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# USE OF CLUSTER ANALYSIS IN THE DETERMINATION OF THE INFLUENCE OF AGROTECHNICAL DATES AND PHENOLOGICAL PHASES ON FIELD CUCUMBER (*Cucumis sativus* L.) YIELDS IN POLAND

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**Abstract.** The aim of the work was to separate, by means of cluster analysis, sets of agrotechnical dates and phenological phases that are conducive to big and low yields of field cucumber of pickling cultivars and the evaluation of solar and thermal conditions accompanying these sets. On the basis of cluster analysis three, significantly different, groups of observations in relation to the course of growth and development, determining different volumes of cucumber yields in Poland, were isolated. Cluster 2 included observations which were characterised by high yields (amounting to 37.7 $t \cdot ha^{-1}$ for the total yield and 20.1 $t \cdot ha^{-1}$ for the marketable yield), and cluster 3 by low yields (respectively 27.6 and 15.6 $t \cdot ha^{-1}$). The following calendar of agrotechnical dates and phenological phases was conducive to high yield of cucumber (cluster 2): sowing on 14th May, the end of emergence 27th May, the beginning of flowering 29th June, the beginning of fruit setting 4th July, the beginning of harvesting 13th July, the end of harvesting 24th August. The delay, in relation to the dates in cluster 2 (high yield), of the sowing date by 6 days, emergence by 16 days, flowering and fruit setting by 18 days, the beginning of harvesting by 19 days, and the end of harvesting by 22 days may contribute to a decrease in cucumber yields even by about 27% and 22%, respectively for the total yield and the marketable yield. Higher than average values of both sunshine duration and air temperature, which during the vegetation season amounted respectively to 7.9h and 17.5°C, were conducive to earlier agrotechnical and phenological dates, and, in consequence, high cucumber yields (cluster 2).

**Keywords:** cucumber, phenological phases, air temperature, cluster analysis, *k*-means method

## INTRODUCTION

Growing of field vegetables plays an important role in vegetal production in Poland. In 2006 in the Polish crop structure of vegetables, a big, over 9% share, was taken by cucumber, and the biggest share, over 15%, by onion and cabbage [Kulikowski 2007].

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Regarding the occupied land of the crop, Poland is the biggest producer of cucumber among all countries of the European Union. Poland's cultivated area of this vegetable in 2006 amounted to nearly 21 thousand ha, and the average area of the decade 1997–2006 to nearly 24 thousand ha, whereas in Romania (the second country in terms of the area size of cucumber growing in the EU) about 7 thousand ha. Growing of field cucumber in Poland is concentrated in certain regions, especially in the vicinity of big cities and the centres of vegetable processing [FAO 2007, Kulikowski 2007]. A characteristic feature of cucumber production in Poland is a big variation of crops, resulting both from the variation of the cultivated area and yields, which is greatly affected by unfavourable weather conditions delaying agrotechnical dates and phenological phases [Górka 1987, Cieślak-Wojtaszek 2000, Koźmiński and Michalska 2001, Kalbarczyk 2006, Kalbarczyk and Kalbarczyk 2006, Wierzbicka et al. 2007]. In Poland, cucumber yields do not usually exceed 15 $t \cdot ha^{-1}$ in commercial production and 40 $t \cdot ha^{-1}$ in experimental production and in this respect they are among the lowest in countries of the European Union. During the decade 1997–2006, the biggest, amounting to 14.4 $t \cdot ha^{-1}$, country's cucumber crops in commercial production were harvested in 1999, and the lowest, on the other hand, about 12.0 $t \cdot ha^{-1}$ in 1997. The cucumber growing season in 1999, in comparison with 1997, was characterized by higher, by 0.7°C, average air temperature and higher, by 25 mm, atmospheric precipitation total [Agrometeorological Bulletins 1966–2002].

The aim of the work was to separate, by means of cluster analysis, sets of agrotechnical dates and phenological phases that are conducive to big and low yields of field cucumber of pickling cultivars and the evaluation of solar and thermal conditions accompanying these sets.

