

EFFECT OF TEMPERATURE ON THE GROWTH OF BROCCOLI (*BRASSICA OLERACEA* L. VAR. *ITALICA* PLENCK) cv. FIESTA

Alina KALUŻEWICZ, Włodzimierz KRZESIŃSKI, Mikołaj KNAFLEWSKI,
Jolanta LISIECKA, Tomasz SPIŻEWSKI, Barbara FRĄSZCZAK

Department of Vegetable Crops,
Poznań University of Life Sciences
Dąbrowskiego 159, 60-594 Poznań, Poland

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Summary

Three-year studies on the influence of temperature on vegetative growth and growth of broccoli heads (*Brassica oleracea* var. *italica* cv. Fiesta) were carried out at the Experimental Station "Marcelin" of Poznań University of Life Sciences in Poland. The relationship between temperature sum day-degree, number and area of leaves as well as head diameter was estimated. Likewise relationship between number and area of leaves and head diameter was established. The correlations were described using linear, curvilinear and segment linear regression. The relationship between temperature sum day-degree and number of leaves was linear, whereas the correlation between temperature and area of leaves and head diameter was curves function. On the basis of segment linear regression it was found that in the period when slow growth of heads was observed (the size of up to about 1.5 cm), the area of leaves increased the fastest. It occurred between the 24th and 27th day after planting. The fastest growth of broccoli heads was noted, when the plant had about 18 leaves and area 4900 cm². In the period of rapid head growth, the increase of sum temperature of 100 day-degree resulted in head diameter increase by 3.5 cm.

key words: broccoli, vegetative growth, head diameter, day-degree

INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica* Plenck) belongs to *Brassicaceae* family. Like all vegetables from the family, it is derived from a wild cabbage species growing on the northern coast of the Mediter-

anean Sea and in Western Europe, from Greece to the British Isles (Smyth 1995). This vegetable is known as a rich source of health-promoting phytochemicals (Moreno *et al.* 2006, Singh *et al.* 2007).

Weather conditions have a major effect on broccoli yielding (Tan *et al.*

1999). According to (Kałużewicz *et al.* 2010), growth and development as well as yield of broccoli are strictly determined by temperature. Grevsen and Olesen (1999) reported linear relationship between leaf appearance and mean daily temperature. Data presented by Tan *et al.* (2000) showed linear relationship both between mean temperature and sum day-degree and total number of leaves. The correlation between the temperature and broccoli increase in area of leaves was described by Olesen and Grevsen (1997).

Passing from vegetative to generative phase is determined by temperature (Miller *et al.* 1985; Mourao & Hadley 1998) and not by photoperiod (Tan *et al.* 2000). Some authors report that temperature 15-16°C is the most suitable for broccoli head initiation (Wheeler *et al.* 1995; Fellows *et al.* 1997), and above 21-22°C initiation does not occur (Gauss & Taylor 1969). According to Björkman and Pearson (1998), Heather *et al.* (1992) high temperatures in the early phase of head growth lead to occurrence of quality defects like uneven surface or uneven buds. Some authors have attempted to find a correlation between temperature and length of time to initiation or harvest of broccoli heads (Grevsen & Olesen 1999). According to Fujime and Okuda (1994), there is a highly significant correlation between maximum temperature and the number of days to initiation of broccoli head, and between temperature and the minimum number of days to harvest. Grevsen and Olesen (1999) characterized the effect of temperature on the length of developmental phases of broccoli plants using sum day-degree.

Many authors have tried to describe broccoli and cauliflower growth using mathematical models taking into account interaction of many factors (Kage & Stützel 1999; Olesen & Grevsen 2000; Tan *et al.* 2000).

The aim of this study was to determine the effect of only one factor, namely temperature, both on vegetative growth (number and area of leaves) and growth of broccoli head. The relationship between vegetative growth and head growth was also established.

MATERIALS AND METHODS

The experiment was carried out in 1997-1999 at "Marcelin" Experimental Station of Poznań University of Life Sciences. The studies comprised one cultivar of broccoli - Fiesta. Transplants were planted out in the field in four terms (April, May, June, July). The trial was established in randomised block design with four replications. In the each plot one hundred transplants were planted at the stage of four leaves at a spacing of 0.5×0.5 m.

