# DETERMINATION OF THE CRITICAL DAY LENGTH OF AMARANTHS *(Amaranthus sp.)*

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***Abstract***

*This study discusses the research of photoperiodic reaction A. hypochondriacus L. variety No. 1008, A. cruentus L. variety No. 17 and A. hypochondriacus x A. hybridus variety Koniz.*
*The field experiments manifested critical day length longer than l6 hours. Also the photoperiodic experiment with special equipment showed that all three varieties of amaranth classified in literature as short-day plants are not strictly, in reality, short-day plants. However, the compulsary short-day plants are very tolerant to the length of the day. The observed species and varieties behaved under the conditions of mild climate (50°n.lat.) as plants responsive slightly to shorter days as plants facultatively photoperiodically sensitive which burst into bloom and produce seeds also during the summer period with longer days. Such as this it is possible to explain the successful* cultivation of grain amaranths in the Czech Republic.

**Key words:** *Amaranthus hypochondriacus, Amaranthus cruentus, Amaranthus hypochondriacus x Amaranthus hybridus*, photoperiodic reaction, critical day length, facultatively short-day plants.

## INTRODUCTION

Amaranth is an old cultural plant of American continent which ancient Incas, Aztecs and Mayas cultivated 5-8 thousand years ago. Amaranth was the third most widespread plant in Central America before the discovery of America following corn and beans (MICHALOVÁ, 2000).

Among old cultures of the Andes research recently concentrated on a group of amaranths (*Amaranthus* sp.) an old pseudocereal of an original Indian population in Central and South America. In comparison with cereals, the seed of amaranths had considerably better nutritional properties.

In the Czech Republic the firm Bohemia Amarant s.r.o. under special operating conditions solved the questions of agricultural technology of amaranth. Consequently, also production went into effect and the seed was sold. Biological properties and demands of various species of amaranths, concerning their technology, methods of storage and their use were discovered (JAROŠOVÁ, l997).

The study of literature concerning amaranth had revealed that in spite of the basic information about photoperiodism of amaranth it will be useful to research this property in the various species and varieties of amaranth under the conditions in the Czech Republic.

## MATERIALS AND METHODS

I received the seed from the firm Bohemia Amarant in Olomouc in Moravia. The seeds of *Amaranthus hypochondriacus* variety No. 1008, *Amaranthus cruentus* variety No. l7 and a hybrid *(Amaranthus hypochondriacus x Amaranthus hybridus)* variety Koniz were first sowed in l998. The seeds in the second sowing in l999 were harvested during the previous year from the material of our own experiment from the third sowing which was carried out on May 7th l998, i.e. during usual sowing of the seeds of amaranth in Olomouc. The same seed was used in the field and with experimental equipment.

The methodics of the experiment in an experimental area was based on the hypothesis of determination of the critical length of the day of prof. KOPETZ (l958) (PETR, l959, l962).

**Increased sowings**

The experiment with increased sowing was based in plots where each plot had area 2.52 $m^2$. The interval between increased sowing was l0 days. The seed of particular varieties was sown by hand in spots in rows with intervals of 35 cm from each other and the interval between rows was 40 cm such way that produced approximately 30 plants in an experimental area of l $m^2$. During the vegetation period the growth phases of amaranth were monitored according to the macrophenological scale for the evaluation of amaranth published in study Jarošová et al. (l997). The harvest happened in both years after the beginning of the first fall frosts at the end of October up to the beginning of November. The harvested material was dried in room temperature. After drying the length of plant organs were measured and the plants above the ground were measured and their parts were determined.

**Photoperiodic experiment**

Photoperiodic experiment took place in an experimental area of The Department of Plant Science in The Faculty of Agronomy in The Czech Agricultural University adapted by prof. Petr. After the densier sowing in boxes placed in a plastic greenhouse of The Institute of Subtropical Agriculture the seedlings at that time when they had the first true leaves were transplanted to prepared dishes with an average 23 cm and height 23 cm of ten plants in each dish Time after time dead plants were renewed by the same plants. The dishes with plants were placed on carts that were moved on rails between the free area with normal lighting and normal day length and dark area in a vegetation house where night period was assured.

