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Quinoa *(Chenopodium quinoa Willd)* an important Andean food crop

Jenny Ruales [1,2] and Baboo M. Nair [1]

INTRODUCTION

Quinoa *(Chenopodium quinoa willd)* is one of the indigenous foodcrops of the Andean region of Latin American. Archeological evidence (1,2,3) shows that the chenopods were cultivated on the Andean Mountains 2.000 to 4.000 years ago. They have also been used in Europe as grain, and some species are still grown in some areas of north-west India. The seeds of *Chenopodium album* were used as food by the inhabitants of Russia, the Denmark, Greece and the Northern parts of Italy (4).

Unlike potatoes and maize, quinoa was ignored by the Spanish conquistadores and this rejection continued until recently. It was only in 1965, some research to improve different varieties and their cultivation methods in Perú and Bolivia was initiated (5).

Fig. 1
Geographical distribution of quinoa in Latin America

Production of Quinoa in Ecuador, where it is cultivated between 600 to 4.000 m above the sea level, has increased during the eighties. In 1986 the National Research Institute of Agronomy (INIAP) distributed two cultivars (cv. Cochasqui and cv Imbaya) to the farmers as a parts of the National quinoa development program. Debittered quinoa seeds for human consumption are now exported from Ecuador.

Growing conditions

Quinoa grows well at altitudes of 2.000 to 4.000 meters above sea level, from 5 ºN to 30 ºS. In central Chile it is cultivated at sea level, between 36 ºS and 40 ºS. It is resistant to frost and able to develop well and vigorously in places where the annual rain fall is between 200 and 400 mm (4-6). The yield of quinoa can vary between 450 Kg/Ha and 5.000 Kg/Ha depending on the variety and growing conditions. It matures in 5 to 6 months producing an abundance of white or pink seeds. One kilogram of quinoa contains about 300.000 seeds (4).

Clasification

Quinoa belongs to the phanerogams, centrospermae and to the genus *Chenopodium* which has a world-wide distribution and comprises of above 250 species. Among its relative the following are the most common ones: C. Album L. (Lamb's- quarters or pigweed); C. ambrosioides L. (American wormseed); C. Bonus Henricus L. (Good-King Henry); C. Botrys L. (Jerusalem oak or ambrosia); and C. capitatum (L) Asch. (Strawberry blite) (4,7). Tapia and co-workers, (8) classified quinoa in the following ecotypes.

- Valley ecotype (Blanca de Junin, Rosada de Junin, Amarilla de Maranganí, Dulce de Quitopamba and Dulce de Lazo): These types are grown in Andean valleys between 2.000 m and 4.000 meters above sea level. The plants are generally branched and are 2 to 3 meters tall. The growth period is about 7 months.

1 Dept. of Applied Nutrition and Food Chemistry Chemical Centre. University of Lund Box 124 S-221 00 Lund, Sweden.
2 Instituto de Investigaciones Tecnológicas Escuela Politécnica Nacional Box 17 1 2759 Quito, Ecuador.

- Altiplano ecotype (Cheweca, Kancolla and Blanca de Julí): This type of quinoa grows well around Lake Titicaca at about 4.000 meters above sea level. The quinoa plants are 1 to 1.8 meters tall and have very few branches. The growth period varies from 4 to 7 months.

- Salar ecotype: This is grown at an altitude of 4.000 m in salty soils of pH 8.0. The seeds are black, with a very high content of saponins. The variety Real is the most important in this ecotype.

- Sea Level ecotype: Mainly Chilean varieties. They grow at latitudes around 40 ºS. In Cambridge, England this variety grew about 2 m tall. The seeds were small, yellow and with a high content of saponin.

- Subtropical ecotype: This ecotype is found in the subtropical area (Yungas region) of Bolivia. The plant produced very small, yellow-orange grains.

Morphology of the quinoa plant.

Quinoa is a gynomonoecious plant. Its height may vary from 0,7 to 3,0 m, depending on the variety and the environment.

