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Environmental factors in curd initiation and curd growth of cauliflower in the field

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Abstract

In 1982, 1983 and 1984, seedlings of two cauliflower (*Brassica oleracea* L. var. *botrytis*) cultivars were transplanted at several dates during the summer. Physiological events like end of juvenility, curd initiation and maturity were recorded.

Date of curd initiation was correlated with mean temperature in the period after initiation of the 19th leaf. At higher temperatures, curd initiation was later. The number of leaves initiated before curd initiation was best correlated with mean maximum day temperature in the period between initiation of the 19th leaf and curd initiation. The variation in duration of curd growth was less than the variation of the period between transplanting and curd initiation. The duration of curd growth could just as well be explained by the date of curd initiation as by a temperature-time product or by the mean irradiance.

Introduction

The rate at which cauliflowers become ready for marketing can vary enormously during the summer and autumn (Booij, unpublished; Hartmann & Wuchner, 1965; Salter et al., 1972; Wiebe, 1980). This variation occurs in spite of regular transplanting schedules and causes problems in marketing and labour organization.

Variation in growing period (number of days between transplanting and harvest) in a continuous cauliflower schedule cause most of the variation in supply (Booij, unpublished).

Temperature plays an important role (Liptay, 1981; Wiebe, 1973) in disturbing the planning. Because the product to be harvested is an inflorescence, the transition from vegetative to generative stage is necessary. The time of transition depends on the physiological age of the plant and on the temperature at certain times (Fujime, 1983; Wiebe, 1972a,b; Wurr et al., 1981).

This paper describes the effects of environmental factors on this transition and its influence on harvest date. An attempt is made to measure these effects.

Materials and methods

The trials were carried out in 1982, 1983 and 1984 at the research station in Lelystad, on a fertile marine clay soil. The cauliflower cultivars 'Delira' (Rijk Zwaan, De Lier) and 'Elgon' (Royal Sluis, Enkhuizen) were studied by transplanting bare-rooted plants 5 to 6 weeks old at several dates (Table 1). During the period between three weeks after transplanting and a 100% curd initiation, a sample (12 plants) was taken twice a week for dissecting. The total number of leaves (including leaf primordia) and the developmental state of the apex (vegetative or generative) were determined.

When the first secondary primordia became visible, determined with a binocular microscope (magnification ×50), the apex was considered to have reached the generative state (curd initiation) (Fujime, 1983; Margara & David, 1978). The final number of leaves is the number of leaves initiated before curd initiation and was estimated as soon as all plants of a sample had initiated a curd. At harvest, plants were individually assessed for maturity three times a week and were cut as they matured.

Initiation date of the 19th leaf was the date on which the mean total number of leaves in a sample from a plot was 19. Curd initiation date of the population was defined as the date when half of the plants had initiated a curd, harvest date as the date when half of the plants had been harvested.

The weather data were obtained from an official meteorological station situated about 6 km from the research station.

The calculated correlations between weather components and plant development were restricted to linear regressions.

Temperature-time product for curd initiation and curd growth was calculated according the following method (Robertson, 1968). The contribution T_{eff} of every day (i) between two developmental stages to the temperature-time product (T_{sum}) depends on the day temperature (T_i) and a set base (T_b) and maximum (T_m) temperature under the following conditions.

If	: $T_i \leq T_b$	$T_b < T_i \leq T_m$	$T_i > T_m$, then:
T_{eff} for curd initiation	: $T_m - T_b$	$T_m - T_i$	0
T_{eff} for curd growth	: 0	$T_i - T_b$	$T_m - T_b$

$$T_{sum} = \sum_{i=1}^{n} T_{eff}$$

where i = 1 is the first day and n the last day of the considered period. The parameters T_b and T_m are unknown. Different values of T_b and T_m were chosen and with these values the T_{sum} was calculated for every transplanting. The aim was to find values of T_b and T_m that resulted in a minimum standard devation of T_{sum}, by judging the coefficient of variation (standard deviation relative to the mean value, Reinink et al., 1986).

Results

The period between transplanting and harvest can be divided into two parts: between transplanting and curd initiation, and between curd initiation and harvest. These two periods are dealt with separately.

