Flours and starches made from cassava (yuca), yam, sweet potatoes and ñampi: functional properties and possible applications in the food industry

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Keywords

Tropical tubers; starch; cassava; yam; ñampi; sweet potatoes; functional properties.

Abstract

A review was carried out of the physical and chemical properties of flours and starches made from cassava, yam, ñampi, and sweet potatoes. Amyloseamylopectin content, viscosity, nutritional value and fiber content were studied to associate them with their functional and technical-functional properties. A relationship was found between amylose-amylopectin, viscosity and fiber content and digestibility of those starches, as well as with glycemic index values.

It was found that it is possible to introduce modifications through fermentation to enhance the nutritional value of these starches. Fermentation allows the production of gluten-free bread and energy drinks as an option to diversify products. It was also found that there is a relationship between starch viscosity and a reduction of fat absorption in fried foods.

Introduction

Sweet potatoes (*Ipomea batatas*), cassava or yuca (*Manihot esculenta)*, yam (*Dioscorea* sp.) and ñampi (*Colocasia esculenta*) are products which are characteristic of the great borders of the tropics and are part of the daily diet of persons living in these regions. In spite of this, the new generations and the opportunities offered by current trade conditions have lead people to experiment with new products, leaving somewhat to one side the traditional way of consuming these tropical tubers. However, their nutritional value and accessibility, as well as the versatility of the innovative products obtained from starch extracted from these tubers of tropical origin, have drawn the attention of food professionals, who have studied their functional properties.

The curiosity of scientists about finding the most natural way to maintain people's health and to diversify production has lead them to study new food options which, due to their composition and characteristics, are beneficial for health, either in general or specifically, as in the case of preventive or curative treatments.

Learning about the functional properties of foods in general is highly important, since in the case of tubers such as sweet potatoes, cassava, yam and ñampi, investigation is still in an early stage; while some isolated studies of their starches and flours have been carried out, there are still only a few studies of these tubers as food sources.

This paper is a bibliographical revision bringing together the results of studies related to functional properties of these products, to determine which of them are found in these tubers and their possible uses as foods.

Overview

Physical-chemical characteristics of tropical tubers

Influence of the relationship between Amyloseamylopectin content and starch digestibility

The main components of starch are amylose and amylopectin. These polymers are very different in their structural form; amylose has a linear structure, while amylopectin is branching. Each structure plays an important role in the final purpose of native starch and its derivatives. Industrially, the ratio amylose/amylopectin can be genetically, physically and chemically manipulated to modify particular characteristics such as viscosity, gelatinization, texture, solubility, gel stability and retrogradation, to give them stable industrial properties.

Amylose content also plays an important role in food digestibility, because some studies have determined that starches with a low amylose content are more easily digested than those with a high content (Riley et al., 2006). For this reason, amylose and amylopectin content in the tropical products studied will be analyzed.

In the studies reviewed, it was found that amylose content in yuca starch varies according to the species analyzed, and that this amount is affected by crop age or climate. This can be observed in the results obtained in the study carried out by Onitilo (2007), in Africa, who analyzed four yuca species, finding amylose contents between 20.01% and 20.47%; while Moorthy (2004), mentions in his bibliographic review a wider range, between 20.00% and 27.00%, indicating furthermore that approximately 40% of total amylose corresponds to soluble amylose. Vargas et al. (2012), indicate that for yuca varieties cultivated in Costa Rica (Valencia and Brazilian), contents are 37% and 38% respectively. This demonstrates the variability in amylose/amylopectin content that products from different origins may have. It was also found that the amylopectin content in yuca starch ranges from 79.53% to 79.99%, according to Onitilo et al. (2007). The variation in amylose content indicates that starches will show different properties in the process of gelification.

In the case of sweet potato starch, Moorthy (2004) found an amylose content of 15.00%-25.00%, a similar range to the 12.90% to 29.70% reported by Tecson (2007). Osundahusi *et al.* (2003), studied two species of sweet potatoes (white and red) from Nigeria, reporting a range greater than 32.00% for both. This author indicates that the differences between these results may be due to the growing (planting) conditions of the root, which may affect the starches' physical properties, and that, for instance, if soil temperature increases, gelatinization and average size of the granule may vary (Moorthy, 2004).

According to a study carried out by Ting-Jang et al. (2008), amylose content in ñampi varies by species, just as in the case of yuca. These authors report an amylose range in ñampi of 10.20% to 14.90%. This study also shows the effect of climate on amylose content – at lower temperatures, amylose content decreases.

Amylose content in yam starch shows slight variations between different species. On average, amylose content for *Discorea alata* is 28.50%, according to Karam et al. (2006), a percentage very close to that reported by Araujo et al. (2004) for *Discoria bulbifera*, in whose study the percentage of amylose is 29.37%, with an amylopectin content of 70.62%.