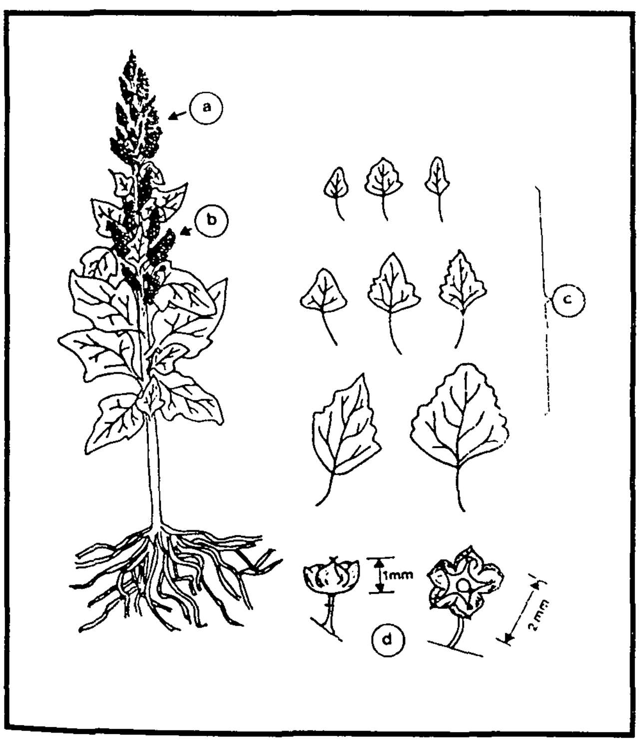

Fig. 2
Quinoa plant. **a.** terminal inflorescence; **b.** Axillary infloresce; **c.** variation in leaf shape: top, apical and bassal leaves; **d.** Flowers. Adapted from Risi and Galwey, (4) and Simmonds (9)

The germination of the quinoa seeds starts a few hours after being exposed to moisture. First, the radicle grows to form a tap root from which the secondary and tertiary roots develop. The root depth is related to the plant heigth and it can reach a depth of 30 cm.

The stem is cylindrical, becoming angular due to the leaves and branches. The leaves are alternate on four sides. The number of branches and the height depend on the variety and the sowing density. The cortex of the stem is tough, but the medulla is soft when the plants are young, and dry and spongy when the plans are mature. The colour of the stem depends on the variety. It may change at maturity to pale yellow or to red in some varieties. The red colour of the stem is due to the betacyanins (9-11).

The leaves are borne on long and narrow petioles which are channeled on their upper side. The lamina has three main veins, which originate from the petiole. The leaves on young plants are green, but as the plant matures, they become yellow or red (11).

The flowers are clearly differentiated on the plant. The panicle emerges on the upper part, and does not have branches. The compact panicle has secondary axes and short petioles. The principal axis of the inflorescence is round in cross section like the stem, and has two parallel channels on each surface. The flowers form groups along the principal axis or the secondary axes (9,11).

Quinoa flowers are incomplete as they have no petals. Quinoa has female and hermaphrodite flowers (12). The hermaphrodite flowers are located at the distal end of a group and the female flowers at the proximal end (11).

Morphology of the quinoa seeds

The fruit of the quinoa is an achene, covered by a perigonium, which is easily removed by rubbing when dry. The pericarp is the outer layer in the form of alveolar cells. On the outer layers, some saponins with bitter taste are present. The bitterness can be removed by dry polishing, by washing with water, or by a combination of both. The remaining bitterness after processing was found to be correlated with remnants of the pericarp, confirming that some saponins are also located in the pericarp (13-16).

The pericarp is transparent, white, orange, red, brown, gray or sometimes black. The next layer is called episperm, which can be white, transparent, brown or black. The embryo is about 60 percent of the volume of the episperm, and the endosperm about 40 percent of it. The high proportion of embryo is the reason for the proporcionately high protein content of quinoa, in comparison with cereals. Quinoa seeds may be cylindrical, conical or ellipsoidal in shape. The seeds vary in size from 1.5 to 3.0 mm, and contain varying concentrations of saponins.

