Pak. J. Bot., 45(2): 411-420, 2013.

RESPONSE OF CAULIFLOWER (*BRASSICA OLERACEA* L. VAR. *BOTRYTIS*) GROWTH AND DEVELOPMENT AFTER CURD INITIATION TO DIFFERENT DAY AND NIGHT TEMPERATURES

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Abstract

Two experimental runs were conducted to assess the response of the growth and development of cauliflower (*Brassica oleracea* L. var. *botrytis*) cv. "Nautilus" F1 hybrid after curd initiation to different day and night temperatures in Saxcil Growth environmental cabinets, which were set to run at 24/12°C, 12/24°C, 20/16°C, 16/20°C, 20/20°C (1^{st} Run) and 24/20°C, 20/12°C and 20/16°C (2^{nd} Run) with a total irradiance of 441 μ mols m^{-2} s^{-1} (90 Watts m^{-2}) at the School of Biological Sciences, University of Reading, United Kingdom. Greater rates of curd growth (curd length, diameter, fresh and dry weights) were achieved at warmer night temperatures than day temperatures, whilst greater leaf and stem growth (leaf area, stem length, fresh and dry weights) were achieved when day temperatures were warmer than night temperatures, even with the same mean temperatures. Greater curd growth (curd length, diameter, fresh and dry weights) were achieved at warmer night temperatures than day temperatures. Similarly greater Relative Curd Growth Rate (RCGR) was recorded in plants grown at warmer night than day temperature (12/24°C) compared to the plants grown at cooler night than day temperature (24/12°C). Moreover, RCGR decreased significantly ($p<0.01$) with increase in day temperature (DT) and increased significantly ($p<0.01$) with increase in night temperature (NT). Similarly, curd length, diameter, fresh and dry weights decreased with increase in DT and increased with increase in NT. Further, cauliflower stem length (SL) was linearly related to the effective mean temperature with optimum day temperature of 24°C and optimum night temperature of 12°C.

Introduction

The effect of different day and night temperature on plant growth was first examined by Went (1944), who demonstrated higher rates of stem elongation in tomato plants under higher day (DT) than night (NT) temperature compared to constant temperature and termed this phenomenon as "Thermoperiodicity". However, his data were reanalysed by Ellis *et al*., (1990) who showed that, when the relative lengths of the day and night were considered, stem elongation was a function of mean temperature rather than of alternating day/night temperatures. Moreover, they reported that a simple error had occurred in Went's original paper, in which mean temperature had been miscalculated as the differing lengths of the day and the night period had not been taken into account.

The effects of mean daily air temperature on the growth rate of horticultural plants are well documented in literature (Ellis *et al*., 1990; Seginer *et al*., 1994). Plant growth, expressed as dry weight, leaf area or stem elongation, reaches a maximum in the range of 21 to 23°C in vegetative sweet pepper (Bakker & Uffelen, 1988), in the range of 19 to 23°C in cauliflower after curd initiation (Rahman, 2002; Rahman *et al.*, 2007), at approximately 25°C in vegetative tomato (Went, 1944; Hussey, 1965), and in the range of 28 to 35°C in young cucumber plants (Karlsen, 1978; Grimstad & Frimanslund, 1993). The optimum temperatures for plant growth appear to increase with increase in solar radiation (Went, 1945; Seginer *et al*., 1994) and decrease with plant age (Went, 1945). Similarly, Challa *et al*., (1995) reported that the optimum temperatures for cucumber plant growth in the generative phase are usually lower than in the vegetative phase due to low leaf area ratio and high respiration in the generative stage. They added further that optimum temperature for cucumber fruit production might also be different from that for overall plant growth (plant dry mass). Rahman (2002) and Rahman *et al.*, (2007) have reported that cauliflower had a higher optimum temperature for curd growth components than vegetative growth components (leaf and stem) after curd initiation. Gary (1989) and Seginer *et al*., (1994) reported that optimum temperature for tomato plant growth, development, and fruit production varies with cultivar. Pearson *et al*., (1994) also found different optimum temperatures of 16°C, 21°C, and 25°C for cauliflowers' cultivars "Jubro", "Revito", and "White Fox" respectively, whereas, the optimum temperature for cultivar "Nautilus" after curd initiation was found to be in the range of 19 to 23°C (Rahman, 2002; Rahman *et al*., 2007).

Different day and night temperatures do not necessarily have exactly the same effect on plant growth (Seginer *et al*., 1994). For example, Hussey (1965) and Heuvelink (1989) found that total dry weight of vegetative tomato plants was more affected by DT compared to NT. During the reproductive phase, tomato dry matter accumulation, stem elongation and fruit setting were increased when DT was warmer than NT (Gent, 1984 and 1988). However, final tomato yield and average fruit size were higher at warmer night temperature, even the mean temperatures (MT) were the same (De Koning, 1988). However, Agrawal *et al.*, (1993) found that warmer night temperatures decreased plant height, number of nodes, leaf area, fresh and dry weights in cucumber. In contrast, Papadopolous & Hao (2000) found that the developmental rates (number of leaves and flowers) of cucumber were positive linear functions of increasing daily mean air temperature, regardless of DT or NT. There are other literature on cucumber and tomato, which show the effects of mean temperature rather than day/night temperature (Grimstad & Frimanslund, 1993; Langton & Cockshull, 1997 a, b). Similarly, Hurd & Graves (1984) and De

Koning (1988) found that total tomato yield was influenced mainly by temperature integral rather than by temperature regime. The same was found for the yield of sweet pepper (Hand & Hannah, 1978) and cucumber (Slack & Hand, 1983). So, it can be concluded that plant growth is a function of mean temperature rather than a separate day and night temperature.

Previously published work on cauliflower (Wurr *et al*., 1990; Pearson *et al*., 1994; De Koning, 1994) has described the response of cauliflower to mean air temperature and no attention had been extended to the effects of different day/night temperatures on cauliflower growth and development after curd initiation. Therefore, the present controlled environment study was designed to investigate the possibility of separate effects of day and night temperature on growth and development of cauliflower after curd initiation and to identify the optimal air temperature regime for cauliflower production.

