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The Worldwide Potential for Quinoa (*Chenopodium quinoa* Willd.)

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ABSTRACT

Quinoa is a highly nutritious food product, being cultivated for several thousands years in South America, with an outstanding protein quality and a high content of a range of vitamins and minerals. Other positive aspects of quinoa are the saponins found in the seed hull and the lack of gluten. Quinoa is one of the main food crops in the Andean mountains, but during recent times there has been increased interest for the product in the United States, Europe, and Asia. Quinoa has been selected by FAO as one of the crops destined to offer food security in the next century.

The genetic variability of quinoa is huge, with cultivars of quinoa being adapted to growth from sea level to 4000 meters 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. Hence, early maturity is one of the most important characteristics if quinoa is grown under these conditions. In southern Europe, the United States in certain parts of Africa and Asia there is good potential for increased production of quinoa.

Quinoa has a significant, worldwide potential as a new cultivated crop species and as an imported commodity from South America. The main uses of quinoa are for cooking, baking, etc.; various products for people allergic to gluten; animal feed, green fodder, and pellets; modified food products such as breakfast cereals, pasta, and cookies;

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industrial use of starch, protein, and saponin; and as a game-cover crop. In developing countries of Africa and Asia, quinoa may be a crop able to provide highly nutritious food under dry conditions.

INTRODUCTION

Quinua (*Chenopodium quinoa* Willd.) has been cultivated in the Andean region for several thousand years, being one of the main grain crops supplying highly nutritious food for the farmers. This may lead quinoa to play a key role in the future (FAO, 1998).

Agriculture in the Andean highlands is characterized by a high degree of risk due to a range of adverse climatic factors such as drought, frost, wind, hail, and soil salinity. Water shortage is a major constraint to plant production due to the combined effect of low rainfall, a relatively high evapotranspiration rate, and poor soils with a low water-retaining capacity. Frost is important in the highlands of the Andes, especially in the southern part of Peru and in Bolivia, with significant diurnal temperature variations, and with frost at night up to 200 days a year. High levels of salt in the soils are of special importance in the salt deserts of Bolivia and other regions of the altiplano, but are generally an increasing problem in dry regions, where irrigation is applied.

Where drought is particularly a problem at the end of the growing season, early maturation is a strategy for minimizing the effects of drought. Early maturity is also important because of the increased risk of frost toward the end of the season, and in addition, early-maturing cultivars require less water. In dry environments, such as found in the Andes, it is important to develop sufficient biomass early in the growing season, while moisture is still available. A small improvement in early growth rate can lead to a yield increase, as growth follows an exponential pattern (Richards, 1987).

Quinoa is a crop that demonstrates a range of requirements for humidity and temperature, with different ecotypes adapted to different conditions. Some genotypes of quinoa are grown under conditions of severe drought, suggesting resistance to this adverse factor (Tapia, 1997). However, little is known about the physiological basis for the mechanisms and the actual stress levels conferred by the environment. Other cultivars are grown under more humid conditions.

The nutritional characteristics of quinoa, its rusticity, its wide adaptability, and its multiple uses, explain the interest in the crop not only in South America but worldwide. Demand for quinoa is increasing in the United States, Europe, and Asia, but the supply in the quinoa producing countries of South America is insufficient. Production and productivity of quinoa could be increased in the traditional sites of the Andes through incorporation of increased resistance to adverse factors, and sowing of larger fields of varieties attractive to the export market. New sites may be sought in South America, such as the coastal region, as well as potential new development outside the Andes. These may be identified in the American and European Test of Quinoa, organized by FAO. It is believed that an increased consumption of quinoa in the developed countries will enhance the internal, urban markets in countries with a traditional production of quinoa.

In the American and European Test of Quinoa, the potential of quinoa outside the traditional growth region of the Andes has been evaluated, with respect to production and consumption. This test includes countries from North America, Europe, Africa, Asia, and Australia. Twenty-four quinoa accessions, have been selected to comprise the seed set for the test.