The colour of the seeds is the result of the colour of the pericarp (outer layer). Gandarillas (17), reported that the ancestral colour of the quinoa seed was black.

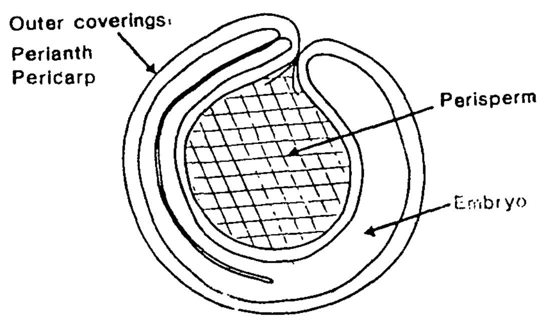

Fig. 3
Quinoa seed

When fruits fall off the quinoa plant, the seeds are often still enclosed in the perianth. The cells of this layer are easily removed by scrubbing and washing with water. A correlation was found between the bitterness remaining after the process and the presence of remnants of the pericarp. In some varieties, seeds has a purple colour, characteristic of betacyaninis. Examination of the surface exposed on cutting the quinoa seed perpendicular to the plane of the coltyledons showed the embryo and starchy perisperm covered by the pericarp and seed coat layers. Beneath the pericarp there are two layers of seed coat. One is about 20 µm thick, and contains polygonal starch granules and other electron dense bodies (15). Cabrera (16) reported a second layer of seed coat. The cells in this layer are located perpendicular to the longitudinal axis of the seed with spaces between the cells.

The mature embryo is dicotyledonus. It differs from the cereal grains in that it surrounds the perisperm. Electron microscopic studies revealed a complex structure containing lipid bodies, protein bodies, nucleus and other organelles, which are necessary for the germination process (14-16).

The perisperm contains the nutrient reserves for the developing embryo. It is situated at the centre of the seed. The presence of starch granules in the perisperm has also been reported (15).

Chemical composition of quinoa seeds

Table 1 shows the average of the chemical composition of 20 ecuadorian quinoa cultivars (18). The protein, fat and ash contents in quinoa seeds are higher than those found in wheat, barley, maize and rice.

The whole grain of quinoa contains very little cell wall material or lignin as compared to corn, wheat, or barley grains (19).

Starch and other carbohydrates

The starch content range from 57.5 to 65.2 % of dry matter. It depends on the variety and the method of analysis (20-22). The starch granules are polygonal units. They have a size distribution of 0.6 to 8.0 µm, for pure quinoa starch (21). Several authors (15,16) reported the presence of starch granules in the perisperm. Wolf et al. , (20) indicated that the starch from *Chenopodum quinoa* could be coloured blue with iodine-potassium iodine solution and that one gram of starch could absorb 45 mg of iodine.

Observation of starch granules under the electron transmission microscope show two groups of starch granules based on the size in the perisperm: one group of granules with a diameter of 0.5 µm in size; and a second group of granules with a diameter of 1.3 µm (15). Starch granules appear as simple separate units and also as part of spherical or oblong aggregates. Protein matrix was found to surround single starch units and the aggregates. The presence of protein and the way how it is modified the availability of quinoa starch to α - amylose. The starch aggregates comprise of 14.000 compact granules, and are between 18 to 20 µm in size (15).

An investigation carried out by Atwell at al., (21), showed that the X-ray diffraction pattern of native cereal starches was also found in quinoa starch. Furthermore, DSC analysis indicated an onset temperature of gelatinization of 50 ºC and ΔH of 0.4 cal/g starch. These data are similar to those reported by Wootton and Bamunuarachchi for wheat starch, (23).