## MATERIAL AND METHODS

The work used the results of experiments on cucumber pickling cultivars, conducted in 28 stations of the Research Centre for Cultivar Testing (COBORU) in the whole Poland in 1966–2005, with the exception of two years, 2003 and 2004, when experiments were not carried out (fig. 1). Starting materials (the number of stations × the number of years) consisted of 318 observations – in one year they came from 6–11 experimental stations. The work took into account the total and marketable yield of cucumber fruits and agrotechnical dates (sowing, the beginning of harvesting, the end of harvesting) and phenological phases (the end of emergence, the beginning of flowering, the beginning of fruit setting). Marketable yield comprised fruits of the length of 6–10 cm and the diameter of 2.5–4.0 cm, however, not smaller than half of fruit length. Starting materials were collected for a standard: cucumber pickling cultivars most common in cultivation in a given year [Methodology of research… 1998, Synthesis of the results… 1966–2002]. Use of a collective research standard was based on an assumption that intraspecific differences do not obfuscate general regularities being searched for the species.

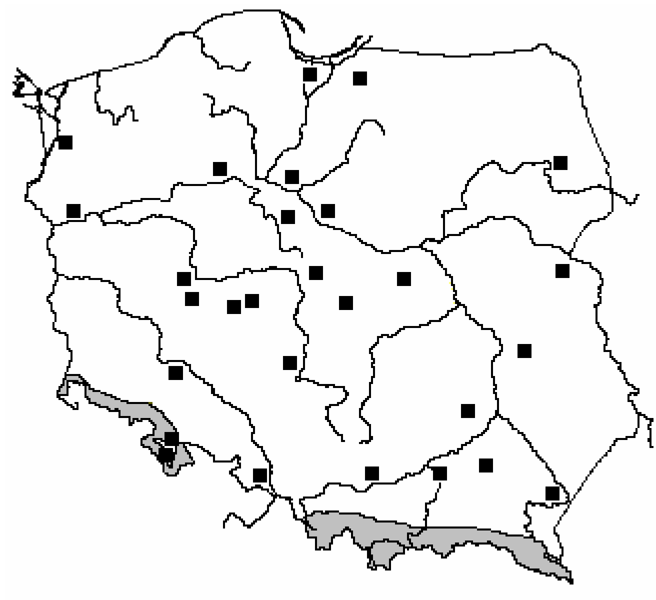


Fig. 1. Distribution of COBORU stations with experiments with field cucumber of pickling cultivars conducted in 1966–2005
Ryc. 1. Rozmieszczenie stacji COBORU z doświadczeniami ogórka polowego odmian konserwowych, przeprowadzonych w latach 1966–2005

Experiments in 1966–2005 were conducted in accordance with the methodology of COBORU used in the 1960s and repeatedly updated in the following years [Methodology of research… 1998, Synthesis of the results… 1966–2002]. Only the results of field experiments conducted on soils typical of cucumber growing, namely, very good wheat and good wheat complexes (high quality soil culture, a big content of humus and good aggregate structure) were used for the analysis. In cucumber growing complete organic manuring was predominantly used, at a dose from 30 to 40 $t \cdot ha^{-1}$, which was ploughed in autumn. Mineral fertilisation, on the other hand, amounted, on average, to 400 kg NPK per 1 hectare of the crop, including N and $P_2O_5$, which were utilized respectively at the amount of 115 and 90 kg, and $K_2O$ at the amount of 195 kg [Methodology of research… 1998, Synthesis of the results… 1966–2002].

To determine the influence of the sowing date, phenological phases and the occurrence of the beginning and end of harvesting on the size of the total and marketable yield of field cucumber a generalized cluster analysis was used. Before the analysis all the examined dates underwent a normalisation based on the formula:

