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Effects of Lighting Period and Temperature on Growth, Yield and Keeping Quality of *Gerbera jamesonii* Bolus.

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Summary

The experiments were conducted between January and June to investigate the effects of temperature, lighting period and lighting regimes on gerbera (*Gerbera jamesonii* Bolus.). The plants were subjected to different temperatures (18, 21, 24 and 27 °C), lighting periods (10 and 20 h), and different light regimes (10 h, 10 and 20 h in periods of 4 weeks, 10 and 20 h in periods of 6 and 2 weeks, and 20 h). The highest yield was obtained for plants grown at 21 °C. Increasing temperature to 24 and 27 °C reduced the yield by 21 and 56 %, respectively. Increasing temperature also decreased stem diameter, fresh weight and keeping quality. The highest yield was obtained from the plants grown under 20 h lighting period as a total of the whole experimental period. In the first part of the experimental period, when the natural light conditions were poor, plants grown under 20 h lighting period produced the highest yield. However, when the natural light conditions improved in the spring, the plants grown under 10 h lighting period, partly or continuously, produced the highest yield.

Zusammenfassung

Wirkung von Belichtungsdauer und Temperatur auf das Wachstum, den Ertrag und die Haltbarkeit von *Gerbera jamesonii* Bolus. Die Versuche fanden zwischen Januar und Juni statt, um die Wirkung von Temperatur, Belichtungsdauer und -programmen auf Gerbera (*Gerbera jamesonii* Bolus.) zu untersuchen. Die Pflanzen wurden bei unterschiedlichen Temperaturen (18, 21, 24 and 27 °C), Belichtungsdauer (10 and 20 h) und Belichtungsprogrammen (10 h, 10 und 20 h in 4-Wochen-Intervallen, 10 und 20 h in Intervallen von 6 und 2 Wochen und 20 h) kultiviert. Den höchsten Ertrag erzielten bei 21 °C kultivierte Pflanzen. Höhere Temperaturen (24 und 27 °C) reduzierten den Ertrag um 21 bzw. 56 %. Höhere Temperaturen verringerten außerdem den Stieldurchmesser, das Frischgewicht und die Haltbarkeit. Den höchsten Ertrag insgesamt erbrachten die Pflanzen, die 20 Stunden Licht bekamen.

Zu Beginn des Versuchszeitraums, wenn das natürliche Lichtangebot gering war, erzielten die Pflanzen im 20 h-Tag den höchsten Ertrag. Dies änderte sich mit zunehmendem Naturlichtangebot im Frühjahr. Ab diesem Zeitpunkt produzierten die Pflanzen, die teilweise oder vollständig bei 10 h Zusatzlicht kultiviert wurden den höchsten Ertrag.

Key words. *Gerbera jamesonii* – *gerbera* – supplementary lighting – photoperiod – temperature – flowering – keeping quality

Introduction

Gerbera as a cut flower has increased its popularity in Norway and other European countries during the last decades. The increased market demand for cut gerbera has increased the interest for a year round production. Year-round production in northern latitudes exhibits a great variation in daylengths and temperature throughout the year.

Gerbera production under natural light conditions has originally been limited mainly to the spring season in the northern latitudes due to the severe climatic conditions which exist during the fall and winter, caused by short natural daylengths and low ambient light conditions. Under these conditions the flower yield and quality are inadequate for an economical production, and supplementary lighting is required if an efficient year-round production of marketable cut flowers is to be obtained. LEFFRING (1973) found that there is a strong positive correlation between flower production and the number of lateral shoots. In a later study, it was found that lateral shoot formation is influenced by photoperiod in some gerbera cultivars, and showed a positive influence of short days on the number of shoots and flower yield (LEFFRING 1975). The effect of short days on lateral branching is also found in several other species (SAILSBURY and ROSS 1992). In pot gerbera, NÆSS (1991) found that short days (10 h) promotes flowering compared to plants grown under long days.