Atwell et al., (21) also studied the loss of birefringence of quinoa starch by polarized light microscopy. At

TABLE 1
Chemical composition of quinoa seeds of 20 ecuadorian cultivars
(g/100 g dry matter)

	RANGE	MEAN
Protein	15.80 - 19.31	16.46
Ash	2.50 - 3.83	3.45
Fat	7.30 - 9.11	8.52
Crude fibre	5.97 - 7.27	5.60

64 ºC quinoa starch lost birefringence. Quinoa starch amylogram studies indicated that the swelling of the granules occurred at the same time as the gelatinization measured as loss of birefringence.

Wolf et al., (20) reported that quinoa starch gelatinized over a lower temperature range than wheat starch. The two non-waxy Chenopodium starches studied yielded no gel on standing. Similar characteristics have also been observed in other small granule starches as in rice.

Further, quinoa starch showed higher values of viscosity than wheat starch in the amylogram curves. Atwell et al., (21) also reported no loss of viscosity when the temperature was held at 95 ºC for 30 minutes. During cooling, the curves indicated increased viscosity. Further analysis of quinoa starch indicated that it con-sists to 11% of amylose. This is low in relation to the amylose content of other cereals. Studies of debranched quinoa starch found that it had a similar structure to the amylopectin from wheat, rice, oats and maize. The mean chain length (CL) of quinoa amylopectin was reported to be 27 compared with 26 for rye amylopectin (21). Quinoa starch granules do not have concentric rings as are usually observed in cereal starch grains. This suggests that there is a special arrangement of amylose and amylopectin molecules within the quinoa starch granules.

Varriano-Marston & DeFrancisco (15) reported that during germination there is no widespread amylolytic action on quinoa starch granules. The electron microscopic observation of the seeds after 24 hours of germination showed no evidence of significant change in the structure of the perisperm. However, some starch granules of the hilum showed to be affected by the amylolytic action. This has been interpreted as starch being protected from enzyme hydrolysis by its polygonal structure, its small size and aggregated nature of the starch granules. Lorenz and Nyanzi (24) reported high α - amylase activity in quinoa seeds, when they were polished to reduce their saponin content. They also reported the presence of high activity for total amylase, cellulase and hemicellulase.

The published literature contains only little information on the content of other carbohydrates. De Bruin (22) reports the content of total carbohydrate in quinoa to be between 67 and 74% of the dry matter. Out of this the monosaccharides and the disaccharides constitute about 2% and 2.3%, respectively of the dry matter. The crude fibre content was 2.5 to 3.9% and pentosans 2.9 to 3.6%.

Protein and amino acids

The protein content in quinoa seeds ranges from 12 to 20% (19,22,25). The major proportion of the protein is located in the embryo, which surrounds the quinoa perisperm. In the perisperm a protein matrix surrounds starch granules and joins them to each other (15).

Transmission electron micrographs of the cells of the cotyledons showed protein bodies, lipids, the nucleus and organelles, forming a complex structure. However, in the

TABLE 2
Amino acid content of quinoa seeds and some other foods
(mg amino acid/g N)

Amino Acid	**Quinoa a**	**Wheat b**	**Oats c**	**Rice d**	**Milk e**
Cystine	175	100	170	76	48
Methionine	156	90	100	160	170
Aspartic acid	431	250	520	550	500
Threonine	269	160	210	200	260
Serine	238	300	340	340	360
Glutamic acid	638	1950	1320	950	1330
Proline	188	670	330	270	630
Glycine	419	210	340	280	125
Alanine	256	190	310	360	230
Valine	313	280	370	410	450
Isoleucine	325	240	250	270	390
Leucine	413	430	450	510	630
Tyrosine	106	135	190	230	240
Phenylalanine	281	300	330	320	320
Lysine	394	140	260	230	730
Histidine	200	135	140	150	185
Tryptophan	48	65	82	80	82
Arginine	406	220	400	480	220

a. Cardozo et al., (27); Mahoney et al., (19); Telleria et al., (28); White et al., (6); Gross et al., (25). **b.** Wheat flour; **c.** Oats flour; **d.** Rice flour; **e.** Standard milk, 3% fat. (Statens Livsmedelsverk, (29).

perisperm protein bodies were not observed. The protein matrix of some protein bodies is granular. Table 2 shows the amino acid composition of quinoa seeds and of some food items.

