Journal of Agronomy and Crop Science

J Agro Crop Sci (2014) ISSN 0931-2250

MISCELLANEOUS

Quinoa in Morocco – Effect of Sowing Dates on Development and Yield

A. Hirich[1], R. Choukr-Allah[1] & S.-E. Jacobsen[2]

1 Agronomic and Veterinary Medicine Hassan II Institute, Complex of Horticulture in Agadir, Ait melloul, Morocco
2 Faculty of Science, Department of Plant and Environmental Sciences, University of Copenhagen, Copenhagen, Denmark

Keywords
growth; photoperiod; quinoa; radiations; yield

Correspondence
A. Hirich
Agronomic and Veterinary medicine Hassan II Institute
Complex of Horticulture in Agadir
80150, Ait melloul
Morocco
Tel.: +212 673 530 963
Fax: +212 528 243 333
Email: Hirich_aziz@yahoo.fr

Accepted March 26, 2014

doi:10.1111/jac.12071

Abstract

Quinoa is a highly nutritious food product, being cultivated for several thousand years in South America, and it is recently introduced in Morocco and showed a high potential of adaptation in Morocco. A field study was carried out in the south of Morocco in order to investigate the effects of sowing date on quinoa performance in a series of experiments conducted for adaptation of quinoa. The experiment took place in Agadir, with a test of 10 sowing dates, each 15 days from 1st November to 15th March. Sowing dates affected the growth and productivity due to differences in temperature, precipitation and radiation over the year. Highest seed yield and dry matter yield were obtained when quinoa sown in November and early December. The growing season length has been affected by accumulated radiation. In addition to abiotic factors (temperature, radiation, rainfall) affecting quinoa growth, biotic factors such as downy mildew and weeds affected the yield. Early sowing in November to early December secured good plant development when low temperatures occurred in January and February and downy mildew appeared in March.

Introduction

Quinoa was widely cultivated in the Andean region by pre-Columbian population, and its seeds have been used in the diet of inhabitants of the valleys and in drier areas (350 mm of precipitation) with higher altitudes (above 3500 m.a.sl) and colder temperatures (average 12 °C) such as the Altiplano. Despite being a fully domesticated species, the seeds still contain saponins, so its removal is necessary before they can be consumed (FAO 2011). The geographical distribution of quinoa in the Andean region extends from latitude 5 degrees North in southern Colombia to latitude 43° South in Chile, and its altitudinal distribution ranges from sea level in Chile to 4000 m in the Altiplano of Peru and Bolivia (Rojas et al. 2010).

Sowing is one of the most important activities of quinoa cropping because the emergence of seedlings impacts plant density and final yield. Seeds are sown, depending on location, variety, soil moisture and sowing depth (FAO 2011). In the southern Altiplano, the sowing period is from late August to early December, while in the central and northern Altiplano, planting time is between October and November, depending on rainfall (Aguilar and Jacobsen 2003).

The genetic variability of quinoa is huge, with cultivars of quinoa being adapted to growth from sea level to 4000 m above sea level (masl), from 40°S to 2°N latitude and from cold, highland climate to subtropical conditions. This makes it possible to select, adapt and breed cultivars for a wide range of environmental conditions. A major constraint for growth in northern parts of Europe, Canada and in high-altitude regions is the short growth season, because quinoa requires a maximal developmental time of 150 days in order to secure seed harvest (Jacobsen 2003). Hence, early maturity is one of the most important characteristics if quinoa is grown under these conditions. In southern Europe, in the United States and in certain parts of Africa and Asia, there is good potential for increased production of quinoa.

In Morocco, quinoa has been tested under different climate and soil conditions with varied yield according to sowing date, cultivar and soil (Hirich et al. 2012a). The seed yield of quinoa sown in Khenifra in the Atlas mountains between October and November was 3.4 t ha^{-1}

(Benlhabib 2005). In Rhamna, quinoa was sown in a silt sandy soil in February on three farms, and the obtained yield was on average 1.5 t ha^{-1}. The same yield was obtained in Rabat where quinoa was sown in April in a sandy soil (Filali 2011).