Temperature was found to affect the development of lateral shoots (LEFFRING 1975). Low temperature was found to have a positive effect on the flower yield. This is consistent with the findings of BERNINGER (1979). The effect of both photoperiod and temperature probably result in the so-called summer depression, which causes a substantial reduction in flower production (LEFFRING 1975). However, there seems to be a wide variation between cultivars in reaction to both photoperiod and temperature (LEFFRING 1973; LIN and FRENCH 1985).

The use of supplementary lighting in a year-round production system of cut gerbera has not been fully investigated; for example the effects of temperature and long photoperiods with high intensity irradiance with respect to flower production and keeping quality. In order to obtain a better understanding of the effects of temperature, lighting period and use of supplementary lighting in a year-round production of cut gerbera two experiments were performed. The first includes four temperatures and two lighting periods, whereas the second includes four different lighting regimes.

Materials and Methods

Experiment one

Plants of *in vitro* cultivated *Gerbera jamesonii* 'Lily' and 'Kaliki' were imported from the Netherlands at the end of September. These were grown in a standard limed and fertilized peat (Floralux, Nittedal Industries) in 12 cm pots for twelve weeks at 16 °C in an air-conditioned greenhouse compartment, with no supplemental lighting. On 5 December 1997 the plants were moved to the phytotrone and two plants of the same cultivar were planted in each container (25 litres), and placed on trolleys about 1 meter above ground level.

Four constant temperature treatments were used, one in each compartment: 18, 21, 24 and 27 °C. Supplementary lighting at a level of 180 µmol $m^{-2} s^{-1}$ photosynthetic photon flux density (PPFD), was established in each compartment, supplied by means of high pressure sodium lamps (Philips SON/T). Within each compartment there were established two different lighting periods: 10 h day^{-1} and 20 h day^{-1}. This was achieved by covering the 10 h lighting period plants each day with black curtains from 18.00 h until 08.00 h. For the plants given 20 h lighting period, the dark period lasted form 22.00 h until 02.00 h. As light intensity was the same in both lighting periods, plants under 20 h lighting period received double amount of supplemental light. Due to this the effects of photoperiod and daily light integral cannot be separated.

Each treatment contained eight plants of each cultivar. Records were taken from week 1 to week 16.

Experiment two

Plants of *in vitro* cultivated *Gerbera jamesonii* cultivar 'Nini', 'Siby', 'Ponsy' and 'California' were imported form the Netherlands in the middle of October. These were planted in rockwool slabs placed in a double acrylic greenhouse under four different lighting regimes. The four treatments were 20 h lighting period, 20 h lighting period for 6 weeks and 10 h lighting period for 2 weeks, 20 h lighting period for 4 weeks and 10 h lighting period for 4 weeks, and 10 h lighting period.

Supplementary lighting at a level of 180 µmol $m^{-2} s^{-1}$ PPFD, supplied by means of high-pressure sodium lamps (Philips SON/T) were applied for 20 h per day. The plants given 10 h lighting period were covered with black curtains each day from 18.00 h until 08.00 h.

The day and night temperature set point was 21,0 °C, and the ventilation set point 23,0 °C. Records were taken from week 3 to week 23.

General for both experiments

The climate in the compartments were continuously controlled and recorded by computer (Priva climatic computer system). Measurements, logged as 1-hour mean values, showed that the temperature variations were within ±0,5 °C of the set temperature, and the relative air humidity varied from 60 to 85 % with the highest levels occurring in the period December – February. The temperature was measured at plant level.

The supplementary lighting was measured at the top of the plant canopy by means of a Li-cor, Inc., Model L1-185B instrument with a quantum sensor (400 – 700 nm).

The plants were watered with a fully compound nutrient solution. This was applied at each irrigation throughout the experimental period; the electric conductivity was between 1,5 and 2,0 mS cm^{-1}.

