Studying the Adaptability of *Zea mays* ssp. Peruvian Morado and *Chenopodium quinoa* Willd. to Temperate Conditions for European Agricultural Diversification

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Abstract: Adaptability is considered as plant ability to respond positively to specific environmental conditions. Sustainable and resilient agriculture systems could mitigate the adverse effects of climate changes to ensure food supplies for a growing population. Thus, alternative crops are potential strategy to ensure the food security and increase the diversity in crop species. Alternative plant species which have been traditionally grown in Peru, Purple corn, *Zea mays* ssp. Peruvian Morado, and quinoa, *Chenopodium quinoa* Willd, were cultivated in Czech Republic. The growth of purple corn and quinoa was monitored in Žabčice experimental station. Temperate conditions affected significantly the plant growth, plant architecture and flowering induction, however, significant differences were observed between early, intermediate and late flowering varieties to long day conditions. Early flowering varieties showed potentiality to be adapted to temperate conditions. Purple corn and quinoa could be cultivated in the Czech Republic and the understanding of the response of tropical plants to temperate conditions is a first step in the plant adaptation.

Key-Words: alternative crops, *Chenopodium quinoa*, *Zea mays* ssp. Peruvian Morado, adaptability, agricultural diversification, temperate conditions, developmental stages.

Introduction

While atmospherical changes were recognized several years ago, the alteration in the earth's climate is clearly perceptible today. The planet is constantly in a state of flux, the climate is warming and weather patterns are shifting. These alterations have severe implications in the agriculture [1, 2]; therefore the actual challenge is to ensure adequate food supplies for a growing population under the changes in climatic conditions, which affect the plants especially through rising temperatures, elevated atmospheric CO_2 concentrations and changes in precipitation patterns [2, 3]. However, the domesticated crops are at a disadvantage due to the selection has been mainly done favoring traits such as high yield rather than adaptability. Moreover, the reduction of used crops increases the risk of the climate change.

The homogeneity of the used crops in the human diet is closer to a global standard composition [4]; this increase in similarity affects the human health by increasing high-energy and low-nutrients diets, [4, 5] and also produces genetic erosion in crops [6]. Micronutrient deficiency is a health problem widespread among 2 billion people in developing and in developed countries [7]. Dietary deficiencies of zinc and iron cause a loss of 63 million life-years annually [8]. The main sources of zinc and iron are C_3 grains and legumes; however, the elevated atmospheric CO_2 produced lower concentrations of protein, zinc and iron in C_3 crops and legumes, whereas C_4 crops seem to be less affected. Breeding for decreased sensitivity to atmospheric CO_2 concentration is a part of new challenges to global health [8].

The diversification of the crop scope as food source is the main approach to guaranty a balanced diet [5] and its potential to produce a sustainable and resilient agricultural system has to be recognized [9]. Decreased diversity of crops should be avoided by growing alternative crops and by greater genetic diversity of cultivated varieties [10]. Alternative crops complements and extends the range of food production. Most of them are characterized by specific qualitative properties (taste, nutrition, health, etc.), they are part of the rational nutrition, therapeutic diets and are recognized as functional food [11].

Two important and traditional Andean crops, purple corn (*Zea mays* ssp. Peruvian morado) and quinoa (*Chenopodium quinoa* Willd). have been cultivated for centuries in the Andean Region and have shown great potential as food and crop. Purple corn, is a corn landrace frequently used for people, it is an important source of anthocyanins [12]. Anthocyanins in purple corn cobs and seeds include cyaniding-3-glucoside, pelargonidin-3-glucoside, peonidin-3-glucoside and their respective malonated counterparts [13]. Purple corn is a crop with great adaptability and can be considered as a potential genetic resource for breeding to increase the spectrum of utilization.

Quinoa has been cultivated by many civilizations for over 7.000 years, it is a strategic crop that contribute to food security due to its highly nutritional composition, with a good protein quality (12.9-21.9%, depending on the variety), balanced amino acid spectrum which include a high lysine and methionine contains, carbohydrates (77.6%), lipids (6.5%), high content of a range of vitamins, antioxidants [14]. Quinoa is rich in dietary fiber and not contains gluten [15]. Its mineral nutrients contents (K, Ca, Mg, P, Zn and Fe) are much higher than those of conventional cereals [16]. This pseudo-cereal is one of the main food crops in the Andean mountains, but recently, the interest for this crop around the world has been increased. Quinoa was selected by FAO as one of the crops destined to offer food security in the next century [17]. This annual, self-pollinating C_4 plant [18], is a crop with great adaptability to the conditions of the Andes region, where the most harmful abiotic adverse such as drought, frost, soil salinity, hail, snow, wind, flooding, and heat are present. Thus, quinoa shows great drought and high salt tolerance, has a high degree of frost resistance and grows in highly acidic, alkaline, heavy metals soils [19].