Due to the variation in amylose content between species of the same product, it is difficult to specify which has a greater or smaller amount of amylose. Among the general ranges there are variations in the amount of amylose depending on the species analyzed. On average, sweet potatoes show the highest value, with 32.00%, followed by yam with 29.00%, yuca with 27.00%, and ñampi with the lowest values, 10.20% to 14. 90%.

Riley et al. (2006), classify starches according to their structures. Type A structures are those with a lower amylose content and a greater amylopectin content, type B have a greater amylose content and a lower amylopectin content, and type C have an intermediate content. The amylose portion in food affects digestibility. Structures A and C are more digestible, i.e., more sensitive to amylase, and type B structures are less digestible, i.e., less sensitive to amylase; according to the authors, this is due to differences in crystalline structure.

According to an *in vitro* study the ñampi has the highest digestibility. However, Moorthy (2004), who analyzed studies carried out using small animals, reports higher digestibility for yuca and sweet potatoes, and lower for yam, but this variable was not studied for ñampi, making it impossible to determine the digestibility of this starch since amylose content is a determinant of digestibility.

While these products are generally considered to be easily digested, they are also associated with flatulence, although available studies do not confirm this fact (Osundahusi et al., 2003).

Viscosity

Food viscosity is associated with chemical composition and structure of the food. During the gelatinization process, the composition, structure and viscosity of a food changes (Robertson, 1988).

In the case of yuca, Moorthy (2004) mentions a viscosity value of 600 BU (Brabender Units), which is considered high. Sweet potatoes showed a value lower than that of yuca of between 160 and 450 BU, demonstrating variability in gelatinization in different starchy sources such as those studied.

According to Osundahusi et al. (2003), in a gel of white and red sweet potato starches, the low viscosity indicates a high enzymatic activity, resulting in low water retention capacity. This study also discusses the low tendency to retrogradation of this starch. In the case of yam there are "peak viscosity" values of 781, 756 and up to 1282 BU (Moorthy, 2004). The differences in viscosity peaks are also due to the structures of the starches.

There are low values (-656 a -950 BU) for retrogradation viscosity, which indicates a low tendency towards this phenomenon (Rached et al., 2006). In the case of ñampi, there were not any specific data for viscosity. In the investigations studied, yam showed the highest value, followed by yuca, while sweet potatoes had the lowest value. However, in general, very different values were obtained among the tubers studied. Robertson (1988), who simulates the digestive process in his study, found a possible relation between digestibility and viscosity: the more viscous the food, the slower the digestion process. Taking this fact into account and relating it to Moorthy's (2004) report concerning digestibility of starches, it is possible to say that the greater the viscosity, the lower the digestibility obtained from the starch. According to this author, yuca and sweet potatoes, which show the lowest viscosity values, have high digestibility, while high-viscosity starches would result in low digestibility, as is the case with yams, which showed very high viscosity values and whose starch has a low digestibility (Moorthy, 2004).

Gelatinization

The gelatinization temperature is a specific characteristic of each starch, and depends on several factors, such as the size of granules, the amylose/amylopectin ratio, and intra- and inter-molecular forces, among others. Gelatinization temperature is an index of intra-granular structure, and the greater this value, the greater the degree of association of the molecules within the starch granule (Rached et al., 2006).

Yuca starch has a relatively low gelatinization temperature as compared to those of other starches, which varies between 49 and 64 °C or between 62 and 73 °C (Moorthy, 2004), depending on variety, genetic composition and the crop development environment. The temperature range for gelatinization given by Moorthy (2004) for this product is in agreement with the temperature of of 62 °C reported by Karam et al. (2006).

With respect to yam starch, the study carried out by Araujo et al. (2004) in Venezuela, found that the gelatinization temperature for this product is 70.8 °C, while Rached et al. (2006) reported gelatinization temperatures between 75 °C and 80 °C for the same product. Both studies present results that are similar to those of the study carried out by Riley et al. (2006), where the gelatinization temperature ranged between 74 and 75 °C in yams from different sources. Based on this information, it may be said that in general, regardless of the origin of the tuber, gelatinization temperature varies, and this variation may depend on the plant's development, which is affected by agro-climatic and fertilization factors, as mentioned by Treche (1996).

The gelatinization temperature of starch from sweet potatoes was also studied, and results showed a wide range of variation in this factor in two varieties, ranging from 63 to 74 °C, according to Osundahusi et al. (2003).

In general, it may be said that native starches from different places have different gelatinization characteristics, and that sometimes the gelatinization temperature range varies considerably.

