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Influence of gibberellic acid on the growth and flowering initiation of two types of peas (*Pisum sativum* L.) differing in photoperiod response

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Abstract

It was found that GA_3 (0.03 mg per one plant) caused significant delay of the flowering of two different genotypes of peas under conditions of an increasing natural day length (March - May). It was expressed both in a greater number of vegetative nodes and in a greater number of days to the first flower. Under conditions of a decreasing day length (August - November) most of G type plants treated with GA_3 reacted with complete inhibition of the flowering. In K type pea, GA_3 treatment in the discussed conditions affected only the number of days from the sowing time to the appearence of the first flower. This stage was greater in treated plants in comparison with the control ones.

INTRODUCTION

Cultivated varieties of *Pisum sativum* L. show great differences with regard to time of senescence. Some midseason and late varieties behave as long-day plants, whereas certain early lines are insensitive to differences in day length (Kopetz 1941; Reath and Wittwer 1952).

Under short-day conditions the influence of the photoperiod dominantes over the influence of temperature, while in a long photoperiod the temperature determines the development of plants (Kopetz 1943). Temperature may also exert an influence on the flowering initiation of peas, through the vernalization process (Highkin 1956; Moore and Bonde 1962). It was stated that vernalized late varieties of peas — in comparison to unvernalized ones — showed a smaller sensitivity to the length of the photoperiod. Generally speaking, early varieties do not react to vernalization, and do not accelarte flowering under the influence of this process (Listowski 1970).

According to Barber (1959), the sensitivity of peas to the photoperiod and to vernalization is controlled by *Sn* gene, which has also at least two other pleiotropic effects (delaying the formation of the first leaf with more than two leaflets, and a small reduction in the internode length). This gene, as was suggested by Barber et al. (1958), exerts its influence by producing a hormonal substance which delays the initiation of flowering.

As was observed by Brian and Hemming (1955), the *Le* gene is responsible to a great extent for the internode length. Segregation at the *Le* locus affects some aspect of the metabolism of the gibberellins.

Pea varieties having dominant *Sn* aud *Le* alleles are late and tall and respond to the day length (Barber et al. 1958). Marx (1968), on the basis of his data on the crosses between lines sensitive and insensitive to the photoperiod, came to the conclusion that "presumably dominant alleles at two different loci are necessary to evoke a response under short day".

The purpose of this work was to make some observations concerning the effect of gibberellin A_3 on the growth and flowering initiation of two genotypes of peas, differing in their photoperiodic responses.

MATERIALS AND METHODS

The experimental material was made up of two types of peas (*Pisum sativum* L.) which show differences concerning photoperiodic reaction. One of those types, known as a G type or inbred line 1326, has a very strong photoperiod sensitivity. Under long-day conditions plants of this type are dwarf, and develop their first flowers on the 16-17th nodes whereas under short-day conditions they form 35 to 85, and sometimes more vegetative nodes. The other line, defined as a K type or Kopetz type, shows a weak response to the photoperiod. Under long-day conditions plants of this type develop about 17 vegetative nodes, but under short-day conditions the beginning of flowering can be observed on the 21-23rd nodes (Marx 1968, 1969).

The experimenst were carried out in 1972 in two series, in a greenhouse on The Experimental Farm at Lublin - Felin.

Experiment I was conducted under conditions o increasing day length (March - May).

Experiment II was done when the days were becoming shorter (August - November).

The natural photoperiod in Lublin (lat. 51°15′; long. 22°34′; elevation 196 m) from March 1 to May 30 ranges from 11 to 16.5 hours and from August 1 to November 30 from 15.5 to 9.5 hours. Temperature in the greenhouse was kept at a level of 15-18°C by night and 25-28°C during the day.

Experiment I

Seeds of both types were sown on March 22 in pots 12 cm in diameter, filled with a mixture of soil, sand and peat in a volumetric proportion of 1:1:1. After the development of 2-3 internodes, the plants were fed weekly with 50 ml/pot of nutrient solution containing about 0.1 g superphosphate and 0.17 g potassium sulphate.