Curd initiation

The number of days between transplanting and curd initiation varied between 25 and 46 days (Table 1). The period was not related to the transplanting date. Curd initiation date of 'Elgon' tends to be a few days later than 'Delira'. The final number of leaves varied considerably too (Table 1); for 'Elgon' the values were higher than for 'Delira'.

The time (days) between transplanting and curd initiation not significantly correlated to the mean temperature in that period (Table 2). The period between transplanting and curd initiation can be subdivided into two parts: between transplanting and the initiation of the 19th leaf, and between initiation of the 19th leaf and curd initiation. The length of the second period significantly correlated with mean temperature during the period considered and with mean temperature in the period three weeks after transplanting and curd initiation (Table 2). The positive correlation coefficients indicate a later curd initiation at higher mean temperatures. Both cultivars showed the same highly significant correlations. The mean temperature in the periods better correlated with the final number of leaves (Table 3). The highest correlation was again found if mean temperature in the period between initiation of the 19th leaf and curd initiation was taken as explanatory variable. The final number of leaves even better correlated with mean daily maximum temperature during this period (Table 4). Using either the daily mean temperature or the daily maximum temperature to explain the variation in length of this period did not make any difference.

The sum of the total daily radiation largely explained the variation in final number of leaves and the variation in time (Table 4).

In Fig. 1, the scatter diagram and the best-fitting regression lines are given for the most important relations. The slope of the regression line between final number and temperature is for 'Elgon' nearly twice as steep as for 'Delira' (Fig. 1A, B). For time (Fig. 1C, D), the slope for 'Elgon' was nearly three times as steep.

It would be interesting to look at the effect of varying the starting point (higher or lower number of leaves) for calculations. The mean number of leaves could not, however, be varied to start with, because data of all the transplantings were not available. However, if some days before or after the time the 19th leaf was initiated were included in the calculations, the correlation coefficients did not change very much. For 'Elgon' also correlation coefficients were calculated starting at the day the 25th leaf was initiated, but the correlation coefficients were then hardly significant.

Temperature-time products did not much reduce the variation in the time between initiation of the 19th leaf and curd initiation. It was not possible to find coefficients of variation lower than 0.25 by varying T_b and T_m.

Table 1. Effect of transplanting date on the length (number of days) of different periods and the final number of leaves. The results of the two cultivars are separately presented.

Date	'Delira'				Date	'Elgon'			
	time (days) between transplanting and		final number of leaves	time (days) between curd initiation and harvest		time (days) between transplanting and		final number of leaves	time (days) between curd initiation and harvest
	initiation 19th leaf	curd initiation				inititation 19th leaf	curd initiation		
1982-05-12	20	33	31.5	42	1981-06-15	23	46	45.9	47
1982-05-18	21	30	27.5	41	1982-06-22	20	38	43.5	49
1982-05-26	21	25	25.0	40	1982-06-29	–	35	40.9	49
1982-06-01	23	28	27.0	41	1982-07-06	–	38	44.6	52
1982-06-08	18	26	27.5	39	1982-07-13	–	36	41.2	53
1982-06-15	20	36	36.2	47					
1982-06-22	18	35	33.8	44					
1982-07-13	21	35	33.3	49					
1983-05-11	28	40	30.5	38	1982-05-20	23	38	40.1	44
1983-05-20	23	31	31.3	42	1983-06-14	21	40	44.8	43
1983-05-30	21	31	31.7	40	1983-06-21	24	43	45.5	47
1983-06-02	24	34	31.4	42	1983-06-28	17	35	44.9	47
1983-06-07	28	41	36.5	44	1983-07-05	20	36	40.4	48
1983-06-14	25	35	35.8	45	1983-07-14	19	31	39.5	53
1983-06-21	24	38	37.6	42					
1983-07-14	22	29	31.5	49					
1984-05-08	28	41	27.9	44	1984-06-19	–	30	31.2	41
1984-05-15	25	32	27.5	45	1984-06-26	25	33	31.8	45
1984-05-23	25	36	27.4	40	1984-07-03	19	28	34.1	49
1984-05-29	28	32	24.8	45	1984-07-10	25	40	39.8	55
1984-06-05	27	33	23.4	40					
1984-06-12	28	41	25.8	37					
1984-06-19	23	32	27.3	39					
1984-07-10	28	38	33.3	52					

Table 2. Correlation coefficients between the length of several periods (days) and the mean temperature in the periods considered. The coefficients are separately presented for the two cultivars.