On each cart there were nine dishes, three dishes for each variety. For each cultivated variety there were prepared 27 dishes on 9 carts together with 810 plants, i.e. 270 plants from each variety. By moving the carts into the dark vegetation house the monitored plants on the eight carts were moved artificially from a normal to a short day.

During the vegetation period the beginning of macrophenological phases according to the increase of macrophenological scale was monitored. After the transplanting all monitored plants grew in all dishes and carts only three days under normal conditions i.e. fourteen to sixteen hours a day during the summer time. Under the first monitored term, that is after three days, the first cart with nine dishes was placed outside the house for eight hours and then was moved inside. Under the second term the first and the second carts were under an eight hour period while the other carts were under a normal day. Under every other term another cart was added. The interval of the eight observed terms was seven days. The plants on the ninth cart which was monitored grew uninterruptedly under conditions of a normal day.

## RESULTS

### The progress of gradual sowings from the time of germination to blossoming

Particular sowings had different number of days from germination to blossoming. That we observed at all monitored varieties in both years. More frequent sowings needed the highest number of days from sowing to blossoming whereas with plants sown later the time to blossoming was shorter. On average after two years observation the difference among early and later sown plants of variety No. 1008 was l8 days; in variety No. 17 l6 days; and in variety Koniz 20 days. The shortening of the time from sowings to blossoming at later sowings is possible to explain by the reaction of amaranths classified as short-day plants to the conditions actually shorter days in the period between July 27th and September 7th l998 (15 hours 20 min. up to l3 hours) than in the period between April l7th and June 19th l998 ( l3 hours 40 min. up to l6 hours 20 min.). In l999 the reaction at *A. hypochondriacus* variety No.1008 and *A. hybridus* variety Koniz was similar.

**Tab.1. :** The influence of gradual sowings on the number of days from germination to blossoming at *A. hypochondriacus* variety No. 1008 (1998,1999)

| Sowings | Sowing | | Germination | | Blossoming | | Number of days from germination to blossoming | |
|---|---|---|---|---|---|---|---|---|
| | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 |
| 1. sowing | 17.4. | 23.4. | 26.4. | 2.5. | 19.6. | 25.6. | 54 | 54 |
| 2. sowing | 27.4. | 3.5. | 4.5. | 10.5. | 24.6. | 3.7. | 51 | 54 |
| 3. sowing | 7.5. | 14.5. | 12.5. | 22.5. | 30.6. | 17.7. | 49 | 56 |
| 4. sowing | 18.5. | 24.5. | 27.5. | 28.5. | 5.7. | 25.7. | 39 | 58 |
| 5. sowing | 28.5. | 3.6. | 1.6. | 8.6. | 10.7. | 5.8. | 39 | 58 |
| 6. sowing | 9.6. | 14.6. | 15.6. | 21.6. | 20.7. | 12.8. | 35 | 52 |
| 7. sowing | 19.6. | 24.6. | 23.6. | 28.6. | 27.7. | 18.8. | 34 | 51 |
| 8. sowing | 26.6. | 7.7. | 29.6. | 11.7. | 8.8. | 25.8. | 40 | 45 |
| 9. sowing | 7.7. | 15.7. | 12.7. | 20.7. | 14.8. | 2.9. | 33 | 44 |
| 10. sowing | 17.7. | 26.7. | 21.7. | 30.7. | 22.8. | 9.9. | 32 | 41 |
| 11. sowing | 27.7. | 5.8. | 1.8. | 10.8. | 7.9. | 14.9. | 37 | 35 |

**Tab.2. :** The influence of gradual sowings on the number of days from germination to blossoming at ***A. cruentus*** variety No. l7 (l998, l999)

| Sowings | Sowing | | Germination | | Blossoming | | Number of days from germination to blossoming | |
|---|---|---|---|---|---|---|---|---|
| | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 |
| 1. sowing | 17.4. | 23.4. | 28.4. | 2.5. | 19.6. | 29.6. | 52 | 58 |
| 2. sowing | 27.4. | 3.5. | 5.5. | 10.5. | 24.6. | 30.6. | 54 | 51 |
| 3. sowing | 7.5. | 14.5. | 11.5. | 22.5. | 5.7. | 8.7. | 56 | 47 |
| 4. sowing | 18.5. | 24.5. | 27.5. | 28.5. | 8.7. | 15.7. | 42 | 48 |
| 5. sowing | 28.5. | 3.6. | 1.6. | 8.6. | 13.7. | 27.7. | 42 | 49 |