Materials and Methods

Two experimental runs were conducted in controlled environment growth cabinets (Saxcil, R.K. Saxton Ltd, UK; at University of Reading, United Kingdom. Cauliflower (*Brassica oleracea* var. *botrytis*) cv. Nautilus F1 seeds (Tozer seeds Ltd, Pyports, Cobham, Surrey, UK) were sown in modular seed trays containing 135 cells (each cell 30mm x 30mm x 45mm deep) filled with a peat-based, seed and modular compost (SHL; William Sinclair Horticulture Ltd, Lincoln, UK). Seeds were germinated and grown until 4-5 visible leaves at 18±2°C in a growth room, providing 90 μmols m^{-2} s^{-1} (PAR) at plant height from a mixture of warm white fluorescent and tungsten bulbs with a 16 hour photoperiod. Plants were watered as required.

Plants were potted into 6 inch pots, using SHL peat-based potting compost mixed with 25% perlite and placed in glasshouses with set point temperatures of 13-15°C (±4°C) until curd initiation. A liquid feed was supplied using a nutrient solution, Sangral 1:1:1 (William Sinclair Horticulture Ltd, Lincoln, UK) as required. About three weeks after potting, a sample of three plants was harvested twice a week until 100% curd initiation. At each harvest, plants were dissected to measure the apex diameter and finally a clearly domed apex of approximately 0.6 mm was considered to be curd initiation (Salter, 1969; Wiebe, 1975; Hadley & Pearson, 1999). After curd initiation, 94 replicate plants were then transferred into five (1^{st} Run) and three (2^{nd} Run) Saxcil Growth environmental cabinets, which were set to run at 24/12°C, 12/24°C, 20/16°C, 16/20°C, 20/20°C (1^{st} Run) and 24/20°C, 20/12°C and 20/16°C (2^{nd} Run) with a total irradiance of 441 μmols m^{-2} s^{-1} (90 Watts m^{-2}) supplied by warm white fluorescent tubular lamps (58 Watts x 56) and tungsten lamps (15 Watts x 30) with a 12hr photoperiod and a vapour pressure deficit of 0.8 kPa. An irrigation system provided Sangral 1:1:1 liquid feed (182ppm N; 78ppm P; 150ppm K) at each watering, at a conductivity of 1500 μs and acidified using a dilute 1:1 mixture of nitric and phosphoric acid to pH 5.8.

Forty-eight cauliflower plants (six plants per treatment, 28 days after transferring to different day/night temperatures) were harvested. Plant components (leaf, stem and curd) were weighed separately to obtain fresh and dry weights (after oven drying at 80°C for 96hrs) using a portable Sartorius balance (Model No 1212 MP, Sartorius AG, Goettingen, Germany). Leaves were cut into sections to measure the total plant leaf area (cm²) using a calibrated leaf area meter (Delta-T Devices Ltd, Cambridge, UK). Leaf area includes the blade, midrib and petiole's area. Stem length (cm) was measured from the soil surface to the base of the curd. Curd length and diameter (measured across width of the curd in two dimensions at 90° from each other) was recorded in cm using Dial Calipers (More and Wright Sheffield, UK). Relative curd growth rate was calculated (Hunt, 1982).

Data were analysed as complete randomised design using SAS (version 8) statistical package. Regression analysis was carried out in Microsoft Excel XP, where required. Moreover, where appropriate, data were also regressed against calculated effective mean temperatures (Pearson *et al*., 1993). Optimum day and night temperatures were included in calculating effective day (DT_e) and effective night temperatures (NT_e), as explained in Pearson *et al*., 1994; Rahman, 2002; Rahman *et al*., 2007, then effective mean temperatures (MT_e) of different day/night temperatures were calculated as follows:

$$MT_e = \frac{(DT_e + NT_e)}{2}$$

where effective day and night temperatures were calculated as follows:

$$DT_e = DT_o - |DT_o - DT_a|$$

$$NT_e = NT_o - |NT_o - NT_a|$$

where DT_o, DT_a, NT_o, and NT_a are optimum day temperature, actual day temperature, optimum night temperature, and actual night temperature respectively.

Results

Vegetative growth: Where comparison was appropriate between alternating day and night temperatures, data showed that plants grown at warmer day than night temperature (24/12°C) produced more leaf area, fresh and dry weights of leaves and stem compared to those plants grown at cooler day than night temperatures (12/24°C) (Figs. 1 & 2, Plate 1). However, there was no significant difference between plants grown at 20/16°C and 16/20°C (Figs. 1 & 2). Maximum fresh and dry weights (g) of vegetative growth components were either recorded at 20/12°C (LFW, SFW, SDW) or 20/20°C (LDW), whereas minimum fresh and dry weights (g) of vegetative growth components (leaf and stem) were recorded at 12/24°C (Figs. 1 & 2). Maximum leaf area (cm^2) and stem length (cm) were measured at 24/12°C, whereas minimum leaf area (cm²) and stem length (cm) were found at 20/16°C and 16/20°C respectively (Figs. 1a & 2c). There was no significant relationship ($p>0.05$) between vegetative growth components (leaf and stem) and DT, NT, and MT (Figs. 3-5). However, stem length increased linearly with increase in DT (Fig. 6a). Similarly, when stem length (cm) was regressed against MT_e, stem length (cm) was found to increase ($p<0.05$) linearly with increase in MT_e with optimised day and night temperatures optima of 24°C and 12°C respectively (Fig. 6d).

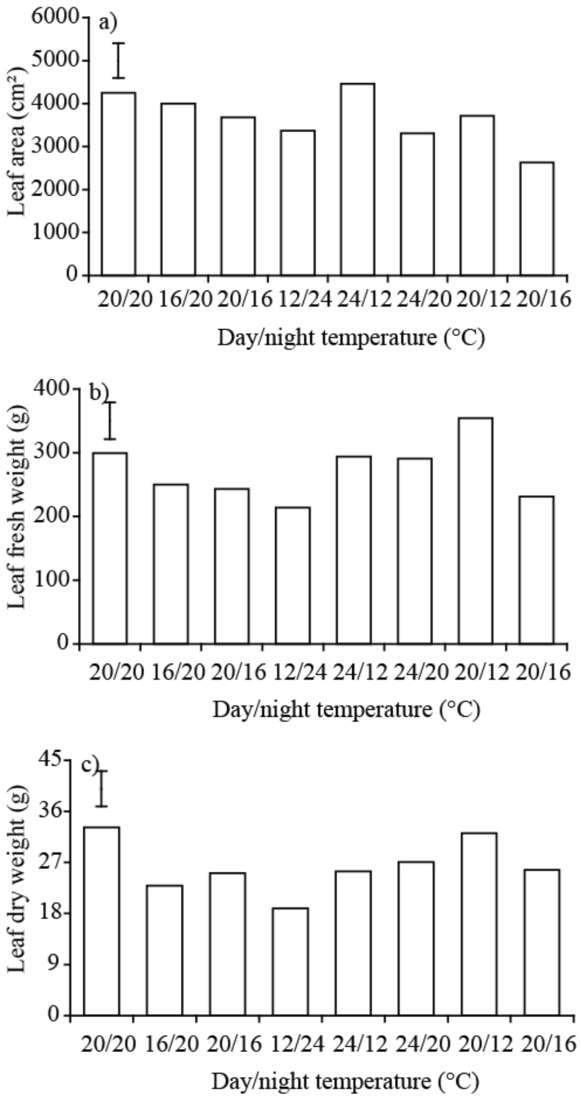

Fig. 1. Effect of different day and night temperature (°C) on leaf area (a), leaf fresh weight (b), and leaf dry weight (c) after curd initiation. Error bars represent least significant difference at 5% probability.