$$Z_j = \frac{X_j - Min(X_j)}{Max(X_j) - Min(X_j)}$$

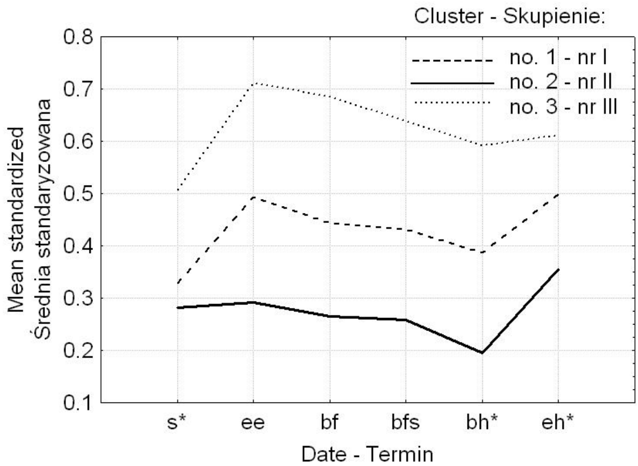
where: $Max(X_j)$ and $Min(X_j)$ denote the lowest and the highest *j* value of this date.

The division of all observations of the analysed agrotechnical dates and phenological phases into clusters was conducted by means of the non-hierarchical method of *k*-means, in which the Euclidean distance, that is the geometrical distance in multidimensional space, was used [Jain et al. 1999, Holden and Brereton 2004]. Grouping of observations with the method of *k*-means consisted in moving the observations from a cluster to another cluster in order to maximise variance between particular clusters, simultaneously minimizing variance inside the examined clusters. For the determination of the best number of clusters the test of the v-fold cross-validation was used. The significance of differences between isolated clusters was assessed by means of variance analysis using the Fisher's test at the level of $P = 0.05$.

The values of sunshine duration and air temperature, calculated for six agro-phenological phases of cucumber (sowing – the end of emergence, the end of emergence – the beginning of flowering, the beginning of flowering – the beginning of fruit setting, the beginning of fruit setting – the beginning of harvesting, the beginning of harvesting – the end of harvesting) in the successive years of the period 1966–2005, came from meteorological stations, functioning at testing stations of COBORU or, in the case of no data available, meteorological stations of the Institute of Meteorology and Water Management (IMGW).

## RESULTS AND DISCUSSION

On the basis of cluster analysis three groups of observations were isolated that were characterised by a different course of growth and development of the cucumber in the climatic conditions of Poland (fig. 2). Cluster 3 was characterised by later than average agrotechnical and phenological dates, cluster 2, on the other hand, by earlier dates. It results from variance analysis that all agrotechnical dates (sowing, the beginning of harvesting, the end of harvesting) and all dates of phenological phases (the end of emergence, the beginning of flowering, the beginning of fruit setting) significantly, at the level of $P = 0.01$, differentiate separated clusters; the date of the beginning of fruit setting most, and the date of sowing least (table 1, fig. 3). The smallest difference between the separated clusters concerned the date of sowing and occurred between clusters 1 and 2, and the biggest concerned the date of the end of harvesting and occurred between clusters 2 and 3 (fig. 3, table 2). Cucumbers are sown when the average daily air temperature amounts to approximately 16.0°C, which in Poland, on average, takes place in the second half of May [Sokołowska 1980, Babik 2004, Kalbarczyk 2006]. Too early sowing of cucumber in unheated soil exposes seeds to diseases and decay in the periods of prolonged emergence [Babik 2004]. Also, earlier sowing often means earlier emergence of cucumber and the danger of its occurrence during spring ground frost, causing damage to young sowings [Koźmiński and Trzeciak 1971, Babik 2004]. As it can be seen in table 2, cluster 1 consisted of 133 observations, cluster 2 of 102 observations, and 3 of 83 observations. In order to assess what was the influence of agrotechnical dates and phenological phases on the size of cucumber crops, for all observations belonging to one cluster, average total and marketable yields with a standard deviation were calculated separately. The biggest average cucumber yield, both total and market-




s* – sowing; ee – end of emergence; bf – beginning of flowering; bfs – beginning of fruit setting; bh* – beginning of harvesting; eh* – end of harvesting
s* – siew; ee – koniec wschodów; bf – początek kwitnienia; bfs – początek zawiązywania owoców; bh* – początek zbioru; eh* – koniec zbioru

Fig. 2. Mean standardized values of agrotechnical* and phenological dates of field cucumber for each cluster
Ryc. 2. Średnie standaryzowane wartości terminów agrotechnicznych* i fenologicznych ogórka polowego dla każdego skupienia

