supplemental irradiation and for the nightbreak (RASUMOV, 1933; PARKER, a.o., 1950).

FUNKE (1948), however, reported that for some species, all *Cruciferae*, only the blue part of the spectrum is active as a supplemental irradiation.

WASSINK a.o. (1950) confirmed this blue light activity for *Brassica rapa*, another cruciferous plant. Moreover, these authors found for this plant species that near infra-red is also active in this respect. It appears, however, that this blue light activity is not restricted to the *Cruciferae*, for blue light also has a greater daylengthening effect than the red part of the spectrum on *Salvia occidentalis*. In nightbreak experiments with the same plant species it was shown that red light is more active than blue light for obtaining a long-day effect (MEIJER, 1957*b*).

For both *Hyoscyamus niger*, a long-day plant, and *Salvia occidentalis*, a short-day plant, it was found that an interruption of the long dark period only has a long-day effect when the preceding main light period contains blue light or probably also near infra-red irradiation. This blue or near infra-red necessity was also shown for some other long-day plants (STOLWIJK e.a. 1955; MEIJER e.a., 1957).

METHODS AND MATERIAL

The equipment used and the characteristics of the coloured light have been described in an earlier paper (MEIJER, 1957*a*). In some experiments near infra-red irradiation was given subsequently to green light. This infra-red was obtained by using a neon lamp (Philips, type 93169) from which the visible part of the emitted radiation

($\lambda < 7000$ Å) was filtered out by a combination of the "Plexiglas" filters "Rot 1" and "Blau 27 neu" (Röhm & Haas, Darmstadt). A water filter was used to absorb the wavelength region: $\lambda > 10000$ Å. The light intensity was measured with a calibrated photocell and given in $\mu W/cm^2$. The intensity of near infra-red radiation is given for the region 7000–8000 Å.

Salvia occidentalis, an obligate short-day plant, was used in all these experiments. Cuttings were cultivated in long days (18 hrs light per day) in a greenhouse. At the beginning of an experiment the youngest visible leaf pair was marked. After the treatment was finished plants were replaced in the greenhouse and kept in long days in order to examine the plants macroscopically on flower formation and to count the number of newly formed leaf pairs.

As *Salvia occidentalis* is a short-day plant, a long-day treatment prevents flowering.

Experimental results

Long-day treatment

The following experiments were carried out in order to investigate whether the effect of near infra-red or blue light necessary for a long-day treatment to be effective can be antagonized by a following red irradiation or not.

Four groups of 5 Salvia plants each were irradiated daily with: a: 16 hrs green light; b: 16 hrs green light followed by ½ hr red light; c: 15 hrs green light followed by 1 hr infra-red and d: as c, followed by ½ hr red light. The intensity of red and green light was 650 $\mu W/cm^2$, the intensity of near infra-red—obtained from a neon lamp—was 120 $\mu W/cm^2$. After a treatment of 28 days the plants were replaced in long days; 60 days after the beginning of the treatment the last observations were made. The results are given in Table 1.

TABLE I

Influence of red and near infra-red irradiation on the daylength effect of a long-day treatment in green light (16 hrs per day). Intensity of red and green light: 650 $\mu W/cm^2$; of near infra-red: 120 $\mu W/cm^2$. Duration of the treatment: 28 days. Number of plants per treatment: 5.

Light treatment: hrs per day			Number of plants		Number of newly formed leaf pairs
15	1	½	gen.	veg.	
Green	Green		5	–	7.6
Green	Green	red	5	–	7.8
Green	i-r		–	5	> 12.6
Green	i-r	red	5	–	8

As can be seen an exposure to 1 hour infra-red, given after a long-day in green light, prevents flowering. When this near infra-red radiation is followed by an exposure to red light, the effect of the near infra-red irradiation is nullified.

Similar results were obtained with blue light. Four groups of 6 plants were irradiated with 15 hrs green light daily, followed by *a*: 1 hr green light; *b*: 1 hr red light; *c*: 1 hr blue light or *d*: 1 hr blue light followed by 1 hr red light. The intensity of the green light was 640 $\mu W/cm^2$, the intensity of red and blue light 760 $\mu W/cm^2$. After the treatment had lasted 25 days the plants were replaced in long days in a greenhouse. The last observations were made 70 days after the beginning of the treatment. The results are given in Table 2.

TABLE II

Influence of blue and red light on the daylength effect of a long-day treatment in green light. Intensity of the green light: 640 $\mu W/cm^2$; intensity of the red and blue light: 760 $\mu W/cm^2$. Duration of the treatment 28 days. Number of plants: 6.

Light treatment: hrs per day			Number of plants		Number of newly formed leaf pairs
15	1	1	gen.	veg.	
Green	Green	–	5	1 *	9, > 14 *
Green	Red	–	6	–	9
Green	Blue	–	–	6	> 15.5
Green	Blue	Red	5	1 *	8.8, > 14 *

* see text.

Although 1 specimen of the plants grown in 16 hrs green light per day remained vegetative—which has never been found before—it is clear that a subsequent irradiation with 1 hr blue light per day promotes a long-day effect and that this promoting effect of blue light can be reversed by a following exposure to red light.

Supplemental irradiation

In preliminary experiments, in which plants were exposed to a short day of 8 hrs white light followed by a supplemental irradiation of 8 hrs blue or red light, it was found that at a low light intensity level a long-day effect could only be obtained with blue light, whereas at higher intensities both blue and red light are active in this respect (MEIJER, 1957*b*). In the following experiments plants were exposed to red or blue light during 10 hrs per day (main light period) at an intensity of 450 $\mu W/cm^2$. This main light period was followed by a supplemental irradiation during another 8 hrs red or blue light at an intensity of 160 $\mu W/cm^2$. The treatment was finished after 30 days after which the plants were kept in long days in a greenhouse. The last observations were made 65 days after the beginning of the treatment.