The experiment was established on podzolic soil, the arable layer of which was loamy sand underlying sandy loam. The soil was tested before planting and 100 kg·ha⁻¹ of P₂O₅, 200-250 kg·ha⁻¹ of K₂O and 60 kg·ha⁻¹ of nitrogen were applied before planting. Additionally, nitrogen (150 kg·ha⁻¹) was applied in three doses in the growing season. Plants were watered when the soil water potential had exceeded -0.04 MPa using reel irrigation machine.

Every 3-4 days, the number of leaves (leaves with length of over 2 cm) for five plants from everyplot was

estimated. Measurements started from the first week after planting. For the same plants head diameter was measured once a week. Leaves area was measured every 3-4 days on the two plants chosen randomly from each experimental plot. Measurements were done using weight method. For this purpose leaf discs of 4 cm diameter (10 discs from each young plant and 75 from older one) were punched out from an attached leaf using a corkborer and immediately weighed. The leaf area was calculated using the following formula: Leaf area=(area of all discs $\times$ total weight of leaf) / total weight of discs.

Temperature sum was calculated from the base temperature, i.e. 0°C. It is in accordance with the assumptions of Marshall and Thompson (1987), Wurr (1990) and also Grevsen and Olesen (1994).

The three-year average of measured parameters were calculated taking into account the temperature sum day-degree. The temperature sum day-degree was divided for 100 day-degree periods. For each period average number of leaves, their area, and head diameter from all data obtained

during three-year measurements were calculated. In order to find the correlation between temperature sum day-degree and a three-year average number of leaves, their area, head diameter, as well as the correlation between vegetative growth and head growth, a segment regression with quasi-Newton method was used. Regression equation and correlation coefficient were calculated for each segment of the curve, as well as for all segments together. Statistical analysis was done using a Statistica 9.0 (Stat-Soft, Inc. 2000) statistic programme. Major statistical values are presented in Table 1. Those values describe number of measurements used for regression analyses. The wide range of data, big standard deviation and standard error as well as big variance proved that the data used for analyses is representative for the period from planting day to harvest.

Meteorological data was obtained from Meteorological Station located 2 kilometers from the Experimental Station. Mean daily air temperature and sunshine hours during the experiment were compared with the multiannual data 1984-2003 (Table 2).

Table 1. Major statistical values for three broccoli parameters

Statistical value	Number of leaves (item)	Area of leaves (cm ²)	Head diameter (cm)
Mean	13.2	2789.8	5.7
Standard error	0.46	203.2	0.41
Median	11.7	1437	4.50
Standard deviation	6.51	2845	4.72
Variance	42.4	8093804.6	22.3
Range	22.2	9907.7	16.6
Minimum	4.5	10.0	0.3
Maximum	26.7	9917.7	16.9
Counter	201.0	196.0	131.0
Confidence level (95.0%)	0.91	400.8	0.82

Table 2. Mean air temperature and sum of sunshine hours in the duration of experiment and deviation from multiannual data 1984-2003

Year	Month	Temperature (°C)		Sunshine hours	
		1997-1999	deviation	1997-1999	deviation
1997	April	5.5	-3.1	194.3	+13.0
	May	13.1	-0.8	222.4	-30.7
	June	16.9	+0.6	263.4	+37.7
	July	17.9	-0.2	237.2	-12.5
	August	19.6	+1.5	313.4	+78.5
	September	12.9	-0.3	185.5	+49.3
	October	6.8	-1.9	101.9	-10.3
1998	April	10.3	+1.7	175.7	-5.6
	May	14.9	+1.0	301.0	+48.0
	June	17.5	+1.2	253.9	+28.2
	July	17.6	-0.6	231.4	-18.3
	August	16.6	-1.6	211.2	-23.7
	September	13.5	+0.3	136.8	+0.6
	October	7.9	-0.7	72.1	-40.1
1999	April	9.2	-3.3	159.5	+37.9
	May	13.5	+0.6	314.3	+195.1
	June	16.3	+3.0	170.9	+54.1
	July	20.2	+6.5	309.2	+194.9
	August	17.9	+3.8	237.4	+125.5
	September	17.0	+2.5	214.2	+104.8
	October	8.5	-6.5	97.2	-9.8

RESULTS AND DISCUSSION

The effect of planting term on the analyzed final characteristic of broccoli plants.