Table 1. Statistical evaluation of isolated clusters on the basis of agrotechnical* and phenological dates of field cucumber with the use of variance analysis
Tabela 1. Statystyczna ocena wyodrębnionych skupień na podstawie terminów agrotechnicznych* i fenologicznych ogórka polowego za pomocą analizy wariancji

| Term – Termin | SS | $Df_{SS}$ | SSE | $Df_{SSE}$ | F | *P* |
|---|---|---|---|---|---|---|
| Sowing*<br>Siew | 6008678.8 | 2 | 4422.7 | 315 | 69053.6 | 0.00 |
| End of emergence<br>Koniec wschodów | 7746913.9 | 2 | 6955.2 | 315 | 175429.5 | 0.00 |
| Beginning of flowering<br>Początek kwitnienia | 11421888.3 | 2 | 4984.3 | 315 | 360922.8 | 0.00 |
| Beginning of fruit setting<br>Początek zawiązywania owoców | 12078912.9 | 2 | 4963.3 | 315 | 383298.8 | 0.00 |
| Beginning of harvesting*<br>Początek zbioru | 13272880.6 | 2 | 10228.2 | 315 | 224383.9 | 0.00 |
| End of harvesting*<br>Koniec zbioru | 19645573.2 | 2 | 44808.4 | 315 | 203978.0 | 0.00 |

SS – sum square error of between-group variation; $Df_{SS}$ – number of degrees of freedom for sum square error SS; SSE – sum square error of within-group variation; $Df_{SSE}$ – number of degrees of freedom for sum square error SSE; F – Fisher's test; *P* – level of probability
SS – suma kwadratów błędów zmienności międzygrupowej; $Df_{SS}$ – liczba stopni swobody dla sumy kwadratów błędów SS; SSE – suma kwadratów błędów zmienności wewnątrzgrupowej; $Df_{SSE}$ – liczba stopni swobody dla sumy kwadratów błędów SSE; F – test Fishera; *P* – poziom prawdopodobieństwa