Gibberellic acid was used in a distilled water solution at a concentration of 100 ppm, when seedlings of both types of peas had developed 3-4 internodes. Treatment with GA_3 was carried out 3 times every second day. Drops of gibberellic acid solution were put on the leaves with the help of an injector. For each plant a total of 0.3 ml of GA_3 solution was used (0.03 mg of GA_3 per one plant).

In each of the four combinations (G type — control and plants treated with GA_3, as well as the K type — control and plants treated with GA_3) there were 19 plants.

The plants were checked each day, the time of flowering was noted, and the vegetative nodes were counted. The mean number of days needed for the appearance of the first flower, from the time of the planting of the seeds was counted, based on the time of the flowering of each group plants. In addition the lengths of the nodes and stems from the first node including the 21st node were measured. Data connected with the number of the vegetative nodes and the number of days from sowing time to the first flower appearance were analyzed statistically, using the F and D tests (O k t a b a 1963).

Experiment II

Seeds of both types of peas were planted on August 3. The preparation of soil, fertilization, GA_3 treatment, as well as observations connected with flowering and plant measuring and statistical analysis of the data were conducted according to the procedure adopted in Experiment I.

In each of the four combinatons (G type — control and GA_3 treated plants and K type — control plant and those treated with GA_3) there were 18 plants.

RESULTS

Experiment I

1. Plant growth

The strongest elongating action of GA_3 under conditions of the lengthening natural photoperiod (March - May) was observed in G type. Plants of this type treated with gibberellic acid reached the 21st node at an average height of 52.4 cm, and were 32.4% higher than the control

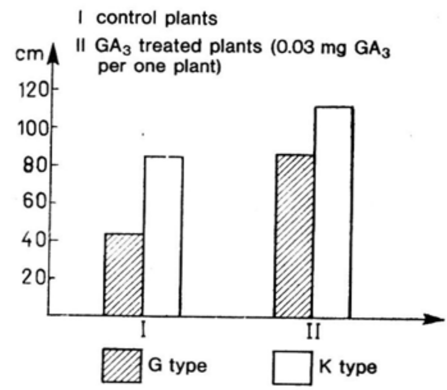
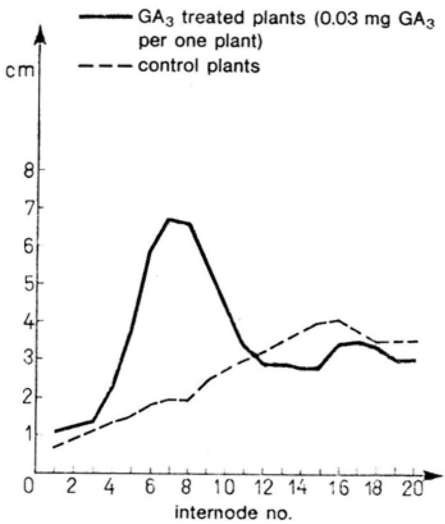


Fig. 1. Diffference in length of the stems

(From 1st to 21st node) between control and GA_3 treated plants of two types of peas. The plants were cultivated in a greenhouse (March - May)

plants. Plants of the K type treated with GA_3 were 25.4% higher than the control ones (Fig. 1).

The stimulating effect of gibberellic acid on the growth of both types of peas was already visible from the 4–5th internodes, so immediately afterward this compound was put on plants. The extreme of the elongated influence of GA_3 is visible in both types of peas on the 7th node.



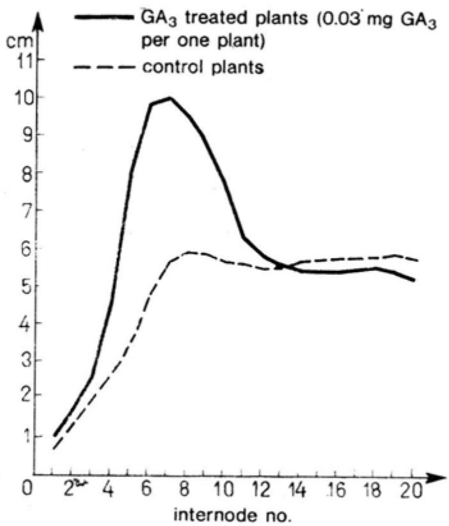


Fig. 2. Length of internodes in the G type of pea

(Control and GA_3 treated plants) grown in a greenhouse under conditions of an increasing day length March - May)

Fig. 3. Length in internodes in the K type of pea

(Control and GA_3 treated plants) grown in a greenhouse under conditions of an increasing day length (March - May)

When 11 internodes developed of the K type, and 13 internodes of the G type had developed, the growth of plants treated with gibberellic acid was weaker, and reached the level which was lower than the one of the control plants (Figs 2 and 3).