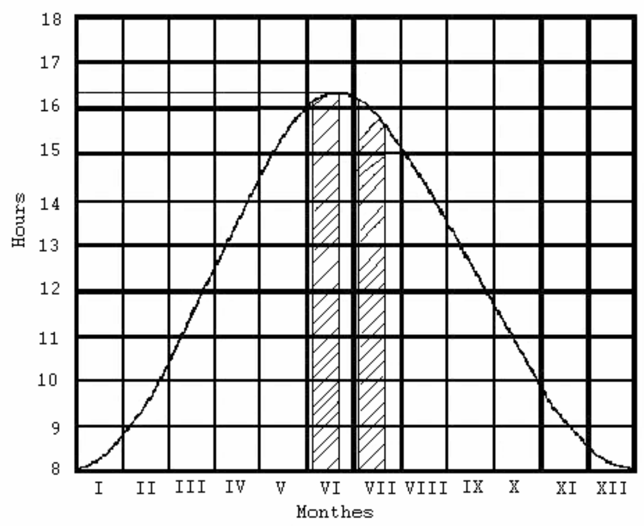
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6. sowing | 9.6. | 14.6. | 15.6. | 21.6. | 17.7. | 6.8. | 32 | 46 |
| 7. sowing | 19.6. | 24.6. | 23.6. | 28.6. | 25.7. | 14.8. | 32 | 47 |
| 8. sowing | 26.6. | 7.7. | 29.6. | 11.7. | 5.8. | 21.8. | 37 | 41 |
| 9. sowing | 7.7. | 15.7. | 12.7. | 20.7. | 17.8. | 30.8. | 36 | 41 |
| 10. sowing | 17.7. | 26.7. | 21.7. | 30.7. | 25.8. | 13.9. | 35 | 45 |
| 11. sowing | 27.7. | 5.8. | 1.8. | 10.8. | 3.9. | 24.9. | 33 | 45 |

*A. cruentus* variety No. l7 reacted in l998 the same. However, in l999, a slight difference when the plants from the last sowing grew between August 5th and September 24th l999 (l4 hours 45 min. up to l2 hours) and between April 23rd and June 29th l999 (14 hours l5 min. up to l6 hours l5 min.).

**Determination of a critical day**

In the experiment with gradual sowings we tried to determine the critical day according to the method of prof. Kopetz. His hypothesis concludes that from the findings of the time of the transition from the period when the development and the growth is photoperiodically slowed down to the period when plants are not slowed down. The above-mentioned author monitors gradual sowings the period from germination to blossoming (at cereals earing) and the limit of the critical day places before the term of such sowing when plants develop the fastest i.e. the shortest time from germination to blossoming, at cereals to earing (PETR, l962).
In order to verify the use of this method we use the results of our experiments with gradual sowings of amaranths in l998 and l999 which are stated in tables 1 and 2. These data in the tables enable the drawing of graph 1 for the study of both years.
The results of our experiment stated in table 1 show that in l998 *A. hypochondriacus* variety No.1008 had the shortest time from germination to blossoming at germination on June 15th. The period of the critical day is approximately from June 1st to June l5th. In l999, it is possible to determine the critical day from June 8th to June 21st. If we calculate from the readings of two years average then the period of the critical day for *A. hypochondriacus* variety No.1008 lies between June 5th and June l8th.
In determining of adequate day length for this period in the graphical drawing of the course of day length in the place of experiments (l4°24´longitude east, 50°08´latitude north) was the day length of l6 hours l6 min. - l6 hours 20 min. The critical period at this time there are the longest days in our country. Also, at *A .hybridus* variety Koniz and *A. cruentus* variety No.l7 in two years ´average the critical day length is longer then l6 hours. This could mean that all three varieties of amaranths characterized in literature as short-day plants are not in reality strictly short-day plants however they are to the length of the day significantly tolerant.