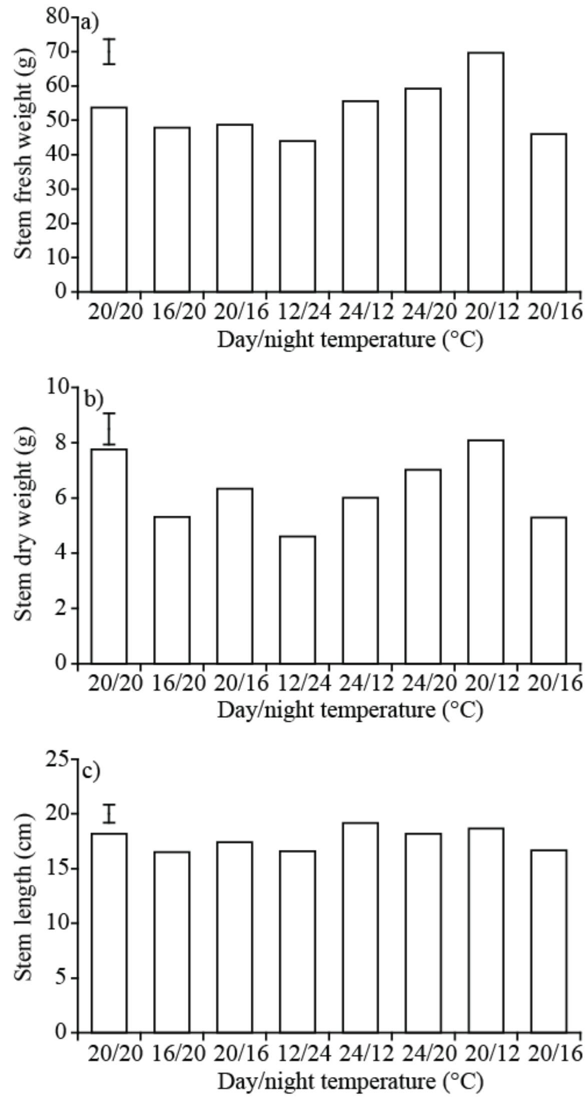

Fig. 2. Effect of different day and night temperature on stem fresh weight (a), stem dry weight (b) and stem length (c) after curd initiation. Error bars represent least significant difference at 5% probability.

Plate 1. Cauliflower plants at different day and night temperatures.

Curd growth: In contrast to vegetative growth parameters, plants grown at warmer night than day temperature (12/24°C) produced larger curd length (cm), diameter (cm), fresh and dry weights (g) compared to the plants grown at cooler night than day temperature (24/12°C) (Fig. 7). Curd length and diameter of the plants grown at 16/20°C and 20/16°C were not significantly different ($p>0.05$). However, plants grown at 16/20°C showed a consistent trend of higher curd fresh and dry weights compared to the plants grown at 20/16°C (Fig. 7).

To separate the effect of the day and night temperatures from that of mean temperatures, regression analysis was carried out by plotting curd growth parameters against DT, NT, and MT. The relationship between curd growth parameters and mean growing temperatures was not significant ($p>0.05$). Moreover, curd length, diameter, fresh and dry weights decreased with increase in day temperature and increased with increase in night temperature (Figs. 8 & 9). However, great care is needed in interpreting this result as there is a negative correlation between the day and night temperature treatments i.e., high day temperatures were always associated with low night temperatures and *vice versa*.

Relative growth rate for the plant and curd calculated over four weeks after curd initiation are shown in Fig. 10. Maximum and minimum plant relative growth rates (PRGR, g $g^{-1}d^{-1}$) were obtained at 20/20°C and 20/16°C respectively, whereas, maximum and minimum relative curd growth rate (RCGR, g $g^{-1}d^{-1}$) were obtained at 12/24°C and 24/12°C respectively. There was no significant difference ($p>0.05$) in PRGR between the plants grown at alternating day and night temperatures with same mean temperature of 18°C i.e., 24/12°C and 12/24°C; 20/16°C and 16/20°C. However, greater RCGR was recorded in plants grown at warmer night than day temperature (12/24°C) compared to the plants grown at cooler night than day temperature (24/12°C). PRGR showed no significant response to DT, NT, and MT (Fig. 11), whereas, RCGR decreased significantly ($p<0.01$) with increase in DT and increased significantly ($p<0.01$) with increase in NT (Fig. 11). Relative curd growth rate showed no significant relationship with mean growing temperature (Fig. 11).