This study reports the adaptability of two important and traditional Andean crops, purple corn and quinoa under temperate conditions.

Material and Methods

Experimental site and conditions

The experimental plots were carrying out on Žabčice experimental station (GPS Loc. 49°C1´18.656´´N, 16°36´56.150´´E) of Mendel University in Brno. This region is part of the geomorphological area of Dyje-Svratka river valley. The experimental station is located at corn production region, barley subtype, situated at an altitude of 184m above sea level. This area is reckoned as a very hot and dry. The average annual temperature is 9.2°C and average annual rainfall 483.3mm. Purple corn and quinoa were evaluated during 2012 and 2014, respectively.

Plant material

One variety of purple corn from Peru (PMV-581) and 9 diverse set of quinoa varieties from different sources were used in the experiment. The Danish quinoa variety Titicaca (QTC) is a hybrid between southern Chilean and Peruvian lines, bred and selected at the University of Copenhagen. Pasankalla (QP), Rosada de Huancayo (QRH), Blanca de Hualhuas (QBH) are commercial varieties in Peru; Amarilla de Marangani (QAM), Blanca dulce (QBD), Tunkahua (QT) and Blanca Sajama (QBS) are commercial varieties in Colombia and a variety Černá (QČ) commercialized in Europe.

Experimental design

Purple corn was stablished in a row of 5m length with 50 plants separated by 10cm between plants, 70 cm between rows. It was cultivated together with Czech hybrid corns. Urea was applied (100 kg/ha N) previous to the experiment and Laudis herbicide (2.25 L/ha) was applied after 23 days of sowing.

Randomized block with three replications was used in quinoa evaluation. The plots size for each replication was 3m x 1.50m. Each plot had 4 rows spaced 50 cm apart and each row had 20 plants separated at 15cm from each other. No chemical fertilizer was applied. Weeds were removed manually once in 30 days.

