# STARCH BEARING CROPS AS FOOD SOURCES

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## Contents

## Summary

Starch bearing crops are the main source of dietary energy for the world’s population. In the human diet cereals and root crops constitute the starchy staple food, but various

types of plant tissues of various plant species are consumed to meet the calorie requirement. According to the origin the starch contained by cereal grains, root and tuber crops and, briefly by shoots and fruits is reviewed.

The properties of the starch in a crop determine its suitability for processing and the quality of the final product. Important traits are gelatinisation, viscosity, tackiness, and inclination for retrogradation, granule size distribution and non-starch constituents.

Starch properties principally depend on the ratio of amylose and amylopectin and their structure in the granules. In some cereals the waxy and non-waxy, moreover sugary genotypes supply starch meet different taste and processing.

Starch - or energy - production of root and tuber crops can be very high, if accounted their yield per growing area, higher, than that of the cereals. Root crops are suitable to supply the calorie intake of a growing population. Especially the cultivation and processing of tropical root crops as cassava, sweet potato and yams are promising in this respect.

The cultivation, processing, value-added products and trade of wheat, maize, rice and potato are well established, while the majority of tropical root crops are produced for home consumption. In some regions they are grown as secondary staples or food reserves in case of shortages in cereal supply. Cassava roots can be stored in the soil for long periods but their shelf life is short, trade, shipment, processing is limited by their bulkiness. There are constraints in cultivation, storage, processing and trade to overcome. Research, technological, economic and political decisions contribute to the solution of these problems. New, improved varieties, resistant to diseases and pests, with higher yield and longer shelf life are now the contribution on the biologists' side.

## 1. Starch bearing plants as the source of dietary energy

Food provides dietary energy to meet human requirements. Nutrition must be more: the supply of adequate and nutritious food to maintain healthy, active life. Carbohydrate foods provide more than energy alone. A wide range of carbohydrate containing foods can be consumed so that the diet is sufficient in essential nutrients as well as total energy. Plant carbohydrates include sugars, cellulose, gums and starches, but starches are the main source of nutritive energy for the humankind. There is a great variety of starch bearing plants, which are food staples of the population in various regions all over the world.

In the human diet cereals and root crops constitute the starchy staple food, but about 100-150 plant species are used as sources of dietary carbohydrate throughout the world. Starchy endosperm of the cereal grains, starchy tissues of roots and tubers, stems and seeds, cotyledons, pericarps, rootstocks are produced for their starch content. Starch are found in most crops including cereals as wheat, maize, rice, sorghum, millet; root and tuber crops as potato, cassava, sweet potato, taro, yams, arrow root; others as sago palm or plantains and bananas. Being in focus as traditional food staples and industrial row materials in the western countries, primarily some cereals and potato has been studied so far, their starch content, structure and chemistry as well as functional properties of their value-added products were thoroughly examined. Whereas the perspectives, objectives and aims of this type of research have been just designated for tropical starches.

Products of some starchy crops are more commercialised, as processed wheat, maize or potato. Others are produced mainly for local consumption, as the majority of the tropical roots and tubers, such as cassava or yams. Their role as a staple, their traits, starch properties, cultivation as well as processing, are discussed.

### 1.1. Starch constituents

Starch is the storage carbohydrate in plants being in different amount in various plant species and varieties. It is the end product of plant carbon assimilation. It accumulates in granules (amyloplasts) in the roots, corms, tubers, stems, seeds and fruits of plants.

In germination, budding, or when it is needed, after solubilizing it is translocated in form of simpler carbohydrates to the organ where it is needed (to the “sink” in biological term), where re-condenses, or breaks down and forms cellulose, lignin, etc., or supplies energy via oxidation.

Starch is white, tasteless carbohydrate food substance building up from hundreds or thousands of D-glucose molecules. It does not dissolve in cold water, while at higher temperature (e.g. heating it with excess water under pressure) starch granules collapse, and an opalescent colloid solution is resulted (gelatinisation). Gelatinisation temperature of the starch is influenced by plant genetic and environmental factors.

In nutritional respects, starch can be divided into glycogenic and resistant starch, which is not absorbed in the small intestine.

