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EVALUATION OF THE DEVELOPMENT AND YIELDING POTENTIAL OF *CHENOPODIUM QUINOA* WILLD. UNDER THE CLIMATIC CONDITIONS OF EUROPE

Part One: Accomodation of *Chenopodium quinoa* (Willd.) to different conditions

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S u m m a r y

Based on the evaluation of selected varieties of *Chenopodium quinoa*, their requirements were identified; it was shown which varieties demonstrated the best effects in what conditions. It was found that the best varieties for Europe's conditions were E-DK-4-PQCIP and RU-5-PQCIP. E-DK-4-PQCIP variety showed the best effects under the conditions of cluster II which included e.g. Bydgoszcz (Poland) and cluster IV which included Southern European countries (Greece and Italy), while the best effects found in RU-5-PQCIP variety were identified in cluster I which included Sweden. E-DK-4-PQCIP variety in cluster II showed a very high yield of green matter and a mean seed yield, and in cluster IV – a very high seed yield and a high yield of green matter.

Key words: *Chenopodium quinoa* Willd., cultivars, accommodation, weather conditions

INTRODUCTION

Chenopodium quinoa is an interesting alternative plant due to a high product quality and low requirements, which is confirmed not only by research carried out in Denmark (Denis-Ramirez and Jacobsen, 1987), but also in other European countries (Risi and Galwej 1989; Ohlsson and Dahlstedt, 2000, Iliadis and Karyotis, 2000). The species is a south-American pseudo-cereal grown in a traditional form in the region of the Andes for more than 5 thousand years (Risi and Galwej, 1989). The most important advantages of *Chenopodium quinoa* is high protein quality (9 exogenous aminoacids), a high share of minerals, no gluten, and low climate and soil requirements. Earlier research on the introduction of this species to Poland's conditions shows to be satisfactory (Gęsiński, Kwiatkowska, 1999 a, b; Gęsiński, 2000; Gęsiński, 2000).

The working hypothesis assumes that due to low species requirements it can be grown under different conditions. However, there is a question what weather conditions are best for the cultivation of *Chenopodium quinoa* and how the cultivars evaluated get accommodated. The comparative analysis of both the effect of the weather and the effects of cultivation in European countries were compared with conditions and potential of the regions of which the species originated, namely the countries of South America.

MATERIALS AND METHODS

The experiments which form the basis of the comparative analysis of conditions and effects of *Chenopodium quinoa* Willd. cultivation in Poland and in Europe and South America are presented based on international research. Test Quinoa was performed in many countries of Europe, America, Asia and Australia. However, for the purpose of this paper, only the results for Europe and South America are reported.

The test involved research centers from Europe representing Copenhagen (Denmark), Larissa (Greece), Bydgoszcz (Poland), Uppsala (Sweden) and Valdichiani (Italy); South America was represented by: Buenos Aires (Argentina), La Paz (Bolivia), Brasilia (BraZil), Cajon (Chile), Cusco and Puno (Peru). Experimental areas were found in the vicinity of those research centers.

The analysis involved 24 *Chenopodium quinoa* cultivars bred in different centers across the world. Single-factor experiments were established in the randomized blocks design in four reps. Experiments were carried out on soil of good culture, permeable, of pH similar to neutral, class IVa. The plot area for harvest was 7 m². The fertilization dose of 60 kg×ha^{-1} N, 60 kg×ha^{-1} P_2O_5, 100 kg×ha^{-1} K_2O was applied. Seeds were sown at the rate of 17 kg×ha^{-1}, sowing depth 1 cm, row spacing 40 cm.

Not all the *Chenopodium quinoa* cultivars were ripening in all the countries. A factor limiting full development of some cultivars in specific conditions of latitude was the length of the vegetation period (G ę s i ń s k i , 2006 a, b). Therefore, seven cultivars were selected which demonstrated the full developmental cycle in the locations analyzed: RU-2-PQCIP, RU-5-PQCIP (England), NL-6-PQCIP (Holland), 02-EMBRAPA (Brazil), BAER-II-U (Chile), E-DK-4-PQCIP, G-205-95-PQCIP (Denmark).

Weather conditions were analyzed (air temperature – minimum and maximum, total rainfall, sun exposure in the months analyzed – daily mean), as well as *Chenopodium quinoa* characters (vegetation period length, seed yield, green matter yield, seed diameter, reproduction effort – ratio of the seed weight to the vegetative parts of the plant).