Parameters evaluated and data analysis

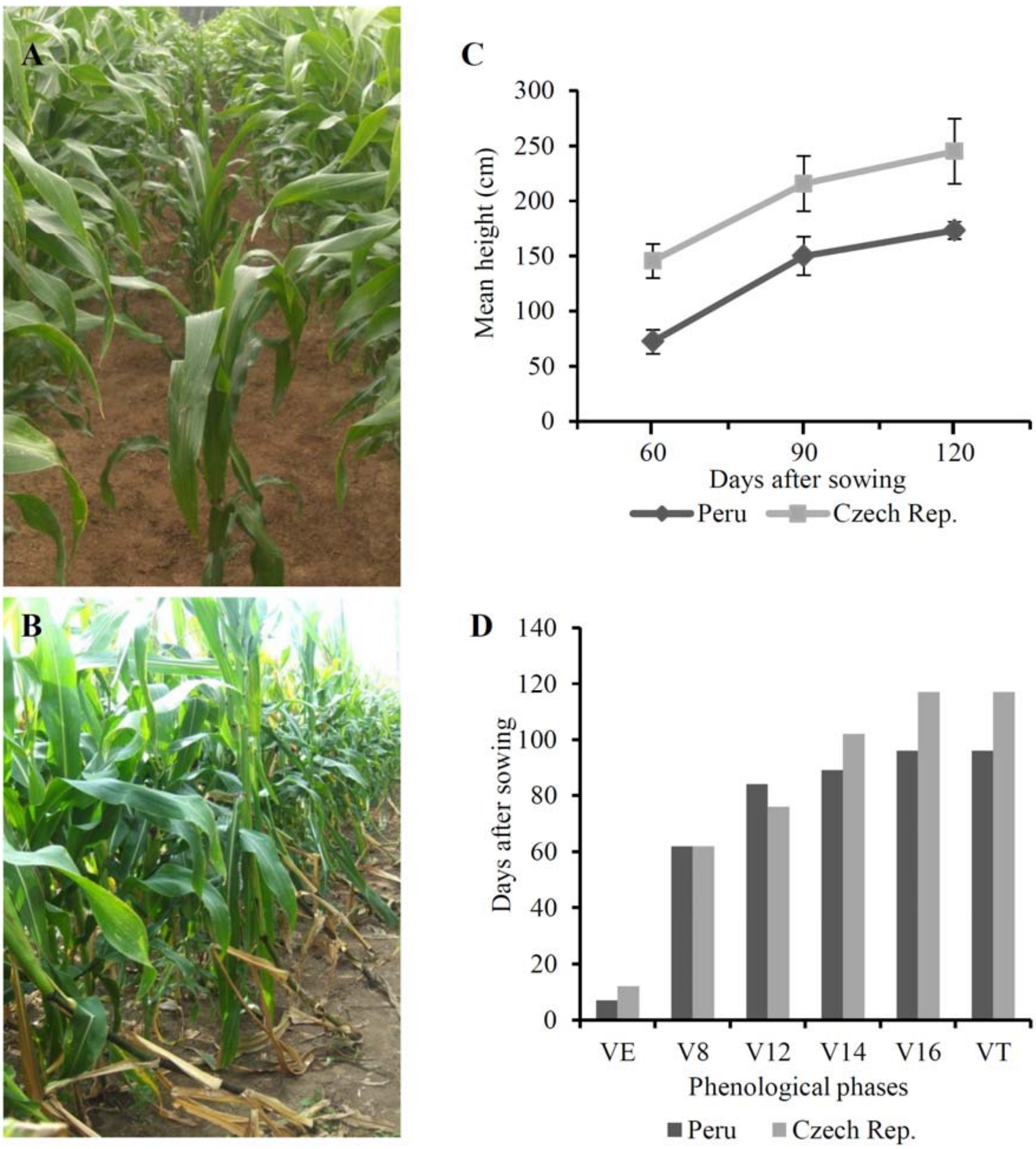
Twenty plants of purple corn were tagged and phenological and growth parameters were measured twice per month until VT phase (beginning of male flowering), according to stages of corn development previously reported [20]. The results were compared with previous studies evaluating PMV-581 variety [21, 22]. In quinoa, 30 plants per replication were randomly tagged and data was recorded every 15 days. Growth parameters were measured after establishment such as plant height, number of leaves and days to flowering. Pest infection was registered using a scale from 0 to 9 according to descriptors for quinoa [23]. Simple statistical parameters were obtained and Tukey test was used to determine significant differences using Minitab software.

Results and Discussion

Purple corn (*Zea mays* ssp. Peruvian Morado) under temperate conditions

At first date of evaluation, purple corn grown under temperate conditions slower than Czech hybrid corns, thus, purple corn plants were smaller (Figure 1A). However, the plants grown until 120 days due to a delay in the time to flowering, therefore the plants exceeded the Czech hybrid corn in plant height and bending was induced due to excessive height (Figure 1B). Similarly, the comparison with previous studies of purple corn phenology carried out in Peru [21, 22], confirmed the excessive growth under temperate conditions (Figure 1C) and delay in phenological phases (Figure 1D). Phenological phases such as emergency (VE), eight true leaves (V8), and twelve true leaves (V12) showed no significant differences, however, after fourteen true leaves (V14), sixteen true leaves (V16) and visible male flowering (VT), a significant delay was observed.