Time (days) between:	Mean temperature in the period between:			
	transplanting and initiation of 19th leaf	transplanting and curd inititation	21 days after transplanting and curd inititation	initiation of 19th leaf and curd initiation
'Delira'				
Transplanting and initiation of 19th leaf	−0.363*	−0.371*	−0.211	−0.189
Transplanting and curd initiation	−0.185	−0.047	0.288	0.319
Initiation of 19th leaf and curd initiation	0.099	0.281	0.567**	0.584**
'Elgon'				
Transplanting and initiation of 19th leaf	−0.475	−0.508	−0.355	−0.310
Transplanting and curd initiation	−0.071	0.250	0.479	0.574*
Initiation of 19th leaf and curd initiation	0.201	0.516	0.775**	0.850**

Significant correlation coefficient: $^{*}P < 0.05$; $^{**}P < 0.01$.

Table 3. Correlation coefficients between final number of leaves of the cultivars and the mean temperatures in several periods.

Cultivar	Mean temperature in the period between		
	transplanting and initiation of 19th leaf	transplanting and curd initiation	initiation of 19th leaf and curd inititation
'Delira'	0.505**	0.686**	0.874**
'Elgon'	0.360	0.724**	0.879**

Significant correlation coefficients: $^{**}P < 0.01$.

Table 4. Correlation coefficients for several weather components in the period between initiation of the 19th leaf and curd initiation. (a) the final number of leaves; (b) time (days) between initiation of the 19th leaf and curd initiation; (c) curd growth with the same weather components during curd growth.

	Mean day temperature	Maximum day temperature	Minimum day temperature	Mean daily radiation	Sum of daily total radiation	Sum of rainfall
(a) Final number of leaves						
'Delira'	0.874**	0.906**	0.650**	0.459*	0.738**	−0.196
'Elgon'	0.879**	0.904**	0.756**	0.408	0.890**	0.420
(b) Time (days)						
'Delira'	0.584**	0.574**	0.480**	0.213	0.919**	0.243
'Elgon'	0.850**	0.850**	0.766**	0.416	0.953**	0.396
(c) Curd growth						
'Delira'	−0.645**	−0.583**	−0.662**	−0.815**	−0.484**	0.766**
'Elgon'	−0.836**	−0.856**	−0.828**	−0.928**	−0.782**	0.618**
'Delira' + 'Elgon'	−0.722**	−0.664**	−0.750**	−0.896**	−0.659**	0.714**

Significant correlation coefficient: $^{*}P < 0.05$; $^{**}P < 0.01$.

