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EUROPEAN COOPERATION IN THE FIELD OF
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AGRICULTURE

Alternative crops for sustainable agriculture

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COST 814

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RESPONSE OF QUINUA (*Chenopodium quinoa* Willd.) TO FROST

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Abstract

Quinoa (*Chenopodium quinoa* Willd.) is regarded as resistant to frost, but little is known about the physiological mechanisms responsible for this character. For that reason was planned an investigation, where frost was applied at increasing intensities and durations, and at various levels of relative humidity, with the objective of determining the physiological response and yield of quinoa to increased levels of frost in three phenological phases. Initially was studied in the cotyledonous stage one cultivar regarded as susceptible and four cultivars more tolerant to frost, at three intensities (–2, –4 and –8 °C), three durations (2, 4, and 6 hours), and two relative humidities (60 and 90%), and then was compared two distinct cultivars in 12 leaf stage and anthesis. Results showed that quinoa was most tolerant to frost in 12 leaf stage, and most frost sensitive in anthesis. In the cotyledonous stage, the tolerant cultivars died after 4 hours at –8 °C with a relative humidity of 60%, while the susceptible cultivar died after 2 hours. During anthesis the tolerant cultivar was killed by –4 °C for 4 hours, at low relative humidity (60%), while the susceptible cultivar was killed already at –2 °C. Dry frost was shown to be much more harmful than frost at higher humidity.

Introduction

Frost is one of the principal factors limiting crop production in the Andean region, reducing seed yield of quinoa, one of the most important grain crops of this region, with 20–60%, or sometimes even causing a total loss (Limache, 1992; IBTA-CIID Canada, 1980). Although the frost tolerance of quinoa has been known for several centuries, very little research has been conducted on this subject. Frost resistance in wheat and barley are based on tolerance to the formation of ice outside the cells and, consequently, its tolerance to severe dehydration. Sucrose, glycine-betaine and proline may have important roles in the plants resistance to frost (Rosa, 1997; Bidwell, 1993).

Frost has a negative impact on the normal growth and development of plants, diminishing production potential (Grace, 1985; Aquize, 1987). Black frost is one of the most damaging climatic factors in agriculture, occurring at low air humidity when the dew temperature is not reached, and hence water vapor does not freeze as does the water inside the plant cell (Grace, 1985; Aquize, 1987). After sunrise temperature increases rapidly, and a sudden evaporation of ice is produced, causing death of the cells. This type of frost occurs before sunrise, lasting for 1–6 hours (Fig. 1). White frost, occuring at high relative

humidity, when air temperature at night falls to the level of the dew temperature, is less harmful (Fig. 2).

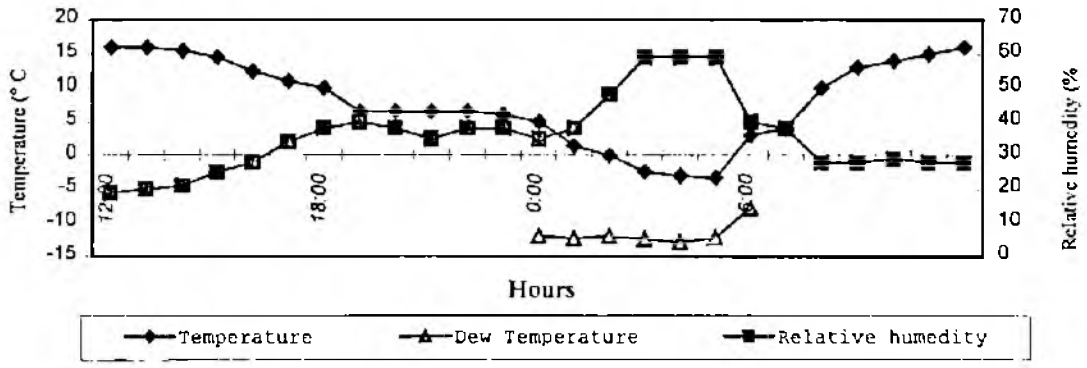

Figure 1. Black frost (Puno, Peru), May, 1996.