2. Flowering of plants

Under conditions of a lengthening natural photoperiod, the earliest flowering pea was the K type. The beginning of the flowering of control plants of this type was observed on the 19th node on the average 55.6 days from the planting of the seeds (3.3 days earlier than in the G type). Plants of K type treated with GA_3 developed their first flowers 2.4 days later than untreated ones. The beginning of the flowering of the K type treated with GA_3 was noted above the 20th node. Control plants of the G type flowered after 58.9 days from the time of sowing of the seeds when they developed about 19 vegetative nodes. In the treated plants of this type, flowering of the first flowers was seen above the 23rd node, on the average, 62.4 days from the sowing time. The delay of generative devlopment caused by gibberellic acid treatment was 4.5 days in comparison with untreated plants (Tab. 1).

Table 1

Effect of gibberellic acid on the flowering initiation of two types of peas cultivated in the greenhouse (Lublin - Felin, 1972) under conditions of an increasing day length (March - May). Each value is a mean of 19 plants

Type of peas	Dose of GA_3 per one plant in mg	Number of nodes to first flower	Number of days to first flower
K	0.00	18.1	55.6
	0.03	19.3	57.2
G	0.00	18.9	58.9
	0.03	22.3	62.4

Differences of 0.7 number of nodes and 1.9 number of days to first flower between treatments are significant at D = 0.05.

Experiment II

1. Plant growth

The growth of both types treated with gibberellic acid under conditions of a decreasing day length was much more intensive than under conditions of an increasing day length. This is especially true of G type plants, which, after developing 21 nodes, reached an average height of 43.8 cm, and were higher than the control plants by about 95%. In the K type, however, the difference in the stem-length between the plants treated with GA_3 and the control plants was considerably smaller, 35,1%

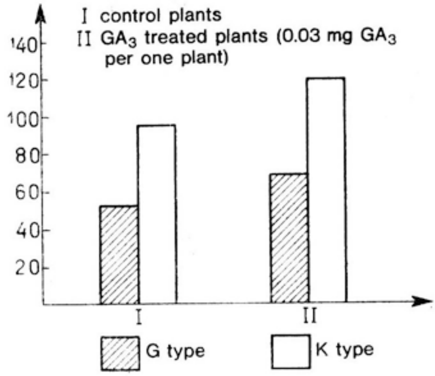
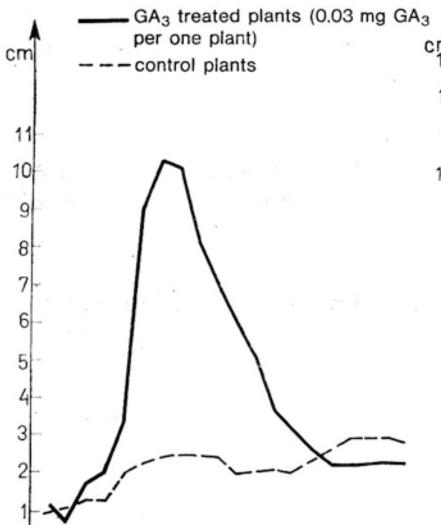


Fig. 4. Difference in length of the stems
(From 1st to 21st node) between control and GA_3 treated plants of two types of peas. The plants were cultivated in a greenhouse (August - November) I — control plants; II — GA_3 treated plants (0.03 mg GA_3 per one plant)



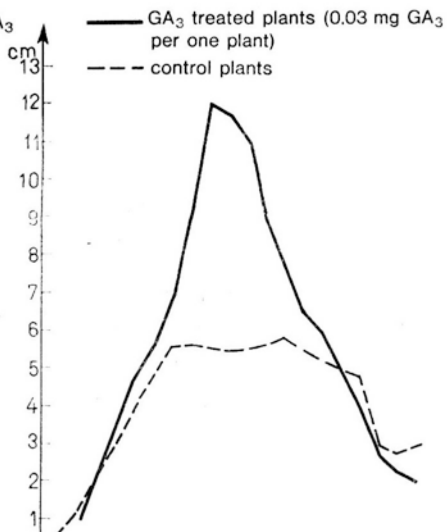


Fig. 5. Length of internodes in the G type of pea
(Control and GA_3 treated plants) grown in a greenhouse under conditions of a decreasing day length (August - November)