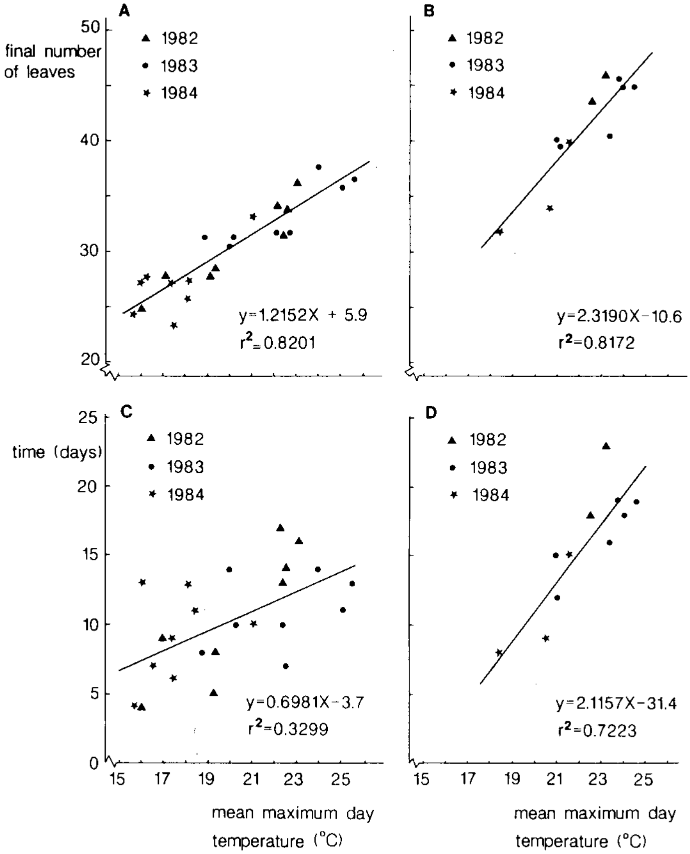

Fig. 1. Relationship between the mean maximum day temperature in the period between initiation of the 19th leaf and curd initiation and the final number of leaves (A, B) or the length of the period (C, D) for 'Delira' (A, C) and 'Elgon' (B, D).

Curd growth

Curd growth lasted 37 to 55 days (Table 1). Its duration seems to be fairly constant for 'Delira' (Table 1); only at the last transplanting date was the growing period a few days longer. The growing period of 'Elgon' tends to be longer at later transplanting dates (Table 1).

The duration was fairly constant when the curd was initiated before Day* 205 (24 July), but when the curd was initiated at later dates, there was a significant positive correlation between duration of curd growth and curd initiation date (Fig. 2). The first part consists mainly of 'Delira' data and the last mainly of 'Elgon' data. The differences between the two cultivars are, however, small. The duration of curd growth significantly correlated with all the weather components studied (Table 4).

* Ordinal date: 1 January is Day 1.

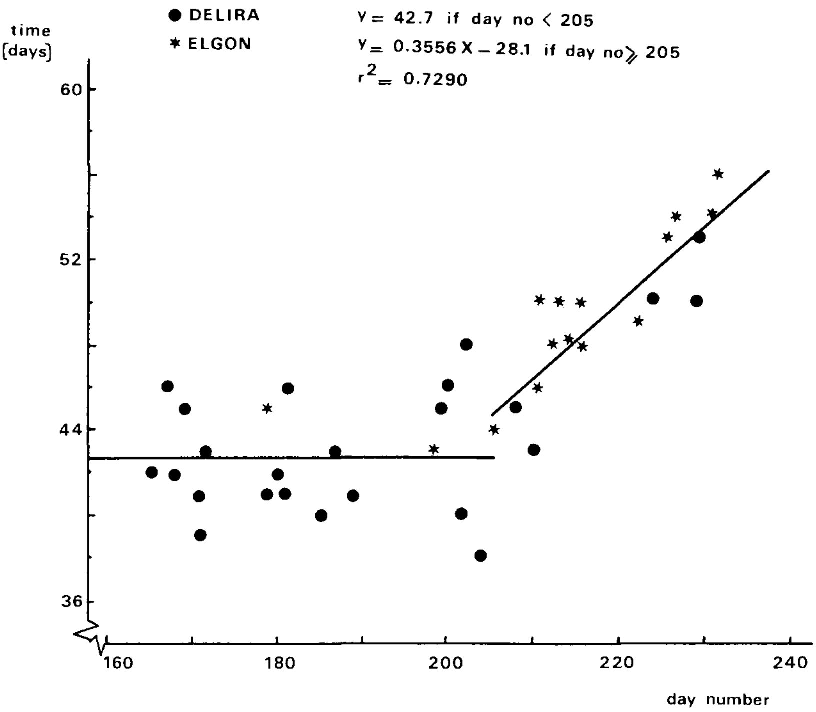

Fig. 2. Relationship between the day number (ordinal date: 1 January is Day 1) of curd initiation and the duration of curd growth of 'Delira' and 'Elgon'.

The highest correlation coefficient was found between duration of curd growth and mean irradiance during curd growth. The duration of curd growth decreased with increasing mean irradiance (Fig. 3). With higher irradiance there is still considerable variation around the regression line.

Another approach is to calculate the temperature-time product to explain the variability. The lowest coefficient of variation (0.062) was found on two occasions, namely with a T_b of 0 °C and a T_m of 19 °C and with a T_b of 5 °C and a T_m of 16 °C. In the latter case, the mean temprature-time product had a value of 445 °C·d.

