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DEPENDENCE OF ELONGATION ON WAVELENGTH OF SUPPLEMENTARY IRRADIATION

by

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1. SCOPE OF THE INVESTIGATION

In recent years, results on photomorphogenesis and photoperiodicity experiments under blue light have been the object of discussion. Especially, the relationship between the effects of blue and near-infrared are of interest.

The main conclusions of our more recent work with *Cosmos*, tomato, *Hyoscyamus*, lettuce and *Brassica* have been published in outline in 1957 at the 2nd International Photobiological Congress in Turin (15). Detailed data of this work, however, so far did not appear, and are given in the present paper.

The results presented, mainly consider the composition of the blue irradiation. They, moreover, present an overall picture of wavelength dependence of formative reactions in a variety of plants.

2. METHODS

Our object is the formative reaction upon daily treatment with some hours of low intensity (ca. 1,000 ergs/cm².sec.) radiation in narrow wavelength regions in the visible and near-infrared (350–1000 mμ) following periods of high intensity radiation from white fluorescent lamps (ca. 15,000 ergs/cm².sec.). Narrow wavelength regions were obtained from adequate combinations of lamps of specific emission and filters of specific transmission (See also 12).

Special attention was paid to the quality of blue radiation with respect to near-infrared admixture by using the same type of fluorescent lamp in combination with two different filters (*cf.* 1). In 1956, a blue filter became available which is opaque for near-infrared (B-), whereas the one used earlier transmits near-infrared (above 700 mμ, B+). The new type was obtained from RÖHM and HAAS, Darmstadt, Germany, *viz.*, their "Plexiglas B 27 alt".

3. EXPERIMENTAL

a. Effects of blue light with and without a near-infrared admixture

At first, transmission in the near-infrared region of the old filter was con-

sidered of minor importance when used in combination with low pressure-Hg fluorescent lamps which have only a very low output above 700 mμ (± 8%). It was suggested, however, that the small contamination of near-infrared might be of importance because of the absence of antagonistically active radiation (See also 1).

An experiment was performed, running side by side all available wavelength regions, in the same way as before (11, 12, 18, 21), now, however, with two qualities of blue (old, B+; and new, B–). The complete series included: near-infrared (I), red (R), yellow (Y), green (G), new-blue (B–), violet (V), old-blue (B+) and a dark control (D). Tomato plants, raised in the greenhouse, were brought under white light (fluorescent "daylight" type; 15,000 ergs/cm².sec.) during 10 hours daily and supplemented with 8 hours of the available colours (ca. 1,000 ergs/cm².sec.) or dark. After 52 days, internode and leaf lengths were measured. Internode and stem lengths are presented in Table 1; leaf lengths in Table 2.

TABLE 1. *Solanum lycopersicum*, cv. 'Ailsa Graig': stem and internode lengths. Plants sown 14-4-'56, and grown in natural days in the greenhouse. Experiment started 1-6-'56. Treatment: 10 hours white fluorescent light ("daylight" 15,000 ergs/cm².sec.) followed by 8 hours supplementary irradiation (1000 ergs/cm².sec.) in the wavelength regions: near-infrared (I), red (R), yellow (Y), green (G), new-blue (B–), violet (V), old-blue with some near-infrared (B+), and a dark control with 10 hours white light only (D). Data from a measurement at 23-7-'56, after 52 days of treatment. Temperature ca. 20 °C.

Supplementary wavelength region	Number of plants	Stem length (mm)	Lengths of succesive internodes (1–9) in mm								
			1	2	3	4	5	6	7	8	9
I	6	324	38	35	52	53	41	46	36	20	3
R	6	208	16	20	30	37	31	30	23	16	5
Y	6	195	16	21	31	26	30	31	24	16	
G	6	202	20	20	29	34	32	29	23	15	
B–	6	236	23	23	39	43	35	35	22	16	
V	6	225	20	24	38	42	32	31	23	15	
B+	6	296	22	24	41	42	47	54	47	19	
D	6	308	19	29	47	48	43	45	38	29	10

TABLE 2. *Solanum lycopersicum*, cv. 'Ailsa Graig'. Treatment: 10 hours white plus 8 hours supplementary irradiation. Colour treatment and further data see legend Table 1.

Supplementary wavelength region	Number of plants	Lengths of successive leaves (1–9) in mm								
		1	2	3	4	5	6	7	8	9
I	6	138	159	193	211	219	220	206	170	23
R	6	143	180	213	223	229	211	205	178	67
Y	6	145	179	217	240	253	233	206	168	
G	6	150	188	219	256	244	233	215	196	
B–	6	154	187	218	239	236	205	202	183	
V	6	142	173	218	222	241	231	185	163	
B+	6	160	193	217	224	228	207	167	158	
D	6	142	178	218	228	231	241	223	201	63

The mean lengths of internodes 4, 5 and 6 are presented in Figure 1a (upper curve).

There is a large difference between B+ and B–, as was pointed out in the earlier papers (15, 16): plants in blue without near-infrared admixture do not produce elongation, contrary to those in old-blue and in near-infrared. The reaction of internode and stem lengths in the new-blue cabinet is much the same as in red, yellow and green. Leaf lengths did not differ reliably (*cf.* Table 2).

A second experiment with tomato gave similar results. This time, the reaction was somewhat stronger, which may have been due to the circumstance that the intensity of the basic illumination was higher (ca. 20,000 ergs/cm².sec.). The treatment deviated slightly from that in the foregoing experiment inasmuch as 10 hours of white light now were supplemented with only 2 hours of low intensity coloured radiation. The mean lengths of internodes 4, 5 and 6 are given in the lower curve of Figure 1a. Representative plants were photographed 17-8-1956 and 31-8-1956 (Plate 1, a and b).