Fig. 6. Length of internodes in the K type of pea
(Control and GA_3 treated plants) grown in a greenhouse under conditions of a decreasing day length (August - November)

(Fig. 4). Intensive lengthening of the internodes in both types of peas treated with GA_3 could be seen in a way similar to that in Experiment I, immediately after this compound had beeen used. The stimulating action of GA_3 in both types stopped rapidly after 15-16 internodes were deve-

Table 2

Effect of gibberellic acid on the flowering initiation of two types of peas cultivated in the greenhouse (Lublin - Felin, 1972) under conditions of a decreasing day length (August - November)

Type of peas	Dose of GA_3 per one plant in mg	Number of flovering plants (before November 26) and average number of nodes developed by these plants to first flower (in brackets)	Average number of days to first flower	Number of plant not flowering (till November 26) but forming only abortive buds and number of vegetative nodes to first aborative buds (in brackets)	Average number of days till the first abortive bud appearance	Average number of nodes formed by non-flowering plants at the moment of the experiment was stopped (till November 26)
G	0.00	14(19.0)	74.6	4(19.0)	80.2	28.4
	0.03	5.(19.0)	73.0	13(20.8)	80.6	30.8
K	0.00	18(71.1)	55.6	—	—	—
	0.03	18(16.4)	60.6	—	—	—

Difference between number of days to first flower in K type is significant at $P_{0.05} = 4.13$.

loped. From that moment as in Experiment I, one can observe the inhibition of growth in plants treated with GA_3 in comparison with the control plants (Figs 5 and 6). Contrary to the plants treated with GA_3, the growth of the control plants of both types under conditions of a decreasing day length was less intensive than under conditions of an increasing photoperiod length. The differentiation of the average stem length in both types of peas in Experiment I and II was caused, not only by the changing length of day light intensity, but also by the interaction of these factors with temperature.

2. Flowering of plants

Comparing the data concerning generative development of both types of peas under conditions of a shortening natural photoperiod (August - November), specific flowering of the G type is conspicuous.

Out of 18 control plants of the G type, only 14 flowered — 74.6 days after sowing, generally on the 20th node. The remaining, untreated plants of this type developed only abortive buds. At the end the experiment (November 26) those plants had over 28 vegetative nodes (Tab. 2).

Among 18 plants of the G type treated with gibberellic acid only 5 flowered. The beginning of their generative development was noted on the 20th node, 73 days after sowing time. The remaining 13 plants of this combination formed only flower buds with different degrees of development. These buds, like the ones in the control plants, aborted after withering. On November 26 these plants had about 31 vegetative nodes (Tab. 2).

In peas of the K type the flowering was normal, and was similar to that in Experiment I. Untreated plants of the K type flowered 55.6 days after sowing time, having over 17 vegetative nodes. However, plants treated with gibberellic acid developed their first flower 5 days later — above the 17th node on the average (Tab. 2).

DISCUSSION

Gibberellins are active in the control of many thermal and light controlled inductive processes in peas (Brian et al. 1958; Lockhart 1956, 1957, 1958; Moore 1965).

According to McComb's (1964) gibberellic acid is transferred first of all to the upper stem (to the developing internodes and leaves) after being applied to young pea seeedlings. Small amounts of exogenous GA_3 were carried to the base of the plants, to the older parts of their stems and roots. The general pattern of the movement of synthetic GA_3 seems to confirm the data obtained in this report from the measurement of the internode length. Intensive elongation of stems in both types of peas treated with GA_3 took place directly after this compound was used. In spite of some temperature differences, the stimulating action of GA_3 was visible under both conditions of an increasing and decreasing day-length. In particular, internodes formed later reached a greater length than those whose development had partly begun at the time of GA_3 application. Internodes already developed before the application of GA_3 were sligthly longer in comparison to the control plants. When analyzing the length of all stems, one can come to the conclusion that the stimulating action of GA_3 was considerably stronger in dwarf plants of the G type than in medium tall plants of the K type. Similarily, a more intensive growth reaction to GA_3 treatment in dwarf pea varieties than in tall ones was observed Gorter (1961).