In fact, there are now three variables to explain the variation in duration of curd growth, namely curd initiation date, mean irradiance, and the temperature-time product. To compare these three methods, the residual standard errors are compared. For the relation with curd initiation date (Fig. 2), the residual standard error was 2.29 days; for mean irradiance (Fig. 3), the error was 2.07 days. For the temperature-time product, the coefficient of variation was 0.062 and the mean T_{sum} 445 °C·d, i.e. a standard deviation of 27.6 °C·d. Translation of this value into a certain number of days depends on the day temperature. At a constant temperature of 16 °C, it corresponds to a standard error of 2.63 days. Lower temperatures result in higher values; higher temperatures give the same value.

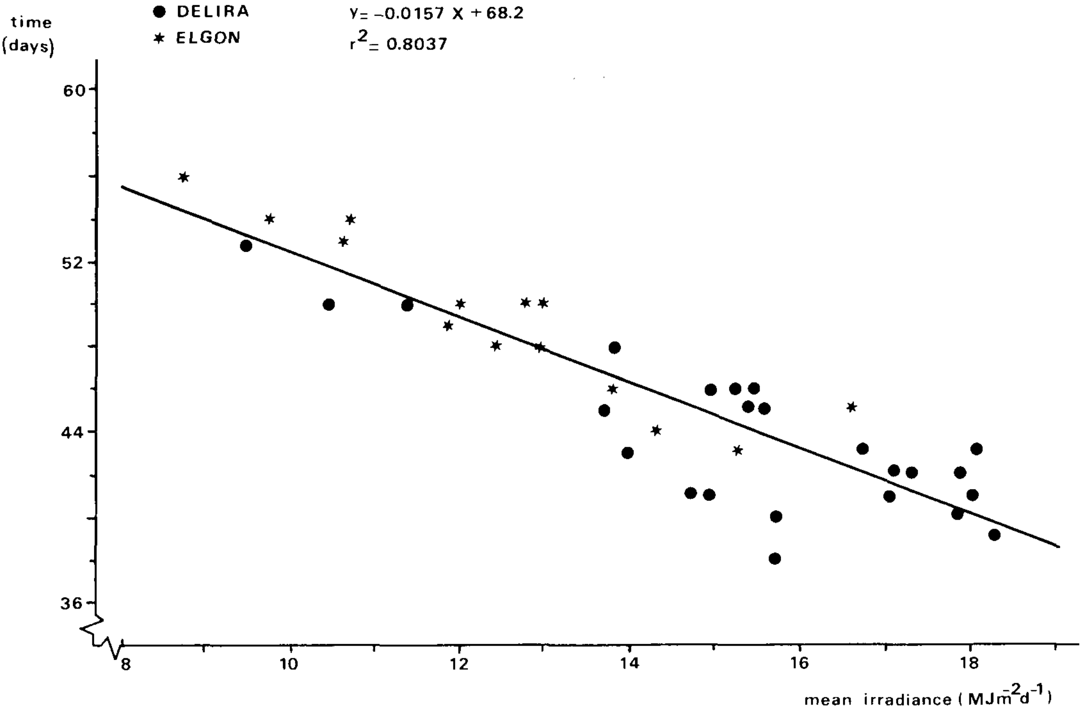

Fig. 3. Relationship between mean irradiance in the period between curd initiation and harvest and its duration (days) for 'Delira' and 'Elgon'.

The differences between the three methods are small, although mean irradiance gave the least residual standard error.

Discussion

During growth of a cauliflower crop in the field, two major transitions occur: the end of juvenility and curd initiation. Three developmental stages can therefore be recognized after transplanting: the juvenile phase, the curd induction phase, and the curd growth phase (Wurr et al., 1981). The date (i.e. number of days after transplanting or sowing) at which the phase transitions take place has consequences for the harvest date.

The correlations of temperature with curd initiation (Tables 2 and 3) show that the effect of temperature depends on the developmental stage of the plant. This clearly suggests the existence of a juvenile phase. Experiments under controlled conditions showed that the plant should reach a certain physiological age before the curd could be initiated by lower temperatures (Fontes et al., 1967; Fujime, 1983; Sadik, 1967; Wibe, 1972a), although Fujime & Hirose (1979) were able to enhance curd induction by cold treatment of germinating seeds. The physiological age at which the plant reaches the end of the juvenile phase can best be characterized by the number of leaves that have been initiated (Wiebe, 1972a). In our trials the best correlation was when the end of the juvenile phase was set at 19 initiated leaves. None of the variables studied satisfactorily explained the date at which the 19th leaf was initiated. Although leaf initiation rate depends on temperature (Wiebe, 1972c), in our experiments the time at which growth restarts after transplanting plays a role.