The mean final number of leaves (Table 3) and broccoli head diameter (Table 5) depended on the planting term. Broccoli plants had the smallest

number of leaves and the smallest head diameter when plants were planted in July. The highest head diameter was obtained in June planted broccoli. The mean final area of leaves did not differ in different planting terms, although there were some differences in 1998-1999 (Table 4).

Table 3. The effect of planting term on the final number of leaves (item)

Planting term	Year			Mean
	1997	1998	1999	
April	23.1 ab*	19.4 b*	20.1 b*	20.9 ab*
May	22.3 bc	24.7 a	21.0 b	22.7 a
June	24.2 a	23.4 a	25.6 a	24.4 a
July	21.0 c	7.4 c	25.4 a	17.9 b

*Means in a column followed by the same letters are not significantly different at $\alpha=0.05$ according to the Student test

Table 4. The effect of planting term on the final area of leaves (cm²)

Planting term	Year			Mean
	1997	1998	1999	
April	5559 a*	5896 b*	4481 c*	5312 a*
May	5487 a	6822 ab	9271 a	7194 a
June	6680 a	7979 a	6285 b	6981 a
July	6215 a	437 c	8223 a	4958 a

Note: see Table 3

Table 5. The effect of planting term on the final broccoli head diameter (cm)

Planting term	Year			Mean
	1997	1998	1999	
April	10.5 b*	14.0 b*	12.9 ab*	12.4 b*
May	11.7 ab	12.6 b	14.4 a	12.9 b
June	12.8 a	16.8 a	12.5 b	14.0 a
July	10.3 b	13.1 b	9.9 c	11.1 c

Note: see Table 3

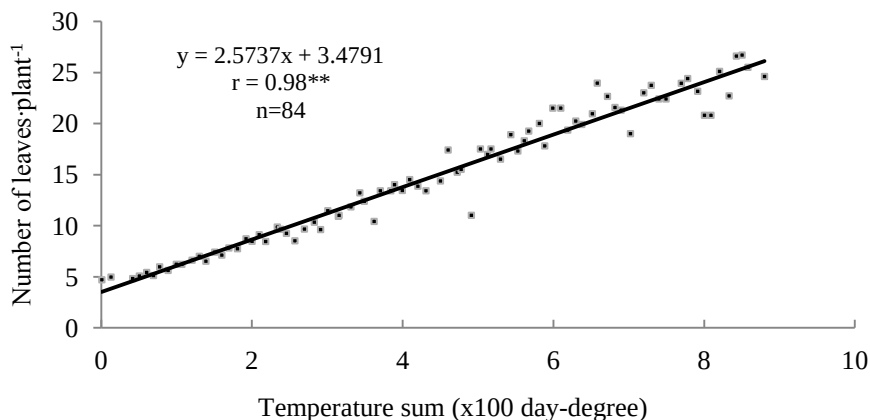
Influence of temperature on vegetative growth of broccoli.

In our study the relationship between temperature sum day-degree and number of leaves was linear from planting day to harvest. The correlation coefficient was very high $r=0.98$ (Fig. 1). The same dependence was found by Grevsen and Olesen (1999). These authors reported that leaf appearance in relation to mean daily temperature was linear with $r=0.62$. Their observations were made from the time when plants had 3-4 visible

leaves until appearance of 12 visible leaves. Tan *et al.* (2000) found a linear relationship both between mean temperature and sum day-degree and total number of leaves. They carried out observations in the period from plant emergence to head initiation. The same relationship was found for Chinese cabbage (Kalisz & Kostrzewa 2012). Hadley and Pearson (1998) found that the leaf production rate increases approximately linearly with an optimum in excess of 20°C and falls to zero at approximately 6°C.

Booij and Struik (1990) reported that cauliflower cv. Delira grown at 22°C

had much higher leaf appearance rate than at 14°C.