INTRODUCTION OF QUINOA OUTSIDE SOUTH AMERICA

The growth and production of quinoa is not necessarily restricted to the Andean mountains. Quinoa may have a potential in other mountainous regions in the developing world, such as the Himalayas and the central mountain region of Africa (Jacobsen, 2001; Jacobsen and Risi, 2001). Initial research results from quinoa cultivation in Kenya indicate high seed quality and a yield level comparable to that obtained in the Andes, the crop's traditional area of cultivation (Mujica et al., 2001). This is particularly significant for Kenya, which relies heavily on its agricultural sector for economic growth, with about 80% of its population living in rural areas and, thus, dependent on agriculture for subsistence. Increased crop diversification is regarded as important for improving food security, and quinoa is considered a prime candidate for successful introduction and adaptation to Kenya and other African countries.

Quinoa was introduced to England in the 1970s, after which studies were started on the crop in Denmark. In 1993, a project was approved in the European Union, titled "Quinoa—A multipurpose crop for EC's agricultural diversification," with field trials in England, Denmark, the Netherlands, and Italy, in addition to laboratories in Scotland and France. Additional countries have recently shown interest in the crop, including Sweden, Poland, Czech Republic, Austria, and Greece, who are all participating in the American and European Test of Quinoa, and Finland (Iliadis et al., 1999, 2001; Keskitalo, 1997; Ohlsson, 1997).

In the United Kingdom, quinoa is sold in health food shops, but its main application is as a game-cover crop, alone or mixed with kale. A blend of early, medium, and late maturing types of quinoa is sown, mainly for game birds, such as pheasants and partridges, causing natural seed drop throughout the shooting season from October to January (Nicholls, 1996). Quinoa seed for game crops is grown successfully in the southeastern part of England. Breeding work on quinoa has been conducted at Cambridge University for more than 10 years (Fleming and Galwey, 1995; Galwey, 1989; Risi and Galwey, 1984; 1989a,b; 1991).

The wild quinoa, fat-hen (*Chenopodium album*), has since the Iron Age been a secondary crop in Denmark. More recently in Denmark, attention has been given to quinoa for people with coeliac disease as an alternative to the four cereals, wheat, rye, oat, and barley, which all contain gluten. In addition has been elaborated products, such as bread, cakes, and biscuits, for the general consumer. Projects on the production of green pellets from quinoa have been conducted (Jacobsen, 1997, 1999; Jacobsen and Bach, 1998; Jacobsen and Stølen, 1993; Jacobsen et al., 1994; 1996; 1997; Lomholt, 1996). The price to consumers of quinoa in Denmark is c. US$6/kg.

In Holland, breeding programs have lead to the first European variety, Carmen, of low stature, compact panicle, and early maturation. Work is continuing, especially with the aim of increasing yield and reducing the saponin level (Limburg and Mastebroek, 1996;

Mastebroek and Limburg, 1996; Mastebroek and Marvin, 1997). A second variety, Atlas, has recently been launched.

In the United States, pioneer work with quinoa started in Colorado 20 years ago. Current quinoa consumption in the United States is approximately 1500 t/year. The price to the grower is about US$1.8/kg. The price to the US$/kg consensus at the supermarket is about 4.0 for dehulled seeds. The products sold are dehulled grain, flour, pastas, cookies, and breakfast cereals, but new markets for industrial products have been analyzed (Johnson, 1993). Quinoa is considered a gourmet or novelty item with a high price, which may have prevented it from being used to any significant extent by the big food companies. These companies have experimented with processing quinoa in different ways, but need a large and secure supply at a low price before they will seriously consider using quinoa in their manufactured food products. Seed yield in the growing region of Colorado (c. 2000 meters above sea level) is on average 1000 kg/ha, but about 90% of the quinoa sold in the United States is imported from South America.

In addition, quinoa has been mentioned as a potential new crop for NASA's controlled ecological life support system (CELSS), which utilizes plants to remove carbon dioxide from the atmosphere and to generate food, oxygen, and water for the crew of space missions (Schlick and Bubenheim, 1996).