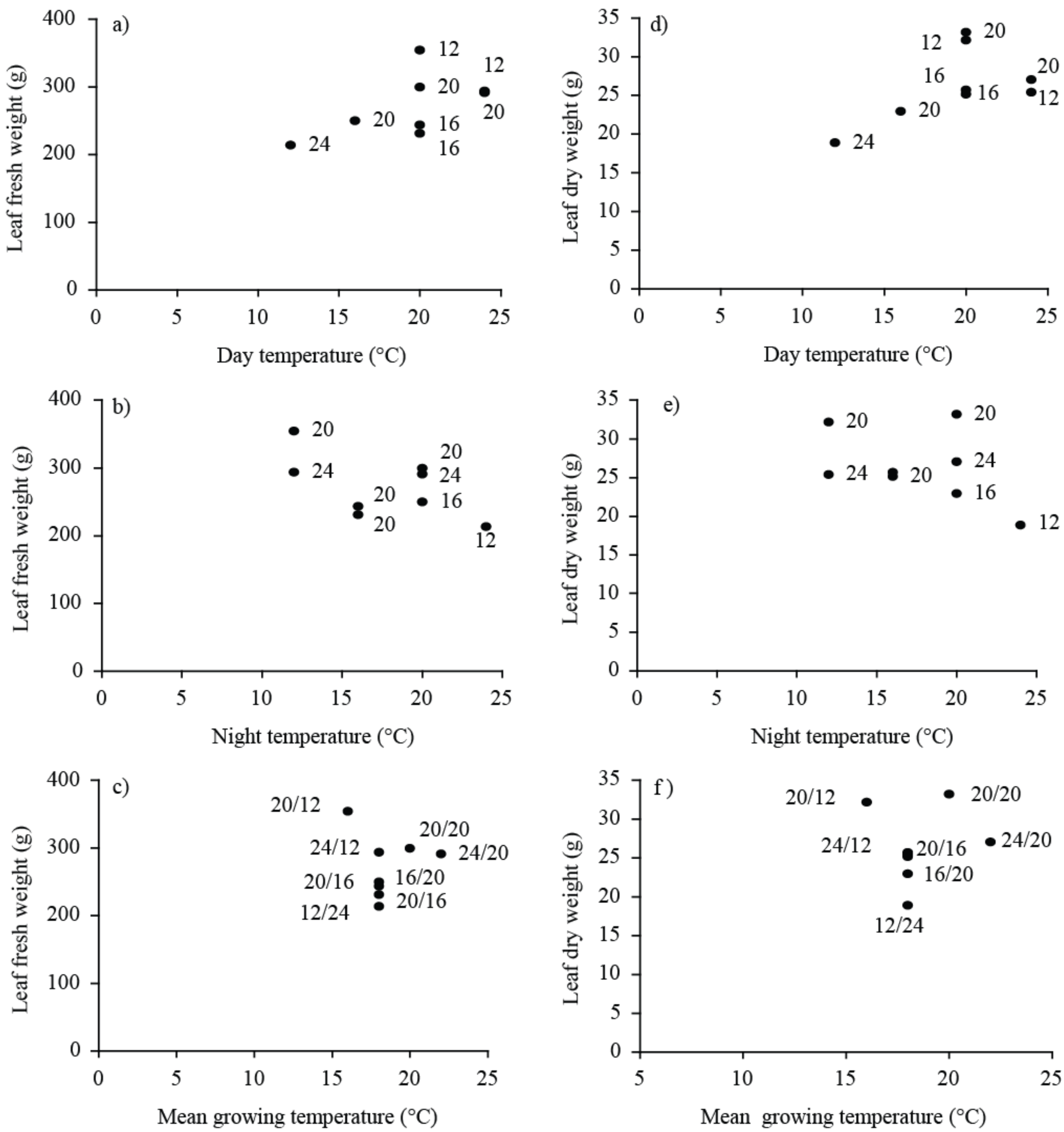

Fig. 3. Effect of day, night, and mean temperature (°C) on cauliflower leaf fresh (a, b, c) and dry (d, e, f) weights (g) after curd initiation. Data point labels show night temperature in ‘a, d’, day temperature in ‘b, e’ and day/night temperature in ‘c, f’.

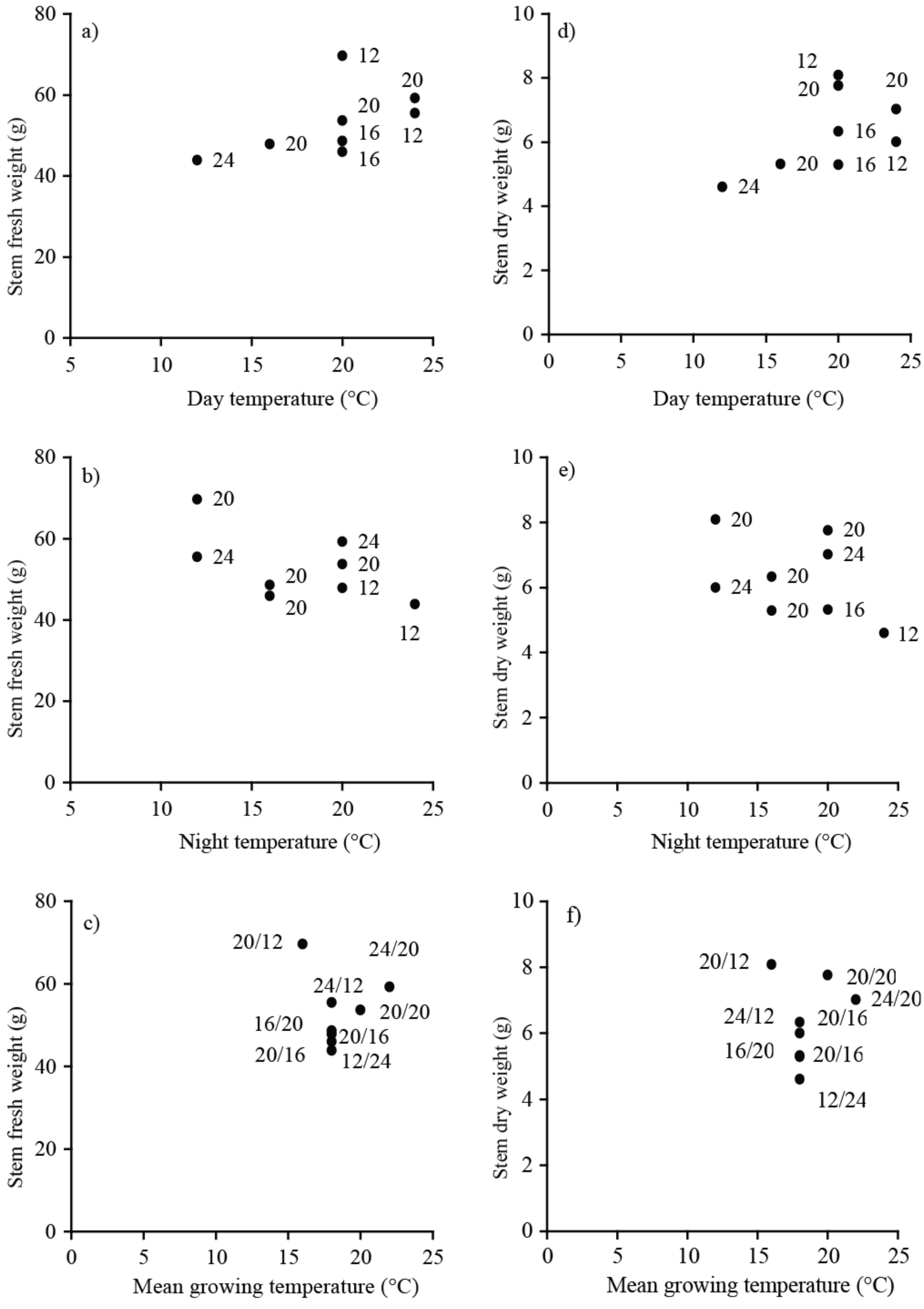

Fig. 4. Effect of day, night, and mean temperature (°C) on cauliflower stem fresh (a, b, c) and dry (d, e, f) weights (g) after curd initiation. Data point labels show night temperature in ‘a, d’, day temperature in ‘b, e’ and day/night temperature (°C) in ‘c, f’.