In the south of Morocco in Agadir, quinoa was cultivated in several field trials investigating the effect of deficit irrigation using treated wastewater, salinity and organic manure. Yield varied according to sowing date and the irrigation water source. Yield under experimental conditions was 7.4 and 6.1 t ha^{-1} for quinoa sown in February and April, respectively, irrigated with treated wastewater rich in nutrients (Hirich et al. 2012b,c). In the same field conditions, quinoa was sown in October with the yield of 5.7 t ha^{-1} (Hirich et al. 2013). In a field trial testing the salinity effect on quinoa sown in July, yield was 4.7 t ha^{-1} (El Youssfi et al. 2012). Those high yields are obtained at plot scale and cannot reflect the farm conditions; in addition to this, quinoa in those experiments was irrigated with treated wastewater which is very rich in nutrients and organic matter.

The objective of this study was to investigate the impact of sowing dates on quinoa growth and productivity in responses to photoperiod, radiations, temperature and some abiotic factors in order to find out the best sowing date allowing good adaptation of quinoa in the south of Morocco conditions.

Materials and Methods

Experimental set-up

The research has been conducted in the experimental field of the Agronomic and Veterinary Medicine Hassan II Institute, Complex of Horticulture in Agadir in the south of Morocco. Quinoa (*Chenopodium quinoa* Willd, accession DO708) was grown between November 2012 and June 2013. Experimental units of 8 m^2 area each were organized in a completely randomized block design with three replications for each sowing date (Fig. 1). 4 rows were established in each plot, 50 cm apart, with a rate of 3 kg of seeds per ha. All treatments have received full irrigation in their growing period in order to avoid any difference in terms of water uptake. Sowing was carried out each 15 days from 1st November to 15th March, which gives 10 sowing dates in total, and repeated three times in the experimental design.

Air and soil temperature were measured by temperature sensors installed in the middle of the experimental field at 1.5 m of height for air temperature and in each treatment plot for soil temperature.

Measurement

Plant height, fresh and dry matter of roots, leaves, stems and panicle were measured at the end of seed filling stage, with a total of 10 plants per treatment. Fresh weight was measured first, and then leaf area was measured using area measurement system. Dry matter was measured after 48 h where the biomass was dried at 60 °C. At harvest, the yields of seed and straw were measured from all plants present in the pots. The harvest index (HI) was calculated as the ratio between seed yield and total dry biomass (aboveground + roots).

Statistical analysis

Differences between response variables to applied treatments were assessed with a general linear model in the STATSOFT STATISTICA 8.0.550 software (Statistica, S. Version 8. StatSoft Inc, Tulsa OK, 74104). All statistical differences were significant at $\alpha = 0.05$ or lower. Tukey's HSD test was used to reveal homogeneous groups. Comparison of means was based on one-way ANOVA.

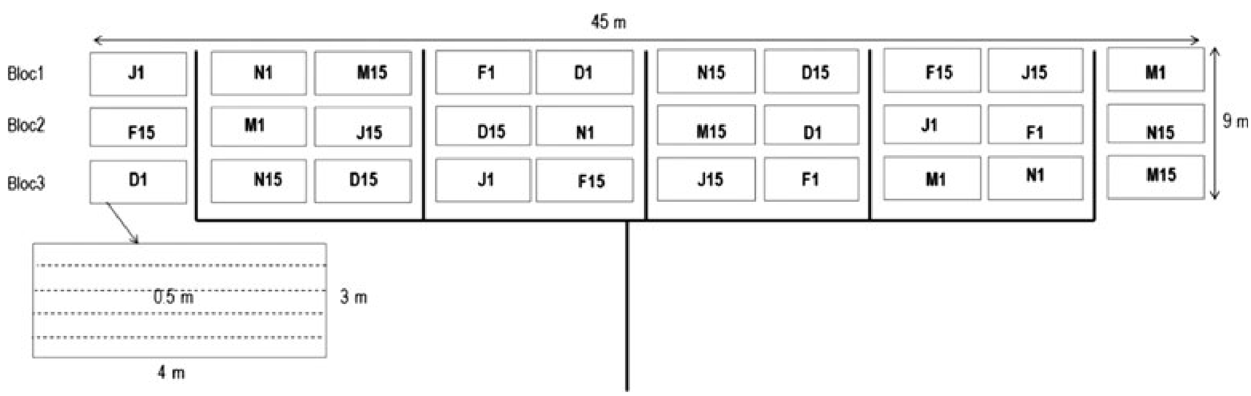

Fig. 1 Experimental design, N1: 1st November, N15: 15th November, D1: 1st December, D15: 15th December, J1: 1st January, J15: 15th January, F1: 1st February, F15: 15th February, M1: 1st March, M15: 15th March.