** – correlation coefficients (r) significant at $P = 0.01$

Fig. 1. Relationship between temperature sum day-degree and number of leaves of broccoli cv. Fiesta planted four times in three subsequent years

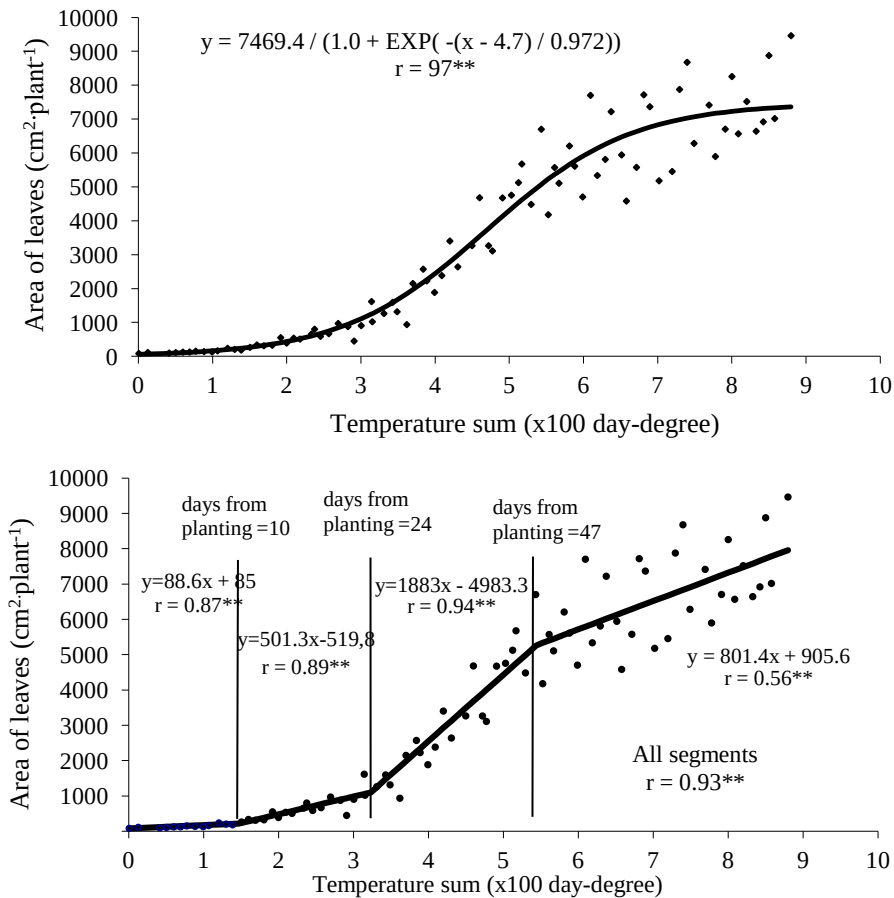
The relationship between the temperature and broccoli increase in area of leaves was described by Olesen and Grevsen (1997). These authors reported that the relative leaf area expansion rate was a linear function of mean daily leaf surface temperature with a base temperature of 0.7°C. They also observed lower expansion rates in the temperature above 21°C. Linear responses of leaf expansion rate to temperature were also found for sugar beet (Milford *et al.* 1985). In the study conducted by Rahman *et al.* (2007) the relationship between leaf area of cauliflower and mean growing temperature was curvilinear. Leaf area increased with increase in mean growing temperature from 8.8 to 20.6°C and declined thereafter with further increase in temperature up to 27.5°C in the first season of growing. In the second

season, leaf area increased with increase in mean growing temperature from 9.9 to 13°C and declined with further increase in mean growing temperature to 24.5°C.

Our study have shown the opposite results (Fig. 2a & 2b). The relationship of temperature sum day-degree and leaf area expansion rate was a linear curve. The segment curve determined in the presented study enabled to differentiate four stages of leaf expansion rate. It was found out that the slowest leaf expansion rate (only 88.6 cm² per 100 day-degree) occurred before the tenth day after planting, when 147 temperature sum day-degree was reached. It was a period when the plants started to grow again after planting. For the next two weeks 100 temperature sum day-degree increase resulted in leaf expan-

sion of 500 cm². At this stage the expansion of leaves area was probably affected by the root growth. The fastest increase of leaf area was observed between 24th and 27th days after planting, which corresponded to temperature from 323 to 545 sum day-degree. At this stage leaf expansion rate was 1883 cm² per 100 day-degree and the

increase in diameter of broccoli head was started. At the last stage the expansion leaf area decrease to 801 cm² per 100 day-degree because of intensive broccoli head growth. The breakpoints of the curve were correlated with breakpoints for broccoli head diameter (Fig. 3b).



