Comparison of Fluorescent and Incandescent Lamps for Promotion of Flowering in Sugar Beet Seedlings[1]

JOHN O. GASKILL[2]

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Incandescent-filament lamps are known to be superior to fluorescent lamps for use as a supplement to sunlight for the promotion of flowering in certain types of long-day plants including relatively mature sugar beets (2,3)[3]. Incandescent lamps have been used successfully in studies at Fort Collins, Colorado, as the sole source of light for very young sugar beet seedlings during the process of induction under low-temperature conditions—sometimes called vernalization—and as the source of supplemental light during the postinduction period (5,6,7). The seedling induction technique has been rather widely adopted by sugar beet breeders as a means of reducing the length of the life cycle and expediting the development of new varieties. Some of the induction installations are relatively large (1,4) and require considerable electricity for refrigeration as well as for illumination. A suitable light source producing less heat than the incandescent type would be desirable as a means of reducing refrigeration costs.

The investigations reported in this article were undertaken primarily to determine whether fluorescent lamps could be substituted, at least in part, for incandescent lamps during the induction treatment. Also in some experiments, the two types of lamps were compared during the postinduction period. The contrasting plant response to illumination by fluorescent lamps during the two developmental stages is of special significance and suggests a new concept with respect to the process previously referred to by the writer as photothermal induction. The 1959 results were presented at the 11th General Meeting of the American Society of Sugar Beet Technologists[4], but publication was postponed until additional data could be obtained.

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[2] Plant Pathologist, U.S. Department of Agriculture, Fort Collins, Colo. Assistance of Luther W. Lawson and Joseph A. Elder, Agricultural Research Technicians, in conducting the experimental work, is acknowledged.

[3] Numbers in parentheses refer to literature cited.

[4] An informal report, "Further studies on the use of artificial illumination during and after photothermal induction of sugar beet seedlings", presented by John O. Gaskill on February 4, 1960, Salt Lake City, Utah.

Material and Methods

Open-pollinated, relatively heterogeneous, biennial-type sugar beet varieties or strains with about average low-temperature induction requirements were used for all studies reported in this article. The commercial variety GW359 was used in experiments 1 and 2 and noncommercial material in experiments 3 and 4. Seed was planted in steamed soil in aluminum tubes 1½ × 1½ × 3½ inches in size. The tubes were held initially in flats on a bench in the greenhouse with moisture and temperature suitable for rapid growth. Incandescent lamps were used to furnish nightlong supplemental light throughout the preinduction growth period in all experiments except No. 1, in which no supplemental light was provided during that period. Soon after emergence, the plants were thinned to four per tube.

Between 9 and 14 days after planting, the tubes were transferred to a refrigerated induction chamber where continuous artificial illumination was provided in complete absence of sunlight. Temperature among the plants in each experiment, with the thermometer bulb about ½ inch above the soil and exposed to the direct rays of light, fluctuated between 6° and 9° C, approximately, and averaged about or slightly above 7°. The air was circulated continuously in the induction chamber by means of fans, and air flow among the seedlings of each group was regulated in such a manner as to counteract the differing heating effects of the experimental light units. By this means, the differences among the temperature averages recorded for the respective treatments, within any given experiment, were held to less than 0.5°. In some experiments, comparable, noninduced control plants were included. These plants were started in the greenhouse with timing such that they were about the same size as the induced plants when the latter were ready for removal from the induction chamber.

At the end of the induction treatment, the 4-plant cluster in each tube was transplanted in soil in one 6-inch pot. The pots were placed in the greenhouse or outdoors, with or without supplemental light, as described for the respective experiments. The greenhouse was cooled artificially during hot weather, and temperature conditions favorable for rapid plant growth were maintained. Plants located outdoors were covered with ¼-inch-mesh wire screen for protection against hail. In certain instances the postinduction treatments were discontinued and the plants were returned to the greenhouse, a short time before the final counts were made, as a safeguard against freezing injury. Artificial fertilizers were applied as needed during the postinduction period. The plants were examined periodically and a record kept of initial flowering. Ordinarily each plant was removed from the pot when recorded as flowering.

The Gro-lux fluorescent lamp was developed by Sylvania Lighting Products, and all other fluorescent lamps used were products of the General Electric Company. Only the Gro-lux, with energy emissions concentrated in the red and blue regions of the spectrum, had been designed especially for use in plant-growth chambers. Nonreflecting shields were used as needed in the induction chamber, field, and greenhouse to protect each treatment group from extraneous light. An ordinary foot-candle meter was employed for measuring light intensities at or near the level of the plant foliage. These measurements were made merely for reference purposes, in recognition of the fact that, for the various types of lamps used, the data do not accurately reflect either total radiant energy or relative biological effectiveness (3).