The evaluation of the weather conditions was made based on cluster analysis with the most distant neighbor method based on which clusters were defined (each cluster group included cultivars of similar weather conditions). At the successive stage, data unitarization was made for the characters of the selected cultivars of *Chenopodium quinoa* and the cultivation effects of these cultivars were compared with the multi-factor method – profile analysis using the 9-degree scale, where 1 stands for very low value of the character and 9 – very high value of the character (B r z e z i ń s k i , 2002).

This analysis was made based on own research (1989-2000) and the following publications: M u j i c et al., 2001; G ę s i ń s k i , 2000, 2001; I l i a d i s and K a r y o t i s , 2000; O h l s s o n and D a h l s t a d t , 2000.

In developing this analysis, Microsoft Word Microsoft Excel and Statistica software were used.

RESULTS

Based on the initial evaluation of the locations where Test Quinoa was performed in Europe and America both regarding weather conditions and the effects of cultivation of the cultivars analyzed, clear differences were identified.

Assuming that an element common for the locations where the test was performed and very much important because of the geographic locations and the climate are weather conditions which most considerably affect the growth and development of the plants, and so based on them cluster analysis was performed; it identified four groups of locations different from one another in weather conditions. Each group (cluster) combined locations most similar in that respect. Cluster I joined Cusco (Peru), Puno (Peru) and Uppsala (Sweden) (Fig. 1). Cluster II joined La Paz (Bolivia), Bydgoszcz (Poland), Copenhagen (Denmark). Cluster III clearly differed from the other locations analyzed and included Brazil (Brazil), while cluster IV joined Buenos Aires (Argentine), Cajon (Chile), Larisa (Greece), Valdichiani (Italy) (Fig.1). The minimum air temperature in Cluster I was 4.8ºC and it was the lowest minimum temperature in all the clusters analyzed (Tab. 1), while maximum temperature in cluster I was 14.7ºC and it was the lowest maximum temperature of all the clusters. The amount of

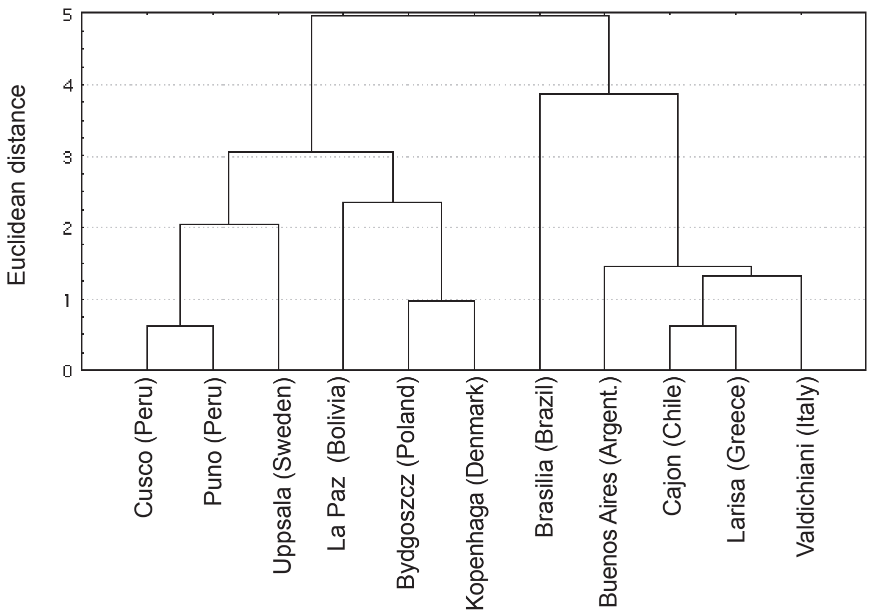

Fig. 1. Grouping of sites covered by the Quinoa Test according to the greatest similarity of weather conditions with the method of the most distant neighbor.

Table 1
Value of weather characters for the clusters analyzed.

