PSEUDOCEREALS – AN OVERVIEW

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INTRODUCTION

From the variety of plants, which can potentially be used for human nutrition, today fewer and fewer species are used. Especially within the starch-rich plants this development has advanced to a great extend. The three cereal species wheat, maize and rice dominate more and more the nutrition within the world's population. This tendency cannot be seen positively for many obvious reasons, in particular as appropriate alternatives are available. In the "International AACC list of recognised grains" also the pseudocereals are mentioned (Gordon, 2006). Table 1 shows their botanical classification. Although many plants from the family of *Chenopodiaceae* are used for human nutrition (e.g. spinach, beet), only three plants have gained importance as grains, so-called pseudocereals, worldwide. Besides amaranth *(Amaranthus sp.,)* these are quinoa *(Chenpodium quinoa)* and buckwheat *(Fagopyrum esculentum* and *Fagopyrum tartaricum).* Botanically they are assigned to the *dicotyledonae* (unlike cereals, which are *monocotyledonae*), but they all produce starch-rich seeds that can be used like cereals.

All three pseudocereals have advantageous nutritional properties and are very well able to increase the range of starch-rich plants for human nutrition. A pre-condition for an increased integration into the Western diet is the production of appropriate convenience products from these raw materials. But amaranth and quinoa were long forgotten plants, therefore still many questions regarding processing remain unanswered. Additionally, due to their different morphology and different functional properties, the known cereal processing methods cannot be applied on processing of pseudocereals without adaptation. Another challenge is the fact that these seeds possess a new, unknown taste compared to conventional cereals.

Historical background

Amaranth and quinoa were two of the major crops for the Pre-Colombian cultures in Latin-America. After the Spanish conquest, amaranth and quinoa consumption and cultivation was suppressed and thereafter only continued in a small scale. Since it was recognised that both grains show good nutritional properties, the interest in these grains has risen again. The production of quinoa was 39,000 mt in Bolivia, 929 mt in Ecuador and 28,694 mt in Peru in the year 2005 (FAOSTAT, 2006). However, until today amaranth and quinoa cultivation is still low. Amaranth is not even listed in the FAO statistics on production data. An appreciable commercial cultivation of amaranth for human nutrition does, however take place. Besides Latin American countries, it is produced in the USA, China and Europe.

Buckwheat originates from the middle Asia and was transferred by nomadic people to Central and Eastern Europe. Within the 13th century, buckwheat reached some importance in Germany, Austria and Italy, which was however lost due to cultivation of other cereals. Today, buckwheat celebrates a come-back due to the demand of gluten-free diet and the world wide production reaches 2.5 M ha providing 2 M tons of buckwheat. In 2005, China produced 800,000 mt, followed by Russia (605,640 mt) and Ukraine (274,700 mt) (FAOSTAT, 2006).

In Europe, 72,096 mt were produced in Poland, 124,217 mt in France and little in Hungary, Slovenia, Latvia and Lithuania. Japan is the main importer for buckwheat.

Table 1: Botanical classification of pseudocerals

	BUCKWHEAT	AMARANTH	QUINOA [Quinua]
CLASS	*Dicotyledoneae*		
SUBCLASS	*Caryophyllidae*		
ORDER	*Polygonales*	*Caryophyllales*	
FAMILY	*Polygonaceae*	*Amaranthaceae*	*Chenopodiaceae*
GENUS	*Fagopyrum*	*Amaranthus*	*Chenopodium*
SPECIES	*F. tartaricum* *F. esculentum* MOENCH	at least 60, e.g. *A. caudatus* *A. cruentus* *A. hypochondriacus*	more than 250, e.g. *Ch. quinoa* WILLD *Ch. pallidicaule* AELLEN (Kanigua, Kanihua, Canihua) *Ch. nuttalia* SAFFORD

MORPHOLOGY OF THE SEEDS OF PSEUDOCEREALS

According to several phylogenetic classifications the *Amaranthus* and *Chenopodium* genus together belong to the *Caryphyllales*, whereas buckwheat (*Fagopyrum*) belongs to the *Polygonales*. *Polygonales* and *Caryphyllales* are closely related and are combined together in *Caryphyllidae*. However, the data obtained by Drzewiecki et al. (2003) indicate occurrence of significant genetic distance between *Polygonales* and *Caryphyllales*.