** – correlation coefficients (r) significant at $P = 0.01$

Fig. 2a, 2b. Relationship between temperature sum day-degree and area of leaves of broccoli cv. Fiesta planted four times in three subsequent years

Influence of temperature on broccoli head growth.

Rahman *et al.* (2007) found that in cauliflower relationship between head diameter and temperature was curvilinear. Head diameter increased with increase in mean growing temperature up to 20.6°C in first season and to 21.5°C in second season, and declined thereafter.

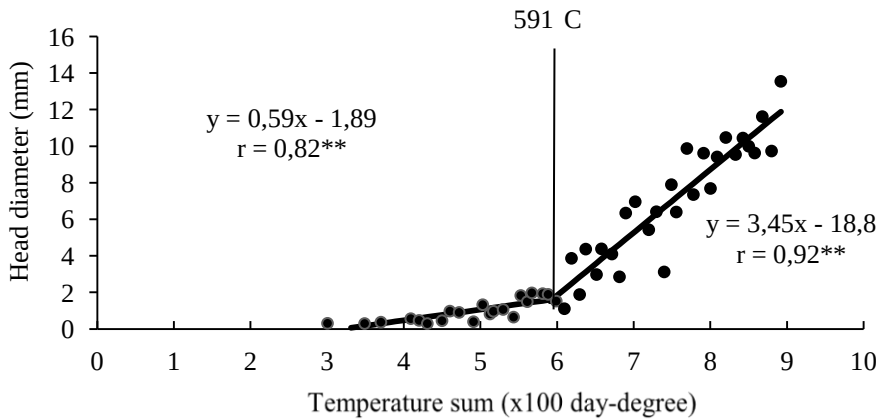
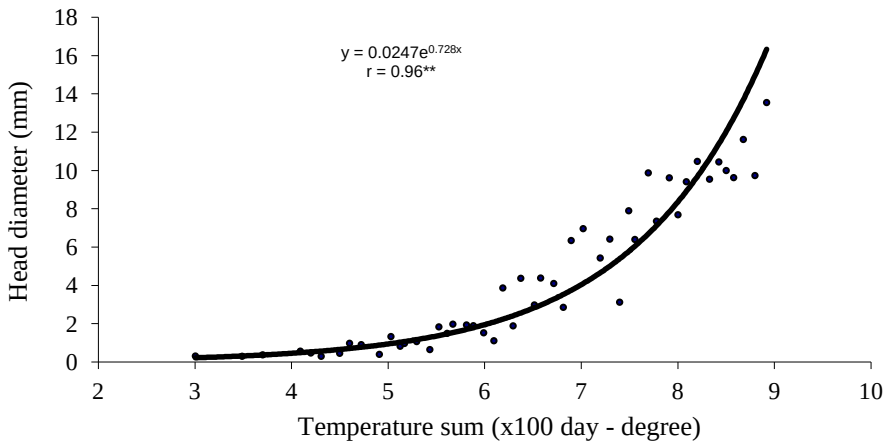
Pearson and Hadley (1988) found that the relationship between temperature sum day-degree and logarithm of broccoli head diameter was linear. It was contradictory to results of our study and the study of Wurr *et al.* (1991).

In our study increase of head diameter was characterised by exponential curve (Fig. 3a & 3b). For heads sized up to 1.5 cm (plants had 18 leaves - Fig. 4) increase of head diameter was slow. In this period temperature sum increase by 100 sum day-degree led to increase of head diameter by 0.6 cm. It was also a period of very rapid leaf area expansion (Fig. 2a & 2b). When the head diameter exceeded 1.5 cm, its diameter started to increase very fast. The correlation coefficient between head diameter and temperature sum in this period was very high ($r=0.92$). Temperature sum increase by 100 day-degree resulted in head diameter increase by 3.5 cm.