The protein of *Chenopodium quinoa Willd* contains a relatively high amount of lysine and sulfur-containing amino acids, in contrast to cereal proteins which are deficient in the amino acids (4,6,19). Analysis of the seeds from different quinoa varieties indicated that the Sajama variety contains less methionine than other varieties. The Blanca variety contains less lysine. Methionine and tryptophan were the limiting essential amino acids. No correlation was found between the amount of saponins and the proteins (30).

White et al., (6) evaluated the protein quality of quinoa. In the first experiment, six young rats were fed on diets of whole quinoa (free of saponin) for 50 days. The diets were supplemented only with vitamins A and D. The results showed that the protein of quinoa was of high quality, supplying the rats with sufficient amino acids to increase their weight by 258 g and to reach an average weight of 334 g In another experiment, the nutritional quality of the protein was compared to that of skim milk powder. The experiment was carried out with 30 rats 35 days old. They were divided into six groups of five rats each.

Food and water was given ad libitum. After 54 days the rats which had received 6% quinoa protein in their diet gained significantly more weight than the other group fed with 6% milk protein. However, the same experiment showed that supplementing the quinoa with a small amount of milk protein did not produce an improvement in the amount of weight gained by the rats.

Mahoney and co-workers, (19) evaluated the quality of the quinoa protein of the Sajama variety. The experiments were carried out in terms of the response of rats and also of the amino acid composition. The protein efficiency ratio (PER) and the nitrogen efficiency for growth (NEG) and weight gain were improved by 29%, 40% and 100%, respectively, by cooking the quinoa. Blends of 20% quinoa and 80% wheat flour improved the NEG by 43%, the weight gain by 11% and the PER by 72% above the values for a diet of wheat flour alone. The NEG, weight gain, amino acid composition and PER showed no difference between cooked and uncooked quinoa.

Cardozo and Baterman (27) studied the quality of the protein of quinoa on pigs by comparing a quinoa diet with one containing palm oil cake and another containing defatted milk powder. A lower increase in the growth of the pigs, fed on quinoa was reported. The weigths gained on the three diets were 31.1, 37.3 and 57.1 Kg, respectively.

The slightly lower weight gain found in chicks fed on a diet of raw quinoa for 30 days, compared with chicks fed on washed and cooked quinoa and maize, was not significant (4). However, Cardozo and Baterman (27) reported harmful effects in chicks when they were fed washed quinoa grain. These observations were corroborated by Cardozo and Dávalos (31), who found vitamin A and D deficiency symptoms in these chicks.

Some pathological effects on internal organs of chicks when they were fed with unwashed quinoa, due to the haemolytic action of the saponins, have been reported by Risi and Galwey (4). In a study on chickens raised on quinoa and cañihua for 56 days, the mortality rate due to altitude sickness ("mal de altura") decreased, among those on this diet, in contrast to those fed with commercial feed.

The protein quality of quinoa has also been investigated by studying the growth and egg-laying capacity of quail *(Coturnix japonica)*. The results showed that the diets fulfilled their daily requirement for growth. However fewer eggs were produced by quails fed on quinoa diets (15% protein) than by quails fed on diets recommended for chickens by the National Research Council. When the quinoa diets contained less protein (5%, 10% protein) the egg production was even lower. When diets of calves were supplemented with quinoa, a greater weight gain in calves was noted in comparison with the diets supplemented with equivalent amounts of wheat or vicia beans (26).