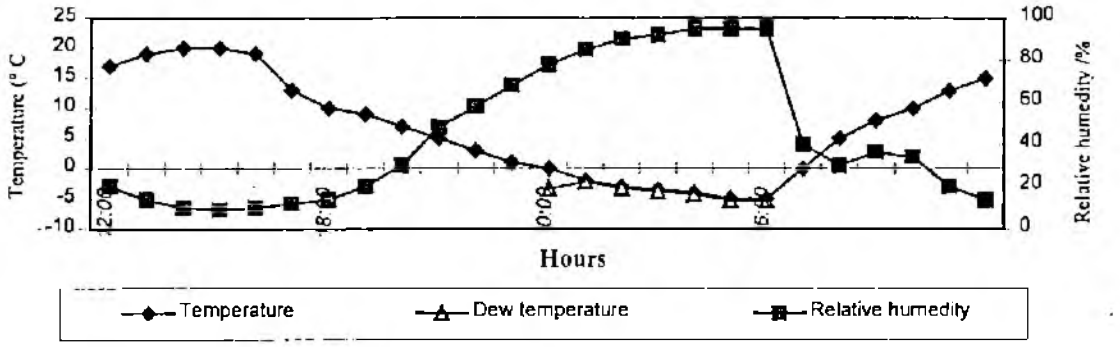

Figure 2. White frost (Puno, Peru), October, 1996.

Quinoa is a valuable genetic resource for the Andean region, but more information is needed, however, about the frost tolerance physiology of quinoa in order to better select material with improved resistance.

Materials and methods

Greenhouse and laboratory investigations were conducted at the International Potato Center (CIP), where frost was applied in a phytotron at various levels of relative humidity, intensity, and duration. The investigation was conducted as follows:

- Cotyledonous leaf stage of one cultivar, regarded as susceptible (Quillohuaman), and four cultivars regarded as tolerant to frost (Wariponcho, LB-4B, Witulla, Ayara), at three intensities (–2, –4, and –8 °C), three durations (2, 4, and 6 hours), and two relative humidities (60 and 90%) in a four factor randomized complete block design with three replicates.

- 12 leaf stage and anthesis of one cultivar regarded as susceptible and one cultivar regarded as tolerant at two intensities (–2 and –4 °C), three durations (2, 4, 6 hours), and two relative humidities (60 and 90%), in a four factor randomized complete block design with three replicates.

Each experimental unit was comprised of eight plants (two pots of 4 plants) in pots of 6 kg soil mixture made from 3 kg pot soil, 1.5 kg moss, and 1.5 kg sand. Factors to be evaluated were frost damage, according to the scale in Table 1, morphological modifications, seed yield, biomass yield, harvest index, leaf area, osmotic potential, stomata conductance, relative water content, and content of proline, glycine betaine, sucrose, and proteins.

Table 1. Frost damage.

Level	Observation
1	Plant with no apparent damage
2	Plant erect, with plasmolyzed leaves, able to recover
3	Top third of stem hanging 45°, plasmolyzed leaves, able to recover with some defoliation
4	Top third of stem hanging 90°, plasmolyzed leaves, able to recover with much defoliation
5	Top third of stem and base stem hanging 180°, strong plasmolyzis of leaves and stem; plant unable to recover (dead plant)

Results

No significant difference in frost damage between cultivars in the cotyledonous stage was seen (Table 2), although it was indicated that Quillohuaman was the most susceptible, and Ayara and Witulla the most tolerant cultivars.

Table 2. Analysis of frost damage when frost was applied in the cotyledonous stage of five quinoa cultivars.

Variables	**df**	**MS**	**Statistical significance**
Cultivar	4	1.747	Ns
Frost intensity	2	278.284	**
Frost duration	2	60.962	**
Relative humidity	1	48.981	**