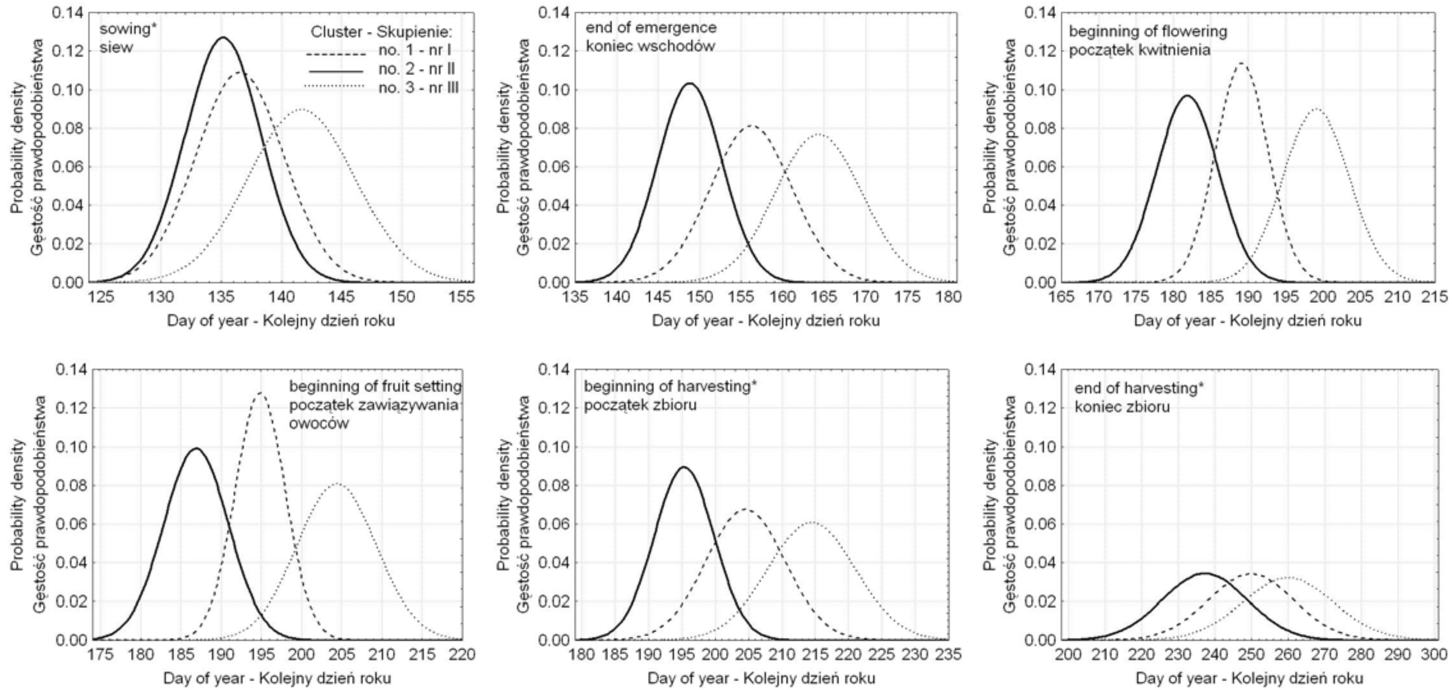



Fig. 3. Distribution of agrotechnical* and phenological dates of field cucumber for each cluster
Ryc. 3. Rozkład prawdopodobieństwa terminów agrotechnicznych* i fenologicznych ogórka polowego dla każdego skupienia

Table 2. Statistical characteristics of agrotechnical* and phenological dates of field cucumber for each cluster and the whole set of data (clusters: 1, 2 and 3)

Tabela 2. Statystyczna charakterystyka terminów agrotechnicznych* i fenologicznych ogórka polowego dla każdego skupienia oraz dla całego zbioru danych (skupienia: I, II i III)

| Cluster number Numer skupienia | Number of Observations Liczba obserwacji | Yield – Plon, $t \cdot ha^{-1}$ | | Characteristics Charakterystyki | Term – Termin, day | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | total± std. dev. ogólny± odchyl. stand. | marketable± std. dev. handlowy± odchyl. stand. | | sowing* siew | end of emergence koniec wschodów | beginning of flowering początek kwitnienia | beginning of fruit setting początek zawiązywania owoców | beginning of harvesting* początek zbioru | end of harvesting* koniec zbioru |
| 1 | 133 | 33.4±13.9 | 18.6±11.2 | a | 8-05 | 22-05 | 23-06 | 5-07 | 13-07 | 6-08 |
| | | | | b | 27-05 | 18-06 | 16-07 | 23-07 | 9-08 | 30-09 |
| | | | | c | 15-05 | 4-06 | 7-07 | 12-07 | 22-07 | 5-09 |
| | | | | d | 3.7 | 4.9 | 3.5 | 3.1 | 5.9 | 11.7 |
| 2 | 102 | 37.7±14.9 | 20.1±11.7 | a | 6-05 | 17-05 | 19-06 | 23-06 | 4-07 | 24-07 |
| | | | | b | 22-05 | 10-06 | 6-07 | 15-07 | 29-07 | 21-09 |
| | | | | c | 14-05 | 27-05 | 29-06 | 4-07 | 13-07 | 24-08 |
| | | | | d | 3.2 | 3.9 | 4.1 | 4.0 | 4.5 | 11.7 |
| 3 | 83 | 27.6±13.0 | 15.6±9.8 | a | 10-05 | 2-06 | 9-07 | 14-07 | 20-07 | 20-08 |
| | | | | b | 4-06 | 23-06 | 30-07 | 8-08 | 21-08 | 20-10 |
| | | | | c | 20-05 | 12-06 | 17-07 | 22-07 | 1-08 | 15-09 |
| | | | | d | 4.5 | 5.2 | 4.5 | 5.0 | 6.6 | 12.5 |
| 1, 2, 3 | 318 | 33.2±14.5 | 18.3±11.1 | a | 6-05 | 17-05 | 19-06 | 23-06 | 4-07 | 24-07 |
| | | | | b | 4-06 | 23-06 | 30-07 | 8-08 | 21-08 | 20-10 |
| | | | | c | 16-05 | 3-06 | 7-07 | 12-07 | 22-07 | 4-09 |
| | | | | d | 4.5 | 7.5 | 7.7 | 7.7 | 9.2 | 14.7 |