Results

Air and soil temperature

Air and soil temperature affect seed germination and seedling rate as well as plant growth.

Figure 2 shows air and soil temperature in the experimental field. Temperature decreased from November to December, and an average air and soil temperatures were 19.10 and 18.31 °C in November and 13.92 and 13.23 °C in December. January was the coldest month with air and soil temperature of 13.26 and 12.77 °C, respectively; the absolute minimal air and soil temperatures were −0.1 and 5.8 °C, respectively, recorded in January.

Rainfall and solar radiation

Rainfall is presented in Figure 3. March was the rainiest month with 73.6 mm of rainfall, with 47.4 mm only in 1 day. Total radiation accumulated during the day is also presented in Figure 3. It follows the same tendency as temperature where the lowest radiation was December, January and February and the highest March and April.

Growing degree days (GDD) and photoperiod

Cumulative GDD and photoperiod variation during the period of the experiment is presented in Figure 4. Photoperiod varied from November to May with the lowest photoperiod in the end of December and the highest in May. GDD was calculated based on the following formula:

$$\mathrm{GDD} = \frac{(T_{\max} - T_{\min})}{2} - T_{\mathrm{base}}$$

with T_{base} is equal to 3 °C for quinoa (Jacobsen and Bach 1998), and for many tropical crops, T_{base} is equal to 10 °C.

Growing degree days increased slightly from November to February, and then, the increasing rate started to be higher till May.

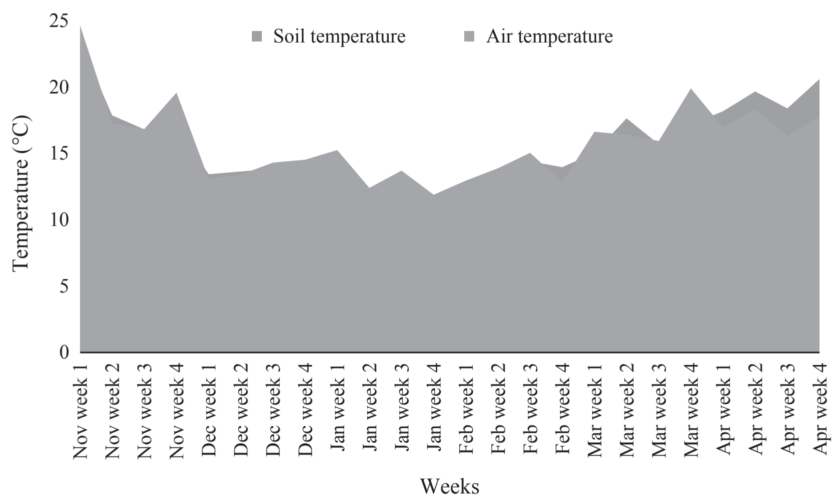

Fig. 2 Variation of air and soil temperature during the growing period.

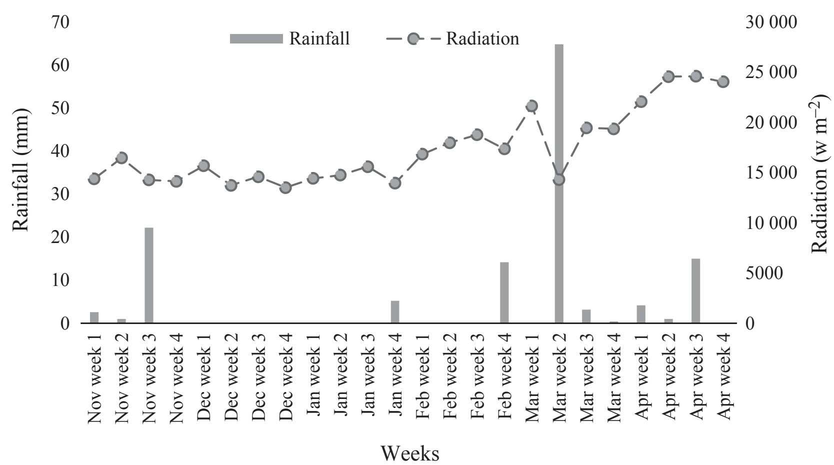

Fig. 3 Variation of rainfall and radiation during the growing period.