Plants of *Hyoscyamus niger*, annual strain, were treated daily with 10 hours white light (15,000 ergs/cm².sec.) followed by 2 hours coloured light (1,000 ergs/cm².sec.). These plants, however, suddenly became unhealthy so that the experiment had to be finished early. The difference in effect between the two qualities of blue light is similar to that in tomato (Plate 2a). Plants in the old-blue cabinet show leaf petiole elongation as those in near-infrared, whereas those plants in the other blue cabinet are similar to those in red, yellow, green and violet.

A similar experiment was performed with *Cosmos bipinnatus*. The treatment consisted of 10 hours of high intensity white light, supplemented with 8 hours of the different colours. For a special reason (p. 10), 2 hours of darkness were intercalated, following the white light period. As STOLWIJK has demonstrated, this has no significant effect on the action of supplementary irradiation (10). The internode lengths were measured after 28 days. Lengths of second internodes are plotted in Figure 3 (lower curve). Internode lengths and total stem lengths are presented in Table 9a. On Plate 2b, representative plants on the 25th day are shown.

Plants in old-blue light have elongated internodes, be it somewhat less than those in near-infrared. Plants in all other wavelength regions including the new blue have about equal, short internodes. May be, the internodes in red and yellow are somewhat shorter than those in green, pure blue, violet and in the dark control (10 hours white light only). This, again, is in accordance with the results obtained with the other plant species investigated.

In conclusion, the new-blue light quality has no elongative action when given daily at low intensity (1,000 ergs/cm².sec.) supplementary to an irradiation with high intensity white light (15,000 ergs/cm.²sec.).

b. Effects of the near-infrared contamination present in the blue light

There are minor differences between the two blue filters in the cut off in the blue and green wavelength regions. The observed difference in activity, thus, could as well be due to the presence of a higher percentage of yellow-green radiation (working in the same sense as red light) in the new-blue quality. This has been checked by separately testing the near-infrared admixture of the old-blue ("+"), obtained by using blue lamps in combination with the old-blue *and* the red filters.

Uniform lots of six *Cosmos bipinnatus* plants were selected and divided into two groups, one of which daily received 8 hours, the other 16 hours of strong white light (15,000 ergs/cm².sec.) from fluorescent lamps. Immediately following the irradiation with white light, two hours of the colour series were given. The wavelength regions available were the same as in earlier experiments, moreover there was the weak near-infrared contamination from old blue ("+"), and finally a dark control group (receiving 8 or 16 hours of white light only). All wavelength regions were given at equal intensity (1,000 ergs/cm².sec.); except the "+" cabinet in which the intensity was only 30 ergs/cm².sec., *i.e.* the intensity at which near-infrared is present in the old-blue light quality. The temperature throughout the experiment was about 20°C.

Internode and total stem lengths after 28 days of treatment are presented in Table 3, a and b. Figure 1b shows the stem lengths and Figure 1c the mean lengths of the first and second internodes in relation to the wavelength region.

In general, plant parts are shorter in the 16-hour white series than in the 8-hour group with the same supplement, but the relation between the colours is equal in both groups. The plants in "+", B+ and I are equally long, whereas those in all other colours are much shorter, but mutually more or less equal. The results for total stem length vary somewhat more than those for the first two internodes (Compare Figure 1b with 1c), but they are similar. This demonstrates, as is evident also from Table 3 that the number of internodes per stem is almost unaffected by the supplementary irradiation.

Besides confirming earlier observations, it is evident that the elongation in the "+" cabinet is almost the same as in old-blue.

FIG. 1a. *Solanum lycopersicum*, cv. 'Ailsa Graig': average lengths of internodes 4, 5, and 6, under 10 hour days in white fluorescent light supplemented with a series of narrow wavelength regions (See Table 1, p. 2) during 8 (o) or 2 (●) hours. White light intensity 15,000 (o) or 20,000 (●) ergs/cm².sec.; coloured light intensity 1000 ergs/cm².sec. Measurements after 52 (o) or 23 (●) days. Recalculated in percentages of lengths in near-infrared (I): o = 38 mm, ● = 47 mm.

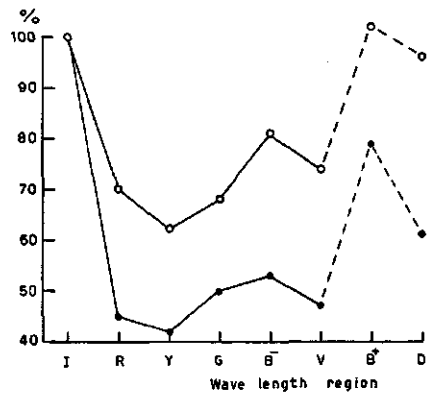
FIG. 1b. Stem length of *Cosmos bipinnatus* in 16 (●) or 8 (o) hours white fluorescent light (15,000 ergs/cm².sec.) followed by 2 hours of low intensity (1,000 ergs/cm².sec.) radiation in narrow wavelength regions (See Table 3, p. 6). Observations of 22-11-'56, after 28 days of treatment. Recalculated in percentages of the lengths in the "8 hours white plus near-infrared" group (100% = 154 mm).

FIG. 1c. Length of first and second internodes of *Cosmos bipinnatus*. Treatment as for Figure 3. (100% = 113 mm).

FIG. 1d. Stem length in *Brassica Rapa* var. in 16 (●) or 8 (o) hours white fluorescent light (15,000 ergs/cm².sec.) followed by 2 hours of low intensity (1,000 ergs/cm².sec.) radiation in narrow wavelength regions (See Table 3, p. 6). Plants grown before in the greenhouse on 9-hour days. Observations of 21-11-'56, after 27 days of treatment. Recalculated in percentages of the group receiving 16 hours white plus 2 hours near-infrared (100% = 128 mm).

FIG. 1e. Stem length in *Brassica Rapa* var. in 16 (●) or 8 (o) hours white fluorescent light (15,000 ergs/cm².sec.) followed by 4 hours of low intensity (1,000 ergs/cm².sec.) radiation in narrow wavelength regions (See Table 3, p. 6). Plants grown before in the greenhouse on 9-hour days. Observations of 11-12-'56, after 13 days of treatment. Recalculated in percentages of the group receiving 8 hours white followed by 4 hours near-infrared (o I) (100% = 19.2 mm).