Terms: a – earliest; b – latest, c – mean; d – standard deviation
Terminy: a – najwcześniejsze, b – najpóźniejsze, c – średnie; d – odchylenie standardowe

able, was calculated for cluster 2 and it amounted respectively to 37.7 and 20.1 $t \cdot ha^{-1}$, the lowest, on the other hand, for cluster 3 – respectively 27.6 and 15.6 $t \cdot ha^{-1}$. Cluster 2 (big yields) was characterised by a bigger standard deviation of cucumber yields than cluster I (medium-sized yields) and 3 (low yields), and it amounted to 14.9 and 11.1 $t \cdot ha^{-1}$ respectively for the total and marketable yield. Cucumber yields in 1966-2005 (clusters: 1, 2 and 3) were at a similar level like in cluster 1 (medium-sized yields); it amounted to 33.2 $t \cdot ha^{-1}$ and was by about 55% bigger than the marketable yield. Both total and marketable yield in experimental production, as opposed to the yield of commercial production, was characterised by significant growth. Each year of the analysed period of several dozen years they increased, on average, by respectively 0.39 and 0.45 $t \cdot ha^{-1}$.

Earlier sowing and earlier emergence, flowering, fruit setting and also the earlier beginning of harvesting and the end of harvesting (tab. 2) were conducive to big yields of cucumber, amounting to 37.7 $t \cdot ha^{-1}$ for the total yield and 20.1 $t \cdot ha^{-1}$ for the marketable yield (cluster 2). Big yields of cucumber (cluster 2) were harvested when plants were sown on average on 14$^{th}$ May and the end of emergence took place on 27$^{th}$ May, the beginning of flowering on 29$^{th}$ June, the beginning of fruit setting on 4$^{th}$ July, the beginning of harvesting on 13$^{th}$ July and the end of harvesting on 24$^{th}$ August. The delay, in relation to the dates in cluster 2 (big yield), of the date of cucumber sowing by 6 days, emergence by 16 days, flowering and fruit setting by 18 days, the beginning of harvesting by 19 days and the end of harvesting by 22 days may contribute to a decrease in yields even by 10.4 and 4.5 $t \cdot ha^{-1}$ respectively for the total yield and the marketable yield. As Table 2 illustrates, in all separated clusters the lowest standard deviation was characteristic of the date of sowing and the end of emergence, the highest, on the other hand, of the dates of the end of harvesting and, then, the beginning of harvesting. Among all the determined clusters, the biggest variation of agrotechnical and pheno–logical dates of cucumber was characteristic of cluster 3 (low yield), in which a standard deviation for sowing was almost three times lower than for the end of harvesting. As it could have been expected, in the years in which big yields of cucumber were harvested (cluster 2) absolute agrotechnical and phenological earliest dates were noted. On the other hand, in the years when low yields were harvested (cluster 2) absolute earliest dates were reported.

For the sets of agrophenological dates of field cucumber, separately for cluster 2 and cluster 3, the frequency of their occurrence was calculated. For cluster 2 (high yield), however, below the determined average periods and for cluster 3 (low yield) above the determined average periods (fig. 4). The biggest risk of harvesting low yields of cucumber (cluster 3) resulted from high frequency of the occurrence of the sowing date after 20$^{th}$ May (about 26%), and next, the date of the end of harvesting after 15$^{th}$ September (about 21%). Big yields, like low yields, also depended on the date of sowing and the end of harvesting, which occurred respectively before 14$^{th}$ May and 24$^{th}$ August with the frequency of about 19 and 24%; the remaining analysed dates influenced them to a lower extent. Hence, it results that out of agricultural dates the date of sowing has a decisive influence on the yield of crop plants, including field cucumber. Delayed dates of sowing, in relation to the optimal date, cause that plants develop in different light, thermal and moisture conditions [Vinit-Dunand et al. 2002, Ngouajio and Mennan

2005]. These factors shape the growth of plants, durability of particular development stages, the mass of a formed photosynthetic apparatus, the dynamics of fruit mass growth and, in consequence, the volume of final yields [Sysoeva et al. 1997, Popov et al. 2003, Ahmed et al. 2004, Ertek et al. 2006].