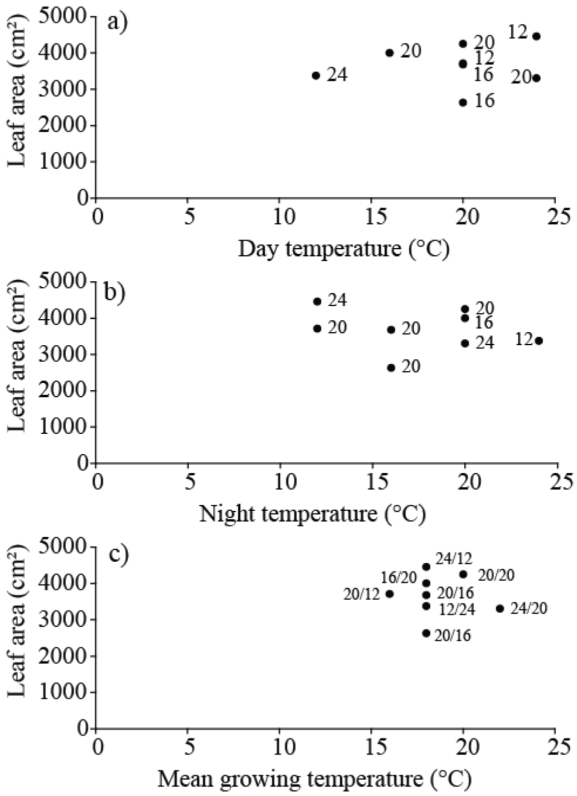

Fig. 5. Effect of day temperature (a), night temperature (b), and mean growing temperature (c) on cauliflower leaf area (cm²) after curd initiation. Data point labels show night temperature (°C) in 'a', day temperature (°C) in 'b' and day/night temperature (°C) in 'c'.

Discussion

This study suggests that warmer night temperatures combined cooler day temperatures enhanced curd growth rather than vegetative growth and *vice versa*. However, the variations in vegetative and curd growth could not be explained easily on the basis of mean temperature or separate day and night temperatures due to small range of mean temperatures (16-22°C) and the correlation between warmer day temperatures with cooler night temperatures and *vice versa*. Clearer relations between vegetative and curd growth may have been observed, if a wider range of day and night temperatures had been studied against a wide range of mean temperatures.

Variations in plant growth have been explained on the basis of DIF (difference between day and night temperatures) between the alternating day and night temperatures. Positive DIF has been associated with increase in vegetative growth, whereas, negative DIF have been reported to decrease vegetative growth (De Koning, 1988; Heuvelink, 1989, Agrawal *et al*., 1993; Grimstand & Frimanslund, 1993). However, Langton & Cockshull (1997 a) argued that "DIF is merely a different parameterisation of day and night temperature effects which makes it difficult to understand the real importance of the absolute day and night temperatures at which plants are grown".

Day and night temperatures can be manipulated to control plant height in ornamental plants. For many species, warmer day than night temperature promotes stem elongation more than constant or cooler day than night temperatures (Heuvelink, 1989; Erwin *et al.*, 1989; Moe, 1990; Al-Said, 2000). This was also found to be true in this study for cauliflower. The plants were taller when the day temperature was warmer than night temperature. This is in accordance with the results for other vegetable crops. For example, De Koning (1988) found an increase in stem length in glasshouse tomatoes with conditions with warmer day than night temperatures. Agrawal *et al.*, (1993) also reported an increase in cucumber plant height when the day temperature was warmer than night temperature. Similarly Al-Said (2000) found greater stem lengths in lettuce at warmer day than night temperatures. Cauliflower stem length showed no response to night and mean temperatures, whilst stem length increased with increasing day temperature. However, the effective mean temperature approach provided a simple way to explain the variations in stem length, which increased linearly with effective mean temperatures with optimum temperature estimated for both day and night temperatures.

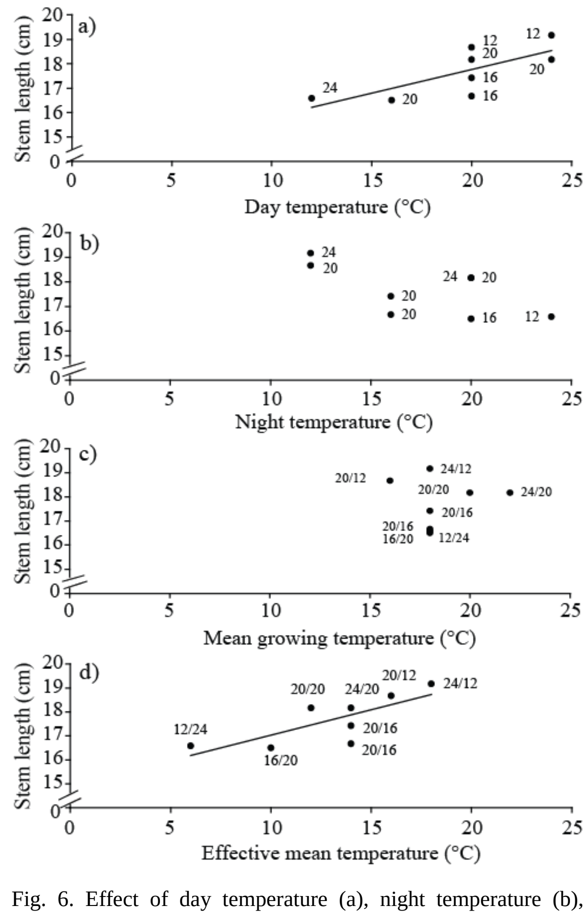

Fig. 6. Effect of day temperature (a), night temperature (b), mean growing temperature (c), and effective mean temperature (d) on cauliflower stem length (cm) after curd initiation. Data point labels show night temperature in 'a', day temperature in 'b' and day/night temperature in 'c, d'. The lines were fitted by linear regression, where;

Stem length (g) = 13.88(±1.38) + 0.19(±0.07) DT (r^2=0.56, 7d.f, P<0.05)

Stem length (g) = 14.91(±0.98) + 0.21(±0.07) MT_e (DT_o=24°C, NT_o=12°C, r^2=0.59, 7d.f, P<0.05).