FIG. 1f. Mean petiole lengths of third and fourth leaves. Legend as for Figure 1e (100% = 167 mm).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80
70
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50
40
I R Y G B⁻ V B⁺ D
Wave length region

a


%
100
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80
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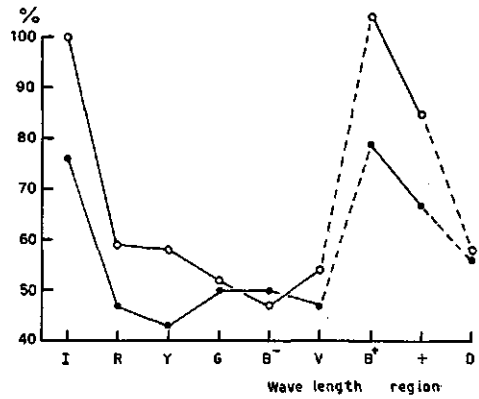
40
I R Y G B⁻ V B⁺ + D
Wave length region

b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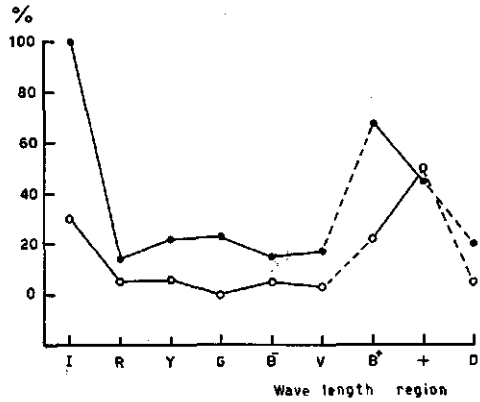
Wave length region

c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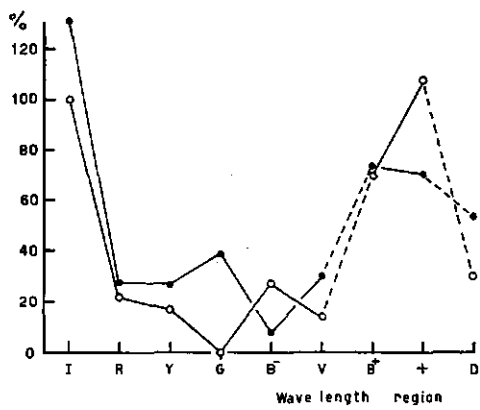
Wave length region

d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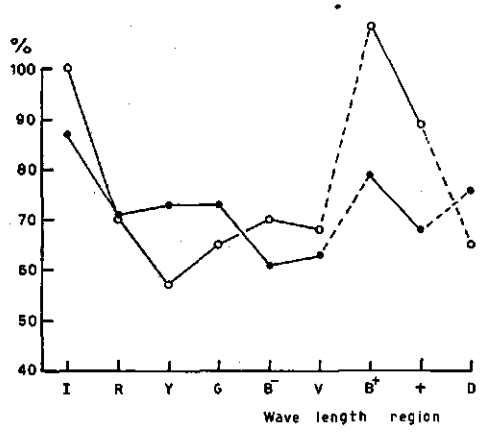
I R Y G B⁻ V B⁺ + D
Wave length region

e


%
100
90
80
70
60
50
40
I R Y G B⁻ V B⁺ + D
Wave length region

f

TABLE 3. *Cosmos bipinnatus:* stem and internode lengths. Plants grown in the greenhouse. Observations of 22-11-'56, after 28 days of treatment.
Treatment: (a) 16 and (b) 8 hours white fluorescent light (15,000 ergs/cm².sec.) followed by 2 hours light of narrow wavelength regions (near-infrared (I), red (R), yellow (Y), green (G), new-blue (B–), violet (V), old-blue with some near-infrared (B+), the near-infrared admixture of the old-blue (+), and a dark control). Temperature ± 20°C.

	Supplementary wavelength region	Number of plants	Stem length (mm)	Lengths of successive internodes (1–5) in mm.				
				1	2	3	4	5
a. 16 Hours white light	I	6	138	36	50	36	14	2
	R	6	69	30	23	13	3	
	Y	6	65	27	22	13	3	
	G	6	79	33	24	19	3	
	B–	6	82	31	25	18	8	
	V	6	70	30	23	13	4	
	B+	6	132	40	49	33	10	
	+	6	120	37	39	33	11	
	D	6	103	34	29	26	13	1
b. 8 Hours white light	I	6	154	43	70	38	3	
	R	5	95	35	32	21	7	
	Y	6	105	35	30	25	11	4
	G	6	81	33	26	18	4	
	B–	6	96	28	25	27	14	2
	V	6	97	29	32	25	9	2
	B+	6	146	48	69	27	2	
	+	6	146	38	58	42	8	
	D	6	93	30	36	26	1	

Brassica Rapa f. *oleifera* subf. *annua* plants were subjected to a similar treatment. The plants had been grown on a 9-hour day in the greenhouse before. Stem lengths and petiole lengths, measured after 27 days of treatment, are given in Table 4, a and b. Figure 1d shows the relation between average stem length and wavelength region of supplementary radiation. Like in other plants, elongation occurs in the cabinets "+", old-blue (B+) and near-infrared (I). In the series with 16 hours of strong white light, stems are longer than in that with 8 hours. This is the reverse of the reaction in *Cosmos*, and must be due to an interaction of the formative inhibition reaction and the photoperiodic reaction (6).

Leaf counts (Table 4) demonstrate that in *Brassica*, as in *Cosmos*, the number of internodes is nearly equal under all supplementary wavelength regions. Thus, stem length differences are due to differences in internode lengths (See also Table 7, p. 8). Petiole lengths did not react in a reliable way (Table 4a), contrary to our observation for tomato leaf lengths (Table 2, p. 2). In the 8-hour series, however, there is an effect similar to that for stem length (*cf.* Table 4b).