Figure 1 shows the morphological structure of amaranth and quinoa compared to wheat. While in cereals the embryo is located within the starchy endosperm, in pseudocereals the embryo surrounds in the form of a ring the starchy tissue, which in this case is the perisperm. This can also be seen in the SEM photographs in Figure 1. Additionally, the seeds of amaranth and quinoa are much smaller compared to cereals. These morphological differences have great effects on the processing properties of pseudocereals.

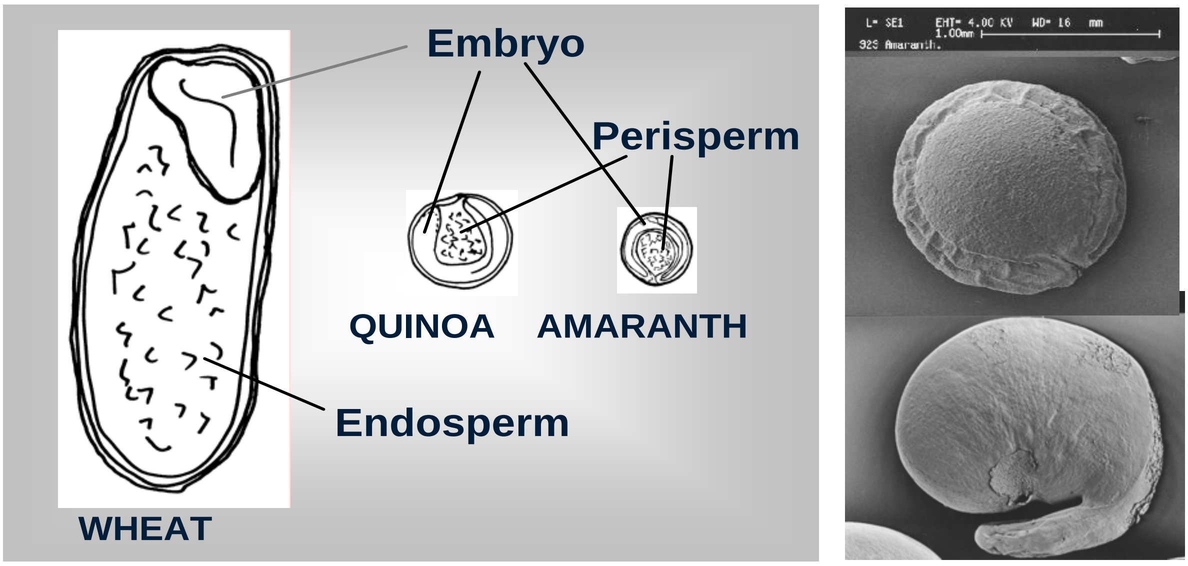

Figure 1: Botanical structure of amaranth and quinoa seeds

CHEMICAL COMPOSITION AND NUTRITIONAL PROPERTIES

Table 2 shows the chemical composition of the pseudocereals regarding their main components compared to wheat. Some components are higher in content than those of cereal species, for which wheat is given as the main representative. Its nutritional value is thus very high.

Protein

The protein content of pseudocereals is higher than in cereals species. But important is the fact that the quality of the protein is much better. In particular lysine, the limiting amino acid in cereals can be found in high amounts. The high content of arginine and histidine, both essential for infants and children, makes amaranth and quinoa interesting for the nutrition of children. Protein quality not only depends on the amino acid composition, but also on the bioavailability or digestibility. Protein digestibility, available lysine, net protein utilisation (NPU) or protein efficiency ratio (PER) are widely used as indicators for the nutritional quality of proteins. In this respect, the values for pseudocereal proteins are definitively higher when compared to cereals and are close to those of casein. The protein composition of the pseudocereals is typical for dicotyledoneae (2S albumins, 11S and 7S globulins) and therefore similar to proteins of legumes, crucifers and composites (Marcone, 1999). As only a very low amount of prolamins, which differ from those found in wheat, is present pseudocereals are suitable for diets of persons suffering from coeliac disease.

Lipids

The fat content of pseudocereals is also higher compared to most cereal species. Additionally, the fat is characterised by a high content of unsaturated fatty acids (very high content of linolenic acid). Amaranth contains a high amount of squalene, a highly unsaturated open-chain triterpen, which is usually only found in liver of deep see fish and other maritime species. Squalenes are widely used in pharmaceutical and cosmetic applications.

Carbohydrates

Mono- and disaccharides can only be found in small amounts in pseudocereals. With a diameter of only 1-3 µm amaranth and quinoa starch granules are among the smallest known. Typical is also their low amylose content of max. 10%. The size of buckwheat starch granules with 2-7 µm is also still below the size of cereal species, but its amylose content is extraordinarily high. Especially in *F. esculentum*, it can reach values of up to 50%. The fibre content of amaranth and quinoa lies in the range of other cereals and shows great variation within different species.