Results from the American and European Test of Quinoa showed that in Italy and Greece, the Danish quinoa gave the best yield, with up to 2280 and 3960 kg/ha, respectively (Mujica et al., 2001). The growth period in Greece was 100–116 days for the varieties that matured, which is in contrast to the growth period of 110–180 days in northern Europe (Table 1). In Denmark and Sweden, yields were low, and only the European and Chilean varieties matured. In Vietnam at 21°N latitude, sea level, and at temperatures from 15–30°C, the length of the growth season was only 87–96 days. Seed yield was 1125–1685 kg/ha, and biomass yield was up to almost 9 t/ha. In Kenya, the growth season was short, only 65–98 days, and all cultivars matured. Seed yields were up to 4 t/ha, with the late cultivars from Colombia and the inter-Andean valleys giving the highest yield. Biomass yields were up to 15 t/ha.

Photoperiodic Response of Quinoa

The response to photoperiod in quinoa has been described by various authors. It was found that Ecuadorian cultivars needed at least 15 short days of 10 hours to induce anthesis

Table 1. Length of growth period (days after sowing to maturity) of cultivars (cv.) of quinoa in Denmark.

cv.	1991	1992	1995
KVL233	126.74	108.5	148.67
KVL205	128.83	112.25	147.66
KVL224	134	125.25	152.33
Olav	156	125.25	155
KVL210	181.99	135	160.34

(Sivori, 1947), whereas Füller (1949) found that Bolivian quinoa cultivars would flower under a broad range of photoperiods but not under continuous illumination. The shorter the photoperiod, the faster they flowered. Although Simmonds (1965) argued that flowering in quinoa is mediated by a nutritional–genotypic interaction rather than by day length, suggesting that the more restricted the rooting space, the more quickly the plants come into flower, quinoa seems to be a quantitative short-day species, where the length of the vegetative period depends not only on day length and latitude of origin but also on altitude of origin (Risi and Galwey, 1984). Hence, experiments involving a large number of genotypes emphasized that genotypes from different origins differed in the duration of all developmental phases (Bertero et al., 1999; Jacobsen, 1997; Risi, 1986), and all cultivars of quinoa evaluated behaved like quantitative short-day plants for time to anthesis (Bertero et al., 1999). The sensitivity to photoperiod and temperature was a function of origin. Cultivars originating from the tropics were characterized by a major sensitivity to photoperiod and a longer vegetative phase. Cultivars from the altiplano of Peru and Bolivia and from sea level of southern Chile were least sensitive to photoperiod, with the shortest vegetative phase. This evidence indicates that, in order to characterize growth and development of quinoa, it is necessary to analyze the response to temperature and photoperiod in all developmental phases and for a large number of genotypes.

The photoperiodic sensitivity for seed filling plays an important role in the adjustment of plants to the Andean environment, which is a climate characterized by a growth season with water deficit or frost by the end of the season. The sensitivity permits an accelerated seed filling when photoperiod shortens. However, this characteristic limits the adaptation of quinoa to higher latitudes. Thus, the adaptation of quinoa to high latitudes has been a selection for the lack of or for less sensitivity to photoperiod in seed filling, a characteristic found in the cultivars of south Chilean origin. The knowledge of the variation in sensitivity to photoperiod, and its genetic base, allow us to obtain genotypes for sowing in high latitudes with little or no sensitivity, or for sowing cultivars in the traditional sites of the Andes with increased sensitivity.

The length of the growth period of material from Southern Chile or Peru (KVL210) was tested in field experiments in Denmark at latitude 56°N (Table 1). It was seen that the range among cultivators was almost the same within a given year, but the actual growth period was highly dependent on the year. The interaction parameter between cultivar and year was highly significant (Jacobsen, 1997). 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.