The stems were harvested at the commercial stage of flowering (when the stamens of about two circles of bisexual disc florets were ripe) three times per week throughout the experimental period. At harvest the stems were assessed as first class (saleable) and second-class yield, total stem length. The diameter of stem and inflorescence were recorded for all first class stems harvested throughout the experimental period.

Three times during the production period (February, March and April), extended measurements were made on ten first class stems from each treatment and cultivar. The stems were cut at 40 cm length, the inflorescence was cut of the stem, and measurements of fresh and dry weight of both stem and inflorescence were made.

In the same three periods stems were harvested for testing of keeping quality (not in experiment two). Each treatment contained ten stems. After harvest the stems were placed in vases containing tap water (one stem per vase), and kept for 24 h in a cool storage room at 5 °C. The vases were then placed in an interior holding room under the following conditions to simulate indoor climatic conditions: an irradiation of 14 µmol $m^{-2} s^{-1}$ PPFD by means of warm white fluorescent lamps (Thorn) for 12 h per day, a temperature of 20 °C (±0,5 °C) and 50±10 % relative air humidity. The occurrence of "bent neck" was recorded daily. Vase life was determined as time until a stem had lost its decorative value, that is, the development of "bent necks" or natural senescence of the flower.

All data were subjected to an analysis of variance (ANOVA). Differences between means were determined using Tukey's pairwise comparison test.

Results

Yield

Both temperature and lighting period significantly affect the flower yield of gerbera (Table 1). The total number of stems harvested for both cultivars increased by 22 % when the temperature increased from 18 to 21 °C. A further increase in temperature from 21 to 24 and 27 °C resulted in a decrease in yield by 25 and 56 %, respectively (Table 1). The yields (mean of both cultivars and temperature levels) for the whole experimental period were 193 stems at 10 h lighting period

Table 1. The effect of lighting period (PP) and temperature (T) on the yield of first class stems in *Gerbera* (mean for 'Lily' and 'Kaliki'). The experimental period of 16 weeks was divided into four periods consisting of four weeks and the data are the yields harvested in these periods. Significance levels: ns, not significant; *, p<0,05; **, p<0,01; ***, p<0,001.

Harvest period	10 h lighting period					20 h lighting period					Significance level		
	Temperature °C					Temperature °C							
	18	21	24	27	Mean	18	21	24	27	Mean	T	PP	T x PP
1 (week 1–4)	35	52	49	7	28,3	54	58	67	53	58	**	*	ns
2 (week 5–8)	58	68	52	20	49,5	72	77	70	39	64,5	**	ns	ns
3 (week 9–12)	66	78	57	30	57,8	64	87	51	43	61,3	**	ns	ns
4 (week 13–16)	62	70	46	28	51,5	55	72	31	27	46,3	***	*	ns
Total	220	268	203	84		244	294	218	161				

Table 2. The effect of lighting period (PP) and temperature (T) on stem length and diameter of the stem and inflorescence of *Gerbera* 'Lily' and 'Kaliki' in experiment one. Significance levels: ns, not significant; *, p<0,05; **, p<0,01; ***, p<0,001.

	10 h lighting period				20 h lighting period				Significance level		
	Temperature °C				Temperature °C						
	18	21	24	27	18	21	24	27	T	PP	T x PP
Stem length (cm)	53,1	59,7	61,5	61,2	59,7	63,2	63,0	59,1	***	**	ns
Stem diameter (mm)	5,8	5,6	5,0	4,8	6,3	5,9	5,7	5,0	***	*	ns
Inflorescence diameter (cm)	7,2	6,92	6,6	6,7	7,5	7,2	7,3	7,2	**	*	ns