Minerals

The content of minerals (ash) in amaranth and quinoa is about twice as high as in other cereals (Table 1). Particularly high are the amounts of calcium, magnesium, iron, potassium and zinc. The calcium/phosphorus ratio (Ca:P), which should be around 1 to 1.5, shows a good value of 1 to 1.9-2.7. The content of minerals (ash) in buckwheat seeds is lower than in wheat (Table 1). However, except for calcium, buckwheat is a richer source of nutritionally important minerals than many cereals such as rice, sorghum, millet and maize (Adeyeye and Ajewole, 1992).

Vitamins

Overall, amaranth does not constitute an important source of vitamins. According to Souci et al. (2000), the content of thiamine in amaranth is higher than in wheat, in contrast with previous investigations (Bressani, 1994). Both amaranth and quinoa are good sources of riboflavin, vitamin C and in particular of folic acid and vitamin E (Gamel et al., 2006, Ruales and Nair, 1993, and others). Folic acid has been found in amounts of 78.1 µg/100 g in quinoa and 102 µg/100 g in amaranth, 2.5 times higher than in wheat (40 µg/100 g) (data not published). The vitamins B_2 and B_6 are also present in buckwheat seeds (Fabjan et al., 2003).

Total vitamin B content is higher in tartary buckwheat than in common buckwheat, and, generally, the highest quantity of B vitamins is in the bran.

Phenolic compounds

High concentration of phenolic compounds can be found in the hulls of cereals and legumes and they can negatively influence the digestion and absorption processes by forming complexes with various nutrients or digestive enzymes.

The content of phenolic compounds (expressed as tannins) ranges form 40-520 mg/100 g in the literature, dark amaranth seeds contain more tannins than light ones (104-116 mg/100 g vs. 80-120 mg/100 g) (Bressani, 1994). Thermal treatment or germination seems to decrease the content of phenolic compounds. Total phenolics in amaranth seeds expressed as ferulic acid (an alkali-extractable phenolic compound) were measured by Klimczak et al. (2002). Dependent on the species considered, values ranging from 39.17 to 56.22 mg/100 g were measured. These values are comparable to other cereals. In buckwheat rutin, a rhamnoglucoside of the flavonol quercetin, is of particular interest, as it is used for medical purposes in many countries. Different values for the amounts of rutin and flavonoids have been reported. The bitter taste of tartary buckwheat seeds has been ascribed to these flavonoids (Fabjan et al., 2003). Additionally, alkenylresorcinol were found in buckwheat grits (whole grain). Although the content in buckwheat is the same as that in wheat flour, the presence of alkenylresorcinol adds extra value to this unique crop. This compound is neither present in oat products nor in rice, millet or maize flour.

Saponins

Saponins are strongly bitter tasting, surface active agents (surfactants), which can cause intensive foaming activity in aqueous solutions. They can form complexes with proteins and lipids, e.g. cholesterol, and possess a haemolytic effect. Saponins are only absorbed in small amounts, and their main effect is restricted to the intestinal tract. Saponins can form complexes with zinc and iron, thus limiting their bioavailability (Chauhan et al., 1992). With regard to health promoting effects, saponins are anti-carcinogenic, anti-microbial, cholesterol decreasing, immune modulating, as well as anti-inflammatory. Amaranth seeds contain rather low amounts of saponins (0.09%), and it is agreed that this low concentration of saponins in amaranth seeds and their relatively low toxicity guarantee that amaranth-derived products create no significant hazard to the consumer. The saponin content of quinoa (whole seeds) ranges from 0.03 to 2.05% in the literature, but these values are still below those found in soybeans. Thirty-four percent of the saponins can be found in the hull (Chauhan et al., 1992), thus dehulling and washing decrease the content to a great extend. Processing can also destroy saponins, but a reduction in the content is not as great as that observed after washing or dehulling. Another way to reduce the saponin content in quinoa seeds is by breeding of so-called sweet (low saponin content) quinoa species. If the saponin content is less than 0.11% the variety can be considered as a sweet variety.