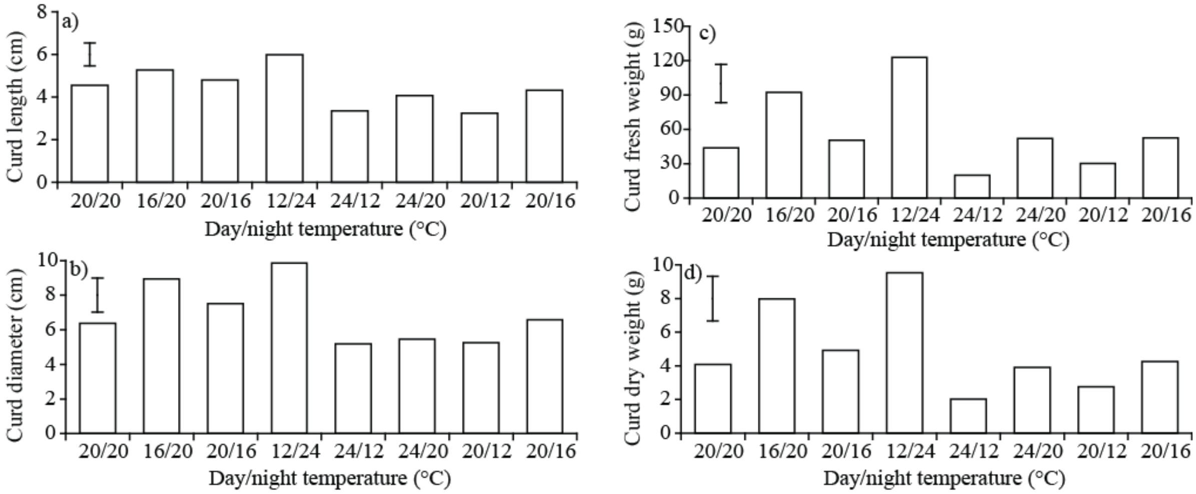

Fig. 7. Effect of different day and night temperature (°C) on curd length (a), curd diameter (b), curd fresh weight (c), and curd dry weight (d) after curd initiation. Error bars represent least significant difference at 5% probability.

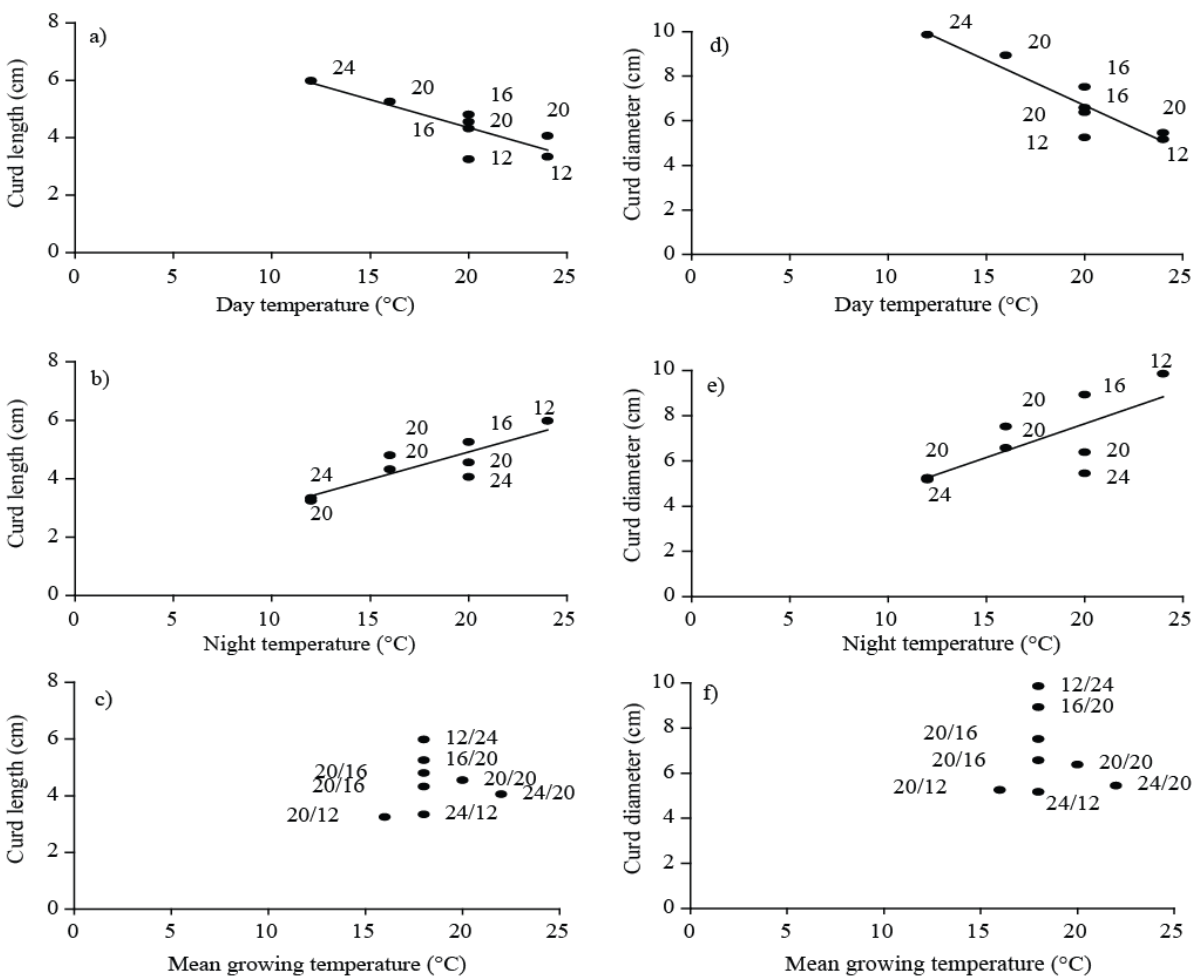

Fig. 8. Effect of day, night, and mean growing temperature on cauliflower curd length (a, b, c) and curd diameter (d, e, f) after curd initiation. Data point labels show night temperature in ‘a, d’, day temperature in ‘b, e’ and day/night temperature in ‘c, f’. The lines were fitted by linear regression, where:
Curd length (g) = 8.26(±1.03) - 0.196(±0.052) DT (r^2=0.7, 7d.f, $p<0.01$)
Curd length (g) = 1.16(±0.81) + 0.19(±0.05) NT (r^2=0.74, 7d.f, $p<0.01$)
Curd diameter (cm) = 14.78(±1.43) - 0.41(±0.07) DT (r^2=0.84, 7d.f, $p<0.01$)
Curd diameter (cm) = 1.68(±2.09) + 0.298(±0.116) NT (r^2=0.52, 7d.f, $p<0.05$)