López de Romaña and co-workers, (32) made a study in Peru with eight children aged between 4 and 29 months, who were recovering from malnutrition. They were put on six different diets, five based on potatoes and wheat products (noodles) and the sixth based on quinoa and oats. The results showed satisfactory acceptability and tolerance of all the diets including that containing quinoa. The intake of calories and protein was found to be enough for all children except for one. Mean apparent absorption of nitrogen from the quinoa-oats diet was 67% which was significantly lower in comparison with other diets.

López de Romaña et al., (33) reported results of experiments in which diets based on whole quinoa seeds and quinoa flour were compared with a casein diet, on six children between 10 to 18 months, who were recovering from malnutrition. Results showed that the digestibility of quinoa seeds was the limited factor in the protein and energy utilization, and that milling improved the digestibility significantly. Based on these results the authors confirmed that the protein quality of processed quinoa seeds could be adequate for feeding children.

Romero et al., (26) reported an increase in the nutricional value of quinoa products, as well as in its acceptability, in samples free of saponins and also in cooked quinoa samples.

Fat

Quinoa contains between 5.8 and 9.5 %. fat. De Bruin (22) studied the oil from four varieties. The compo-sition of fatty acids is reported as follow: oleic acid 48%, linoleic acid 50.7%, linolenic acid 0.8%, and saturated fatty acid 0.4%. The fat content and the fatty acid composition of a sample of quinoa grown in Ecuador is given in Table 3.

TABLE 3
Composition of fatty acid in raw quinoa and washed quinoa [a]
(g/100 g fat)

Fatty Acid		Raw Quinoa	Washed Quinoa
Myristic acid	C14	0.1	0.1
Palmitic acid	C16	9.7	9.9
Palmitoleic acid	C16:1C	0.2	0.2
Stearic acid	18	0.6	0.6
Oleic acid	C18:1C	24,8	24.5
Linoleic acid	18:2 C	52.3	52.3
Linolenic acid	18:3 C	3.9	3.8
Arachidic acid	20	0.4	0.4
	C 20:1 C	1.4	1.4
	20:2 C	0.2	0.1
Behenic acid	22	0.5	0.6
	C 22:1w9	1.4	1.5
	C 24	0.2	0.2
	C 24:1	2.4	2.6

a Ruales and Nair (34). Data to be published

Vitamins and minerals

The vitamin content of quinoa has been analysed by Cardozo et al., (27); De Bruin, (22); Mahoney et al., (19); White, (6), The results are presented in Table 4.

It is common practice to wash quinoa seeds before consumption in order to remove the bitter taste due to saponins. by washing, the outer layers are removed. High contents of K and Cl and smaller amounts of Mg, Al, Si, P, S and Ca are found in the perianth, which is removed by washing (4).

TABLE 4
Content of vitamins and minerals in quinoa seeds
(mg/100 g dry matter)[a]

	Range
Vitamins	
Vitamin A	0.12 - 0.53
Vitamin E	4.60 - 5.90
Thiamin	0.05 - 0.60
Riboflavin	0.20 - 0.46
Niacin	0.16 - 1.60
Ascorbic acid	0.00 - 8.50
Minerals	
Calcium	46.0 - 340.0
Phosphorus	145.0 - 570.0
Iron	1.3 - 32.0
Magnesium	170.0 - 230.0
Potassium	840.0 - 1145.0
Copper	0.6 - 1.2
Manganese	1.2 - 5.1
Zinc	2.1 - 6.1

a. White et al., (6);Cardozo et al., (27); De Bruin (22); Mahoney et al., (19).

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Haemaglutinins and trypsin inhibitors

Romero (26) could not find any haemaglutinin in eight quinoa verieties. Studies on trypsin inhibitor carried out on quinoa seeds showed no physiological effect due to trypsin inhibitors. the amount of trypsin inhibitor per unit of sample (1.36 - 5.04 TIU/ml sample) were lower than those found in legumes (soya 24.5 TIU/ml). Moreover, the trypsin inhibitor present in quinoa is easily inactivated by heat treatment before consumption.