Table 2: Chemical composition (% dry mass)of amaranth, quinoa and buckwheat compared to wheat (Souci et al., 2000)

component	**Amaranth** *(A. cruentus)*	**Quinoa (abrased)** *(Ch. quinoa)*	**Buckwheat** *(F. esculentum)*	**Wheat** *(T. aestivum L.)*
protein	15.2	13.3	10.9	11.7
fat	8.0	7.5	2.7	2.0
starch	67.3	69.0	67.2	61.0
ash	3.2	2.6	1.59	1.8

FUNCTIONAL PROPERTIES

Starch

The small size of the starch granule as well as its high amylopectin content explains most of the physical properties of amaranth starch. Compared to other cereal starches, amaranth starch shows excellent freeze-thaw and retrogradation stability. Quinoa starch granules can be found as single polygonal granules, but also in complexes, where up to 14,000 single granules can be bound together to form one complex, either spheroidal or oblong. Therefore full gelatinisation of the quinoa starch is difficult. After drum drying, for example, part of the starch remains in its native form, whereas all other starches are fully gelatinised by drum drying. The high amylose content of buckwheat leads to high expansion indices during extrusion cooking and gives a fine, crispy texture of the extrudates.

Proteins

All pseudocereal proteins are highly soluble and thus applicable in functional foods. Protein concentrates from amaranth exhibited much better solubility, foaming and emulsification than two commercial soy proteins (Bejosano and Corke, 1999) and it has been suggested that amaranth protein isolate can act as an effective foaming agent (Fidantsi and Doxastakis, 2001). Good functional properties were especially found for amaranth globulins, while amaranth albumins showed excellent foaming capacity and foaming stability at pH 5, suggesting that they could be used as whipping agents like egg albumins. Depending on protein and thermal conditions, amaranth proteins are able to form self-supporting gels that could be applied in different gel-like foods.

POTENTIAL USE OF PSEUDOCEREALS

In Table 3 the possible utilisation of pseudocereals is summarised. From the processing point of view, among all three pseudocereals, buckwheat can be processed most similarly to wheat, while for amaranth and quinoa many processes ask for specific adaptations due to the different morphology and functional properties. Amaranth seeds are usually used as wholegrain, whereas quinoa seeds need to be dehulled, in order to remove most of the bitter tasting saponins. Also buckwheat seeds are dehulled due to their high portion of hulls, which contain antinutritive secondary plant metabolites. The Pre-Colombian cultures used amaranth and quinoa mainly in cooked form (whole kernels). Investigations of Reiselhuber (2000) showed that the cooking properties of amaranth, in particular, differed greatly from cereals. After termination of the cooking process the texture of the cooked seeds still changes – the cooked seeds soften further during the cooling period. Also popping was applied in Pre-Colombian times and thus presents one of the oldest processes applied for amaranth. Besides maize, only amaranth can be popped directly without increased pressure. For extrusion cooking the high fat content of amaranth and quinoa has to be considered. For most extruder types, they have to be blended with low-fat raw materials in order to obtain good expansion.

CONCLUSIONS – OUTLOOK TO FUTURE

Due to its high nutritional value and interesting functional properties pseudocereals present an interesting alternative in order to increase the range of used plants for nutrition. To reach this aim, still intensive research is necessary to develop food products, which meet the taste of the Western diet consumer. Additionally, increased efforts are necessary to make these plants more known among the population. Until now, it is still only a low percentage of the population that know or consume these plants, in particular amaranth and quinoa. These aspects have to be considered primarily, if pseudocereals shall be marketed successfully in general and in large supermarkets in particular. Only this way the nutritional advantages of pseudocereals can be offered to a large portion of the population.

Table 3: Possible utilisation of pseudocereals seeds

Process	Products	suitable for/specific processing properties
cooking	cooked seeds	amaranth – texture changes of cooked seeds during cooling, quinoa and buckwheat
puffing or popping	popped, expanded seeds	amaranth
milling	wholemeal flour	amaranth, quinoa, buckwheat
milling and classification	flour fractions, protein-rich or starch-rich flour fractions	amaranth and quinoa after adaptation or processing parameters, buckwheat
cooking and flaking	Flakes	amaranth, quinoa, buckwheat
drum drying	pregelatinised flours	amaranth, buckwheat quinoa – no full starch gelatinisation
cooking extrusion	cooked, expanded or non expanded products	amaranth and quinoa only by blending with low-fat raw material due to its high fat content buckwheat – very good expansion
cooking extrusion and milling	pregelatinised flours	
cooking extrusion and flaking	Flakes	
germination (malting)	sprouts, malt	amaranth, quinoa, buckwheat
direct starch hydrolysis	protein concentrates, glucose syrup	amaranth, quinoa, buckwheat
starch isolation	isolated starch	amaranth, quinoa, buckwheat

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