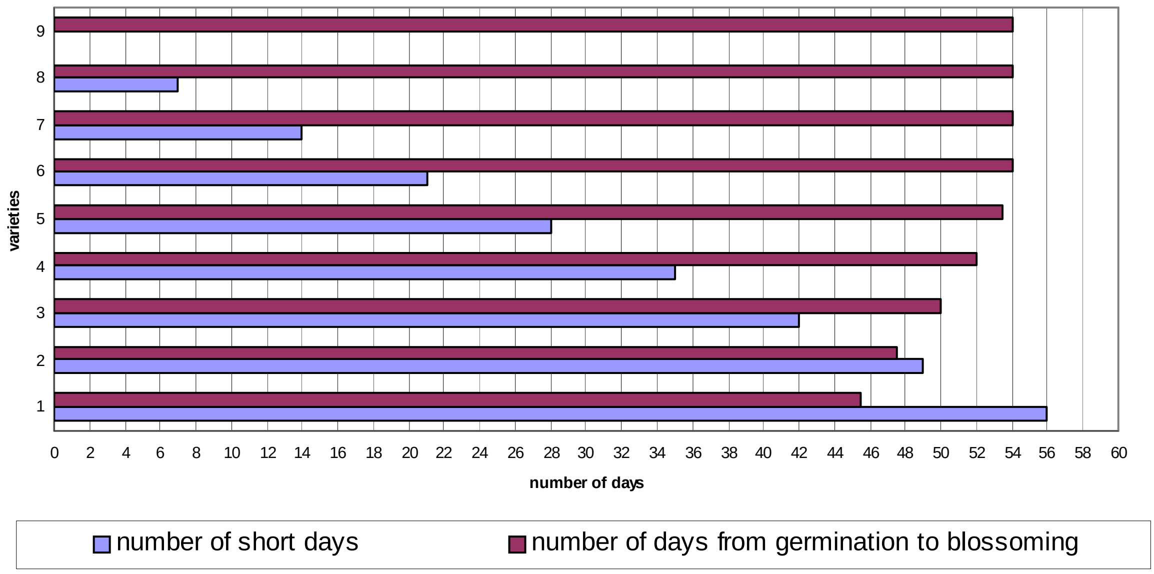
**Graph 1:** The course of natural day during a year in the place of experiment with marked out period of the critical day length at *Amaranthus hypochondriacus* variety No.l008 (the average of observations in l998 and l999)



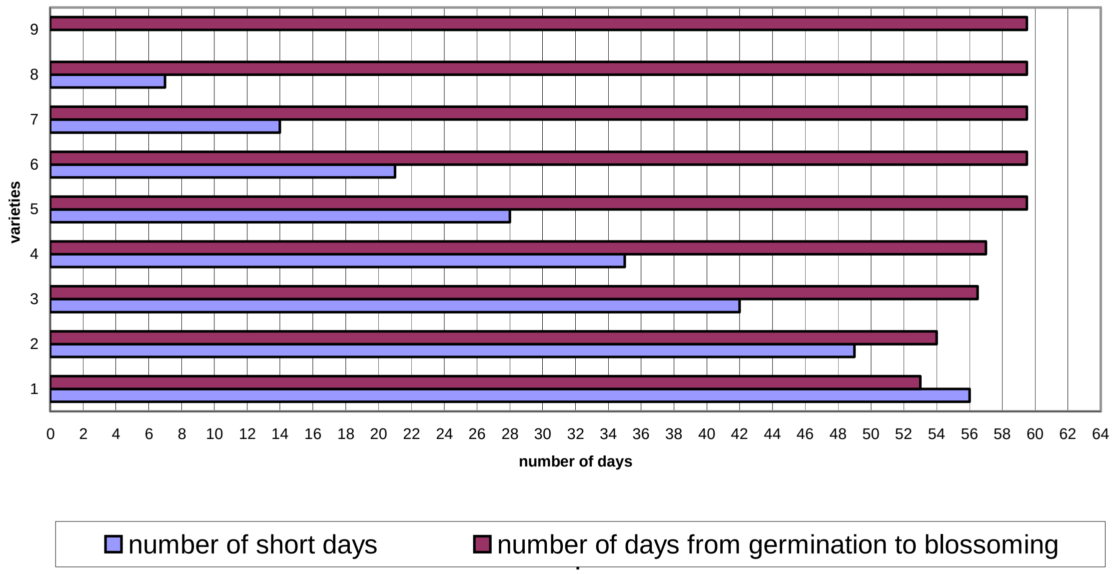
The influence of the transfer of plants to eight hours´ short day to the number of days necessary to blossoming at photoperiodic experiment