Starch consists of two constituents, amylose and amylopectin, which are high molecular weight polymers of D-glucose bound by $\alpha$-1,4-glycoside linkages. It means, that the first and fourth carbon atoms of each glucose molecule are linked to the carbon atoms of a neighbouring glucose molecule through an oxygen atom.

The physical and chemical properties of amylose and amylopectin are different. Their ratio affects viscosity, shear resistance, gelatinisation, textures, solubility, tackiness, gel stability, cold swelling and retrogradation properties of starch. All these properties have high importance in the suitability of the starch of a given crop for various processing and use.

Amylose is considered to be a linear polymer, containing the $\alpha$-1,4-glycosidic linkages. It contains 300-1000 glucose molecules. Though there is evidence that amylose is not completely linear, its behaviour is that of a linear polymer.

Amylopectin is a branched polymer, in which roughly every twenty, twenty-fifths glucose molecules have branch points (see Fig.1.).

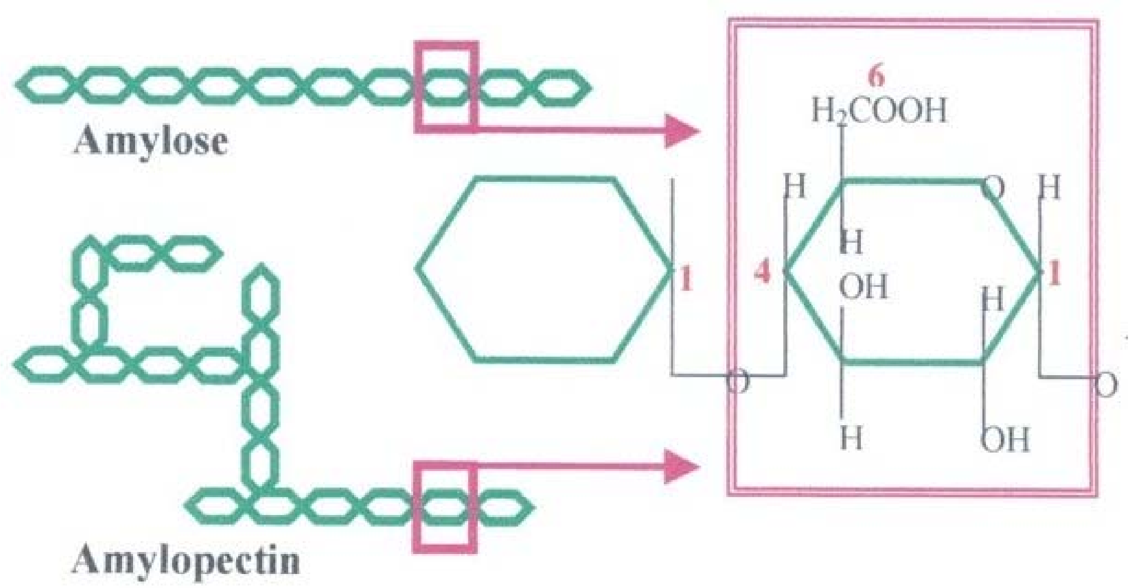

Figure 1. Schematic representation of amylose and amylopectin

Amylose forms intense blue complex with iodine, with a maximum absorption at 660 nm. Pure amylose is considered to have an iodine binding capacity of 20 per cent. This trait is used for quantifying amylose content. The colour reaction of amylopectin with iodine is purple (violet-red).

Amylose forms complexes with some organic compounds such as emulsifiers: monoglycerides, sucrose esters, etc. which are widely used as antistaling agents and dough conditioners in baking industry. Retrogradation (or setback) that is association and partial crystallisation of amylose due to its linear structure occurs also during staling of bakery products. It is enhanced with low temperature and high starch concentration.

Enzymatic degradation of amylose by β-amylase enzyme results in maltose, which contains two glucose molecules linked α-1,4. β-amylase breaks down the highly branched amylopectin only by about 50 %.