The complexity of the photoperiodic response of quinoa is such that seed filling preanthesis photoperiods and photoperiods applied after anthesis can affect seed growth, and the response to photoperiod is strongly affected by temperature (Bertero et al., 1999). The greatest inhibition of seed growth and yield was seen with a combination of high temperature and long days, and all growth stages were sensitive to photoperiod (Bertero et al., 1999).

Response to temperature and photoperiod can be quantified using linear models and assuming independent responses to these environmental factors. A model developed under controlled conditions, which has proven to be satisfactory in predicting field behavior based on the thermal time approach (Major and Kiniry, 1991) and was later adapted for quinoa (Bertero et al., 1999), can be used to quantify such responses using field data if a selected set of genotypes and environments are used. The environments should combine a range of temperatures and photoperiods from different sites and sowing dates.

In the thermal time model, which weights the effect of photoperiod on the thermal time requirement for development, it is assumed that the developmental rate during the various phenological phases, at a given photoperiod, increases linearly above a base temperature up to an optimum temperature, and then decreases linearly to zero at higher temperatures (Ritchie and Ne Smith, 1991). This behavior has also been demonstrated for the germination of quinoa (Jacobsen and Bach, 1998). Thermal time requirement for phenological phase completion is estimated as the inverse of the slope relating developmental rate and temperature in the suboptimal range. The model showed reliable responses of time to flowering to temperature and photoperiod in nine selected cultivars of different origins (Bertero et al., unpublished).

Environmental responses should be quantified from recorded daily maximum and minimum temperature data and calculations of photoperiod (Charles-Edwards, 1986). Data on the locality of origin or best adaptation of the genotypes should be collected and utilized to interpret specific responses of genotypes. This data should include latitude, longitude, altitude, historical data of rainfall intensity and distribution, number of frost-free days, frost intensity, potential evapotranspiration, length of the growing season [estimated from FAO (1985)], average temperature through the crop cycle, and crop management should be collected and utilized to interpret specific responses of genotypes, i.e., sowing, maturity and harvest dates.

The variability between cultivars in sensitivity to photoperiod and temperature for the processes determining the onset of seed filling has not been quantified, however, it has been suggested that cultivars from sea level in Chile are less sensitive to the harmful effect of high temperature and long days, which may explain its wider adaptation. The objective of this type of research is to characterize photoperiod and temperature responses of flowering of quinoa in order to understand the basis for adaptation of quinoa to different environments. The use of a range of cultivars allows us to quantify intraspecific variability in temperature and photoperiod response and their interactions, which can be used in the breeding for targeted environments.

MECHANICAL PRODUCTION OF QUINOA

The most critical period in the cultivation of quinoa is the time of establishment. It is sensitive to adverse conditions for seed germination, such as too dense a sowing, a heterogeneous or crusty seed bed, low soil temperature and low seed quality any or all of which can cause significant yield reductions. Optimal conditions are obtained by sowing high-quality seeds in a depth of 1–2 cm in a homogeneous, fine-structured, moist seed bed at a temperature of 8–10°C. The seed bed must be free from weeds at the time of sowing, because no herbicides can be recommended for use on quinoa. If sown at a row spacing of 25 or 50 cm, mechanical hoeing for weeding can be performed, and the plants will grow to suppress the weeds. Pests and diseases do not normally cause major problems, although downy mildew (*Peronospora farinosa*) is seen all years, especially under humid and warm conditions. It is of less importance when the summer is dry and cold. Early harvest is essential at high latitudes or high altitude conditions, requiring that growth starts early in the spring to avoid cold, humid autumn weather in high latitudes, rendering harvest difficult and reducing seed quality. In high altitudes, drought or night frost will be avoided by the end of the growth season. A late sowing or cold weather in the growth season may delay crop development, and thereby delay the harvest date.

COST–BENEFIT ANALYSIS FOR THE GROWING OF QUINOA

The economic result for the farmer depends on the yield and the price to be achieved for the crop (Table 2). Assuming a yield of 2500 kg/ha, the price should be US$0.6/kg, in order to obtain a result similar to spring barley. An improved result will be obtained with

Table 2. Cost–benefit analysis for quinoa.