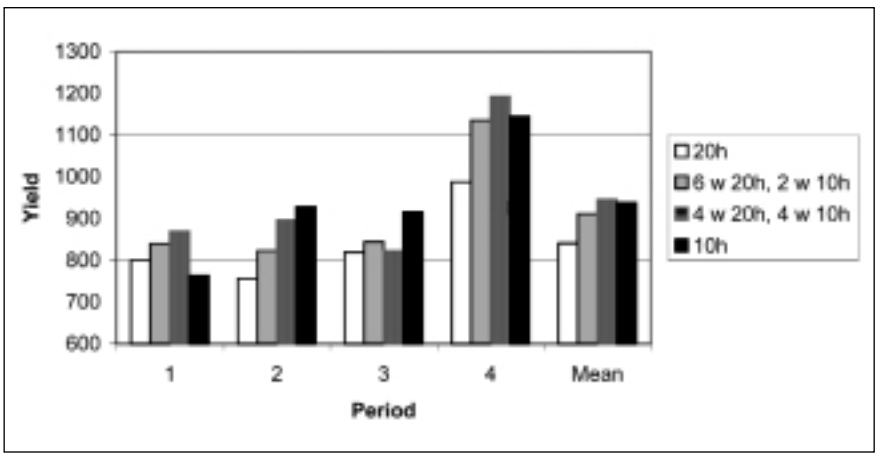


Fig. 1. The effect of lighting regime (LR) on the total yield of first class stems in *Gerbera* as a mean of four cultivars in experiment two. The experimental period of a total of 20 weeks is divided into four periods of five weeks. See material and methods for details of the lighting treatments.

and 229 stems at 20 h lighting period, equivalent to an increase in yield of 18 %. However, when dividing the experimental period in 4 periods of 4 weeks, the yield (mean of both cultivars and temperatures) of plants grown at 10 h lighting period increased by 44 % from the first period to the last one. For the plants grown under 20 h lighting period the opposite effect was found represented by a decrease in yield of 20 % even though the double amount of supplementary lighting were supplied. However, there was a substantial increase in natural radiation from period one to period four.

In experiment two, the yield of gerbera was significantly affected by the lighting regimes (Figure 1). The highest yield (mean of all cultivars) was obtained from the plants treated with a combination of 10 and 20 h lighting periods in four weeks intervals ($p<0.05$). The yield was about 10 % higher than from the 20 h lighting period treatment. The yield harvested in the last period (period four) was significantly higher than the first three periods ($p<0,05$).

Stem length and diameter of stem and inflorescence

Stem length increased with the temperature up to 24 °C (Table 2) at 10 h lighting period. At 20 h the stem length increased when temperature increased from 18 to 21 °C, and decreased when temperature increased from 24 to 27 °C. In both experiments there was a significant effect of lighting period on stem length (Table 3), where stem length decreased with decreasing lighting period.

The diameter of the stem and inflorescence decreased by 19 and 6 % respectively as the temperature increased from 18 to 27 °C. Lighting period and lighting regime significantly affected the diameter of stem and inflorescence in both experiments (Tables 2 and 3).

Table 3. The effect of lighting regimes (LR) on the stem length and diameter of the stem and inflorescence of *Gerbera* (mean of all cultivars) in experiment two. Significance levels: ns, not significant; *, p<0,05; **, p<0,01; ***, p<0,001. See materials and methods for details of the lighting treatments.

	20 h	6 w 20 h, 2 w 10 h	4 w 20 h, 4 w 10 h	10 h	LR	Cultivar	LR x Cultivar
Stem length	61,4	59,8	57,3	54,9	***	***	ns
Inflorescence diameter	8,23	8,12	8,05	7,92	*	***	ns
Stem diameter	6,19	6,02	5,91	5,51	***	***	ns

Table 4. The effect of lighting period (PP) and temperature (T) on fresh and dry weight of *Gerbera* (as a mean for both cultivars) in experiment one. Significance levels: ns, not significant; *, p<0,05; **, p<0,01; ***, p<0,001.