Heads reached the maximum size at 900 temperature sum day-degree. The correlation between the rate of head growth and its size was also confirmed by Wurr *et al.* (1990) in cauliflower.

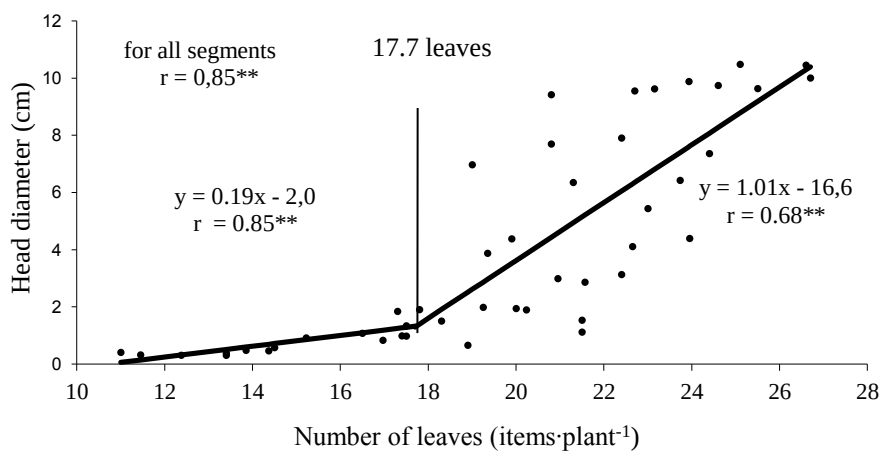
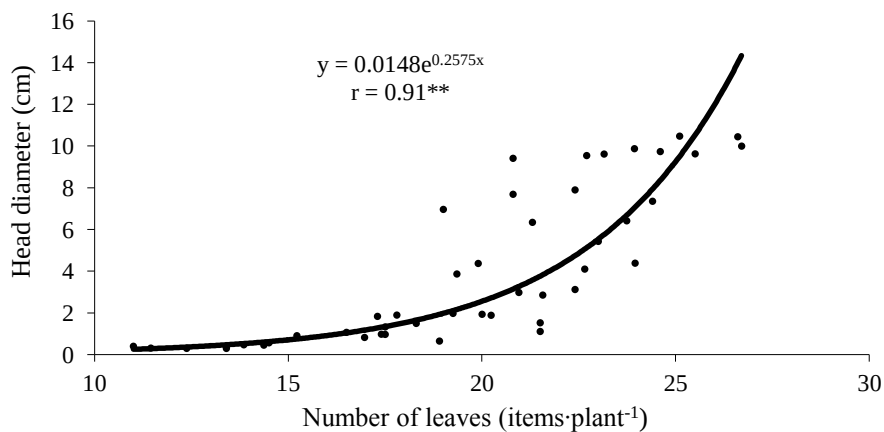
Correlation between vegetative growth and head growth.

Head diameter increase depended on both number and area of leaves (Fig. 4a, 4b & 5a, 5b). In both cases the correlation was represented by second-degree curve. After determining segment curve and calculating regression equations and correlations coefficients, a higher correlation between number of leaves and head diameter was observed for the first segment of the curve, i.e. until the phase of about 18 leaves. In this period increase of leaves number by 1 corresponded to head diameter increase by 0.2 cm, whereas in later phase of plant growth it resulted in increase by 1 cm. The correlation between area of leaves and head diameter represented by segment curve was also very significant for both segments of the curve. Up to the phase when leaf area was 4900 cm², increase of leaf area by 100 cm² resulted in increase of head diameter by 0.07 cm, and then by 0.14 cm.