Nutritional value

Tubers and roots are one of the main sources of carbohydrates feeding the global human population, without forgetting that other nutrients are part of their components, as shown in Table 1. Therefore, the energy value of these products is mainly provided through the caloric contribution of carbohydrates, and particularly of starches.

For energy content, Table 1 shows that these products are a good energy source: yuca, with a carbohydrate content of 86.9% dry base, is the one providing the greatest caloric contribution in Kcal/100 grams dry base.

Fiber and glycemic index

The study carried out by Tecson in 2007 indicates the importance of fiber on health, and its relationship with an enhanced digestive process, as well as its importance in the treatment of diseases such as diabetes through its positive influence on the glycemic index.

Table 2 presents data from Tecson's study in 2007, which reported on yam, sweet potato, yuca and ñampi flours, showing variations in fiber content as well as glycemic index results. The glycemic index corresponds to a measurement of glucose absorption in the body, and data from this study showed that it is slightly different for persons with diabetes as compared to absorption for persons who do not suffer from this disease. In general, it is observed that yam and ñampi –the products with the largest amount of total fiber– showed a lower glycemic index value for both diabetic and non-diabetic persons. A comparison of insoluble fiber content of the four tubers analyzed (Table 2) shows that fiber content is greater for ñampi and yam, while sweet potatoes and yuca contain lower amounts.

Table 1. Caloric content of some tropical starches *

Root or Tuber	Dry matter (g/100 g of fresh product)	Protein	Fat	Total carbohydrates	Total fiber	Energy (Kcal) g
100 g dry base						
Yuca	31.3	2.7	0.62	86.9	7.9	364
Potatoes	22.2	9.2	0.50	66.7	9.3	316
Sweet potatoes	30.8	5.3	1.95	78.2	10.2	351
Yam	31.1	6.4	0.42	72.8	17.9	318

*Treche. 1996

Table 2. Diet fiber content and glycemic index of some tropical tubers * /

Example	Diet fiber (g/100g m.s.)			Glycemic index **	
	Total	Insoluble	Soluble	Normal	Diabetic
Yam	11	8	3	41	33
Sweet potatoes	7	3	4	48	48
Yuca	3	2	1	53	52
Ñampi	12	8	4	46	46

*Tecson. 2007

**The control for the examples was white bread.

Soluble fiber content is similar for all products. Another interesting finding is that the lower the content of total fiber – as in yuca and sweet potatoes – the higher the glycemic index values.

Modifications, applications and treatments of starches from different tropical tubers on an industrial scale

Starch modification and glycemic index

Of the starch fractions, amylose is absorbed much slower than amylopectin, because the proportions of these two polymers may have an effect on the range of digestion, and therefore on absorption (Chiasson, 2000). For this reason, scientists seek to modify the relation of amylose/amylopectin content so that the product has more amylose, and a consequent potential for the reduction of the glycemic index value. With this in mind, Niba (2003) carried out a study with corn, potatoes, malanga and yam flours to test several physical treatments for measuring their effect on the glycemic index (using the enzymatic method).

Flours were subjected to treatments such as autoclaving, microwaving, pre-cooking and lyophilizing (freeze drying). Samples were stored for a 10-day period, at freezing temperature and room temperature, and the resistant starch (RS), slowly-digestible starch (SDS) and total starch (TS) contents were studied. It was found that of all flours studied, malanga flour has the greatest RS content (8.16 g/100), and that the autoclaving and pre-cooking effect increases RS content, while the microwaving effect reduces it as compared to untreated starch. Storing at room temperature also had the effect of reducing RS content. The information obtained through this study is important for food development and storage to modify resistant starch content to benefit health.

Bioactive components

Many foods of common consumption contain physiologically beneficial bioactive components, such as antioxidants, carotenoids, phenols, alkaloids, and other phytochemical components. These active components have been studied with the purpose of preventing numerous diseases such as cancer and heart conditions. They have also been associated with reduction effects of aging and improvements in general health (Niba, 2003).

The yam family (*Dioscorea*), for instance, contains phytoestrogens, which have been shown to have physiological benefits (Araujo et al., 2004), and some varieties of sweet potatoes have showed an anti-diabetic potential (Osundahusi, 2003). Tecson's (2007) study reports that tropical roots such as sweet potato, yuca, yam and ñampi, contain equal or higher levels of potential antioxidants as the butylhydroxyanisol (BHA) and α–tocopherols controls, the same in Niba (2003).

The bioactive components of ñampi (*Colocasia a esculenta*), have not been widely studied. However, the author indicates that anthocyanins have been found in ñampi produced in New Zealand. Hedges (2006) indicates that the information available on this respect is very scarce; it may therefore be concluded that there is not enough information available to assess the value of roots and tubers as bioactive functional products.