Cluster number	Trait			
	Minimum temperature (ºC)	Maximum temperature (ºC)	Precipitation (mm)	Sun exposure (h)
Cluster I	4.8	14.7	98.2	5.2
Cluster II	6.9	18.6	44.0	7.2
Cluster III	16.7	28.1	157.5	6.3
Cluster IV	10.9	24.0	34.4	8.4

rainfall in cluster I was evaluated to be about 98.2 mm, while the number of hours of sun exposure in cluster I was 5.2 in all the clusters analyzed and it was the lowest number of sunny hours over the vegetation period of *Chenopodium quinoa* (Tab. 1).

In cluster II the minimum air temperature was 6.9ºC, while the maximum 18.6ºC and it was higher temperature than in cluster I but lower than in the other clusters. Rainfall in that cluster was estimated to be 44.0 mm, while the sun exposure was 7.2 hours.

Cluster III showed that minimum temperature was 16.7ºC and it was the highest minimum temperature in all the clusters. The maximum temperature was 28.1ºC and it was also the highest maximum temperature in all the clusters analyzed. Rainfall in that cluster was 157.5 mm and it was also the highest of all the clusters, while the number of hours of sun exposure was 6.3.

Minimum temperature for cluster IV was 10.9ºC and it was average as compared with others, while the maximum – 24.0ºC. The rainfall level was evaluated to be 34.4. mm and it was the lowest of all the clusters, while the number of sun exposure hours in that cluster was 8.4 and it was the highest number of hours with the radiation to the surface of the earth direct as compared to all the clusters analyzed.

Based on the profile analysis of seven cultivars in four clusters of different weather conditions, it was found that the cultivars differed from one another. Based on the above analysis, the best cultivars in the clusters were identified (under specific weather conditions). From the point of view of weather conditions of cluster I (Cusco (Peru), Puno (Peru) and Uppsala (Sweden), the most favorable cultivar was RU-5-PQCIP which showed a high seed yield and mean green matter yield, 02-EMBRAPA was slightly worse and demonstrated an average seed yield. The values for the other cultivars were low.

Under weather conditions of cluster II (La Paz (Bolivia), Bydgoszcz (Poland), Copenhagen (Denmark), the cultivars analyzed showed high and very high green matter yield and a low and average value of the seed yield. The best cultivar, as far as the green matter yield is concerned as well as the seed yield, was E-DK-4-PQCIP (Fig. 2) which reached the average seed yield value and a very high green matter yield. Based on the green matter yield, good effects were identified for G-205-95-PQCIP and BAER-II which showed a very high yield of green matter and a low seed yield. The other cultivars demonstrated a high yield of green matter and low of the seed yield, and in the case of 02-EMBRAPA – even a very low seed yield.

The conditions for cultivating *Chenopodium quinoa* in Brazil (cluster III) showed to be unfavorable for the cultivation of the cultivars researched. Only RU-5-PQCIP and BAER-II showed low seed and green matter yields. However, these characters were connected with the vegetation period length which was the shortest of all those analyzed. The other cultivars in Brazil demonstrated their yielding potential at the level of very low.

From the point of view of cluster IV (Buenos Aires (Argentina), Cajon (Chile), Larisa (Grecja), Valdichiani (Italy), the most favorable cultivar was E-DK-4-PQCIP which showed a very high seed yield and high yield of green matter. Slightly worse was RU-5-PQCIP which reached high values of these characters, whereas the lowest values of the characters were presented by 02-EMBRAPA which showed a low seed yield and very low yield of green matter.

Chenopodium quinoa characters in specific clusters differed depending on the weather conditions (Fig. 2, Tab. 2). Based on that, one can observe the following tendencies of changes of this species. Conditions of clusters I and II stimulate a longer vegetation period of *Chenopodium quinoa*, while clusters III and IV – a short

Table 2
Mean values of *Chenopodium quinoa* traits in the varieties analyzed in clusters.