	10 h lighting period				20 h lighting period				Significance level		
	Temperature °C				Temperature °C						
	18	21	24	27	18	21	24	27	T	PP	T x PP
Fresh weight stem (g)	10,7	9,7	8,1	7,4	13,4	11,8	10,5	7,6	***	***	ns
Dry weight stem (g)	0,94	0,85	0,66	0,68	1,32	1,13	1,01	0,83	***	***	ns
Fresh weight inflorescence (g)	6,6	6,0	5,0	5,0	7,6	6,9	6,7	5,9	**	*	ns
Dry weight inflorescence (g)	1,02	0,91	0,73	0,78	1,28	1,14	1,10	1,01	***	**	ns

Table 5. The effect of lighting regimes (LR) on fresh and dry weight of *Gerbera* as a mean for all cultivars. Significance levels: ns, not significant; *, p<0,05; **, p<0,01; ***, p<0,001. See materials and methods for details of the lighting treatments.

	20 h	6 w 20 h, 2 w 10 h	4 w 20 h, 4 w 10 h	10 h	LR	Cultivar	LR x Cultivar
Fresh weight stem (g)	12,82	11,91	11,35	9,97	***	***	ns
Dry weight stem (g)	1,70	1,52	1,52	1,40	*	*	ns
Fresh weight inflorescence (g)	7,49	7,18	6,09	6,32	***	***	**
Dry weight Inflorescence (g)	1,21	1,11	1,04	1,02	***	***	ns

In both experiment one and two, the stem diameter increased when increasing the lighting period from 10 to 20 h, with 17 and 11 %, respectively.

Fresh and dry weight

The fresh and dry weights (g) of the stem and inflorescence were significantly affected by temperature, lighting period in experiment one, and lighting regime in experiment two. In experiment one, fresh and dry weight of the stem and inflorescence increased by 19,9 and 15,5 %, respectively, when increasing the lighting period from 10 to 20 h (Table 4). Difference between 10 h and 20 h lighting period regarding dry weight of stem and inflorescence was 36 and 31 %, respectively.

Increasing the temperature resulted in a decrease in both fresh and dry weight of stem and inflorescence. An increase of temperature from 18 to 27 °C decreased the fresh weight of stem and inflorescence by 23,2 and 37,8 %, respectively. When increasing temperature from 18 to 27 °C the dry weight of stem and inflorescence decreased with 33 and 22 %, respectively.

In experiment two, lighting period was found to affect fresh and dry weight of the stem and inflorescence (Table 5). Fresh and dry weight of stem and inflorescence increased with increasing lighting period. When lighting period increased from 10 to 20 h the fresh and dry weight of the stem increased with 28,5 and 21 %, respectively.

Keeping quality

In 'Kaliki' vase life was significantly reduced as the temperature increased (Table 6). Increasing the temperature from 18 to 24 and 27 °C resulted in a decrease in vase life of 21 and 23 %, respectively. In 'Lily', the same tendency was observed, but this was not significant (p<0,1).

Lighting period was found to affect the vase life of 'Kaliki'. Increasing the lighting period from 10 to 20 h, decreased vase life by 13 %.

Discussion

In the present study, the highest yield was obtained at 21 °C. The yield increased with temperature up to 21 °C and a further increase in temperature reduced the yield in both cultivars. LEFFRING (1975) found that temperature had a marked effect on the development of lateral shoots and thereby flower yield. In her experiment,

Table 6. Effect of temperature and lighting period on the vase life (days) of *Gerbera* 'Lily' and 'Kaliki' in experiment one. Significance levels: ns, not significant; *, p<0,05; **, p<0,01; ***, p<0,001.