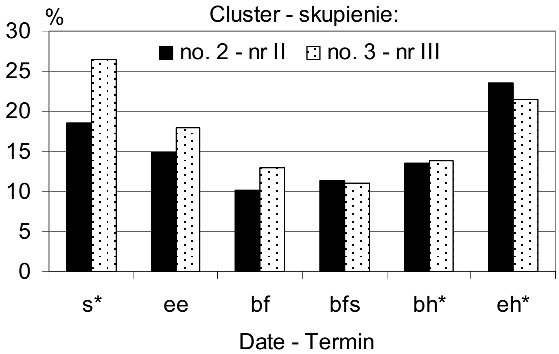



Fig. 4. Frequency of the occurrence of agrotechnical* and phenological dates of field cucumber for cluster 2 (below the determined average periods) and cluster 3 (above the determined average periods)

Ryc. 4. Częstość występowania terminów agrotechnicznych* i fenologicznych ogórka polowego dla II (poniżej wyznaczonych średnich terminów) i III skupienia (powyżej wyznaczonych średnich terminów)

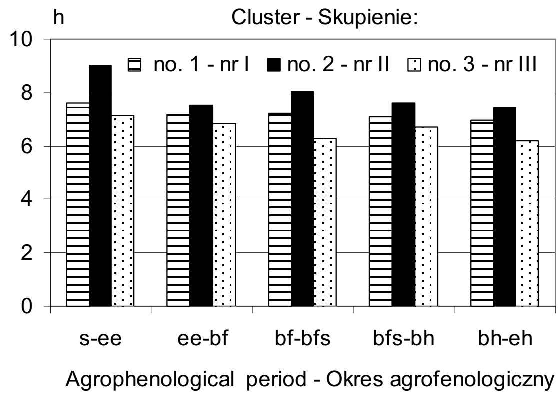



Fig. 5. Average values of sunshine duration in agrophenological periods of field cucumber calculated for each cluster

Ryc. 5. Średnie wartości usłonecznienia rzeczywistego w okresach agrofenologicznych ogórka polowego obliczone dla każdego skupienia

Calculated in agrophenological phases of cucumber, average values of sunshine duration and air temperature supported the existing view that plant growth and development mostly depends on light and thermal conditions of air [Chmielewski and Rötzer

2001, Dalezios et al. 2002, Chmielewski et al. 2004, Tao et al 2006]. Bigger sunshine duration (fig. 5) and higher air temperatures (fig. 6) in all the analysed agrophenological periods were conducive to earlier agrotechnical and phenological dates, and thus, cucumber yields (cluster 2). Lower sunshine and lower temperature were, on the other hand, conducive to later dates. In the years, when high yields of cucumber occurred, amounting to 37.7 and 20.1 t·ha$^{-1}$ respectively for the total yield and the marketable yield, the highest sunshine occurred in the period of sowing – the end of emergence (9 h), and the lowest in the period of the beginning of harvesting – the end of harvesting (7.4 h). On the other hand, air temperature conducive to high yields of cucumber amounted to, on average, 17.5°C within the entire growing season and oscillated from 15.6°C, in the period from sowing to the end of emergence, to 18.5°C, in the period from the beginning of fruit setting to the beginning of harvesting.

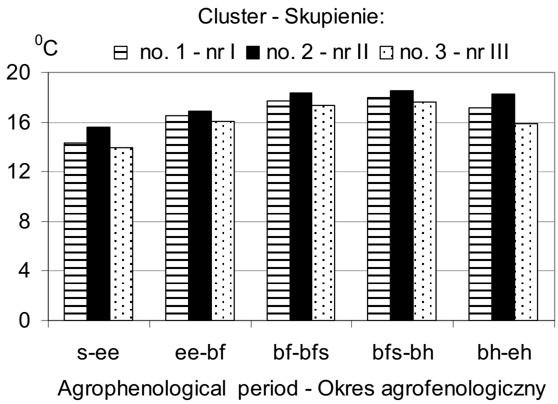



Fig. 6. Average air temperature values in agrophenological periods of field cucumber calculated for each cluster
Ryc. 6. Średnie wartości temperatury powietrza w okresach agrofenologicznych ogórka polowego obliczone dla każdego skupienia