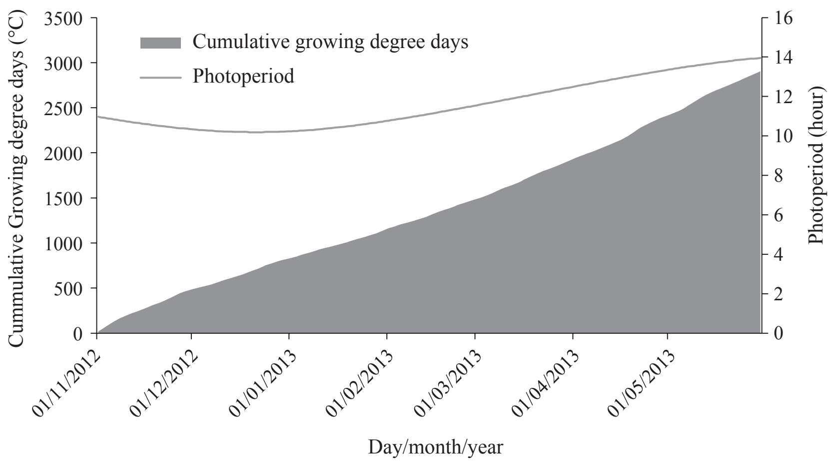

Fig. 4 Variation of cumulative growing degree days and photoperiod.

Plant height

Plant height variation for each sowing date is presented in Figure 5. There was a significant difference between tested sowing dates. The highest plant was obtained in November and December, while later January plant height started to be lower and reached its minimum for quinoa sown in March.

Yield components, biomass partitioning and growing period length

There were significant differences between sowing dates in terms of total dry matter, seed yield, harvest index (HI), dry weight of roots, shoots, leaves and panicles and growing period length (Table 1). Dry matter and yield were measured for the whole plot at the harvest time, while biomass partitioning was carried out for 10 mature plants taken from each plot.

The highest dry matter production was obtained for quinoa sown in 1st December (D1), followed by quinoa sown in November, while the lowest values were obtained for quinoa sown in January, February and March. In the later months, quinoa dry matter accumulation was dramatically reduced. Yield had the same tendency as dry matter; the highest yield was harvested when quinoa was sown in November and 1st December, while the lowest was obtained when quinoa was sown in January, February and March. Harvest index was also affected by sowing dates, and the highest HI was obtained when quinoa was sown in November and the lowest value was recorded when quinoa was sown in 1st January.

Results related to biomass partitioning indicated that quinoa sown early had the highest dry weight of roots, shoots, leaves and panicles and correlated positively with total accumulated dry matter. The longest growing season was that of quinoa sown in 1st January and the shortest was of quinoa sown in 15th March. Growing season length

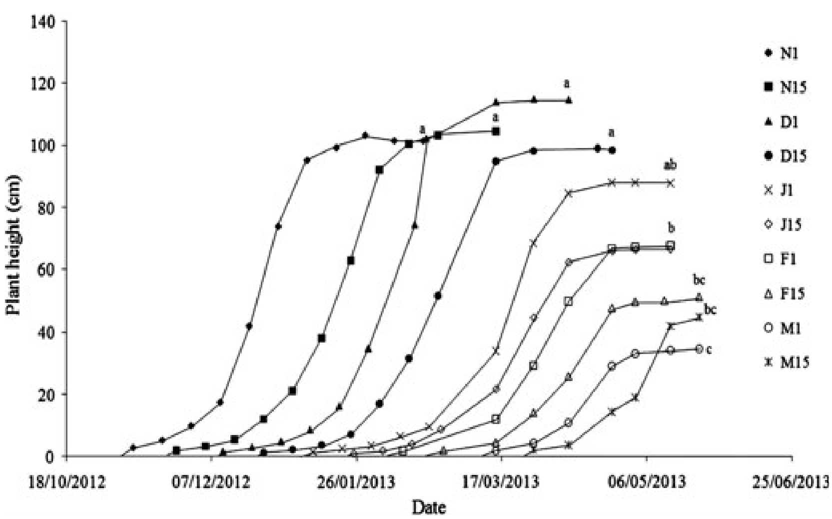

Fig. 5 Variation of plant height during the growing period, and statistical analysis was carried out for the final plant height. Any two values at a time are significantly different ($P \leq 0.05$) if they have no letter in common.