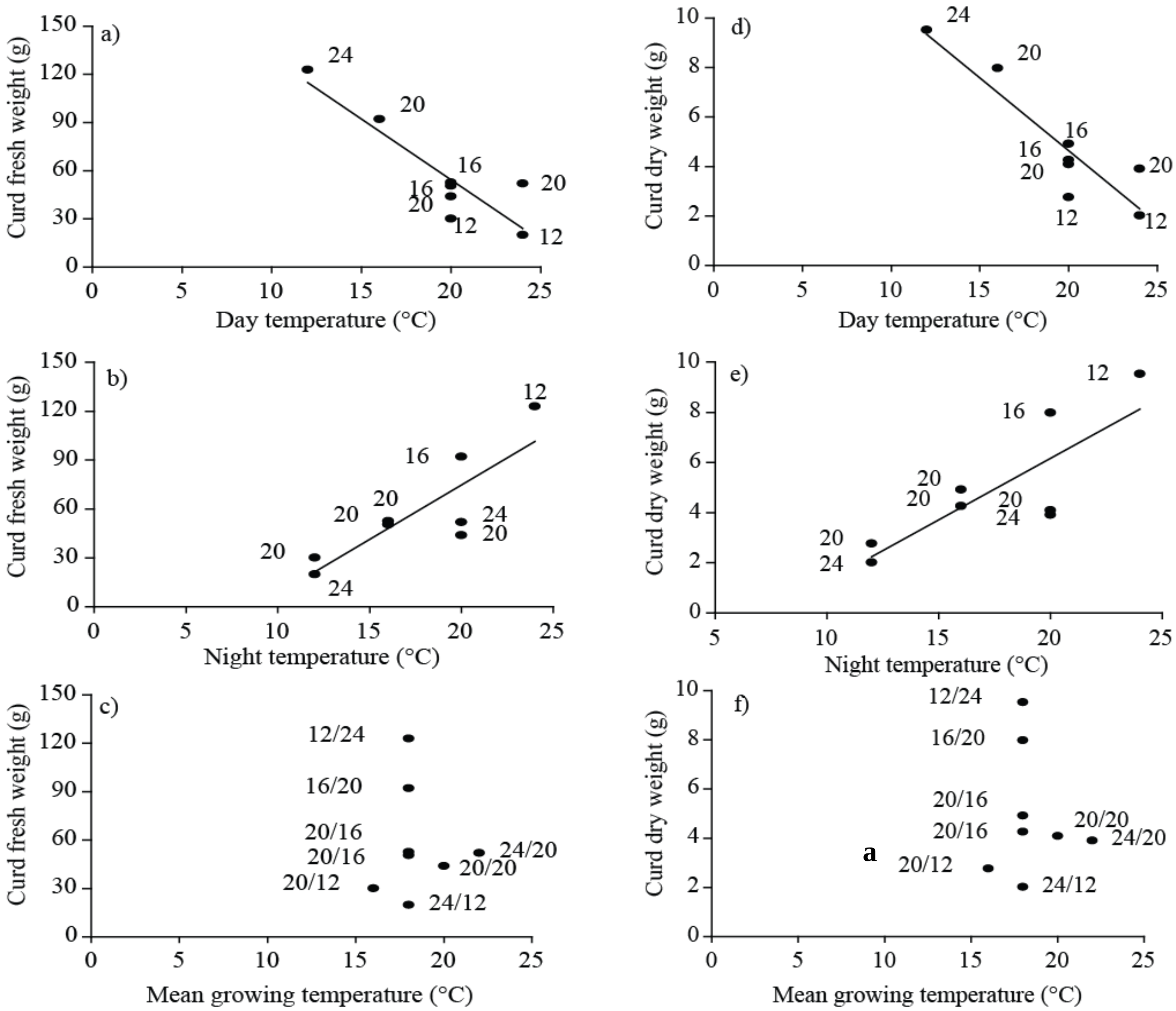

Fig. 9. Effect of day, night, and mean growing temperature on cauliflower curd fresh (a, b, c) and dry (d, e, f) weights (g) after curd initiation. Data point labels show night temperature in ‘a, d’, day temperature in ‘b, e’ and day/night temperature in ‘c, f’. The lines were fitted by linear regression, where:

Curd fresh weight (g) = 205.63(±31.17) - 7.57(±1.57) DT (r^2=0.8, 7d.f, p<0.01)

Curd fresh weight (g) = -58.53(±31.55) + 6.66(±1.76) NT (r^2=0.7, 7d.f, p<0.01)

Curd dry weight (g) = 16.41(±2.15) - 0.59(±0.11) DT (r^2=0.83, 7d.f, p<0.01)

Curd dry weight (g) = -3.65(±2.57) + 0.49(±0.14) NT (r^2=0.66, 7d.f, p<0.05)