In another experiment with *Brassica*, 8 or 16 hours of white light (15,000 ergs/cm².sec.) per day were followed by 4 hours of coloured light (1,000 ergs/cm².sec.), against 2 hours in the foregoing experiment. Results of a measurement after 13 days are presented in Figures 1e (stem length) and 1f (petiole lengths of third and fourth leaves).

Stem elongation was similar to that described above for *Brassica* and *Cosmos*. Petiole length differences again are weak. There is, however, a tendency

TABLE 4. *Brassica Rapa* var.: stem length and petiole lengths. Plants grown in the greenhouse on short day (9 hours). Observations of 21-11-'56, after 27 days of treatment. Treatment: (a) 16 and (b) 8 hours white fluorescent light (15,000 ergs/cm².sec.) followed by narrow wavelength regions (See legend Table 3) during 2 hours daily. Temperature ± 20 °C.

	Supplementary wavelength region	Number of plants	Stem length (mm)	Lengths of petioles of successive leaves (1–9) in mm								
				1	2	3	4	5	6	7	8	9
a. 16 Hours white light	I	5	128	40	52	69	77	74	58	46	15	
	R	6	18	33	42	52	66	66	68	57	32	
	Y	6	28	33	39	55	66	68	65	56	31	5
	G	6	29	34	45	59	63	71	62	53	33	13
	B–	6	19	24	31	43	58	64	67	55	35	7
	V	6	22	29	33	48	58	68	69	68	46	18
	B+	6	87	24	40	55	76	81	73	58	37	15
	+	6	58	23	30	49	65	72	78	61	38	13
	D	5	26	34	45	59	67	69	71	45	17	
b. 8 Hours white light	I	5	39	40	56	78	89	89	72	43	11	
	R	6	6	32	41	57	60	66	49	28	16	8
	Y	6	8	28	33	43	53	59	50	37	10	
	G	6	0	27	41	50	59	66	54	45	7	
	B–	6	6	28	36	54	63	64	64	49	34	15
	V	6	4	28	37	51	63	74	73	53	23	5
	B+	6	28	33	52	78	103	111	103	61	32	6
	+	5	63	23	34	60	89	108	99	63	13	
	D	5	7	24	34	45	64	71	68	51	32	22

towards the type of reaction observed in stem elongation. And, as in the first experiment, the differences are more consistent in the 8-hour group.

Stem and petiole lengths of plants of the 8-hour white light series were measured again after 51 days of treatment (Table 6), while of the 16-hour white light series also separate internode lengths were recorded (Table 5).

Table 7 presents some data of Tables 5 and 6, recalculated as percentage of the lengths obtained with near-infrared supplementary radiation. The successive

TABLE 5. *Brassica Rapa* var.: stem and internode lengths. Treatment: 16 hours white fluorescent light (15,000 ergs/cm².sec.) followed by 4 hours supplementary irradiation in various wavelength bands (See Table 3). Temperature ± 19 °C. Plants grown in 8 hours white light (15,000 ergs/cm².sec., fluorescent lamps). Observations of 18-1-'57, after 51 days of treatment.

	Supplementary wavelength region	Number of Plants	Stem length (mm)	Lengths of successive internodes (1–14) in mm													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
16 Hours white light	I	6	367	8	11	22	30	37	40	48	43	42	34	23	21	8	
	R	5	320	10	16	27	34	40	39	39	39	30	24	15	7		
	Y	6	297	9	15	26	41	42	41	36	36	28	13	7	3		
	G	6	281	11	17	25	31	35	41	40	30	26	15	6	4		
	B–	5	280	10	15	29	37	40	43	37	36	26	7				
	V	6	280	10	13	23	32	35	40	33	34	24	16	12	8		
	B+	5	403	9	10	16	27	39	45	42	42	44	36	39	32	18	4
	+	6	380	9	10	15	28	38	52	46	39	42	33	32	21	12	3
	D	5	301	10	15	23	36	40	42	40	36	30	14	11	4		

TABLE 6. *Brassica Rapa* var.: stem length and petiole lengths. Legend as for Table 4b (p. 7). Observations of 18-1-'57, after 51 days of treatment.

	Supplementary wavelength region	Number of Plants	Stem length (mm)	Lengths of petioles of successive leaves (1–10) in mm									
				1	2	3	4	5	6	7	8	9	10
8 Hours white light	I	5	167	107	120	134	113	92	76	41	14		
	R	6	27	73	75	89	89	74	68	43	13	10	
	Y	6	23	69	91	88	93	81	76	48	33	11	
	G	6	12	76	96	97	88	71	43	22			
	B–	6	38	95	101	106	103	89	64	35	11	5	
	V	6	8	73	84	103	97	92	84	84	59	28	8
	B+	6	105	113	140	142	144	119	103	63	46	21	
	+	5	133	120	126	134	134	121	106	65	15		
	D	5	22	63	80	92	99	96	82	70	37	8	

columns show stem lengths in 8 hours, and stem lengths and average lengths of internodes 6, 7 and 8 of the 16-hour group. Representative plants are shown on Plate 1, c and d.

It is evident, from Table 7, that stem length (both in long and in short days), internode length and also, more or less, petiole length (Table 6) react in the same way upon the wavelength region of supplementary irradiation. Plant parts become relatively long under near-infrared irradiation (normal near-infrared cabinet (I), "+" cabinet and old-blue (B+) light). Much shorter plants result from supplementary irradiation in all other available wavelength regions at the intensity used (1,000 ergs/cm².sec.).

Also the reaction of *Lactuca sativa* (cv. 'Wonder van Voorburg') upon the series of wavelength regions during 4 hours supplementary to a 10 hour day in white light has been studied. Stem lengths, after 43 days of treatment, are presented in Table 8. Again, only near-infrared produces elongated plants when given after strong white light.