	Amount per ha	US$ per unit	US$ per ha		
Costs					
Seed for sowing	10 kg	10	100		
Fertilizer					
N	120 kg	0.6	72		
P	50 kg	2.0	100		
K	50 kg	0.4	20		
Pesticides					
Pirimor	0.3 kg	63	19		
Synthetic pyrethroids	0.8 kg	9	7		
Other					
Drying, 20%	3000 kg	0.04	120		
Machinery					
Stubble treatment	2	27	54		
Plowing	1	94	94		
Fertilizer application	1	20	20		
Seed bed preparation	1	47	47		
Rolling	1	25	25		
Drilling	1	43	43		
Spraying	2	24	48		
Threshing	1	250	250		
Total			1019		
Benefits (US$)					
Price (US$/kg)	0.2	0.4	0.6	0.8	1
Yield (kg/ha)					
2000	−619	−219	181	581	981
2500	−519	−19	481	981	1481
3000	−419	181	781	1381	1981
3500	−319	381	1081	1781	2481
4000	−219	581	1381	2181	2981

either an increased yield or a higher price. With the available genetic material of quinoa, the estimated yield seems to be realistic for high latitude conditions, but with earlier maturing cultivars, it should be possible to reduce drying costs. If a yield of 3500 kg/ha can be achieved, the price can be reduced, making it more profitable for the industry, with satisfactory results for the farmer. The industry has to count on additional costs for dehulling, milling, etc., which must be calculated into the cost of the final product to the consumer.

FUTURE OF QUINOA

Quinoa is considered a multipurpose agroindustrial crop (Galwey, 1993). The seed may be utilized for human food and in flour products and in animal feedstocks because of its high nutritive value.

The specific advantageous properties of quinoa for industrial uses must be identified and exploited, and process technologies enabling exploitation of such properties must be developed. To be successful these products must compete with other raw materials that are often cheap, readily available, and of acceptable quality. Quinoa starch with its uniformly small granules, has several potential industrial applications. Possible industrial products suggested from quinoa are flow improvers to incorporate into starch flour products, fillers in the plastic industry, anti-offset and dusting powders, and complimentary protein for improving amino acid balance of human and animal foods. Saponins may be interesting as potential insecticides, antibiotics, and fungicides, and to the pharmaceutical industry as a mediator of intestinal permeability, which could aid the absorption of specific drugs, and for reducing the level of cholesterol.

In research programs, the entire chain from planting through product should be studied, including primary production, harvesting, storage and processing technologies, product development and evaluation, marketing studies, and economics. A multi-disciplinary approach is needed, with both the public and private sectors as participants.

Plant characteristics advantageous for the adaptation of quinoa to other growth regions of the world are available but are scattered throughout the existing germplasm. Further breeding of quinoa in new regions should concentrate on uniformity, early maturity, high yield, quality aspects, and industrial uses of the seed and of specific ingredients. The ideal variety of quinoa for seed production would be one maturing uniformly and early. A growing period of less than 150 days would normally be regarded as beneficial. Quinoa should also have a consistently high seed yield and a low saponin content, and it should be short and nonbranching to facilitate mechanical harvesting. Size, shape, and compactness of the inflorescence may be important for the rate of maturation. A large open inflorescence will dry quicker after rain and morning dew than a small, compact one, but it may also be prone to seed scattering. Fodder types should be tall, leafy, and late-maturing, with a high dry-matter yield and preferably a low saponin content.

Quinoa also may be used as a break crop in crop rotations, because it is not susceptible to cereal diseases, and only slightly susceptible to soil-borne nematodes.

Considerable variation exists between cultivars for many of the examined characteristics, so that it should be possible through selection and breeding to combine many of the desired characteristics in single cultivars, which in turn, could establish quinoa as a novel crop for agriculture in other parts of the world.

REFERENCES

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

Charles-Edwards, D. A., Doley, D., Rimmington, G. M. (1986). *Modelling Plant Growth and Development*. North Ryde, NSW, Australia: Academic Press, p. 235.