Experiment 1

Experiment 1 was designed primarily to compare types of light in the induction chamber. The following light units were used: (a) one ordinary, 100-w, 120-v, inside-frosted, incandescent lamp in a medium-depth reflector; and (b) two 20-w, 24-inch, starter-operated, deluxe warm white fluorescent lamps in a single reflector. Placement of the light units, light shields, and four groups of sugar beet seedlings was such that each group received about 62 ft-c at the center, with percentages of light from the fluorescent source as follows: 0, 10, 84, and 100 for treatments I-1, I-2, I-3, and I-4, respectively. The intermediate percentages, 10 and 84, are approximations. A set of noninduced control plants was assigned the treatment No. I-5.

At the termination of the induction period (47 days, ending on July 21, 1959), each of the five sets of plants was subdivided into five comparable groups which were subjected to the following respective conditions throughout the postinduction period:

P-1: In greenhouse; nightlong supplemental light supplied by one 100-w incandescent unit (same as that used in the induction chamber) suspended 3 feet above the surface of the soil in the pots. The average light intensity at night, 9 inches above the soil, was approximately 37 ft-c.

P-2: In greenhouse; nightlong supplemental light supplied by one 40-w fluorescent unit (same as that used in the induction chamber) suspended 3 feet above the soil. The light intensity measurement comparable to that of treatment P-1 was 30 ft-c.

P-3: In greenhouse; no supplemental light.
P-4: Outdoors; supplemental light same as for P-1.
P-5: Outdoors; no supplemental light.

Experiment 2

The light units listed below were placed at a uniform distance above separate (shielded) groups of seedlings in the induction chamber with approximately 19 inches from lamps to foliage. Each light unit consisted of one reflector with one inside-frosted, incandescent lamp or two 24-inch, fluorescent lamps. Type of lamp, total wattage for the unit, and approximate light intensity at foliage level for the five respective treatments were as follows:

I-6: Incandescent, 75 w, 87 ft-c.
I-7: Incandescent, 40 w, 29 ft-c.
I-8: Fluorescent (deluxe warm white), 40 w, 61 ft-c.
I-9: Fluorescent (standard cool white), 40 w, 92 ft-c.
I-10: Fluorescent, purple (1 red lamp and 1 blue lamp), 40 w, 27 ft-c.

The chief purpose of this experiment was the comparison of light units of equal wattage without regard to the light intensities produced. The 75-w unit was included in order to obtain supplementary information. There were two lengths of induction—4 and 8 weeks—both ending on August 10, 1960. On that date, all plants were transferred to the greenhouse where nightlong supplemental illumination was provided by means of incandescent lamps.

Experiment 3

The Gro-lux fluorescent lamp was compared with the usual type of incandescent lamp, for induction purposes, with equal light intensities at foliage level. The Gro-lux light unit included two 20-w lamps, and one 60-w incandescent lamp was used in the other unit. Each light source was so placed as to provide approximately 68 ft-c to the intended group of plants. The induction treatment (10 weeks) ended on June 6, 1962. The plants subsequently were held in the greenhouse and supplied with incandescent light throughout each night. Noninduced control plants were not included in this experiment. However, the sugar beet strain used was known to require a low-temperature induction treatment in order to produce a high percentage of bolting.

Experiment 4

Evaluation of the Gro-lux fluorescent lamp as the source of supplemental light during the postinduction period was the principal objective of experiment 4. All seedlings were given 12 weeks' induction under Gro-lux lamps, ending on June 21,

Table 1.—Flowering of sugar beet seedlings as affected by type of artificial illumination during the inducton and postinduction periods (experiment 1).