Gibberellins, probably, do not affect the growth of plants directly but only indirectly, affecting auxin biosynthesis easier. Increasing auxin-activity in plants after the application of gibberellins (Kuraishi and Muir 1963; Michniewicz 1962) seems to confirm this hypothesis. McComb (1964) suggests that varieties are not dwarf because they have less gibberellins, but that they deactivate these compounds more quickly than do tall varieties. The longer-lasting activity of gibberellins and auxins in tall pea varieties in comparison to the dwarf ones was noted by Cumakowski and Kefeli (1968) as well.

The influence of GA_3 on flowering initiation should be separately considered. Barber et al. (1958) observed the inhibitory influence of gibberellic acid on pea flowering. However, Wellensiek (1969) stated that gibberellic acid markedly stimulated the flowering of one breeding line of peas. On the average, GA_3 treated plants of this line produced flowers on 44th node whereas untreated ones growing in the same short-day conditions died with approximatively 22 internodes.

Under conditions of a gradually increasing photoperiod, plants of the G type treated with GA_3 reacted with 4.5 days delay in flowering, but plants of K type with 2.4 days delay in comparison to the control plants. Under conditions of a decreasing day-length the delay in flowering in the K type caused by GA_3 treatment was 5 days in comparison to the control plants. In G type, gibberellic acid caused the inhibition of flowering in most of the plants. Bearing these facts in mind, one comes to the conclusion that probably under long-day conditions the endogenous gibberellin level was higher than during a short photoperiod while the response to GA_3 treatment in both types of peas was significantly stronger. Stoddart (1961) cited by Listowski (1970) also noticed a similar dependence of the decrease of endogenous gibberellin content under short-day conditions in comparison ot the plants growing under long-day conditions. Nevertheless, this author suggests that GA_3 does not influence the flowering initiation directly, but its presence is necessary for the normal course of this process. After the plants have flowered, GA_3 quickly changes to GA_7 and this conversion is caused by a phytochrome system which also controls many others processes during the flowering of the plants (Rollin 1970). Thus initiation or inhibition of flowering under the influence of gibberellins is a complex phenomenon, and cannot be explained by means of the balance between endogenous gibberellins and auxins or inhibitors only.

SUMMARY AND CONCLUSIONS

Investigations were carried out in a greenhouse (Lublin - Felin, 1972) under conditions of an increasing (March - May) and decreasing (August - November) day length.

Gibberellic acid was used 3 times in water solutions at a concentration of 100 ppm every second day when the plants had developed 3-4 internodes. Every plant received a total of 0.03 mg of GA_3.

During the course of vegetation the flowering of plants was observed and the number of the vegetative nodes developed to the first flower was stated. Based on the flowering dates of plants, the average number of days from the sowing time till the appearing of the first flower was determined for two types of peas. After the plants were gathered, the length of internodes and that the stems up to 21st node was measured. Results connected with the number of vegetative nodes and the number of days from the sowing time till the first flower appearance were subjected statistical analysis.

The results of the experiments lead to the following conclusions:

1. The reaction of the two types of peas in question to GA_3 was different. The strongest stimulative influence of GA_3 (irrespective of the photoperiod length) visible in greater length of internodes and stems in comparison to the control plants was in peas of the G type (Figs 1, 2, 3, 4, 5 and 6).

2. Under conditions of a decreasing photoperiod (August - November) the growth of both types of peas treated with GA_3 was more intensive than under conditions of an increasing photoperiod (March - May) — Figures 2, 3, 5 and 6.

3. The stimulating action of GA_3 was seen both in the G type and the K type immediately it was applied. Although the strongest elongative influence of GA_3 in both types of peas was noticed on the 7-9th internode, but when the 12-16th internode were developed, the growth of plants treated with GA_3 was considerably inhibited and was lower than in the control plants.