Finally, a survey of stem length results, obtained with different plant species, showing similar reaction, is presented in Figure 2.

TABEL 7. *Brassica Rapa* var.: stem length and lengths of internode 6, 7 and 8 in percentages of the near-infrared group. Treatment and other data are given in the legend for Table 4. Observations of 18-1-'57, after 51 days of treatment.

Supplementary wavelength region	8 Hours white light	16 Hours white light	
	Stem length	Stem length	Internode length
I	**100**	**100**	**100**
R	14	89	87
Y	13	86	81
G	7	84	77
B–	23	88	77
V	4	81	76
B+	63	98	110
+	80	104	108
D	13	89	82

TABLE 8. *Lactuca sativa* cv. 'Wonder van Voorburg': stem length in mm per plant and in percentages of the average length in the group receiving supplementary near-infrared irradiation. The plants were grown in white fluorescent light (10 hours per day; 15,000 ergs/cm².sec.). Observations of 10-1-'57, after 43 days of treatment. Treatment: 16 or 8 hours white fluorescent light (15,000 ergs/cm².sec.) followed by 4 hours supplementary irradiation in various wavelength regions (See Table 3, p. 6). Temperature ca. 19 °C.

Supplementary wavelength region	16 Hours white light		8 Hours white light	
	Stem length		Stem length	
	(mm)	% of I	(mm)	% of I
I	27	**100**	45	**100**
R	21	78	25	56
Y	18	67	22	49
G	22	82	30	67
B–	15	56	32	71
V	17	63	29	64
B+	33	122	53	118
+	28	104	47	104
D	18	67	28	62

From the two facts that blue light free from near-infrared gives no elongation, and that the small amount of near-infrared alone produces full elongation, we may conclude that the elongation which was originally obtained in the blue

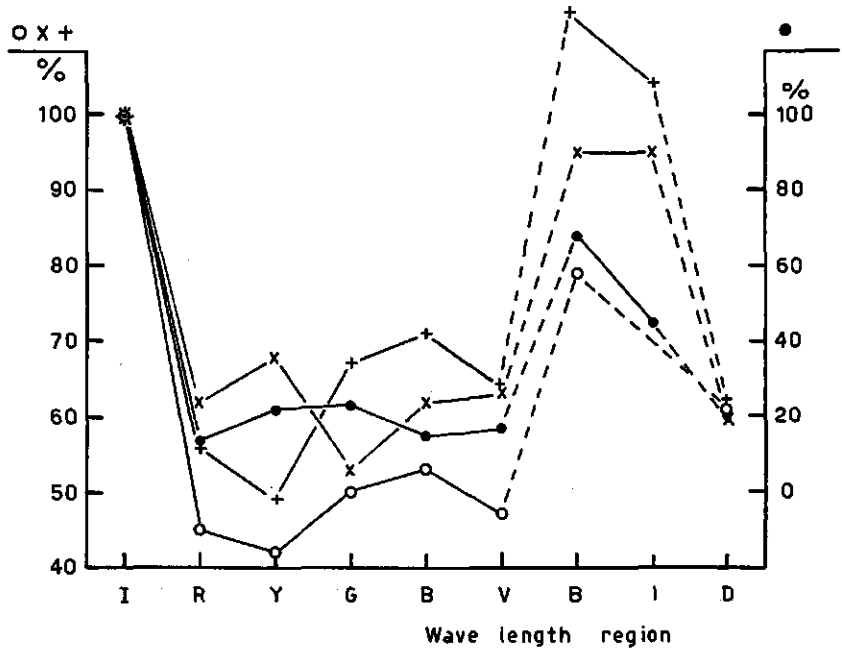


FIG. 2. Stem length of tomato (o), *Brassica Rapa* (●), *Cosmos bipinnatus* (×) and lettuce (+) in percentages of their plots treated with near-infrared (100% = 47, 39, 154, 45 mm, respectively, after 23, 27, 28, 43 days). Treatments: 10 (hours white) + 2 (hours supplementary irradiation) (o); 8 + 2 (●, and ×), and 8 + 4 (+).

region (12) is fully due to the small contamination with near-infrared. These data thus serve to correct the earlier conclusion that blue light causes strong elongation effects at low intensity if following a basic light period of high intensity white fluorescent light (4, 10, 11, 12, 17, 18, 19, 21). With pure blue light such effect could not be reproduced in the plants, and under the conditions studied.

c. Spectra of reversible photo-formative action

For a better understanding of the following experiment, a few statements should be recalled in mind.

1. Etiolation is maximal in absolute darkness (5). The shortening action of light is a linear function of the logarithm of incident energy. The spectrum for this action was first given by PARKER c.s. (8). There is a strong action in the red region (660 mμ); a sharp decline towards the longer wavelengths reaching zero effect at about 700 mμ, and a more gradual diminution of activity towards shorter wavelengths (*via* yellow and green to about zero in the blue).

2. This "red"-inhibition is antagonized by near-infrared radiation (given in due time and at suitable intensities).

3. The antagonistic activity can be repeated several times in sequence.

The trouble with supplementary irradiation in narrow wavelength regions evidently is that the plants have had strong white light before. Thus, the "dark