Postinduction			Induction			Elapsed time after induction and cumulative % of plants flowering [b]				
Treat. no.	Location	Supplemental light source [a]	Treat. no.	Light source [a]	No. of plants	5 wks.	6 wks.	8 wks.	10 wks.	14 wks.
P-1	Greenhouse	Incandescent	I-1	Incandescent, only	24	33	54	75	75	83
			I-2	Largely incandescent	24	21	54	88	88	92
			I-3	Largely fluorescent	24	33	58	71	79	88
			I-4	Fluorescent, only	24	4	46	67	67	79
			I-5	Control (not induced)	24	0	0	0	4	4
P-2	Greenhouse	Fluorescent	I-1	Incandescent, only	24	0	0	0	0	4
			I-2	Largely incandescent	24	0	0	0	0	0
			I-3	Largely fluorescent	23	0	0	0	0	0
			I-4	Fluorescent, only	24	0	0	0	0	0
			I-5	Control (not induced)	24	0	0	0	0	0
P-3	Greenhouse	None	I-1	Incandescent, only	24	0	0	0	4	4
			I-2	Largely incandescent	24	0	0	0	0	0
			I-3	Largely fluorescent	24	0	0	0	0	0
			I-4	Fluorescent, only	24	0	0	0	0	0
			I-5	Control (not induced)	24	0	0	0	0	0
P-4	Outdoors	Incandescent	I-1	Incandescent, only	24	25	63	79	83	88
			I-2	Largely incandescent	24	13	58	79	79	88
			I-3	Largely fluorescent	24	25	67	96	96	100
			I-4	Fluorescent, only	24	17	67	83	88	92
			I-5	Control (not induced)	24	0	8	13	13	17
P-5	Outdoors	None	I-1	Incandescent, only	24	0	4	8	8	8
			I-2	Largely incandescent	24	0	0	0	0	0
			I-3	Largely fluorescent	24	0	0	0	4	4
			I-4	Fluorescent, only	24	0	0	0	0	0
			I-5	Control (not induced)	24	0	0	0	0	0

[a] The flourescent lamps were deluxe warm white.
[b] Induction treatments (47 days) ended on July 21, 1959.

1962. On that date the plants were potted, divided into four identical sets of 10 pots (40 plants) each and placed outdoors, each set arranged in a compact group. Nightlong supplemental illumination was supplied to the respective groups by means of the following lamps in appropriate reflectors: (a) one 75-w, incandescent lamp; (b) two 20-w, Gro-lux fluorescent lamps; (c) two 20-w, Gro-lux lamps and one 15-w, incandescent lamp; and (d) none. The heights of the light units were adjusted at the beginning of the postinduction period to provide 42 ft-c light intensity at night, as measured at the center of each group, 2 inches above the surface of the soil in the pots—i.e. at the approximate level of the plant foliage. Lamp-to-soil distances were 32, 31, and 34 inches for groups a, b, and c, respectively. The arrangement of the light units remained unchanged, and consequently light intensity at foliage level increased as a result of plant growth. The incandescent lamp furnished about 11 percent of the light recorded for group c.

Results

Experiment 1

As shown in Tables 1 and 2, plants receiving supplemental light from incandescent lamps during the postinduction period responded about alike to the four respective induction light treatments. Flowering percentages after the 5th week of the postinduction period were practically identical for the incandescent and fluorescent induction light sources (I-1 and I-4). Corresponding percentages for the mixtures of the two types of light (I-2 and I-3) tended to be higher but the differences were relatively small.

The contrasting effects of supplemental light from incandescent and fluorescent sources, supplied during the postinduction period, were particularly striking (Table 1, treatments P-1 and P-2). Under the fluorescent source, only one plant flowered in

Table 2.—Flowering of sugar beet seedlings as affected by type of illumination during the induction period (experiment 1) [a].

Treat. no.	Light source	No. of plants	Elapsed time after induction and cumulative % of plants flowering: 5 wks.	6 wks.	8 wks.	10 wks.	14 wks.
I-1	Incandescent, only	48	29	58	77	79	85
I-2	Largely incandescent	48	17	56	83	83	90
I-3	Largely fluorescent	48	29	63	83	88	94
I-4	Fluorescent, only	48	10	56	75	77	85
I-5	Control (not induced)	48	0	4	6	8	10

[a] Summary of results for treatments P-1 and P-4, Table 1 (plants receiving supplemental light from incandescent lamps during the postinduction period).

a population of 95 induced seedlings (induction treatments I-1 through I-4). In the corresponding population under the incandescent lamp, 85 percent of the plants flowered. As stated under Material and Methods, the light intensity was somewhat lower under the fluorescent source. However, on the basis of other evidence[5], the extreme contrast in flowering percentage cannot be attributed to differing intensity per se. It is of interest to note that, where no supplemental light was provided during the post-induction period in the greenhouse (P-3), the results were the same as in the plant group receiving fluorescent light (P-2).

Experiment 2

The summarized flowering results obtained from experiment 2 are presented in Table 3. Several LSD values are shown as an aid in appraising differences. LSD values are not given in those instances where variation was seriously restricted by the frequent occurrence of percentages of 0 or 100.

Table 3.—Flowering of sugar beet seedlings as affected by type of illumination during induction periods of different lengths (experiment 2).