FAO (Food and Agriculture Organization of the United Nations), (1985). *Agroclimatological Data. Latin America and the Caribbean*. Rome, Italy: FAO.

FAO, (1998). *Under-utilized Andean Food Crops*. Rome, Italy: FAO.

Fleming, J. E., Galwey, N. W. (1995). Quinoa (*Chenopodium quinoa*). Williams, J. T., ed. *Cereals and Pseudocereals*. London: Chapman & Hall, pp. 3–83.

Füller, H. J. (1949). Photoperiodic responses of *Chenopodium quinoa* and *Amaranthus caudatus*. *Am. J. Bot.* 36:175–180.

Galwey, N. W. (1989). Quinoa. *Biologist* 36(5):267–274.

Galwey, N. W. (1993). The potential of quinoa as a multipurpose crop for agricultural diversification: a review. *Ind. Crops Prod.* 1:101–106.

Iliadis, C., Karyotis, T., Mitsibonas, T. (1997). Research on quinoa (*Chenopodium quinoa*) and amaranth (*Amaranthus caudatus*) in Greece. *Proceedings of COST-Workshop*., 24–25/10 1997 Wageningen, The Netherlands: CPRO-DLO, pp. 85–91.

Iliadis, C., Karyotis, T., Jacobsen, S.-E. (2001). Adaptation of quinoa under xerothermic conditions and cultivation for biomass and fibre production. Jacobsen, S.-E., Portillo, Z., CIP, eds. *Memorias, Primer Taller Internacional sobre Quinua—Recursos Geneticos y Sistemas de Producción*., 10–14 May 1999 Lima, Peru: UNALM, pp. 371–378.

Jacobsen, S.-E. (1997). Adaptation of quinoa (*Chenopodium quinoa*) to Northern European agriculture: studies on developmental pattern. *Euphytica* 96:41–48.

Jacobsen, S.-E. (2001). El potencial de la quinua para Europa. Jacobsen, S.-E., Portillo, Z., CIP, eds. *Memorias, Primer Taller Internacional sobre Quinua—Recursos Geneticos y Sistemas de Producción*., 10–14 May 1999 Lima, Peru: UNALM, pp. 355–366.

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

Jacobsen, S.-E., Risi, J. (2001). Distribución geografica de la quinua fuera de los paises Andinos. Mujica, A., Jacobsen, S.-E., Izquierdo, J., Marathee, J. P., eds. *Quinua (Chenopodium quinoa Willd.)—Ancestral cultivo andino, alimento del presente y futuro*. Santiago, Chile: FAO, UNA-Puno, CIP, pp. 56–70.

Jacobsen, S.-E., Stølen, O. (1993). Quinoa—morphology and phenology and prospects for its production as a new crop in Europe. *Eur. J. Agron.* 2:19–29.

Jacobsen, S.-E., Jørgensen, I., Stølen, O. (1994). Cultivation of quinoa (*Chenopodium quinoa*) under temperate climatic conditions in Denmark. *J. Agric. Sci.* 122:47–52.

Jacobsen, S.-E., Hill, J., Stølen, O. (1996). Stability of quantitative traits in quinoa (*Chenopodium quinoa*). *Theor. Appl. Genet.* 93:110–116.

Jacobsen, E. E., Skadhauge, B., Jacobsen, S.-E. (1997). Effect of dietary inclusion of quinoa on broiler growth performance. *Anim. Feed Sci. Technol.* 65:5–14.

Johnson, D. (1993). Blue corn and quinoa: new grain for the south-west. *New Crops News* 3(11).

Keskitalo, M. (1997). Quinoa (*Chenopodium quinoa*)—a new crop for Finland? *Proceedings of COST-Workshop*., 24–25/10 1997 Wageningen, The Netherlands: CPRO-DLO, pp. 99–102.

Limburg, H., Mastebroek, H. D. (1996). Breeding high yielding lines of *Chenopodium quinoa* Willd. with saponin free seed. *Proceedings of COST-Workshop*., 22–24/2 1996, European Commission EUR 17473/KVL, Copenhagen Copenhagen: KVL, pp. 103–114.