Table 1 Yield components, biomass partitioning and growing period length

Sowing date	Yield components			Biomass partitioning				Growing period Day
	Dry matter t ha^{-1}	Seed yield t ha^{-1}	HI %	Dry weight of roots g $plant^{-1}$	Dry weight of stems g $plant^{-1}$	Dry weight of leaves g $plant^{-1}$	Dry weight of panicle g $plant^{-1}$	
1st November	6.82 ab	3.03 a	0.45 a	2.29 c	10.6 b	8.84 ab	24.37 b	111
15th November	7.01 ab	3.07 a	0.43 a	5.91 a	20.96 a	11.28 a	57.47 a	121
1st December	7.89 a	2.47 a	0.31 b	5.13 a	15.64 ab	6.82 b	43.33 a	130
15th December	4.62 bc	1.03 b	0.23 bc	4.29 ab	14.07 ab	4.69 bc	35.69 ab	131
1st January	1.85 dc	0.22 b	0.12 d	2.78 c	9.7 b	0.94 d	19.06 b	134
15th January	1.24 d	0.21 b	0.17 cd	1.64 d	7.74 bc	0.72 d	17.84 b	121
1st February	1.11 d	0.2 b	0.18 cd	2.78 c	10.72 b	2.38 c	22.92 b	105
15th February	0.82 d	0.15 b	0.18 cd	1.36 d	5.32 c	1.4 d	14.86 bc	99
1st March	1.24 d	0.15 b	0.12 d	1.23 d	5.11 c	1.2 d	15.56 bc	87
15th March	0.58 d	0.13 b	0.22 bc	1.15 d	3.89 d	0.85 d	8.23 c	75

Any two values at a time are significantly different ($P \leq 0.05$) if they have no letter in common.

increased from November to January and decreased from January to March.

Discussion

Temperature is the main abiotic factor affecting quinoa growth, germination and productivity. The sensitivity to photoperiod and temperature was a function of origin (Bhargava et al. 2006, Christiansen et al. 2010, Bendevis et al. 2014). Genotypes originating from the tropics were characterized by a major sensitivity to photoperiod, whereas genotypes from sea level of southern Chile were least sensitive to photoperiod (Jacobsen 2003, Christiansen et al. 2010). This evidence indicates that, in order to characterize growth and development of quinoa, it is necessary to analyse the response to temperature and photoperiod in all developmental phases and for a large number of genotypes (Bertero et al. 1999). Our results indicate that low temperature in January and February affected negatively quinoa development and increased the growing period length. Yield and dry matter production were estimated based on the harvest of the whole plot, and thus, a reduced germination led to few plants in the plot and consequently to lower productivity. The finding supports the results reported by several researches. Quinoa germination was affected by low temperature, decreasing germination rate, leaf elongation and plant growth. Optimal temperature of growth was 22 °C, and the base temperature 3 °C (Jacobsen and Bach 1998).

Bertero (2001) found that both photoperiod (in six of nine cultivars) and temperature affected the rate of leaf appearance in quinoa cultivars, and photoperiod and temperature response functions were derived from those experiments. Long photoperiods increased the phyllochron (thermal time between the appearance of two successive leaves) in quinoa. Radiation also has an effect on quinoa growth and yield, with more radiation led to more leaf elongation and growth and consequently decrease in the growing period of quinoa. Bertero (2001) suggested that the effect of radiations on leaf elongation and quinoa growth was controlled and affected by photosynthesis availability because more light intercepted by leaf canopy of quinoa led to high photosynthetic activity. A negative relationship was found between the average accumulated solar radiation during the day and the growing period length with R^2 is equal to 78 % and between the average photoperiod and the growing period length with R^2 is equal to 51 %. This indicates that increasing solar radiations and photoperiod lead to shortening of the growing period of quinoa (Fig. 6).

The length of growing period of quinoa from southern Chile or Peru was tested in Denmark. It was observed that the range among cultivators was almost the same within a given year, but the actual growing period was highly dependent on the year. In 1991, spring and early summer were wet and cold, causing slow growth and a long growth period. In 1992, there was drought in May–June, which caused a rapid development, and in 1995, the spring was very cold, whereas July–August was dry and warm (Jacobsen 2003).