Induc.[a] time (weeks)	Treat no.	Light source	No. of plants	Elapsed time after induction and cumulative % of plants flowering: 4 wks.	5 wks.	6 wks.	9 wks.	12 wks.
4	I-6	Incandescent (75 w)	63	21	41	56	63	67
	I-7	Incandescent (40 w)	64	5	20	44	53	58
	I-8	Fluores. (del. warm white, 40 w)	64	0	6	17	41	44
	I-9	Fluores. (Stand. cool white, 40 w)	63	2	6	17	29	37
	I-10	Fluores. (purple, 40 w)	60	0	5	13	28	32
	LSD	(5-percent point)				16	16	17
8	I-6	Incandescent (75 w)	63	41	68	87	94	95
	I-7	Incandescent (40 w)	63	14	51	70	87	89
	I-8	Fluores. (del. warm white, 40 w)	63	5	41	62	89	94
	I-9	Fluores. (stand. cool white, 40 w)	64	6	47	66	91	95
	I-10	Fluores. (purple, 40 w)	64	3	27	48	73	84
	LSD	(5-percent point)			17	19		NS
0	I-11	Control (not induced)	64	0	0	0	5	5

[a] Induction treatments ended on August 10, 1960.

For the plants receiving 8 weeks' induction, a rather substantial lag in flowering may be observed for the purple fluorescent light source (treatment I-10) and a strong tendency toward earlier flowering is shown for the 75-w incandescent source (I-6), in comparison with the other three treatments. However, these differences narrowed with time and had largely disappeared when the final counts were made. The fact that a minimum of 84 percent flowering occurred among the five sets of plants (I-6 through I-10) receiving 8 weeks' induction, as

[5] Unpublished results.

contrasted with 5 percent flowering for the noninduced set, is of special interest. Obviously some form of low-temperature induction treatment was required for the initiation of flowering, but the type of light used appeared to be relatively unimportant except as related to earliness of flowering. In this connection, it seems possible that the early- and delayed-flowering tendencies shown for treatments I-6 and I-10, respectively, may have been associated with the vigor of the plants at the end of the induction treatment. At that time, the plants of I-6 were the most vigorous and those of I-10 were the least vigorous of the five treatment sets.

Flowering percentages no higher than those resulting from 4 weeks' induction in this experiment ordinarily would be considered unsatisfactory for sugar beet breeding purposes, but some of the results are of academic interest. The 75-w incandescent source was particularly outstanding, and even the 40-w incandescent lamp appeared to be more effective than the white fluorescent units, taken together, as judged on the basis of final flowering percentages as well as earliness of flowering.

Experiment 3

The results from experiment 3, a simple comparison between two types of light used in the induction chamber, are summarized in Table 4. Final flowering percentages for the two treatments were practically identical. The lag in flowering indicated for the plants receiving incandescent light is attributed largely to two pots which became temporarily water-logged, retarding the rate of plant development. Thus it was concluded that the difference between treatments in flowering response, if any, was negligible. With the exception of the water-logged pots, general plant vigor for the two treatments was about alike throughout the experiment.

Table 4.—Flowering of sugar beet seedlings as affected by type of illumination during the induction period (experiment 3).

Light source	No. of plants	Elapsed time after induction and cumulative % of plants flowering [a] 4 wks.	5 wks.	6 wks.	8 wks.	10 wks.	14 wks.
Incandescent	42	2	60	76	93	93	98
Fluorescent (Gro-lux)	45	0	51	91	100	100	100

[a] Induction treatments (10 weeks) ended on June 6, 1962.

Experiment 4

The results obtained for the fluorescent lamps in experiment 4 (Table 5 and Figure 1) agree with the results from experiment 1 in demonstrating very decisively the ineffectiveness of fluorescent lamps when used alone, as a supplement to sunlight,

Figure 1.—Response of induced sugar beet seedlings to two types of supplemental illumination during the postinduction period: top, incandescent; bottom, Gro-lux fluorescent. The photograph was taken on July 27, 1962, 36 days after transfer of the plants from the induction chamber into the open.

during the postinduction period. A light mixture consisting of approximately 89 percent from fluorescent lamps and 11 percent from an incandescent lamp was much more effective than light from a fluorescent unit alone, but was clearly inferior to light of equal intensity furnished solely by an incandescent lamp.

Table. 5.—Flowering of sugar beet seedlings as affected by type of supplemental illumination during the postinduction period (experiment 4).