The large residue molecules are called β-limit-dextrin. But, using debranching enzymes (pullulanase, isoamylase) for degradation of amylopectin, relatively short linear chains are formed. Based on the studies made on the degradation products of the sequential enzymatic hydrolysis, amylopectin molecule is considered to be randomly branched containing $10^4$-$10^6$ individual chains.

Three types of chains are distinguished: (1) A chains (glucose molecules linked α-1,4), (2) B chains (glucose molecules linked α-1,4 and α-1,6 linkages) and (3) C chains (glucose molecules linked α-1,4 and α-1,6 linkages, plus a reducing group in the molecule).

A and B chains probably make helical conformation. Their ratio is generally used in characterization of amylopectin structure.

## 1.2. Gelatinisation of starch

Gelatinisation and pasting are transformations when heating starch in aqueous solution, with significance in food production.

Starch granules suspended in water considerably swell as they can hold as much moisture as the 30 per cent of their dry mass.

This process is reversible in room temperature. Heating the suspension results in irreversible changes: with increased extent of hydration the structure of starch granule starts to loose step by step, as soon as the energy of heat is sufficiently high to dissociate the week hydrogen bonds in the granule.

During the process hydrated starch molecules diffuse to the solution from the granule. The viscosity of the system increases. Complete solubilization occurs only on high temperatures (e.g.120 $^{o}$C). Loosing of ordered structure after gelatinisation is termed pasting. After the gelatinisation and pasting of starch amylose and amylopectin molecules may be considered as dissolved.

After cooling the system forms a gel. Amylose is considered primarily responsible for gelatinisation.

While baking the starch is heated in a limited amount of water. During gelatinisation starch competes for available water against other ingredients. Thus gelatinisation of starch in bread is more extensive than in sugar containing cakes.

Obviously, changes in starch granules in baked products depend on both temperature and water availability, that is controlled by other ingredients as well, such as sugar or shortening.

## 2. Starch in cereals

Starch products of wheat, maize and rice have the highest significance in the international market both for food and non-food applications. Sorghum and millets are produced and used principally in Africa and the Indian subcontinent.

While most of the wheat, maize and a part of rice produced are processed, transformed into convenience products; sorghum and millets are basic food cereals used mainly without pre-processing.

Regarding the nutritional value of cereals and particularly starch there is an important issue of the resistant starch. The digestibility of starch depending on the hydrolysis by pancreatic enzymes, determines the available energy content of cereal grains. This must be taken into account when evaluating nutritive value.

The amount of partly or fully resistant starch may reach values of fifteen-twenty per cent. Processing the grains by methods such as steaming, pressure-cooking, flaking, puffing or micronization of the starch increases its digestibility.