Lomholt, A. (1996). Biomass production of quinoa in Denmark. *Proceedings of COST-Workshop*., 22–24/2 1996, European Commission EUR 17473/KVL, Copenhagen Copenhagen: KVL, pp. 142–145.

Major, D. J., Kiniry, J. R. (1991). Predicting daylength effects on phenological processses. Hodges, T., ed. *Predicting Crop Phenology*., Chap. 4. Boca Raton, FL: CRC Press, p. 233.

Mastebroek, H. D., Limburg, H. (1996). Breeding for harvest security in *Chenopodium quinoa*. *Proceedings of COST-Workshop*., 22–24/2 1996European Commission EUR 17473/KVL, Copenhagen Copenhagen: KVL, pp. 79–86.

Mastebroek, H. D., Marvin, H. J. P. (1997). Content of sapogenins in leaves and seeds of quinoa (*Chenopodium quinoa* Willd.). *Proceedings of COST-Workshop*., 24–25/10 1997 Wageningen, The Netherlands: CPRO-DLO, pp. 103–115.

Mujica, A., Jacobsen, S.-E., Izquierdo, J., Marathee, J. P. (2001). *Resultados de la Prueba Americana y Europea de la Quinua*. FAO, UNA-Puno, CIP, p. 51.

Nicholls, F. H. (1996). New crop in the UK: from concept to bottom line profits. Janick, J., ed. *Progress in New Crops*. Alexandria, VA: ASHS Press, pp. 21–26.

Ohlsson, I. (1997). Quinoa—a potential crop for Sweden? *Proceedings of COST-Workshop*., 24–25/10 1997 Wageningen, The Netherlands: CPRO-DLO, pp. 93–97.

Richards, R. A. (1987). *Physiology and the Breeding of Wintergrown Cereals for Dry Areas*. UK: John Wiley and Sons Ltd..

Risi, J. (1986). Adaptation of the Andean Grain Crop Quinoa for Cultivation in Britain Ph.D. Thesis, 338.

Risi, J., Galwey, N. W. (1984). The Chenopodium grains of the Andes: Inca crops for modern agriculture. *Adv. Appl. Biol.* 10:145–216.

Risi, J., Galwey, N. W. (1989a). The Chenopodium grains of the Andes: a crop for temperate latitudes. Wickens, G. E., Haq, N., Day, P., eds. *New Crops for Food and Industry*. London/New York: Chapman & Hall, pp. 222–234.

Risi, J., Galwey, N. W. (1989b). The pattern of genetic diversity in the Andean grain crop quinoa (*Chenopodium quinoa* Willd.). I. Associations between characteristics. *Euphytica* 41:147–162.

Risi, J., Galwey, N. W. (1991). Genotype × Environment interaction in the Andean grain crop quinoa (*Chenopodium quinoa* Willd.) in temperate environments. *Plant Breed.* 107:141–147.

Ritchie, J. T., Ne Smith, D. S. (1991). Temperature and crop development. Hanks, J., Ritchie, J. T., eds. *Modeling Plant and Soil Systems*. *Agronomy monograph 31*. Madison, WI: ASA, CSSA, and SSSA, pp. 5–29.

Schlick, G., Bubenheim, D. L. (1996). Quinoa: candidate crop for NASA's controlled ecological life support systems. Janick, J., ed. *Progress in New Crops*. Alexandria, VA: ASHS Press, pp. 632–640.

Simmonds, N. W. (1965). The grain chenopods of the tropical American highlands. *Econ. Bot.* 19:223–235.

Sivori, E. M. (1947). Fotoperiodismo en *Chenopodium quinoa*. Reaccion de la cigota y gametofito femenino. *Darwiniana* 7:541–551.

Tapia, M. (1997). *Cultivos andinos subexplotados y su aporte a la alimentación*. Santiago, Chile: FAO-RLAC.