Light source	No. of plants	Elapsed time after induction and cumulative % of plants flowering [a] 5 wks.	6 wks.	8 wks.	10 wks.	14 wks.
Incandescent (75 w)	40	38	70	95	98	98
Gro-lux fluorescent (40 w)	40	0	3	15	20	28
Gro-lux fluores. (40 w) + incand. (15 w)	40	5	20	53	60	70
None	40	3	10	18	20	23

[a] Induction treatment (12 weeks) ended on June 21, 1962.

Discussion and Conclusions

The ineffectiveness of fluorescent lamps, as used during the postinduction period in these studies, is in agreement with results reported by Borthwick and Parker (2) for relatively mature, thermally induced sugar beet roots. The superiority of incandescent lamps for the promotion of flowering in such sugar beets and in certain other long-day plants has been attributed by Downs et al. (3) to the far-red component of the radiation emitted by those lamps—a feature lacking in the emission of the fluorescent lamps studied. According to information furnished by the manufacturers, neither the deluxe warm white nor the Gro-lux fluorescent lamp emits appreciable far-red energy. Consequently, the ineffectiveness of those lamps during the postinduction period in the current studies was to be expected.

In view of these results it is especially significant that, for the process of induction with at least 47 days' exposure to low temperature, each of those two types of fluorescent lamps was essentially equal to incandescent lamps as measured by the flowering response. Furthermore, it is noteworthy that a third type of fluorescent lamp (standard cool white) also was about equal to those two, and that a fourth type (purple) was nearly so.

From these results it is apparent that the function of artificial light during the induction treatment is quite different from its function during the postinduction period with respect to the mechanisms involved in the flowering process. It is postulated that the physiological or other changes conducive to flowering, occurring during the induction period, are basically due to low temperature, and that light serves primarily as the source of energy for photosynthesis and growth. If this is true, any type of light that is suitable for photosynthesis and growth should be relatively satisfactory for use in the induction treatment. In this connection it is pertinent that field-grown sugar beet roots commonly are induced by prolonged cold storage in complete darkness—a thermal-induction process. Seedling induction, as described in this article, probably involves the same mechanisms with the carbohydrate utilized in growth and other processes being derived largely from the leaves directly instead of from a fleshy tap root. Accordingly, it appears that the term "photothermal", formerly used with reference to seedling induction, is not strictly accurate.

It should be emphasized that the tentative conclusions as stated in the preceding paragraph pertain to sugar beet material of the type used in these studies—i.e., varieties or strains having about average thermal induction requirements. These conclusions may not necessarily apply with equal force to bolting-resistant sugar beet types.

Summary

A series of experiments was conducted for the purpose of comparing the effects of fluorescent and incandescent-filament lamps on flowering of sugar beet seedlings. One phase of these studies involved comparisons between types of lamps used during a prolonged period of low temperature, the induction treatment. In the other phase, comparisons were made between types of lamps used to provide light at night, supplementing sunlight, throughout the postinduction period.

After 9 to 14 days' growth in the greenhouse, seedlings were held in a refrigerated room for varying time intervals, usually ranging from about 7 to 12 weeks, at a temperature of approximately 7° C. Four types of fluorescent lamps were compared with incandescent lamps, and certain mixtures of light from fluorescent and incandescent sources also were included. The lamps were operated continuously, and sunlight was completely excluded.

At the end of the induction period, the seedlings were transferred to the greenhouse or outdoors where the percentage of plants flowering in each population was recorded periodically. Nightlong illumination by incandescent lamps throughout the postinduction period was standard procedure in all experiments. In certain instances, comparisons were made between such supplemental light and that provided by fluorescent lamps.

The results clearly showed that the two types of fluorescent lamps, used as sources of supplemental light during the post-induction period, were wholly ineffective in promoting flowering. Incandescent lamps were highly effective. On the basis of reports by other investigators, these contrasting responses were attributed to the presence of a far-red component in the radiation emitted by incandescent lamps and its absence in the radiation from fluorescent lamps.

A rather wide range of types of fluorescent lamps, as well as the incandescent type serving as the standard, were highly effective in the low-temperature induction process. That is to say, a high percentage of the seedlings, subjected to such conditions for a sufficient length of time and given proper environment thereafter, flowered within a relatively short period after the end of the induction treatment.

From these contrasting results, it was concluded that the function of artificial light, with respect to the promotion of flowering in young sugar beet seedlings having average low-temperature induction requirements, is distinctly different in the induction and postinduction periods. It is postulated that flowerage-promoting changes, occurring in such seedlings during the induction process, are primarily due to low temperature and that the principal function of light at that time is to provide energy for photosynthesis and growth.

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