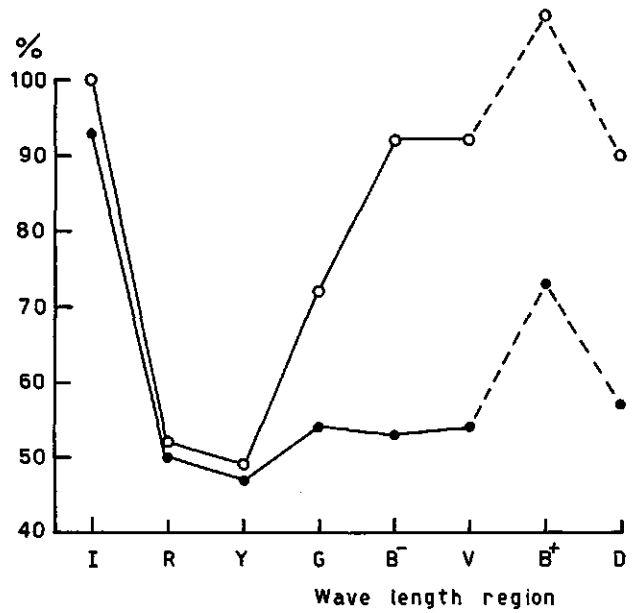


FIG. 3. Action spectra of the antagonism between inhibition and promotion of elongation of second internodes in *Cosmos bipinnatus*. Irradiation treatments: 10 hours of white fluorescent light (15,000 ergs/cm².sec.), 2 hours darkness (●) or near-infrared (○), and 8 hours of a series of narrow wavelength regions at low (1,000 ergs/cm².sec.) intensity. (See Table 1, p. 2). Observations of 3-9-'56, after 28 days of treatment; recalculated as percentages of the group receiving 10W + 2i + 8i (○ I) (100% = 92 mm).

control" of the experiments described above is not a real control. The plants are in a highly specific degree of inhibition, produced by the white light treatment. This may be the reason for the observation in the preceding sections that *Cosmos* and *Brassica* internodes under 8 and 16 hours of light react in different ways.

With low intensity radiation, following strong illumination, only the red-antagonizing function of the near-infrared region can be demonstrated. This is what was demonstrated above: near-infrared produces elongated plants, whereas plants in all other colours have about equal length as the "dark controls".

The "inhibition"-spectrum cannot be produced in this way. This can be obtained only when the plants have been brought in a "real dark" situation before, *e.g.*, by intercalating some treatment with near-infrared between the strong white light period and the supplementary treatment. In the following experiment, a period of 2 hours infrared at 1,000 ergs/cm².sec. (I) was given.

Two groups of plants both received 10 hours of strong white fluorescent light (15,000 ergs/cm².sec.); hereafter, one group was placed in darkness for two hours (D) while the other received 2 hours near-infrared (I). After the two hours, both groups were subjected to the same series of colours at low (1,000 ergs/cm². sec.) intensity during 8 hours daily. The supplementary wavelength regions used were the same as in the experiments described earlier in this paper. Stem internodes were measured after 28 days.

In Figure 3, the lengths of second internodes on the 28th day are shown. The figures of the second measurement are given in Table 9, a and b. Plate 2, b and c, presents plants after 25 days.

TABLE 9. *Cosmos bipinnatus:* stem and internode lengths. Treatment: 10 hours white fluorescent light (15,000 ergs/cm².sec.) followed by 8 hours in narrow wavelength regions as indicated (See legend Table 1, p. 2) in an intensity of 1000 ergs/cm².sec., but between these two irradiations two hours were intercalated during which was given either near-infrared (1000 ergs/cm².sec.) or darkness (above and below, resp.). Temperature ca. 20 °C. Averages of 6 plants. Observations of 3-9-'56, after 28 days of treatment.

		Supplementary wavelength region	Stem length (mm)	Lengths of successive internodes (1–8) in mm							
				1	2	3	4	5	6	7	8
2 Hours near-infrared	a.	I	387	88	92	85	63	37	18	4	
		R	217	83	49	44	28	11	2		
		Y	188	77	44	37	21	8	1		
		G	254	79	66	61	34	12	2		
		B–	355	81	86	76	70	29	11	2	
		V	339	87	84	81	49	24	11	3	
		B+	405	84	98	93	73	38	16	3	
		D	337	85	86	88	56	17	5		
2 Hours darkness	b.	I	404	75	86	84	83	53	16	7	
		R	231	72	46	44	43	20	6		
		Y	204	74	45	40	30	12	3		
		G	255	69	50	49	51	26	9	1	
		B–	328	76	49	49	56	52	35	9	2
		V	309	84	51	46	48	49	23	8	
		B+	370	79	67	66	71	52	30	5	
		D	352	76	53	55	65	53	40	8	2

Figure 3 shows that 2 hours of near-infrared, immediately following the white irradiation are no less effective than 8 hours, given after an intercalation of 2 hours darkness (*cf.* curve 2D point I, and curve 2I point D).

Moreover, 2 hours of near-infrared (Point D in curve 2I) are only slightly less elongative than 10 hours (Point I in curve 2I), so that two hours of near-infrared at the intensity applied give about maximal effect.

Less regular is the reaction in old-blue (B+).

Curve 2I is in good agreement with earlier results on suppression of elongation in different wavelengths (8). The blue and violet regions are inactive. Green light produces shorter internodes, and still more so yellow and red. Like the blue region, the near-infrared is without effect. The near-infrared not really has an elongating effect: Once the inhibition of the preceding irradiation is annihilated, no further elongation occurs.

The lower curve of Figure 3 (2D) also is understandable. Internodes in green, blue and violet are about equal in length to the dark control. Those in red and yellow are still somewhat shorter, indicating that these colours even in low intensity add further inhibition, if given supplementary to white light of high intensity from "daylight" fluorescent lamps. Near-infrared produced strongly elongated internodes, and so did old-blue (due to its content of near-infrared ("+")).

4. Discussion

The data on wavelength dependence of supplementary irradiation, as reported already briefly in 1957 (15). show that near-infrared at an intensity of 30 ergs/cm^2.sec., as present as a contamination in our blue light from fluorescent lamps up to 1956, is as effective in producing elongation as 1,000 ergs/cm^2.sec. of near-infrared obtained from incandescent lamps (filtered by (old) blue glass, red glass, and a 5 cm layer of water). This is surprising, since Stolwijk found the minimum intensity producing the full effect to be about equal for blue and (near) infrared in the qualities originally used (11, and 12 [Fig. 11]), *viz.*, approximately 300 ergs/cm^2.sec. One must conclude that near-infrared from fluorescent lamps is at least 10 times more effective in antagonizing red-inhibitions than is near-infrared from incandescent lamps, obtained as indicated above.