Variety	Cluster number	Vegetation period length (days)	Seed yield (kg× ha^{-1})	Biomass (kg×ha^{-1})	Seed diameter (mm)	Reproduction effort (%)
RU-2-PQCIP	Cluster I	129.3	898.7	2972.2	1.6	76.9
	Cluster II	134	791.4	6537.9	1.7	25.0
	Cluster III	106	658.3	3169.2	1.7	20.8
	Cluster IV	109	1490	6645.6	1.6	33.5
RU-5-PQCIP	Cluster I	135	1520.9	4649.5	1.8	36.5
	Cluster II	134	838.6	6814.6	1.7	14.0
	Cluster III	102	734.2	3720.8	1.7	30.4
	Cluster IV	114	1606.0	6146.5	1.5	46.0
NL-6-PQCIP	Cluster I	130	795.1	2943.5	1.8	36.3
	Cluster II	130	842.4	6188.3	1.7	26.5
	Cluster III	128	511.7	2916.7	1.7	17.5
	Cluster IV	114	1517.0	5270.8	1.6	38.6
02- EMBRAPA	Cluster I	139	1219.6	4017.1	1.9	20.6
	Cluster II	140	599.8	6202.9	1.8	14.0
	Cluster III	101	750.8	2473.3	1.8	30.4
	Cluster IV	104	943.9	2440.5	1.4	46.0
BAER-II	Cluster I	147	1086.5	4272.3	2.0	20.3
	Cluster II	143	898.4	8284.6	1.8	24.7
	Cluster III	97	871.7	3480.8	1.9	25.0
	Cluster IV	122	877.2	5276.0	1.5	23.5
E-DK-4-PQCIP	Cluster I	133	817.0	3757.8	1.9	27.9
	Cluster II	136	1100.8	8052.1	1.9	16.7
	Cluster III	103	547.5	3497.5	1.9	15.7
	Cluster IV	117	2088.0	6724.3	1.7	40.0
G-205-95PQCIP	Cluster I	130	995.7	3797.4	1.8	32.4
	Cluster II	131	730.2	8245	1.8	13.8
	Cluster III	103	691.7	3140.8	1.7	22.0
	Cluster IV	120	1830.3	5713.0	1.7	40.9

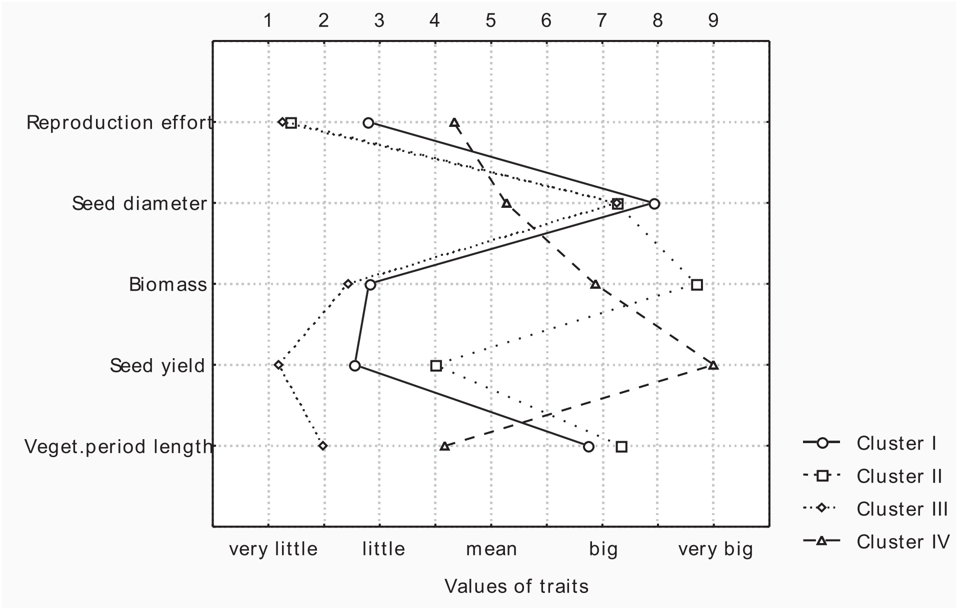

Fig. 2. The example of multi-trait profile of E-DK-4-PQCIP variety for *Chenopodium quinoa* in the clusters analyzed.

vegetation period. The highest seed yields are stimulated by conditions I and IV, and the highest green matter yield is characteristic for cluster II. Conditions of cluster IV stimulated high seed yields and the lowest seed diameter, while the lowest value of the reproduction index (about 20%) is a result obtained for clusters II and III. Neither the length of the vegetation period nor the seed diameter affected the seed yield of *Chenopodium quinoa*.

DISCUSSION

The high differences observed between the respective cultivars of *Chenopodium quinoa* in the clusters analyzed were an effect of the weather conditions.