The experiment showed that at the decrease of the number of short days there increased the number of days necessary for the beginning of blossoming. This became evident in both years of the observation at all three monitored varieties of amaranths. Even though the length of this period from germination to blossoming varied at the monitored varieties (at two years´ average *A. hypochondriacus* variety No. l008 and *A. hypochondriacus* x *A. hybridus* variety Koniz 54 days, at *A. cruentus* variety No. l7 59.5 days) it happened in all three cases that there was a significant change at the number of short days less than 35. Further decrease in the number of short days did not have any substantial influence on the progress of blossoming. At this change (35 short days) it is possible to state that the accuracy for the determination of photoperiodic reaction is ± 7 days. It was at all three monitored varieties the fourth variant of the experiment which is possible to characterize so that these plants germinated around May l8th which were blossoming around July 11th. In our country, i.e. the Czech Republic, at this time there is approximately sixteen hours a day. As an example of this dependence there can be graphs 2 and 3 which relate *to A. hypochondriacus* variety No. 1008 and *A. cruentus* variety No.l7.

**Graph 2: The relationship between the number of short days and the number of days from germination to blossoming during a photoperiodic experiment at** *A. hypochondricus* **variety No. l008 (average l998 and l999)**




**Graph 3 - The relationship between the number of short days and the number of days from germination to blossoming during a photoperiodic experiment at** *A. cruentus* **variety No. l7 (average l998 and l999)**



The conducted photoperiodic experiment showed that the monitored species and varieties reacted as plants slightly responding to the shortening of the day, i.e. as plants facultatively photoperiodically sensitive. These plants at desirable photoperiod speed up the transition to blossoming however they bloom also without this photoperiod.

## DISCUSSION

In frequent studies about photoperiodicity of plants there was earlier payed attention also to various species of amaranths. Fuller (l949) observed photoperiodic reaction at *A. caudatus* and found out that this species is a short-day plant species. It blossomed under an eight hour day period and did not start to blossom during uninterrupted illumination and also in spring during twelve up to fourteen hours´ days. According to Chaudhri (l956) *A. caudatus* had the highest tendency to blossom in winter and early spring and the lowest during summer. Sawhney et al. (l978) enlarged the research upon *A. tricolor* varieta tristis, all their plants were short-day plants with the critical period l5-l6 hours and the minimal number 3-6 eight hours´photoperiodic cycles necessary for the appearance of the first blossoms. Bermejo (l994) came to the conclusion that although *A. caudatus* prefers short days it shows agreeable adaptability in various environments and can blossom also at twelve hours up to sixteen hours a day. According to Angus et al. (l982) there responded in Gatton in eastern Australia (approximately 36°latitude south) *A. mantegazzianus* considered now as the form *A. caudatus* (Sauer, l967) before blossoming as a short-day plant with the critical period around 14 hours. After blossoming it is not sensitive to the photoperiod. At temperature around 20°C and the photoperiod around 12 hours the vegetation period was less than 67 days.

The subject of our interest were the species of amaranth which up to now were little known and they are *A. hypochondriacus*, *A. cruentus* and *A. hypochondriacus* x *A. hybridus*. According to National Research Council (l984) *A. hypochondriacus* did not blossom in summer in Pennsylvania (approximately 40°latitude north). Nevertheless, it blossomed in greenhouses during short days in winter. It reacted like this as an obligatory photoperiodically sensitive short-day plant. This apparently contradicts the experience of Bohemia Amarant s.r.o. (Jarošová et al., l997). In the surroundings of Olomouc (49°34´latitude north) usually grew and the plants blossomed- *A. hypochondriacus*, *A. cruentus* and *A. hypochondriacus* x *A. hybridus* during summer time, that is under conditions of long summer days. O´Brien and Price (l983) found out that under conditions in Southern Florida (approximately 27°latitude north) grain amaranths (*A. hypochondriacus, A. cruentus*) started to blossom in winter at less than half height of plants than those which were grown in May.