Fermentation and bio-processing

Fermentation of starch from tropical tubers usually takes place naturally, with starch as the medium for bacterial growth. This type of fermentation is characterized by the prevailing growth of lactic acid bacteria, evidenced by a rapid and drastic pH reduction. Lactic acid bacteria increase during the first five days of fermentation and lactic acid production continues until day 20 (Brabet et al. 1999). Examples of this process include fermented yuca and yam in several parts of Africa; typically, fermentation affects bacteria and yeasts, making preservation and storage easy. In this process, tannins decrease due to fermentation (Niba, 2003).

Fermentation markedly increases the nutritional quality of food products; for example, it may increase the protein content of some grains. In addition, fermentation results in the modification of starches derived from resistant starches, which are associated with protection against colon cancer and gastro-intestinal diseases. Fermentation has also been studied as a way to prepare gluten-free products, so that they can be used in the bread industry (yuca and bono bread); this type of fermentation has been studied in yuca (Brabet et al., 1999). In a study carried out by Vargas, *et al* (2012), it was found that sour starch has a content of resistant starch (RS) similar to that of durum wheat pasta, opening the possibility of using this raw material in the development of foods with functional properties.

Yuca starch: an ingredient with functional properties

Reduction of fat absorption in fried foods

According to Martelli et al. (2008), it is possible that adding polysaccharides could function as a barrier to fat in fried foods. In this study, yuca starch was added to chicken nuggets before they were breaded, to determine if there was a reduction of fat absorption in the product when it was fried. The study showed that there was a significant reduction of 16% fat content with respect to the control sample.

Another study carried out by Osundahusi et al. (2003), analyzed functional properties of two sweet potato varieties, finding low oil absorption in both of them; this characteristic was attributed to the low amount of protein contained in this starch.

Use of starches with low oil absorption in frying processes would be highly useful in the current fast-food industry, providing new sources of raw material which can both better meet technical requirements (including cost reduction due to lower oil absorption), and in addition benefit consumer health.

Pregelatinized starch for preparing bread and energy drinks

Fermented tuber starches such as yuca starch have been studied with respect to their use as ingredients in the preparation of bread, pudding, and other products that require rapid mixing with other raw materials. This starch expands when subjected to heat and in some ways performs the role of the gluten found in wheat, to which many people are intolerant. Yuca starch is used in this way in India, Brazil and Colombia; this ingredient prevents the dough from “breaking”, and a product very similar to wheat bread is obtained (Prenkumar et al., 2008).

This product is also used to obtain pregelatinized starch. Yucca starch is subjected to a gelatinization process, followed by drying to obtain a firm granule which is finally reduced through grinding to a moderately small size. In India, fine pregelatinized starch is used for preparing an instant energy beverage with water or hot milk for children or people requiring high-energy foods (Prenkumar et al., 2008).

Discussion and conclusions

This study is intended to show that flours and starches from roots and tubers may be more extensively used in the food industry. Several functional properties of these products were found in the literature. Amylose-amylopectin content, as well as viscosity and fiber content, affect starch digestibility, and their use and application in foods may diversify the types of food products available, providing new foods to populations that need to consume foods with a low glycemic index. For instance, the starch from some of these tubers can be used for thickening food for diabetic children, since starch helps give food the desired consistency without substantially increasing the glycemic index.

These flours and starches provide substantial energy, and are sources of carbohydrates. However, their protein and fat content is low, so that they can be used for enhancing the energy content of some foods without providing extra fat, for which they can also be a functional ingredient. Development of special food concentrates for persons whose food intake must be limited in terms of volume, but whose energy intake may be high, could be another use of these products.

Yuca, yam, ñampi and sweet potato fermentation is another alternative that may enhance nutritional value. In addition, the use of fermented starches as substitutes for gluten in preparing breads is also beneficial for another population group: celiac patients, who could consume this type of bread without any problem. These starches can be combined with other products to enhance texture and create an adequate crumb, as well as to enhance the characteristic color and flavor of bread; however, this option needs to be further studied.

Another important use of these starches is as a “barrier” to avoid fat absorption in fried foods, as well as to avoid the loss of water in this type of product. This property allows creating fried foods with lower fat absorption, which may help reduce health problems associated with the consumption of such foods which are very common in the current population.

It is necessary to carry out further studies about the functional properties of these starches, especially as they relate to foods, and to not carry out these studies in isolation. It is important to study clinical cases to observe the behavior of the glycemic index in diabetic patients, as well as fat absorption in fried foods, to develop new products containing these starches for the benefit of population’s health by making use of their functional properties. Innovation associated with foods that improve health may be a way to use tubers and roots as local raw materials.

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