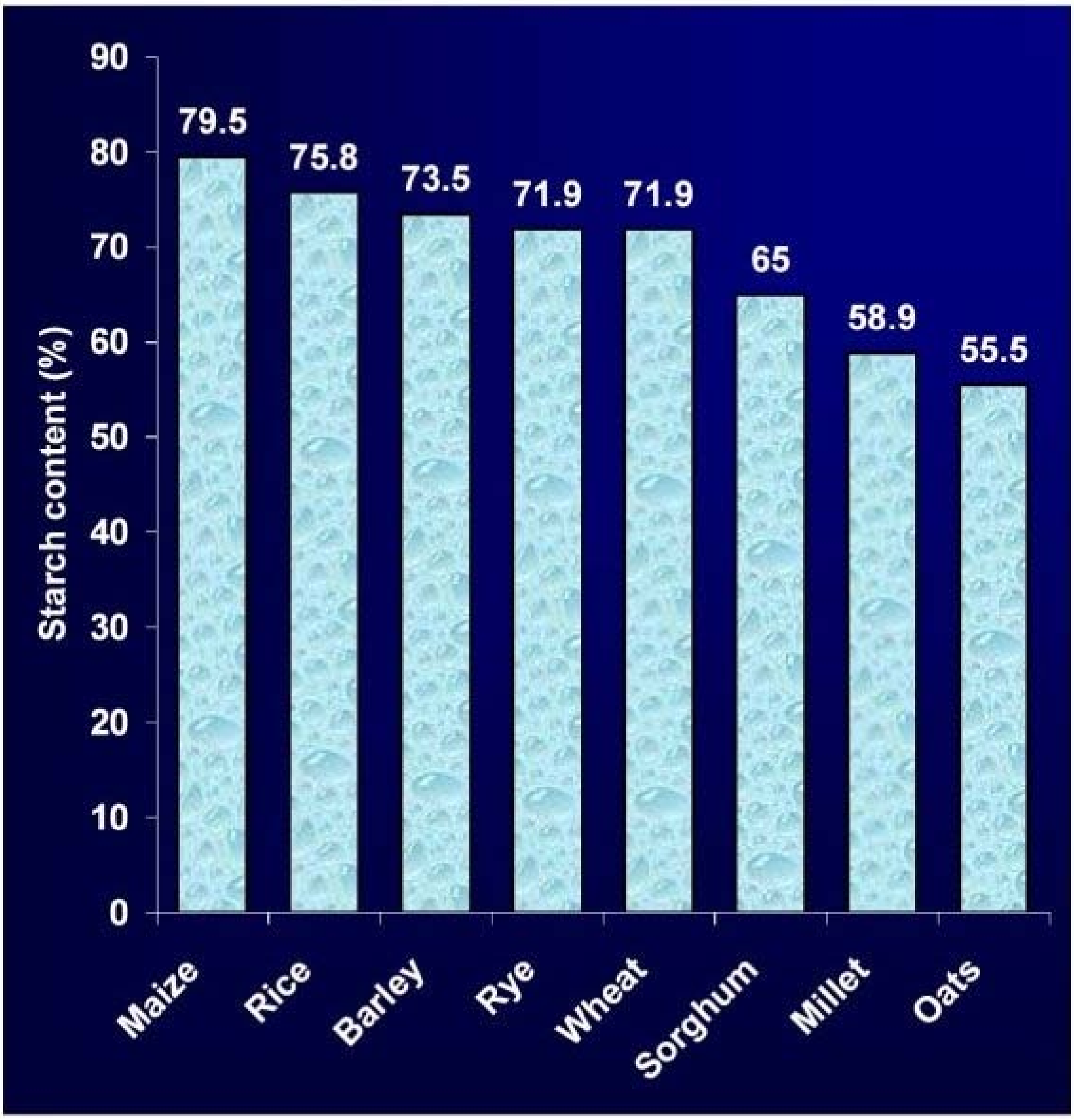

Figure 2. Average starch content of cereal grains (% dry mass basis)*
*Adopted from Lásztity (1999)

### 2.1.Starch in wheat

In the grain the cells of starchy endosperm vary in size and shape. The cells are packed with starch embedding with protein matrix. The wheat kernel is very rich in starch deposited as discrete granules in the cells of the endosperm. The size of the flattened starch granules may be as big as 40 µm in diameter, whereas that of the spherical ones 2-8 µm in diameter. Because of this bimodal distribution of granules wheat starch cannot be used without modification (separation) in special industrial applications where the uniformity of granule size is required (e.g. in carbonless paper production).

The starch content of wheat varieties varies from 60 to 75 per cent. Soft wheat varieties have higher starch content than hard varieties, which contain more proteins. The amylose content of wheat varies from 17 to 29 per cent with an average of 22-25 per cent. It seems to have a relatively low range of genetic variation. However, in waxy wheat varieties amylose content is very low (1.2-2.0 %).

Initial gelatinisation temperature, at which starch granules start to loose original structure (at this temperature hydrogen bonds are weakened and granules absorb much more water, see text above) is about 58 $^{o}$C, midpoint 61, end point 64 $^{o}$C for wheat starch. In conditions with lower water availability gelatinisation range is broader and depends on the starch content. Granules can swell up to 30 times of their original size followed by disintegration at temperatures above the gelatinisation range.

There are non-carbohydrate components such as proteins (0.04-0.3 %), lipids (0.4-0.8 %) and phosphorus (0.05-0.07 %) in wheat starch. Major part of phosphorus is linked to phospholipides, while proteins probably are associated with the granule surfaces.