Inactivity of the blue wavelength region was also reported by Downs *c.s.* in 1958 (2). These authors analyzed the emission of a blue fluorescent lamp in its effect upon elongation in Pinto beans. They could demonstrate the inhibitive action of the full emission, and of the red part only, while promotion occurred with near-infrared; the blue-violet region was inactive.

Vince and Stoughton (13) and Downs *c.s.* (3) reported inactivity of blue light also.

Meyer (7), however, presents results on gherkin hypocotyl elongation using our new blue filter. Seedlings, germinated in white light, were irradiated daily with 8 hours of red light followed by 8 hours blue light in a range of intensities. Up to 3000 ergs/cm^2.sec., blue light was increasingly elongative. Results in accordance herewith were published for *Pisum sativum* by Sale and Vince (9). In view of the data of the following paragraph, then, this plant seems to be more sensitive to the near-infrared action than those discussed in this paper.

De Lint reported stem elongation in *Hyoscyamus niger* as promoted by blue

radiation (new quality, without near-infrared) at much higher intensities. Still better purification with respect to near-infrared, with a copper sulfate solution as additional filter, did not reduce the elongation. The elongative activity of blue light was of the near-infrared type, *i.e.*, antagonizing red-inhibition. Admixture of some red light was strongly suppressive, and the elongating effect of blue radiation with no near-infrared admixture was more affected by the same red addition. In this case also, plants in pure blue light elongated more slowly (6).

Results on seed germination obtained by WAREING and BLACK are in agreement with these data as well (14).

Thus, low intensity blue light may have elongating activity, however, far less regular than was originally assumed.

5. SUMMARY

This paper contains the detailed data, substantiating the conclusion reported earlier (15) that plant elongating effects of low intensity blue light are, at least mainly, due to a near-infrared admixture.

A variety of plants, *i.e.*, *Cosmos*, *Brassica*, lettuce, tomato and *Hyoscyamus* were subjected to white ("daylight") fluorescent illumination of high intensity during several hours per day, followed by light of narrow wavelength regions, at low intensity. Two qualities of blue light were used: blue + 3% near-infrared (B+), and blue without near-infrared (B–). A cabinet with the near-infrared contamination of B+ alone (+) was added.

Blue light without any near-infrared admixture produced no elongation (or very little) while the contamination as such produced fully elongated plants. Thus, elongation upon supplementary irradiation with the quality of blue light originally used is due to its contamination with near-infrared.

Only near-infrared was found to produce a conspicuous elongation of plant parts (stems, internodes, leaves) in all plant species studied at low intensity, supplementary to a basic period in strong white light.

Attention is drawn, however, to the fact that we found elongation in pure blue light of high intensity in *Hyoscyamus* (6) while MEYER reported the same at low intensity supplementary blue light in gherkin seedlings.

The elongating effect of blue light thus appears to depend on light intensity and on other, so far unknown factors.

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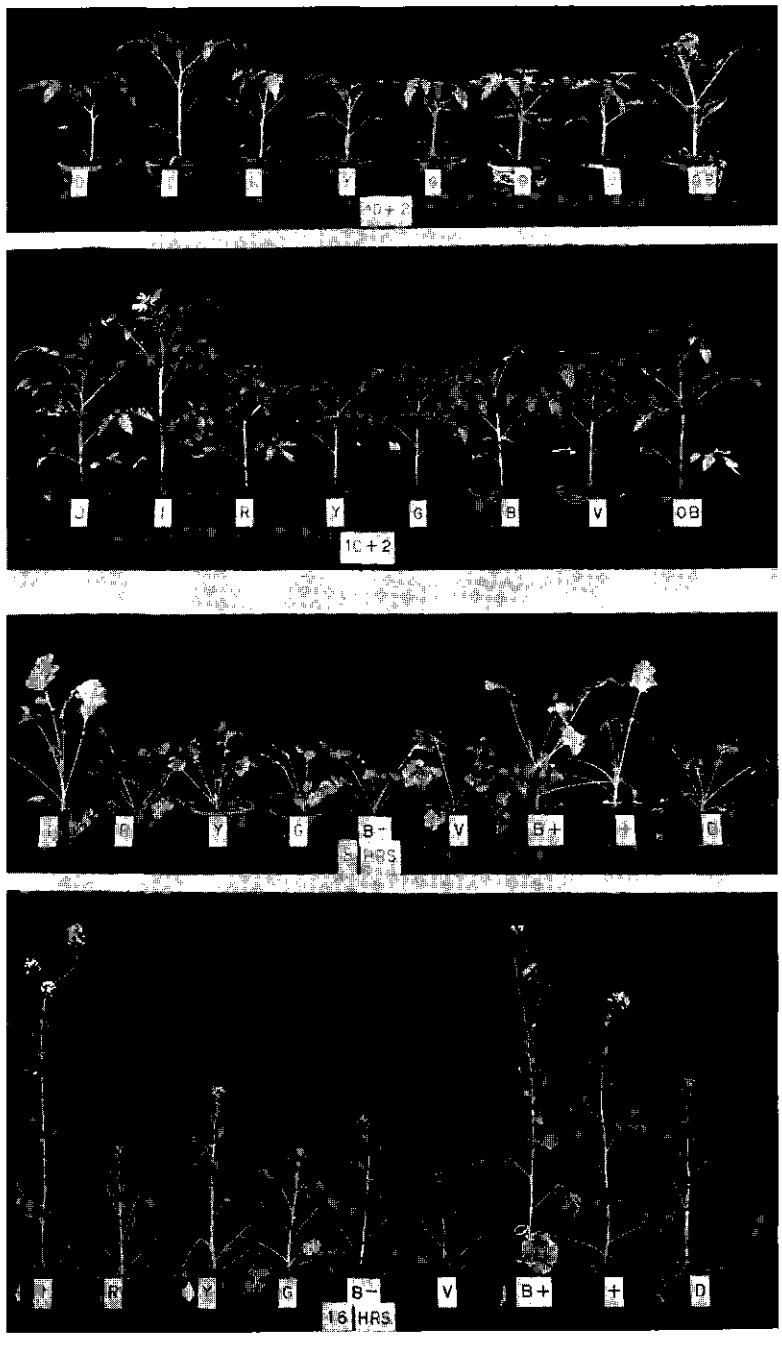