	10 h lighting period				20 h lighting period				Significance level		
	Temperature °C				Temperature °C						
	18	21	24	27	18	21	24	27	T	PP	T x PP
'Lily'	17,2	17,7	16,8	14,9	15,6	16,3	17,4	15,5	ns	ns	ns
'Kaliki'	17,1	14,8	12,4	14,8	19,5	18,3	15,4	15,0	*	*	ns
Mean	17,2	16,3	14,6	14,9	17,6	17,3	16,4	15,3	*	*	ns

high day/night temperature (25/21 °C) reduced flower production compared to low day/night temperature (17/13 °C). This effect was most prominent under long day conditions. BERNINGER (1979) found that increasing air temperature from 11 to 18,5 °C shortened the period of development of individual inflorescences, while increasing soil temperature from 15 to 21 °C shortened the interval between the appearances of successive flower buds. The positive effect of increasing temperature in reducing the time until flowering is known from roses (MOE 1972; MORTENSEN 1991). COCKSHULL (1985) concluded that air temperatures over 20 °C reduces flower production in gerbera. A marked difference between cultivars in respond to temperature in gerbera has been reported (LEFFRING 1975; LIN and FRENCH 1985).

The positive effect of short day photoperiods on flower production has been demonstrated in several studies (LEFFRING 1975; LIN and FRENCH 1985; AUTIO 2000). In experiment one, the 20 h lighting period was found to produce a higher mean yield than 10 h lighting period over 16 weeks. However, this difference was mainly due to a very low flower production of the 10 h lighting period treatment in the first four weeks (dark winter period). In experiment two, the same effect was found. This could be due to reduced assimilation at the lower daily light integral in the 10 h lighting period treatment. The difference in daily light integral between the two lighting periodic treatments (experiment one) and the lighting regimes (experiment two) decreased throughout the experimental period as the natural light conditions improved. Considering the last four weeks in experiment one, the highest yields were obtained in the 10 h lighting period treatment, whereas in experiment two the highest yield were produced under the treatment which consisted of a combination of short and long lighting periods in periods of 4 weeks. With cv. 'Sundance', FJELD and GISLEROD (1996) found that there was almost 50 % increase in yield when the daily light integral was applied at 23 Klux for 10 h rather than 13 Klux for 18 h. AUTIO (2000) showed that with the same daily light integral the yield of gerbera plants grown at 12 h photoperiod were higher compared to plants grown at 18 and 24 h photoperiod. GAGNON and DANSEREAU (1990) found that in pot gerbera, the number of flowers and the dry weight increased with increasing light intensity, and concluded that supplementary lighting increases both vegetative and generative growth. It is also possible that the two cultivars in experiment one are not sensitive to photoperiod in relation to formation of lateral shoots.

Fresh weight and dry matter accumulation in the stem and inflorescence was found to be affected by temperature and lighting period. The fresh weight decreased with increasing temperature. This agrees with the findings of MORTENSEN (1991) who showed that increasing the temperature from 18 to 30 °C reduced the dry weight (g) in pot roses. In cut roses an increase in temperature from 18 to 22 °C resulted in a decrease in dry weight (g) (MORTENSEN and GISLERØD 1999). ERWIN and HEINS (1995) found that dry weight (g) in stems, leaves, flowers and roots of *Dendranthema* increased with decreasing temperature from 30 to 20 °C.

A high percentage in dry weight is often associated with good keeping quality in cut flowers. VAN DOORN et al. (1991) reported that low carbohydrate contents in 'Madelon' roses cut at an early stage reduced the vase life. In gerbera, the stomata on the inflorescences are located on the petals and the immature part of the stem (ROGERS and TIJA 1990). VAN MEETEREN (1978) found that stomata in tissue with high content of carbohydrates are more closed than in tissues with a low content of carbohydrates, resulting in a reduced water loss.

Our results showed no differences in vase life between 10 h and 20 h lighting period indicating that the carbohydrate content in both treatments was sufficient to ensure an acceptable vase life. The reduced vase life of inflorescences grown at high temperature could be caused by low carbohydrate content.

In conclusion, it seems that short day lighting increases the yield of gerbera. However, in winter production of gerbera in poor natural light conditions under short lighting periods, it would be difficult to ensure a high availability of photoassimilates. This could be prevented by a lighting regime composed of periods of short and long lighting periods of some weeks each.

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