Temperature in the period after the end of the juvenile phase influenced the time of curd initiation; high temperatures delayed curd initiation, as has been found in trials under controlled conditions (Fujime, 1983; Wiebe, 1972b). Final number of leaves better correlated with mean temperature in this period. Atherton et al. (in prep.) too found less variable responses to temperature with the final number of leaves than with the time to curd visibility. This implies that the effect of a day at a certain temperature on curd initiation depends also on the leaf initiation rate during the curd induction period, and this is why temperature-time products were not satisfactory. So final number of leaves does not only give information about the time of curd initiation, but also about the temperature conditions during the curd induction period, although often a higher final number of leaves is accompanied by a delay in curd initiation.

The relation between the mean temperature and the final number of leaves depends on cultivar (Fig. 1), as is also found in the literature (Fujime, 1983). The difference in slope indicates that 'Elgon' is more sensitive to temperature than 'Delira'. A temperature increase of, for instance, 1 °C results in a larger increase in final number of leaves for 'Elgon'. Temperature sensitivity is related to earliness: later cultivars are more sensitive to higher temperatures and have higher final number of leaves (Fujime, 1983).

With a wider range of temperatures then under Dutch conditions (11-19 °C), the relation between temperature and final number of leaves is not linear (Atherton et al., in prep.; Wiebe, 1972c). However, when linear regressions are calculated with the data within the range 11-19 °C, the slopes of their regression lines are of the same magnitude.

The good correlation with mean temperature during the different periods suggests that variation in temperature is not so important. Wiebe (1974) and Fujime (1983) have shown that diurnal variation in temperature gave the same results as a constant temperature with the same mean. Also when days with different temperatures were alternated, the results were similar (Wiebe, 1974).

In the correlation between day of curd initiation and duration of curd growth, two phases could be recognized with a rather distinct transition (Fig. 2). This correlation between date of curd initiation and duration of the curd growth indicates that the effects of variable weather factor like temperature and radiation are of less importance. Several authors have found relations between temperature and rate of curd growth (Salter, 1960; Salter, 1969; Wiebe, 1973).

It is necessary to distinguish between the effect of temperature on the increase in curd size and on maturity date. From the data presented by Wurr & Fellows (1984), duration of curd growth can be calculated. The duration of curd growth was fairly constant and independent of mean curd weight at harvest (in spite of buttoning).

The effect of temperatures between 15 and 25 °C on harvest date are small, even if the effect on curd weight at harvest is big (Fujime, 1983); lower temperatures increase the duration of curd growth. The temperatures during our trials were within this range and this may explain the fairly constant duration of curd growth.

The relation between duration of curd growth and radiation (Fig. 3) was mainly determined by the transplantings, which had initiated the curd at a later date (Fig. 2). Daylength decreases very rapidly after the beginning of August and total daily radiation is closely correlated with daylength. So the relation between duration of curd growth and radiation might be an effect of daylength determining maturity of the curd (elongation of the inflorescence).

A temperature-time product could not explain the variation in duration of growth any better. Although Salter (1969) found a good relation between temperature-time product and curd weight during curd growth, temperature-time product did not determine harvest date. The T_b and the T_m that we found were quite close to the values that Salter (1969) found (2.8 °C and 15.6 °C).

The good relation between duration of curd growth and curd initiation date has promising consequences: harvest date can be predicted fairly accurately 6 to 8 weeks in advance, according to the given relation.

To get a better harvest planning of cauliflower, the length of the period between transplanting and harvest date should be regulated. The only way to do so is by regulating the time of curd initiation, because if the curd is initiated at the proper time, harvest will be close to the desired date. To regulate time of curd initiation, it is necessary to regulate the length of the juvenile phase and of the curd induction period. So, especially if curd initiation is delayed by high temperatures, artificial induction is required. If the end of the juvenile phase is determined by a certain number of leaves, regulating of the length of the juvenile phase will have consequences for number of leaves and could have implications for problems like buttoning (Wurr & Fellows, 1984).

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