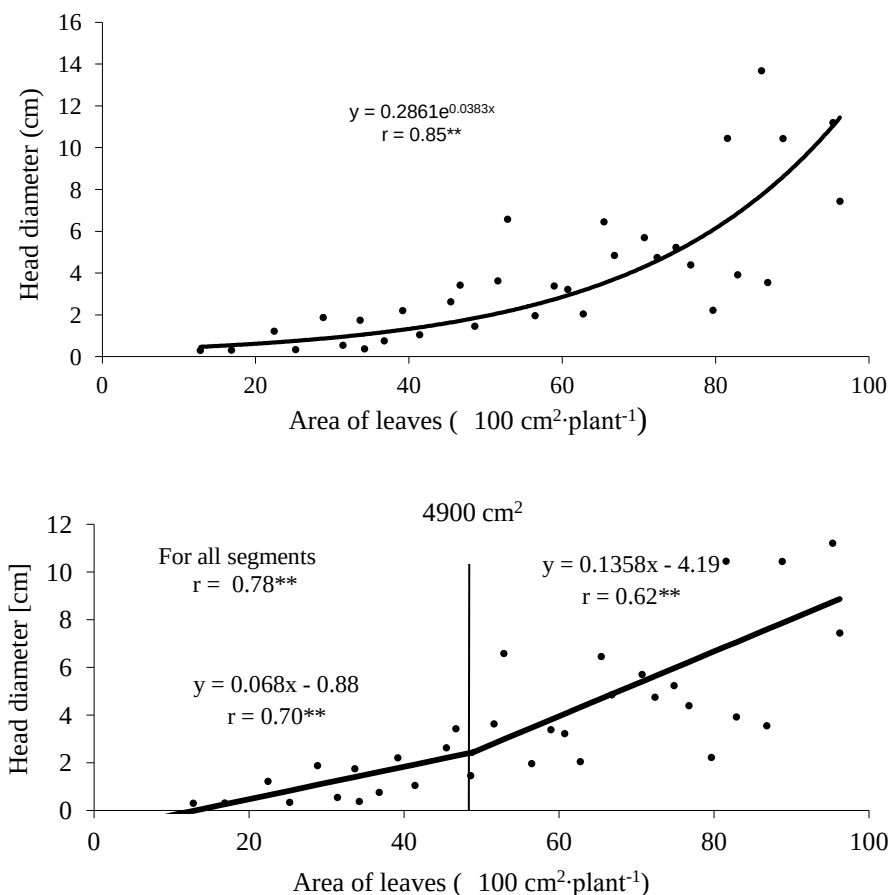
** – correlation coefficients (r) significant at $P = 0.01$

Fig. 3a, 3b. Relationship between temperature sum day-degree and head diameter of broccoli cv. Fiesta planted four times in three subsequent years



** – correlation coefficients (r) significant at $P = 0.01$

Fig. 4a, 4b. Relationship between number of leaves and head diameter of broccoli cv. Fiesta planted four times in three subsequent years



****** – correlation coefficients (r) significant at $P = 0.01$

Fig. 5a, 5b. Relationship between area of leaves and head diameter of broccoli cv. Fiesta planted four times in three subsequent years

CONCLUSIONS

1. The correlation between temperature sum day-degree and number of leaves was linear, while the relationship between temperature sum day-degree and area of leaves and head diameter was a linear curve.
2. The rate of head diameter increase during the whole period of growth depended on both number and area of leaves.
3. In the period of very rapid growth of leaf area, the broccoli head growth was the slowest. The fastest increase in head diameter was noted, when the plant had about 18 leaves with an area 4900 cm².

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WPLYW TEMPERATURY NA WZROST BROKUŁA (*BRASSICA OLERACEA* L. VAR. *ITALICA* PLENCK)

Streszczenie

Doświadczenie, którego celem było określenie wpływu temperatury na wzrost brokuła, przeprowadzono w Katedrze Warzywnictwa Uniwersytetu Przyrodniczego w Poznaniu w latach 1997-1999. Określono zależność między sumą temperatury a liczbą i powierzchnią liści oraz średnicą róży. Scharakteryzowano również zależność między liczbą i powierzchnią liści, a średnicą róży. Na podstawie regresji segmentowej stwierdzono, że w okresie wolnego wzrostu róży, następował najszybszy przyrost powierzchni liści, tj. między 24 a 27 dniem po posadzeniu. Najszybszy przyrost średnicy róży stwierdzono, gdy rośliny miały około 18 liści o powierzchni 4900 cm². W okresie szybkiego przyrostu średnicy róży, przyrost sumy temperatury o każde 100 stopniocentów powodował przyrost średnicy róży o 3,5 cm.