### 2.2.Starch in maize

Starch is the most abundant carbohydrate component of maize kernel, ranging from 65 to 80 per cent, depending on the variety. The starchy endosperm - horny (hard, translucent) and floury (soft) are found in the maize kernel.

The amylose content of maize starch ranges from 25 to 30 per cent but it can vary among cultivars, particularly in cultivars with mutant genes. In these genotypes intermediate polymers between amylose and amylopectin are present in the starch. Amylomaize varieties, the amylose-extender (ae) genotypes with high amylose content may have 50-80 per cent short chain amylose in starch. Whereas starch granules of waxy maize with waxy (wx) gene consist of almost entirely amylopectin. Maize sugary (su) mutant synthesizes and accumulates a highly branched polysaccharide, phytoglycogen to 25 per cent or more of the dry mass of the kernel. The digestibility of isolated starch of maize cultivars is a range of 53-58 per cent.

Maize is not only energy source, but also the source of dietary fibres.

The group of non-glycaemic carbohydrates that are not absorbed in the small intestine and, therefore, move down to become fermented in the colon, is termed dietary fibre. From a human dietary standpoint, the most important source of dietary fibre is the pericarp of maize.

### 2.3.Starch in rice

In the grain the endosperm cells are tightly packed, with polygonal compound starch granules and protein bodies.

There is a central role of starch in determining cooking and eating quality of rice. Starch structure, the ratio of amylose to amylopectin is close correlation with rice quality (See Chapter 1.2. “Rice” in the same volume). Starch in waxy rice varieties has an amylose content of 0.8-1.3 per cent probably located in the centre of the starch granule. Amylose content of the starch of nonwaxy genotypes is ranging from 8 to 37 per cent. Waxy and nonwaxy rice starch granules have similar gelatinisation temperatures, which are in the range from 55 to 79 °C from the beginning of the process to the final gelatinisation. Volume expansion and water absorption during cooking are positively, while stickiness and tenderness of cooked rice are negatively correlated with amylose content. These two properties, which are so important for Japanese consumers, are properties attributable principally to amylopectin content of the rice starch.

Parboiled rice is the major processed-rice product, which has priority in the export of Thailand long rice. In this process soaked rice grain is steaming to gelatinise the starch without much swelling of the granules than drying slowly. During this process amylose-lipid complexes are formed that influence cooking losses and physical properties of cooked rice.

The small granule size of rice starch makes it highly suitable for laundry sizing of fine fabrics and for skin cosmetics as it has been used for centuries in Japan.

## 2.4. Starch in sorghum

Sorghum is a savannah crop, not well suited to the high rainfall or the forest zones. It is a staple food for African population, consumed in various types of dishes.

Sorghum growing area is the largest in the African continent, more than half than that of the world as is shown on Fig 3.