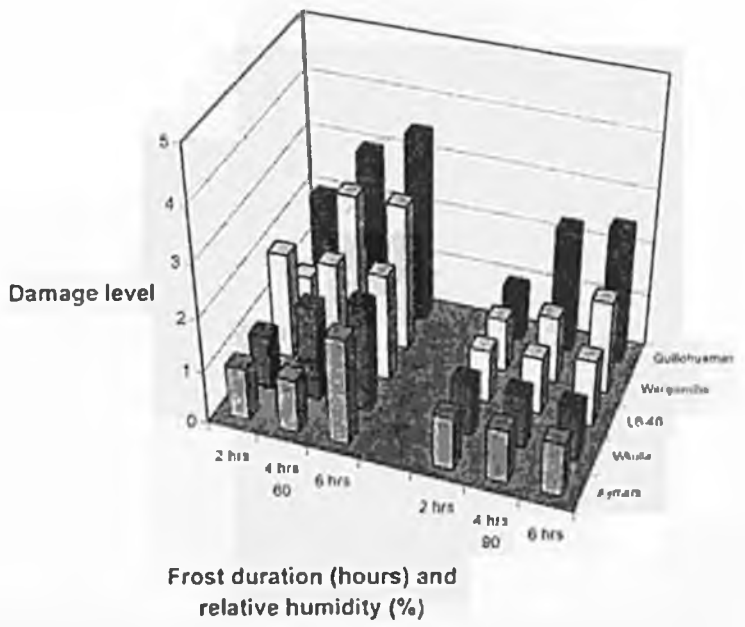

Figure 3. Frost damage of five cultivars at –4 °C in cotyledonous stage .

In the cotyledonous stage, the plants of the susceptible cultivar were affected when exposed to frost of –4 °C for 4-6 hours at a relative humidity of 60%, while there was almost no effect at 90% relative humidity (Fig. 3). At –8 °C the effect of frost was much more severe, already after 2 hours producing damage in all cultivars, and death after 4 hours, while the damage at high relative humidity was reparable (Fig. 4).

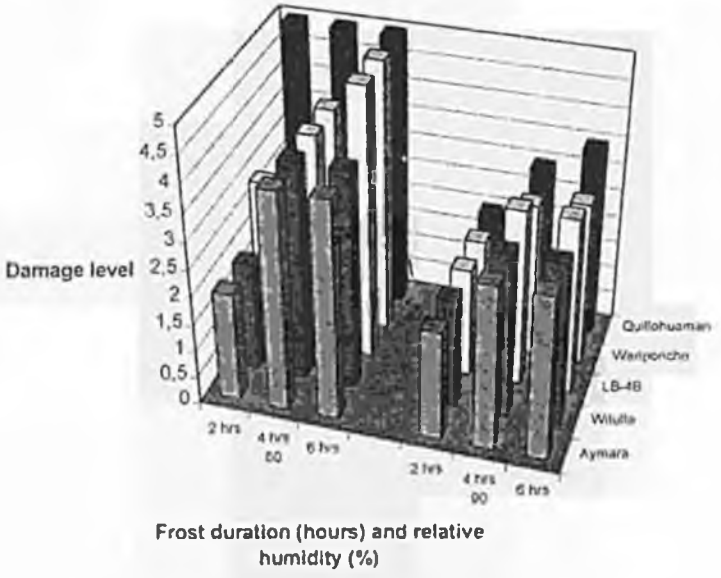

Figure 4. Frost damage of five cultivars at – 8 °C in cotyledonous stage.