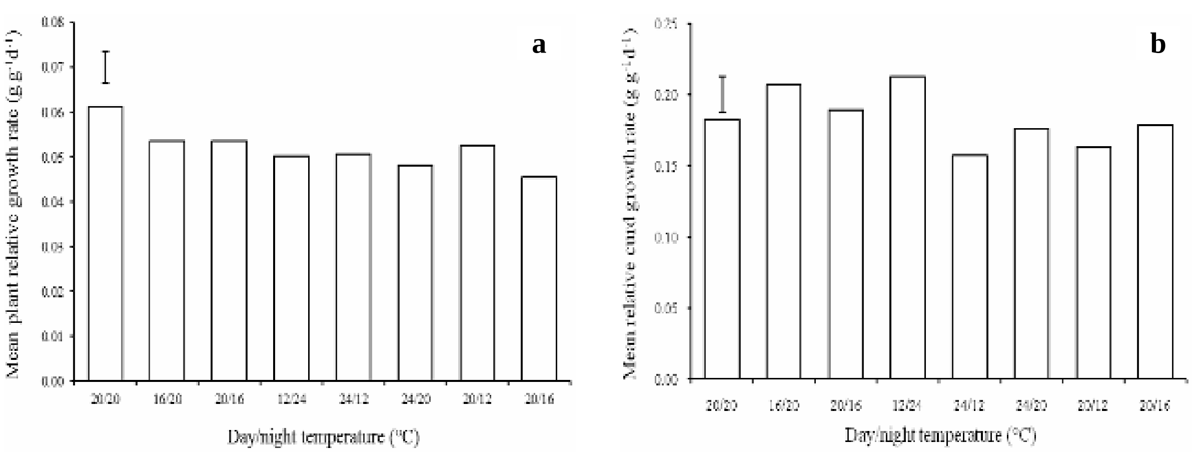

Fig. 10. Effect of different day and night temperature on (a) mean plant relative growth rate and (b) mean relative curd growth rate (g $g^{-1}d^{-1}$) after curd initiation. Error bars represent least significant difference at 5% probability.

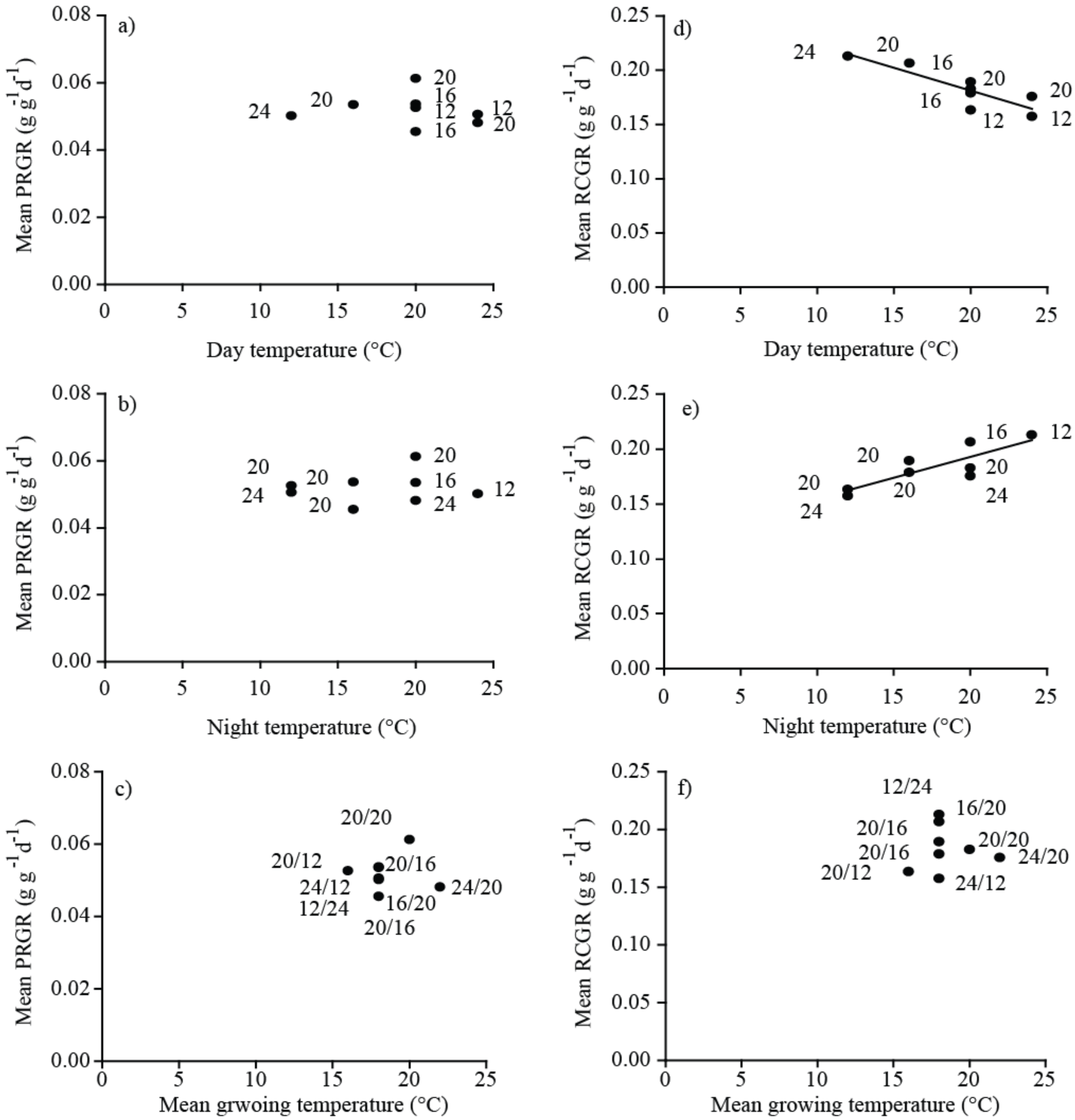

Fig. 11. Effect of day, night, and mean growing temperature on mean relative curd growth rate of cauliflower (a, b, c) after curd initiation. Data point labels show night temperature in 'a, d', day temperature in 'b, e' and day/night temperature in 'c, f'. The lines were fitted by linear regression, where:
Relative curd growth rate = 0.27(±0.02) - 0.004 (±0.001) DT (r^2=0.75, 7d.f, p<0.01)
Relative curd growth rate = 0.12 (±0.02) + 0.004(±0.001) NT (r^2=0.70, 7d.f, p<0.01)

Conclusion

In conclusion, greater cauliflower curd growth was achieved during cool days and warm nights, whereas, warm days and cool nights increased vegetative growth after curd initiation. However, further studies are needed to elucidate the difference between the curd growth rate during the day and night since differences in growth rates during the day and night have been reported for many other species. For example, tomato fruit (Holder, 1984; Ehret & Ho, 1986), cucumber (Tazuki & Sakiyama, 1984) and pea (Hole & Scott, 1984) all had greater growth rate during the day than at night. This knowledge could be useful in allowing growers to optimise cauliflower production to fulfill the day-to-day market demand.

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(Received for publication 30 June 2011)