From these results it can be seen that only a blue supplemental irradiation causes a long-day effect whether it is given supplementarily to 10 hrs Red or to 10 hrs Blue light. One of the three plants grown in 10 hrs Red + 8 hrs blue (asterisk in table 3) formed after 7 normal leaves 3 pairs of bractlike leaves, after which normal vegetative growth was resumed.

TABLE III

The photoperiodic response of Salvia occidentalis to supplemental irradiation of 8 hrs red or blue light (160 $\mu W/cm^2$). Main light period: 10 hrs red or blue light per day at an intensity of 450 $\mu W/cm^2$. Duration of the treatment 30 days. Number of plants per treatment: 3.

Main light period	Supplemental irradiation	Number of plants gen.	Number of plants veg.	Number of newly formed leaf pairs
10 hrs Red	Dark	3	–	4.6
10 hrs Red	8 hrs red	3	–	4.6
10 hrs Red	8 hrs blue	–	3 *	> 12
10 hrs Blue	Dark	3	–	4
10 hrs Blue	8 hrs red	3	–	5.6
10 hrs Blue	8 hrs blue	–	3	> 12.3

* see text.

From the results obtained from nightbreak experiments it was expected that with a main light period of 10 hrs Red light no long-day effect should be obtained. Since red light, when given as an interruption of a long dark period, is more active than blue light in producing a long-day effect, and since on the other hand blue light is more active than red light in this respect when it is given supplementarily to the main light period, the following experiment was carried out. After an irradiation with 10 hrs blue light (main light period) at an intensity of 760 $\mu W/cm^2$, a supplemental irradiation was given with: a: 8 hrs red; b: 4 hrs darkness—4 hrs red; c: 6 hrs darkness—2 hrs red; d: 7 hrs darkness—1 hr red or e: 7½ hrs darkness—½ hr red. The intensity of the supplemental red light was 185 $\mu W/cm^2$. The treatment lasted 26 days, the observations were made 56 days after the beginning of the treatment. The number of generative and vegetative plants and the number of newly formed leaf pairs are given in Table 4.

TABLE IV

The photoperiodic response of *Salvia occidentalis* to an irradiation with red light (185 $\mu W/cm^2$), supplementarily given to 10 hrs blue light per day (670 $\mu W/cm^2$). Duration of the treatment 26 days. Number of plants per treatment: 3.

Supplemental light treatment hrs. Dark	Supplemental light treatment hrs. Red	Number of plants gen.	Number of plants veg.	Number of newly formed leaf pairs
0	8	3	–	5.3
4	4	–	3	> 8.5
6	2	–	3	> 8
7	1	–	3	> 8
7½	½	–	3	> 8.3
8	0	3	–	4.6

It may be concluded that the inactivity of 8 hrs red supplemental light for obtaining a long-day effect is only apparent and can not be due to the inactivity of the red light as supplemental irradiation but to an antagonizing effect of red light (the first half of the supplemental light period) on the preceding main light period (10 hrs blue light). This conclusion is confirmed by the results of the experiments mentioned in the first part of this paper.

Discussion

From the experiments described above it can be concluded that the effect of blue light or infra-red radiation, necessary to obtain a long-day effect can be reversed by an subsequent irradiation with red light. In photoperiodism, Borthwick e.a. (1952) had already described a reversible antagonism between red and near infra-red.

De Lint found also an antagonism between blue and red light given simultaneously in experiments with *Hyoscyamus niger* (personal communication).

The results which were obtained with a supplemental light treatment (Table 2) are in agreement with the conclusion of Funke (1948), which was confirmed by Wassink e.a. (1950), that for some species blue light is the most active part of the spectrum for producing a long-day effect by prolonging a short day with a supplemental light period. As could be shown for *Salvia occidentalis*, 8 hrs red light, supplementarily given to a short main light period, is not active in producing a long-day effect because the effect of the preceding main light period is antagonized by the first part of the supplemental red light period (Table 4). The long-day effect of 10 hrs Red (or White) + 8 hrs blue light (Table 3) can be explained by the assumption that the 8 hrs supplemental blue light act as the real main light period. In that case the "main light period" of 10 hrs Red (or White) light, seperated by 6 hrs darkness from the blue light period, will act as night interruption. It is possible to explain the results of Funke and of Wassink e.a. in the same way.

Stolwijk e.a. (1955) found that, to obtain a long-day effect with a supplemental irradiation, near infra-red radiation is more active than red light. The results of Hendricks e.a. (1954) showed that the antagonizing effect of near infra-red (1 min.) on a night interruption with red light disappeared when the exposure to infra-red lasted a longer time (30 min.). This might be explained by assuming that under these conditions the supplemental irradiation or the night interruption with a long exposure of infra-red act as the main light period.

If this assumption is correct it might also be possible to understand why "white" light from fluorescent lamps (practically no near infra-red) is often less active in producing long-day effects than a combination of "white" light and infra-red from incandescent lamps. As Roodenburg (1954) stated: "This light source (incandescent lamp) has a much more daylenthening effect than daylight itself, owing to the excess of the short wave infra-red rays of the tungsten filament lamp". In "white" light (without infra-red), the red part neutralizes the effect of the blue part of the spectrum; the presence of infra-red increases the blue infra-red activity.

It seems not impossible that the same pigment system is involved in both the main light-period reaction and in the night-break reaction.

SUMMARY

In photoperiodic response of *Salvia occidentalis* an antagonism between blue light and red light and between near infra-red radiation and red light was described.

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