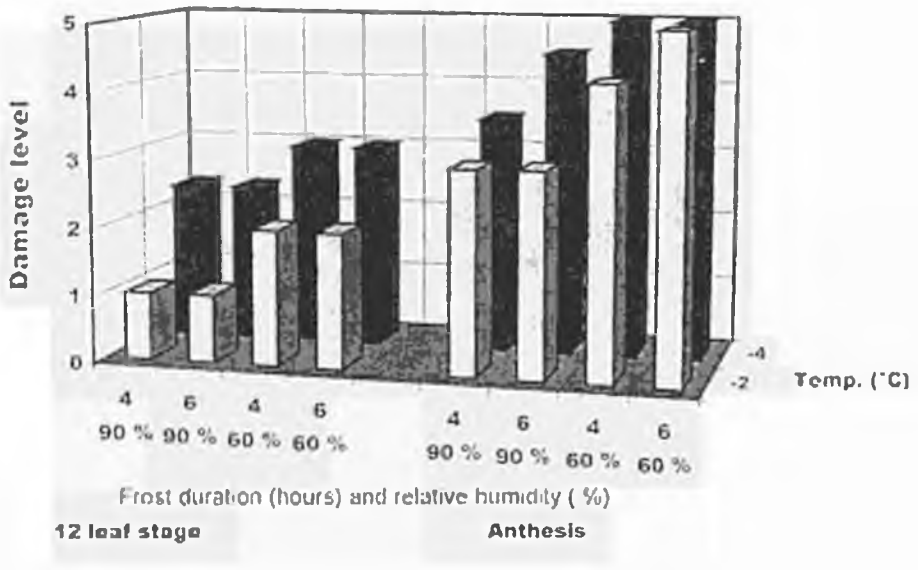

Figure 5. Frost damage in cv. Quillohuaman.

In the 12 leaf stage Quillohuaman tolerated frost of –4 °C, just a little affected at low relative humidity, but at anthesis frost of –2 °C for 4 hours, at low relative humidity, killed this cultivar (Fig. 5, Table 3).

When Witulla had 12 leaves, frost of –4 °C, even in 6 hours at 60% relative humidity had almost no effect, however, frost of –4 °C for 4 hours during anthesis killed this cultivar (Fig. 6, Table 3).

Conclusion

In the cotyledonous stage at a relative humidity of 60%, which causes a significantly stronger effect on the plants than less dry conditions, at –8 °C, tolerant cultivars died after 4h., while the susceptible cultivar Quillohuaman died already after 2 hours. Frost of –4 °C did only affect the susceptible cultivar at low relative humidity in cotyledonous stage and in 12 leaf stage. In anthesis, frost of –2 °C for 4 hours killed the susceptible cultivar, while the tolerant cultivar survived up to 4 hours of –4 °C at 60% relative humidity.

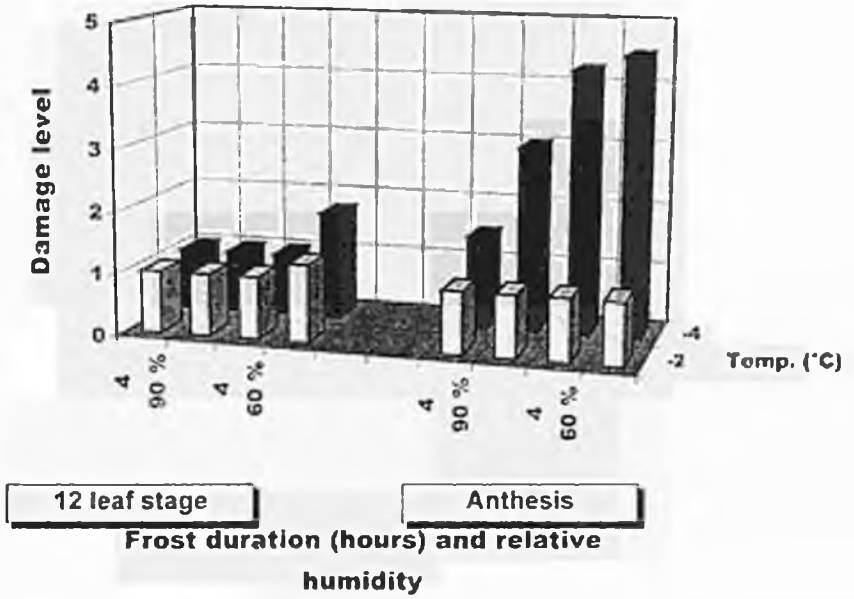

Figure 6. Frost damage in cv. Witulla.

Table 3. Percentage of dead plants of two quinoa cultivars in different phenological phases, with varying frost intensity, frost duration, and relative humidity.

Phenological phase/ Cultivar	Duration of frost (hours)	Relative humidity 90%		Relative humidity 60%	
		Temperature (°C)		Temperature (°C)	
		-2	-4	-2	-4
12 leaf stage					
Quillohuaman	2	0	0	0	0
	4	0	0	0	0
	6	0	0	0	25
Witulla	2	0	0	0	0
	4	0	0	0	0
	6	0	0	0	0
Anthesis					
Quillohuaman	2	0	0	0	100
	4	0	50	50	100
	6	25	100	50	100
Witulla	2	0	0	0	0
	4	0	0	0	100
	6	0	25	0	100

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