The observed reactions of cultivated plants to changes in phenology occurring as a result of an increase in air temperature and the sum of actual insolation, depending on a species and a region of the world, are totally different – from an increase to a drop in the achieved yields [Tao et al. 2006, Caliskan et al. 2008, Wang et al. 2008, Xiao et al. 2008]. For example, in central China a rise in the maximum air temperature in spring accelerates the date of sowing and flowering and maturity of wheat and, simultaneously, reduces the plant yields. However, the same air temperature occurring in the same period but in the northwestern part of the country accelerates the date of sowing and flowering of maize, which in turn contributes to an increase in the yields of this plant [Tao et al. 2006], like in the case of cucumber cultivated in Poland; earlier agrotechnical dates and phenological phases and above-average air temperature occurring during all stages of cucumber growth and development were conducive to higher cucumber yields.

## CONCLUSIONS

1. On the basis of cluster analysis three, significantly different, groups of observations in relation to the course of growth and development, determining different volumes of cucumber yields in Poland, were isolated. The observations the characteristic of which was an average yield were classified as cluster 1, those of a large yield were classified as cluster 2 and those of a small yield were classified as cluster 3.
2. All the analysed agrotechnical and fenological dates significantly differentiated the selected clusters, the most strongly – the dates of the beginning of flowering and setting of fruit.
3. Earlier than average dates of sowing, emergence, flowering, setting of fruit and harvesting were favourable for large yields of cucumber.
4. The largest risk of gathering small crops of cucumber was when the sowing was carried out after the $20^{th}$ May and after the end of harvesting after the $15t^{h}$ September.

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## ZASTOSOWANIE ANALIZY SKUPIEŃ W OKREŚLANIU WPŁYWU TERMINÓW AGROTECHNICZNYCH I FAZ FENOLOGICZNYCH NA PLONY OGÓRKA POLOWEGO (*Cucumis sativus* L.) W POLSCE

**Streszczenie.** Celem pracy było wydzielenie na drodze analizy skupień zespołów terminów agrotechnicznych i faz fenologicznych sprzyjających dużym i małym plonom ogórka polowego odmian konserwowych w Polsce oraz ocena warunków solarno-termicznych tym zespołom towarzyszących. Wydzielono trzy grupy obserwacji, istotnie różniące się, pod względem przebiegu wzrostu i rozwoju, determinujące różne wielkości plonu ogórka. Do skupienia II zaliczono obserwacje, które charakteryzowały się dużym plonem (wynoszącym 37,7 t·ha$^{-1}$ dla plonu ogólnego i 20,1 t·ha$^{-1}$ dla plonu handlowego), a do skupienia III – małym plonem (odpowiednio 27,6 i 15,6 t·ha$^{-1}$). Dużym plonom ogórka (skupienie II) sprzyjał następujący kalendarz terminów agrotechnicznych i faz fenologicznych: siew – 14 maja, koniec wschodów – 27 maja, początek kwitnienia – 29 czerwca, początek zawiązywania owoców – 4 lipca, początek zbioru – 13 lipca, koniec zbioru – 24 sierpnia. Opóźnienie, w stosunku do terminów w skupieniu II (plony duże), terminu siewu o 6 dni, wschodów o 16 dni, kwitnienia i zawiązywania owoców o 18 dni, początku zbioru o 19 dni, a końca zbioru o 22 dni, może przyczynić się do zmniejszenia plonu ogórka nawet o około 27% i 22% odpowiednio dla plonu ogólnego i handlowego. Wcześniejszym terminom agrotechnicznym i fenologicznym, i tym samym dużym plonom ogórka (skupienie II), sprzyjały wyższe od ponadprzeciętnych wartości zarówno usłonecznienia rzeczywistego, jak i temperatury powietrza, które w okresie wegetacji średnio wynosiły odpowiednio 7,9 h i 17,5°C.

**Key words:** ogórek, temperatura powietrza, fazy fenologiczne, analiza skupień, metoda *k*-średnich

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