Of all the cultivars of *Chenopodium quinoa*, the shortest vegetation period was found for the cultivars in clusters III and IV. Cluster III is represented by Brazil, while cluster IV covers the following locations: Buenos Aires (Argentina), Cajon (Chile), Larisa (Greece) and Valdichiani (Italy), which shows that *Chenopodium quinoa* goes into the generative stage faster at higher temperatures and sun exposure (Iliadis and Karyotis, 2000), and thus under conditions similar to the subtropical, Mediterranean and equatorial climates. Under temperate climate with considerably lower mean temperatures, the vegetation period gets much longer. Even though the species of *Chenopodium quinoa* has not been classified as a short-day plant and as for the photoperiod – it is neutral (Bertero et al. 1999b), the day length affects the length of respective development stages (Bertero et al. 1999a). Christiansen and Jacobsen (2006) observed that the length of the flowering and fruiting periods under short-day conditions gets much shorter.

The highest seed yield was noted in cluster IV. It showed a short vegetation period and a high value of sunshine exposure (8.4 h daily). The lowest seed yield was observed in cluster III (Brazil), mainly due to extreme weather conditions: low rainfall at high air temperature in the first months of growing, which stimulated a slight plant growth, and then high total rainfall over the last months of the vegetation (reaching even up to 350 mm per month) (Mujica et al. 2001). Grochowski (2000), evaluating the morphotype from Chile, found that an excess of water for *Chenppodium quinoa* is more unfavorable than the deficit. Evaluating this reaction in *Chenopodium album*, Sage, Sharkey and Pearcy (1990) observed a parallel decrease in air temperature, photosynthesis parameters, transpiration and WUE despite an increase in conductivity.

The greatest amount of biomass was found for *Chenopodium quinoa* cultivars in cluster II (Bolivia, Poland, Denmark) due to the longest vegetation period under these conditions, which facilitated abundant formation of green matter by the plant, which is conformed by Risi and Galwey (1989) based on the characteristics of Bolivian cultivars that *Chenopodium quinoa* under European conditions has a more abundant vegetative growth and longer vegetation period. The lowest yield of green matter was found in *Chenopodium quinoa* in cluster III (Brazil) due to the conditions there and at the same time a considerably shorter vegetation period which limited an intensive plant growth. The best adaptation to the conditions analyzed was found in E-DK-4-PQCIP and clusters II and IV. Cluster II was characterized by a very high green matter yield and a mean seed yield, and in cluster IV – a very high seed yield and a high green matter yield.

CONCLUSIONS

1. High values of sun exposure and moderate rainfall stimulate yielding of *Chenopodium quinoa*. Excessive rainfall has an unfavorable effect.
2. The most favorable characters of all the cultivars analyzed were: E-DK-4-PQCIP in cluster II and RU-5-PQCIP in cluster I.
4. The cultivar E-DK-4-PQCIP under Poland's conditions demonstrated a very high yield of green matter and a mean seed yield, and under the conditions of Italy and Greece – a very high seed yield and a high yield of green matter.

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Ocena możliwości rozwoju i plonowania komosy ryżowej (*Chenopodium quinoa* Willd.) w warunkach klimatycznych Europy

Część pierwsza: Przystosowanie *Chenopodium quinoa* (Willd.) do różnych warunków

Streszczenie

Na podstawie oceny wybranych odmian komosy ryżowej stwierdzono jakie są ich wymagania, czyli które odmiany wykazały najlepsze efekty w określonych warunkach. Stwierdzono, że najlepsze odmiany dla warunków Europy to E-DK-4-PQCIP i RU-5-PQCIP. Odmiana E-DK-4-PQCIP wykazała najlepsze efekty w warunkach skupienia II w którym była między innymi Bydgoszcz (Polska) oraz IV skupienia w którym były kraje Europy Południowej (Grecja i Włochy). Natomiast najlepsze efekty odmiany RU-5-PQCIP stwierdzono w skupieniu I w którym z Europy znalazła się Szwecja. Odmiana E-DK-4-PQCIP w skupieniu II charakteryzowała się bardzo dużym plonem zielonej masy i średnim plonem nasion, a w skupieniu IV bardzo dużym plonem nasion i dużym plonem zielonej masy. Jednocześnie stwierdzono, że wysokie wartości usłonecznienia i umiarkowane opady stymulują plonowanie *Chenopodium quinoa*. Nadmiar opadów wpływa niekorzystnie.