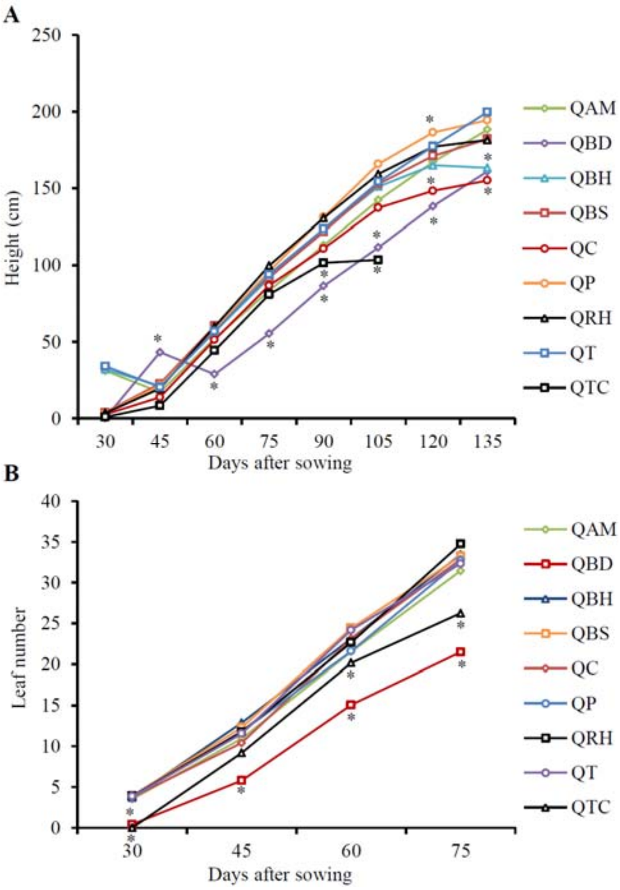
Fig. 1 Purple corn grown under temperate conditions. (A) Plants at V6 stage between Czech hybrid corns. (B) Abnormalities in plant architecture that induce bending. (C) Mean plant height of purple corn cultivated in Peru and Czech Republic. (D) Delay of phenological phases of purple corn cultivated in Czech Republic compared with Peru.



Quinoa (*Chenopodium quinoa* Willd.) under temperate conditions

Most of the quinoa varieties grew up to 150cm, being extreme values compared to these varieties cultivated in South America [24, 25], probably due to a delay in the flowering initiation. The variety Titicaca (QTC) is adapted to temperate conditions, thus, the flowering finished the plant growth at 90 days after sowing (Figure 2A).

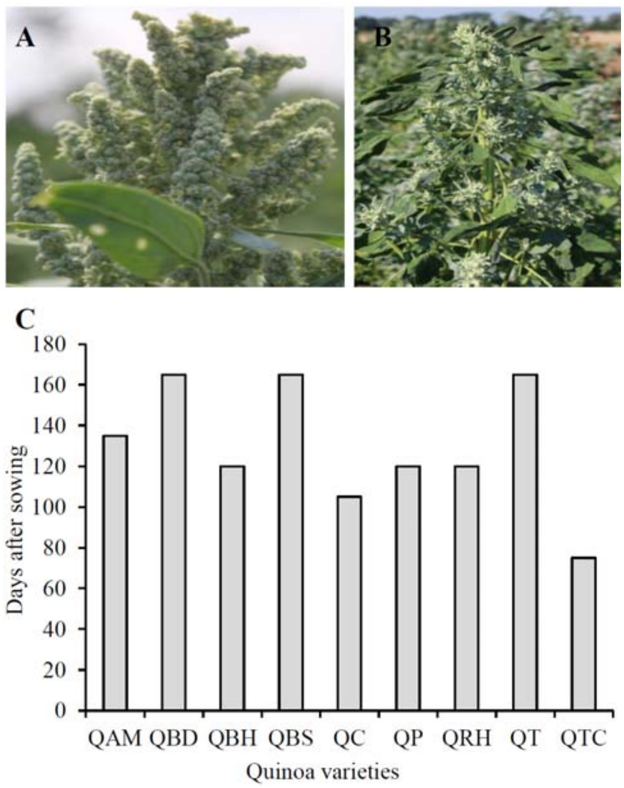
Fig. 2 Growth of quinoa varieties under temperate conditions. (A) Plant height of nine varieties of quinoa. (B) Increase of leaf number. Statistically significant differences are marked *, Tukey test $p< 0.05$.



The varieties QBH, QAM and QBD showed a reduction in the averaged plant height due to beetles infestation. QBH and QAM tolerated the pest attack, while the growth of QBD was significantly affected. The number of leaves was similar among the varieties, QBD and QTC showed the lower values, QBD due to pest infestation previously mentioned and QTC variety showed early induction of reproductive phase. These results are consistent with the differences found among several photoperiod conditions [26]. The increase in the number of leaves in quinoa plants under long day conditions was confirmed in an intermediate flowering cultivar that showed significant differences compared to short day conditions which were visible 40 days after sowing [27].