PLATE 1.

a and b. Tomato plants irradiated during (a) 11 or (b) 25 days with 10 hours high intensity (15,000 ergs/cm². sec.) white fluorescent light, followed by 2 hours low intensity (1,000 ergs/cm². sec.) radiation in narrow wavelength regions (See Table 1, p. 2; B = B–, OB = B+). Experiment started 6-8-'56.

c and d. *Brassica Rapa* var. plants treated during 40 days with (c) 8 or (d) 16 hours of high intensity (15,000 ergs/cm². sec.) white fluorescent light, followed by 2 hours of low intensity (1,000 ergs/cm². sec.) radiation in narrow wavelength regions (See Table 3, p. 6). Photographed 7-1-'57.

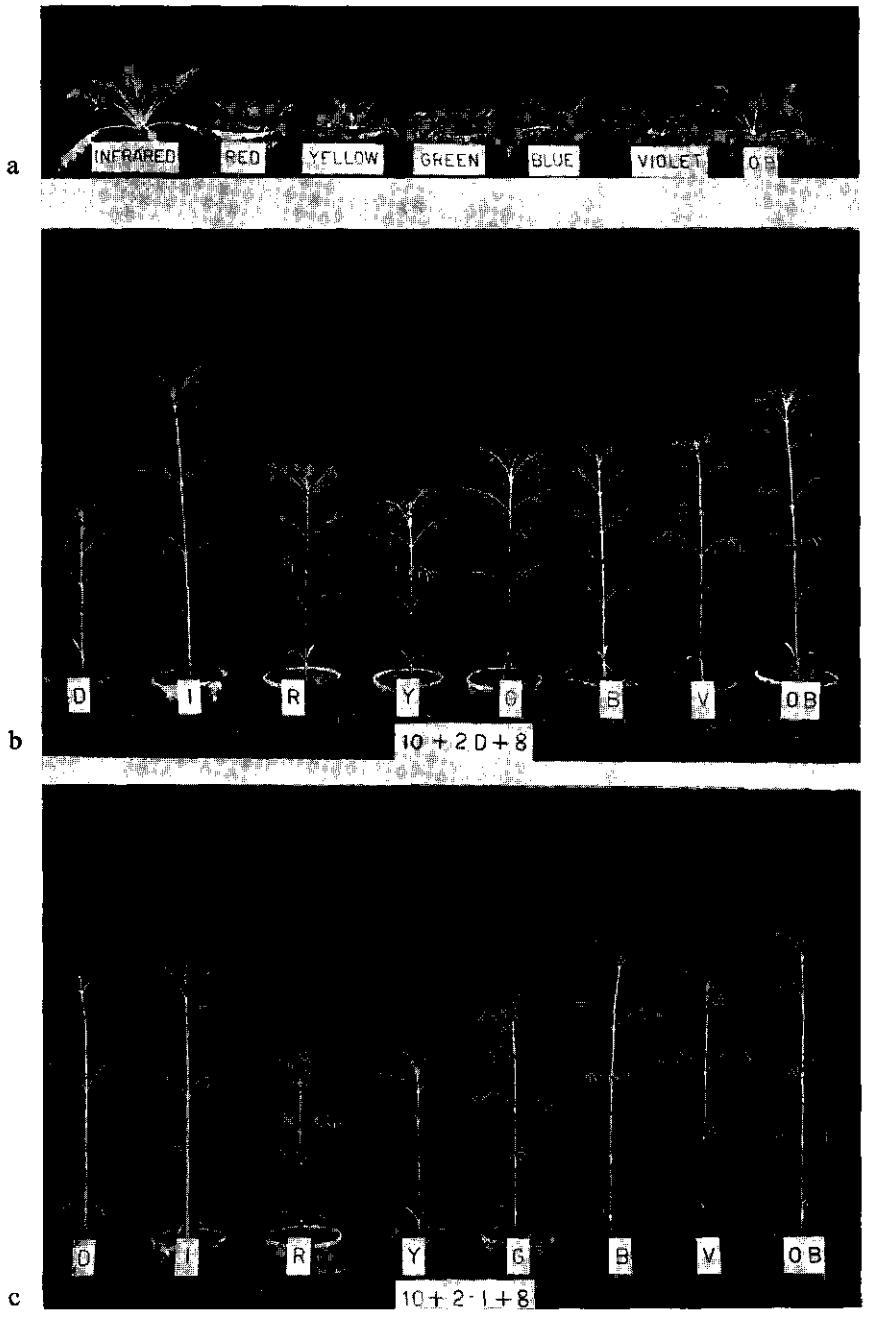

PLATE 2.

a. *Hyoscyamus niger* plants treated during 36 days with 10 hours of high intensity (15,000 ergs/cm².sec.) white fluorescent light, followed by 2 hours of low intensity (1,000 ergs/cm². sec.) radiation in narrow wavelength regions (See Plate 1). Photographed 7-8-'56.

b and c. *Cosmos bipinnatus* plants after 25 days in a threefold irradiation treatment. All plants received 10 hours of high intensity (15,000 ergs/cm².sec.) white fluorescent light and 8 hours of low intensity (1,000 ergs/cm².sec.) radiation in narrow wavelength regions, between these two irradiations were given 2 hours of darkness (b) or near-infrared in low intensity (c). Photographed 31-8-'56.