Our research with gradual sowing of seeds *A. hypochondriacus* on a piece of land in agreement with the results of photoperiodic experiment with the plants artificially moved from a long to a short day in the vegetation house showed that the plants germinated in Prague - Suchdol (50°latitude north) from the seed originated in Olomouc reacted as facultatively photoperiodically sensitive short-day , for the length of the day the plant were adaptable.

On the basis of our experiments we don't agree with the statement of Jarošová et al. (l977), that „the majority of genotypes of amaranth needs for the production of seeds a short-day.“ After all, all our plants which germinated from the first up to the seventh sowing grew, blossomed and gave germinable seed under conditions of days longer than l2 hours.

*A. cruentus* stayed in Nigeria according to the National Research Council (l984) at vegetation phase, i.e. without flowers for an extended time under their equatorial conditions with twelve hours´days and was used only as a vegetable. Kauffman and Webber (l990) found out that *A. cruentus* is less sensitive to the length of the day than other amaranths. According to Williams (l995) there were selected types neutral to the length of the day. When it was introduced to Pennsylvania under the conditions of long days during summer time it was sown mostly very early in order to breed early ripening plants (National Research Council, l984). When it was cultivated near Olomouc it was possible to sow it as late as the middle of May, i.e. after the danger of late frosts. In spite of this fact the plants thrived, grew and blossomed during long days. Their seed normally ripened and was germinable. (Jarošová, l997)

During our observation in the experimental area and the vegetation house *A. cruentus* did not react with its demands to the length of the day differently in comparison with *A. hypochondriacus*. Also at *A. hypochondriacus* x *A. hybridus* variety Koniz there was found the similar sensitivity to the length of the day.

During the evaluation of the results our observations realized that if we don´t know an exact locality, place and its latitude where there was originally produced the seed of plants which we used in our research we cannot properly appreciate the significance of various influences acting at multiple repetition growing environment very different from the areas of original abundance.

Jarošová et al. (l997) although stated that *A. hypochondriacus* variety No. l008 was produced by the selection from original Nepalese forms, *A. hypochondriacus* x *A. hybridus* variety Koniz is a hybrid originally from Russia and *A. cruentus* variety No.l7 has an origin in Guatemala. They however mention about a subsequent selection of early and hardy plants at *A. hypochondriacus* x *A. hybridus* variety Koniz. However, it is important to mention however, that Amaranthus was introduced to Nepal and Russia long time ago (SAUER, 1967). It is very probable that by repeated long term cultivation of amaranths under the conditions of mild climate happens because of the influences of environment the lowering of differences among the original plants. We also cannot eliminate undesirable influences of the uncontrolled pollination by a pollen of introduced and wild also native weedy amaranths as evident in the differences of the coloured tinges of flower heads.

## CONCLUSION

In the experiment with gradual sowings the critical day lengths at *A. hypochondriacus* variety No. l008, *A. cruentus* variety No.l7 and *A. hypochondriacus* x *A. hybridus* variety Koniz appeared after June 1st, i.e. during the period when there are in Czech Republic the longest days. All three monitored varieties had the critical day longer than l6 hours. It means that all three varieties of amaranth in literature described as short-day plants are not in reality strictly of a short day however they are to the length of the day significantly tolerant.

During the photoperiodic experiment we figured out that at the decrease of the number of short days there increased the number of days necessary for the beginning of blossoming. *A. hypochondriacus* variety No. l008 and *A. hypochondriacus* x *A. hybridus* variety Koniz needed 54 days and *A. cruentus* variety No. l7 59.5 days.

The photoperiodic experiment showed that monitored species and varieties react under the conditions with mild climate (50°latitude north) as plants reacting slightly to a shorter day, i.e. as the plants facultatively photoperiodically sensitive. Under the desirable photoperiod these plants accelerate the transition toward blossoming however they will blossom also without this photoperiod. Like this it is possible to explain the successful cultivation of the grain amaranths in the Czech Republic.

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