The reduced yield and growth observed in January and February can be explained by low temperature and reduced germination rate, while reduced yield of March is explained mainly as observed during the running of the experiment by mildew disease and weeds competition due to increased temperature accompanied with high rainfall rate which was increasing air humidity, the best conditions of mildew development (Věchet and Jarošík 1993, Guzman-Plazola et al. 2003, Mortensen and Gislerød 2005). The mildew affected severely quinoa especially during the initial stage (quinoa sown in March), particularly the young leaves

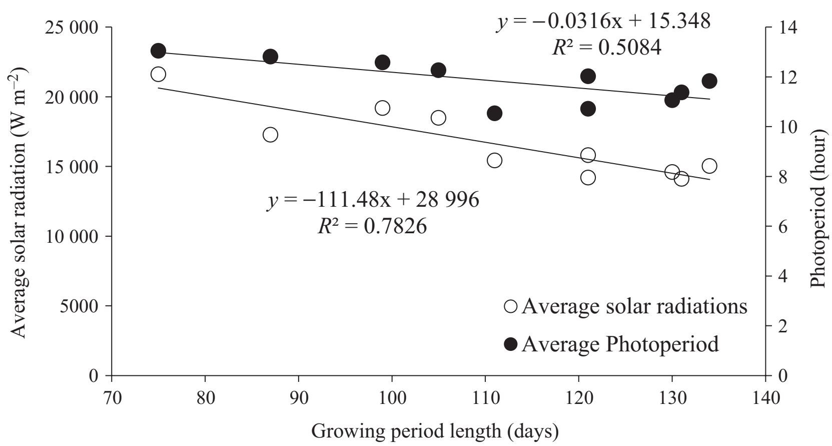

Fig. 6 Relationship between the growing period length, average accumulated solar radiations during the day and photoperiod.

which were subjected to early senescence, and consequently, plant growth and productivity decreased due to reduced leaf area and photosynthetic activity. According to Danielsen et al. (1999), Danielsen and Munk (2004), downy mildew is the most severe pathogen on quinoa and is known to cause yield reduction of 33–58 %, even in the most resistant cultivars. The mildew attack has reduced the plant height and growing season as well, and it led to early senescence of leaves.

The heavy rain recorded during 04/03/2013 caused waterlogging of quinoa seeds just sown in 1st March which was affecting their germination and seedling. Sarlistyaningsih et al. (1995) reported that germination failed to occur in lupin seeds exposed to waterlogged soil, and survival was reduced to 0 % after 4 days of waterlogging. This suggested that lack of O_2 may limit the growth of lupin seeds in waterlogged soil. The same statement is valid in the case of quinoa (Christiansen et al. 2010).

Conclusion

It was demonstrated that sowing dates had a great effect on quinoa growth and productivity, influenced by climate parameters, such as temperature, photoperiod and solar radiation, and some biotic factors. Germination and growth was affected by low temperatures in January and February, while in March with increased temperature and rainfall, quinoa was subjected to increased problems with downy mildew and weeds. Germination was inhibited by heavy rain in March which caused waterlogging. It was concluded that with sowing in November and early December, low temperatures in January and February and downy mildew in March should be avoided.

Acknowledgements

This research was funded by the EU 7th Framework Programme through the project 'Sustainable water use securing food production in dry areas of the Mediterranean region (SWUP-MED)'. We are also grateful to the technical staff of the salinity and plant nutrition laboratory and the soil water plant analysis laboratory in the IAV-CHA Institute, Agadir, Morocco.

References

Aguilar, P. C., and S.-E. Jacobsen, 2003: Cultivation of quinoa on the Peruvian Altiplano. Food Rev. Int. 19, 31–41.

Bendevis, M. A., Y. Sun, S. Shabala, E. Rosenqvist, F. Liu, and S.-E. Jacobsen, 2014: Differentiation of photoperiod-induced ABA and soluble sugar responses of two quinoa (*Chenopodium quinoa* Willd.) Cultivars. J. Plant Growth Regul. doi:10.1007/s00344-013-9406-9.

Benlhabib, O., 2005: Les cultures alternatives: quinoa, amarante et épeautre. Trans. Technol. Agric. 133, 1–4.

Bertero, H. D., 2001: Effects of photoperiod, temperature and radiation on the rate of leaf appearance in quinoa (*Chenopodium quinoa* Willd.) under field conditions. Ann. Bot. 87, 495–502.