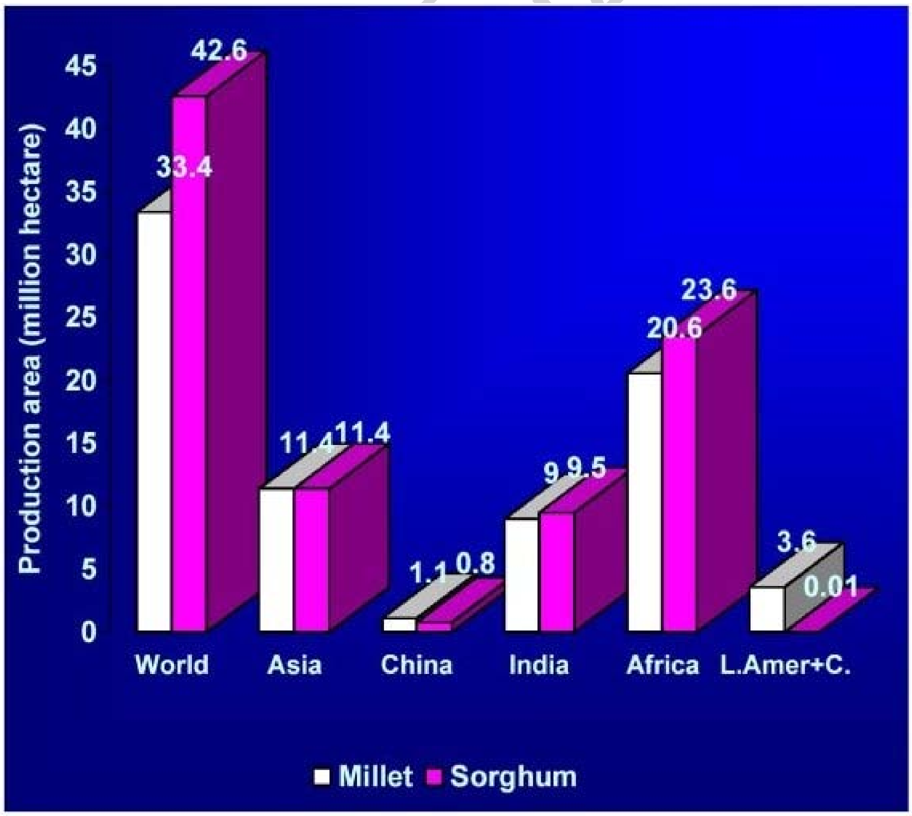

Figure 3. Area of sorghum and millet production in 2002. (Source: FAO)

On the other hand, less than half of the world's sorghum production falls on Africa, as a consequence of the lower grain yields (Fig 4. and 5.).

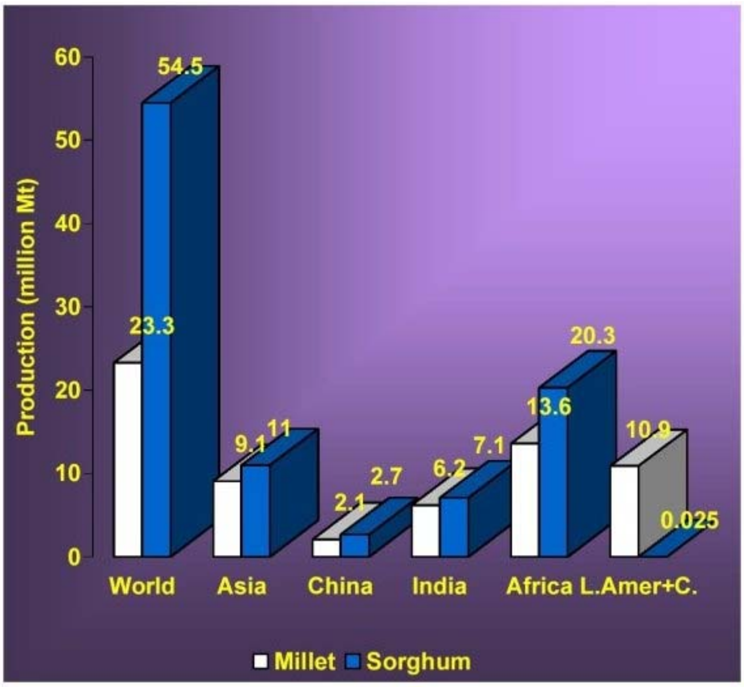

Figure 4. Production of sorghum and millet in the world in 2002. (Source: FAO)