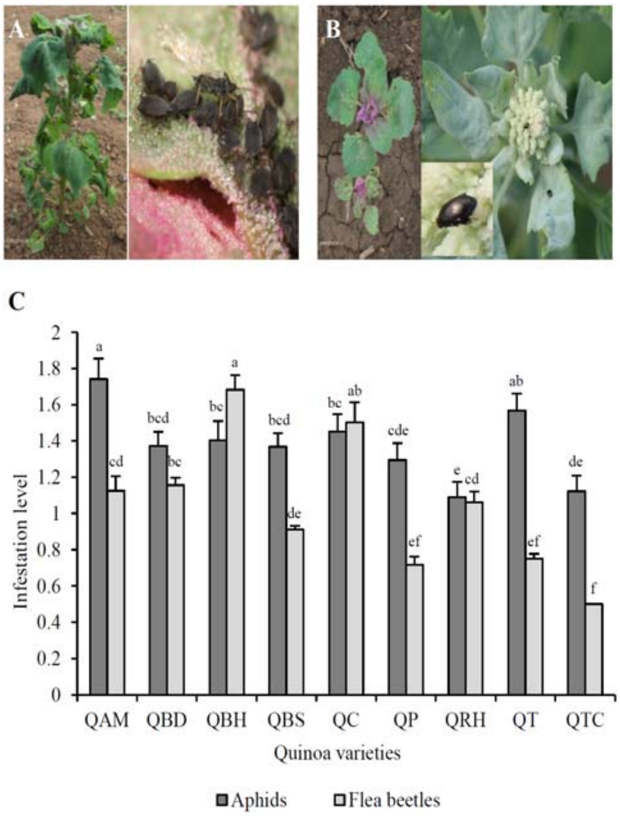
Quinoa shows three shapes of panicle, glomerulate, intermediate and amarantiform. Varieties with panicle glomerulate shows glomerules inserted in the primary axis showing a globose shape, i.e. QBS, QP, QTC. Varieties with panicle amarantiform have glomerules inserted directly in the secondary axis and have an elongated shape, i.e. QRH, QAM, QBH. Varieties with panicle intermediate show both shapes [23]. However, the inflorescence of some varieties were strongly affected by temperate conditions, producing abnormalities in its architecture (Figure 3A,B).

Fig. 3 Quinoa flowering under temperate conditions. (A) Normal amarantiform inflorescence of QBH variety. (B) Abnormal extra-laxed inflorescence of QBH variety. (C) Days to flowering of nine evaluated varieties, date at which 50% in a plot show blooming.



Flowering time was variable (Figure 3C); QTC had the earlier time of flowering as European adapted variety. The varieties QBH, QC, QP and QRH showed less than 120 days to flowering and showed potentiality to be adapted to temperate conditions.QAM, QBD, QBS and QT as late flowering varieties showed more than 140 days to flowering. The delay in flowering initiation due to long day conditions was previously reported in intermediate flowering cultivar, cv. Blanca de Junin [27].

Fig. 4 Main pests attacking quinoa under temperate conditions. (A) Quinoa plant infested with black bean aphids (*Aphis fabae*) and detailed view. (B) Quinoa plant infested with flea beetles (*Chaetocnema concinna and Ch. tibialis*) and its detailed view. (C) Infestation levels of both aphids and beetles in nine quinoa varieties. Significant differences are marked by different letters, Tukey test *p*< 0.05.



The main pests in the field were black bean aphids (*Aphis fabae*) (Figure 4A), flea beetles (*Chaetocnema concinna* and *Ch. tibialis*) (Figure 4B) and leaf-miner flies (*Agromyzidae* spp.). Beetles affected quinoa plants from emergency until four true leaves, while aphids affected later (from six true leaves until ear formation). QAM and QT were sensitive varieties to aphids attack; however, it did not pass to intermediate level of infection. Aphis are not recognized as quinoa pest in South America, however, it is an important pest in Europe [28]. QRH showed high level of tolerance to aphids. QBH and QC were more affected for beetles, and QP, QT and QTC showed lower level of infestation.

Conclusion

Temperate conditions affected significantly the plant growth, plant architecture and flowering induction. Increase in vegetative phenological phase and significant delay of flowering induction were observed in both plant species. However, significant differences were observed between early, intermediate and late flowering varieties to long day conditions. Early flowering varieties showed potentiality to be adapted to temperate conditions. Purple corn and quinoa could be cultivated in the Czech Republic and the understanding of the response of tropical plants to temperate conditions is first step in the genotype adaptation.

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