Bertero, H. D., R. W. King, and A. J. Hall, 1999: Photoperiod-sensitive development phases in quinoa (*Chenopodium quinoa* Willd.). Field Crop Res. 60, 231–243.

Bhargava, A., S. Shukla, and D. Ohri, 2006: *Chenopodium quinoa* —An Indian perspective. Ind. Crop Prod. 23, 73–87.

Christiansen, J. L., S.-E. Jacobsen, and S. T. Jørgensen, 2010: Photoperiodic effect on flowering and seed development in quinoa (*Chenopodium quinoa* Willd.). Acta Agric. Scand., Sect. B, Soil 60, 539–544.

Danielsen, S., and L. Munk, 2004: Evaluation of disease assessment methods in quinoa for their ability to predict yield loss caused by downy mildew. Crop Protec. 23, 219–228.

Danielsen, S., S. Jacobsen, J. Echegaray, and T. Ames, 1999: Impact of downy mildew on the yield of quinoa. Scientist and farmer. Partners in research for the 21st century. CIP Program Rep. 2000, 397–401.

El Youssfi, L., R. Choukr-Allah, M. Zaafrani, T. Mediouni, M. Ba Samba, and A. Hirich, 2012: Effect of domestic treated wastewater use on three varieties of Quinoa (*Chenopodium quinoa*) under semi arid conditions. World Acad. Sci. Eng. Technol. 68, 306–309.

FAO, 2011: Quinoa: An ancient crop to contribute to world food security. In: A. Bojanic ed. Regional Office for Latin America and the Caribbean, pp. 63. Food and Agriculture Organization, Rome, Italy.

Filali, K., 2011: Caractérisation et évaluation du rendement de lignées de quinoa (*Chenopodium quinoa*) dans la région de Rhamna. Master thesis. *Biotechnologie végétale*. Institut Agronomique et Vétérinaire Hassan II, Rabat, Morocco. pp. 109.

Guzman-Plazola, R. A., R. M. Davis, and J. J. Marois, 2003: Effects of relative humidity and high temperature on spore germination and development of tomato powdery mildew (*Leveillula taurica*). Crop Protec. 22, 1157–1168.

Hirich, A., R. Choukr-Allah, S.-E. Jacobsen, and O. Benlhabib, 2012a: Could Quinoa be an alternative crop of wheat in the Mediterranean region: Case of Morocco? Les notes d'alerte du CIHEAM No. 86 – Octobre 2012, 1–8.

Hirich, A., R. Choukr-Allah, S.-E. Jacobsen, L. El Yousfi, and H. El Omari, 2012b: Using deficit irrigation with treated wastewater in the production of quinoa (*Chenopodium quinoa* Willd.) in Morocco. Rev. Cient. UDO Agrí. 12, 570–583.

Hirich, A., R. Choukr-Allah, R. Ragab, S.-E. Jacobsen, L. El Youssfi, and H. El Omari, 2012c: The SALTMED model calibration and validation using field data from Morocco. J. Mater. Environ. Sci. 3, 342–359.

Hirich, A., R. Choukr-Allah, and S.-E. Jacobsen, 2013: The combined effect of deficit irrigation by treated wastewater and organic amendment on quinoa (*Chenopodium quinoa* Willd.) productivity. Desalination Water Treat., 52, 1–6.

Jacobsen, S. E., 2003: The worldwide potential for Quinoa (*Chenopodium quinoa* Willd.). Food Rev. Int. 19, 167–177.

Jacobsen, S., and A. Bach, 1998: The influence of temperature on seed germination rate in quinoa (*Chenopodium quinoa* Willd.). Seed Sci. Technol. 26, 515–523.

Mortensen, L. M., and H. R. Gislerød, 2005: Effect of air humidity variation on powdery mildew and keeping quality of cut roses. Scientia Hortic. 104, 49–55.

Rojas, W., M. Pinto, and J. Soto, (2010): Distribución geográfica y variabilidad genética de los granos andinos. In, Roma, Italia.

Sarlistyaningsih, L., K. Sivasithamparam, and T. Setter, 1995: Influence of waterlogging on germination and survival of lupin seeds (*Lupinus angustifolius* L. cv. Gungurru) coated with calcium peroxide and streptomycin. Aust. J. Exp. Agric. 35, 537–541.

Věchet, L., and V. Jarošík, 1993: Prediction of powdery mildew epidemic in spring barley. Zentralbl. Mikrobiol. 148, 413–418.