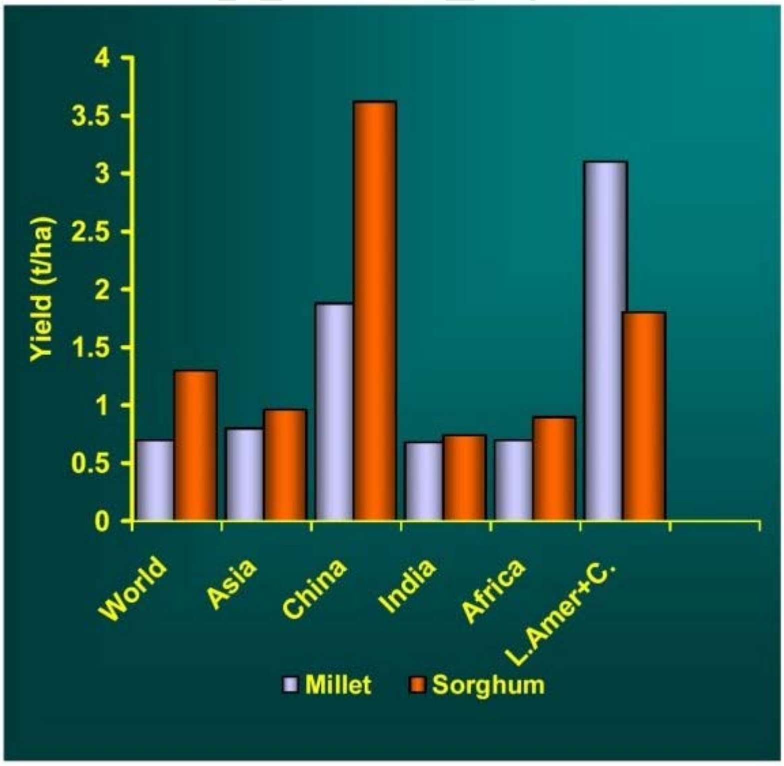

Figure 5. Grain yield of sorghum and millet in the world in 2002. (Source: FAO)

Sorghum varieties vary considerably with respect to pericarp colour (white, yellow, red, brown), kernel size and shape, hardness of endosperm (corneous and floury), and condensed tannin content (low and high tannin sorghum). In the endosperm starch granules and protein bodies are the main components of the cells.

The starch content of sorghum varies from 56 to 73 per cent, with an average starch content of 69.5 per cent. About 20-30 per cent of the starch is amylose and the remaining 70-80 per cent is amylopectin. The starch of waxy sorghum genotypes is practically 100 per cent amylopectin. In the contrary starch in sugary sorghum contains by 5-15 per cent higher amount of amylose, than normal varieties. Starch digestibility isolated from sorghum varieties ranged from 33 to 48 per cent. There is a close relationship among the texture of grain endosperm, the particle size of the flour and digestibility of the starch. The smaller particle size accompanied with the greater surface area open for enzymatic effects improves starch digestibility. Additionally, digestibility is higher for low amylose (waxy) sorghum genotypes than normal sorghum, maize or millet grains. Sorghum digestibility is also influenced by the concentration of tannins in starch granules.

The swelling power of starch and its solubility - which properties of sorghum starch are depending on its amylose and protein content - significantly influence on the cooking quality. Plasticity and stickiness of dough made from sorghum flour is the function of gelatinisation while preparing it in hot water. For the unleavened bread (roti) and for porridge, which are the most common foods processed from sorghum and millet, different sorghum varieties are used. For preparing the unleavened bread a type of flour required with high water uptake on low gelatinisation temperature, high peak paste viscosity and high setback. Whereas high gelatinisation temperatures, low peak paste viscosity and low inclination for retrogradation are the parameters of the flour’s suitability for porridge.

Malting of sorghum grains is widely used in Africa for the preparation of traditional foods. However, careful removal of rootlets and sprouts is very important, because they are toxic, containing dhurrin, a cyanogenic glucoside, which on hydrolysis produces strongly toxic hydro cyanic acid (HCN).

Different varieties have been selected for different use: sweet sorghum for chewing, white seeded types for bread, small, dark red-seeded types for beer and varieties with strong, fibrous stems for house construction and basketry have been selected during the long joint history of man and sorghum crop.

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http://www.globalcassavastrategy.net : (A great deal of information is found hear in this website on possibilities of cassava production and use, and constraints to the cultivation, economy, trade, etc. Different scale strategies are shown.)

## Biographical Sketch

**Krisztina R. Végh** is a research worker in the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences (RISSAC) Budapest, Hungary. She completed her MSc in Biology in Budapest Science University (ELTE) Hungary. Her PhD thesis analysed the nutrient dynamics in the rhizosphere, by using measurements and modelling. Her interests also include system modelling in sensitive environments, in drought-prone areas, and, in nutrient deficient conditions. She has conducted several research projects on plant nutrition, water use and drought tolerance, and cooperated in both Hungarian and international research. She has worked in Uppsala, Sweden, in Tokyo, Japan, and now she works in joint projects on sustainable plant nutrition, together with Indian universities and research institutes.