4. Gibberellic acid caused significant delay in the flowering of both types of peas under conditions of an increasing day length. It was ex-

pressed both in a greater number of vegetative nodes developed to the first flower and in a greater number of days from the sowing time till the plants flowering (Tab. 1).

5. In pea of the K type treated with GA_3 under conditions of a decreasing day length, the number of days from sowing time till the flovering of the first flower was greater in comparison to the control plants. More plants of G type reacted to GA_3 in the discussed conditions by showing complete inhibition of the flowering.

Out of 18 plants treated with GA_3 (till November 26) only five flowered, whereas in the control experiment the beginning of the normal generative development was observed in 14 plants till the moment the experiment was over (Tab. 2).

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Wpływ kwasu giberelowego na wzrost i inicjację kwitnienia dwóch typów grochu (*Pisum sativum* L.) wykazujących zróżnicowanie pod względem reakcji fotoperiodycznej

Streszczenie

Doświadczenia prowadzono w szklarni (RZD Lublin - Felin, rok 1972) w warunkach wzrastającej (marzec - maj) i malejącej (sierpień - listopad) długości dnia naturalnego.

Kwas giberelowy zastosowano w roztworach o koncentracji 100 ppm, trzykrotnie, w odstępach jednodniowych, w momencie, gdy rośliny rozwinęły 3-4 międzywęźla. W sumie na każdą roślinę naniesiono 0,03 mg GA_3.

W trakcie wegetacji, prowadzono obserwacje nad kwitnieniem roślin i określano liczbę węzłów wegetatywnych wykształconych do pierwszego kwiatu. W oparciu o daty kwitnienia poszczególnych roślin, obliczono dla obydwu typów grochu średnią liczbę dni od siewu nasion do kwitnienia pierwszego kwiatu. Po zbiorze roślin mierzono długość międzywęźli i całych łodyg do 21 węzła włącznie. Wyniki dotyczące liczby węzłów wegetatywnych i liczby dni od siewu nasion do kwitnienia pierwszego kwiatu poddano analizie statystycznej.

Wyniki doświadczeń pozwalają na wyprowadzenie następujących wniosków:

1. Reakcja wzrostowa badanych typów grochu na działanie GA_3 była zróżnicowana. Niezależnie od długości fotoperiodu, najsilniejszy stymulujący wpływ GA_3, wyrażający się znacznym wzrostem długości międzywęźli i całych łodyg w porównaniu do roślin kontrolnych zaobserwowano u grochu typu G.

2. W warunkach skracającego się fotoperiodu (sierpień - listopad), wzrost obydwu typów grochu traktowanych GA_3 przebiegał intensywniej niż w warunkach wzrastającej długości fotoperiodu (marzec - maj).

3. Stymulujące wzrost działanie GA_3, widoczne było zarówno u grochu typu G, jak też u grochu typu K, bezpośrednio po zastosowaniu tego związku. Najsilniejszy

jednak elongacyjny wpływ GA_3 u obydwu typów grochu, dał się zauważyć na 7-9 międzywęźlu, z chwilą zaś wykształcenia się 12-16 międzywęźli, wzrost roślin traktowanych GA_3 uległ wyraźnemu zahamowaniu i utrzymywał się na poziomie niższym niż u roślin kontrolnych (rys. 2, 3, 5 i 6).

4. Kwas giberelowy spowodował istotne opóźnienie kwitnienia obydwu typów grochu w warunkach wzrastającej długości dnia. Wyrażało się to zarówno we wzroście liczby węzłów wegetatywnych wykształconych do pierwszego kwiatu, jak również w zwiększeniu liczby dni od siewu nasion do początku kwitnienia roślin (tab. 1).

5. U grochu typu K traktowanego GA_3 w warunkach skracającej się długości dnia, stwierdzono istotny, w porównaniu do roślin kontrolnych, wzrost liczby dni od siewu nasion do kwitnienia pierwszego kwiatu. Większość natomiast roślin typu G, zareagowała na działanie GA_3 w omawianych warunkach całkowitym zahamowaniem kwitnienia. Spośród 18 roślin w tej kombinacji zakwitło (do 26 XI) tylko pięć, podczas gdy w kombinacji kontrolnej początek normalnego rozwoju generatywnego zaobserwowano do momentu likwidacji doświadczenia u 14 roślin (tab. 2).

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