Saponins

Saponins consist of one to six hexose or pentose units joined to the sapogenin aglycone. The saponins contain steroidal aglycone or triterpenoid aglycone. Large number of them are characterized by their bitter taste. They are able to produce stable foam in aqueous solutions, lower plasma cholesterol levels and haemolyse red blood cells (35-37).

Quinoa saponins are triterpene glucosides, located on the pericarp of the seeds. They are soluble in methanol and in water. Meyer et al., (38) isolated and characterized Quinoside A, one of the bitter and toxic saponins of the quinoa seeds. Mizui et al., (39) isolated six saponins from quinoa bran and elucidated their structures as 28-0-β-glucopyranosyl esters of hederagenin 3-0-β-glucopyranosyl-(1->3) -α- arabinopyranoside and 3-o-β- glucopyranosyl -(1->3) - β- galactopyranoside, and 28-0-β-glucopyranosyl esters of phytoccagenic acid 3-0-α-arabinopyranoside, 3-0-β-glucopyranosyl-(1->3) -α-arabinopyranoside, 3-0-β-glucopyranosyl-(1->3)-β-galactopyranoside.

Saponins are toxic for cold-blooded animals. Saponins were used as fish poison by the people of South America, and the fish killed in this way are edible. In humans it is poisonous when administered intravenously, due to the haemolytic activity, but non-toxic when taken orally. Saponins are not absorbed by the intestinal system, but they can affect the absorption of some nutrients in the gut (35-37). Southon et al., (40) reported that iron absorption was inhibited in rats when they were fed on a saponin rich diet.

Saponins, because of their bitter taste, they have to be removed from the quinoa seeds by washing, dried polishing or by cooking before consumption.Various research work has been done in order to develop methods to remove saponins from large quantities of quinoa seeds. Molina, (41) develop a method by which saponins were removed by washing with water and high turbulence. Torres and Minaya (13) designed and constructed a machine able to polish quinoa seeds and in this way remove the saponins. Rigdout et al. , (42) reported results of the saponin content after seeds were treated by different process. The saponin content in seeds washed with water, only 20 percent of the original content of saponins remained in the seeds.

Uses of quinoa and quinoa products

Quinoa an its products have been used for thousands of years in different kinds of foods by the natives of the Andeas region of Latin America. The whole grains and flour made out of it, were used for making bread, biscuits and porridge. Fermented products with quinoa alone or in various combinations with other cereals were also in use (43-46). In Chile, Bolivia, Peru, and Ecuador, the whole seeds are used in soups, broths and potages, roasted and ground in many kinds of desserts with milk or with honey. It is also eaten mixed with sugar and warm water, milk of fruit juice, sometimes with chicha and wine.

The tender stems and leaves are used as green vegetables, in salads, soups and stews. Quinoa leaves have been studied as a source of leaf protein for animal consumpttion and as human food (47-48).

In Bolivia 5 % of quinoa flour is added to comercial wheat flour (43) used for baking. In Peru, bread (10 % quinoa), noodles and other pasta products with up to 40 % and biscuits with 60 % quinoa flour, were produced (45, 49). A beverage has also been developed by Benvenuto et al. , (45). In France a patent on a process for making quinoa milk was sanctioned by Giacometti et al., (50). Vela et al. , (46) in Colombia, studied the use of quinoa seeds in foods and presented data on the chemical composition of the seeds, the sensory evaluation of various food prepared with quinoa, the production and uses of pre-cooked flours, and the sensory qualities of arepas and pastas, incorporating pre-cooked quinoa flour to a level of 15 % (43).

Romero et al. , (51), showed that a Wenger x-5 extruder can be used for production of quinoa products with high nutritional quality and acceptability on an industrial scale.

Robalino and Peñaloza (52) prepared tempeh for human consumption using quinoa after solid fermentation with *Risopus oligosporus.*

The alcaline ash from the stems of quinoa, called "Iliptu", is used for chewing with coca leaves by the Indians from Altiplano (4).

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