Non centrifugal cane sugar (NCS) (panela, jaggery, gur, muscovado) process technology and the need of its innovation

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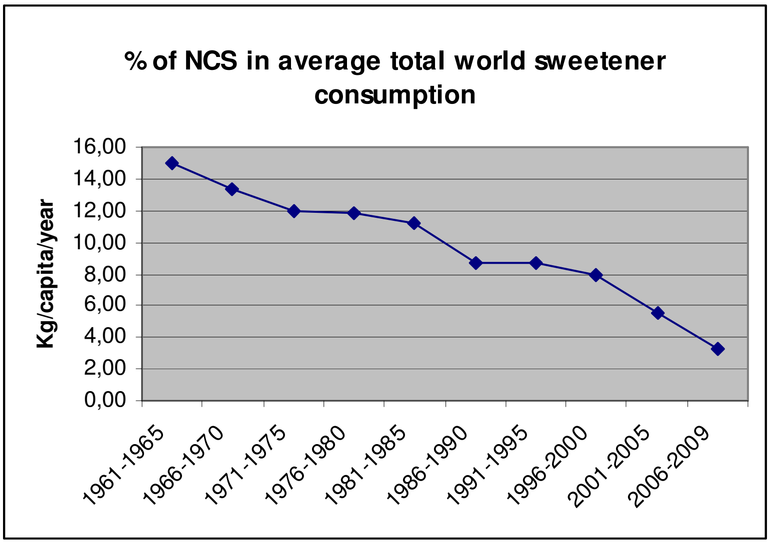
1. Introduction

Non centrifugal sugar (NCS) is a traditional minimally processed sweetener from sugar cane with many health and environmental advantages vis-à-vis refined cane sugar. NCS probably was the dominant form of cane sugar consumption before the large-scale production of refined sugar for export markets after 1700 (Galloway 2000). The displacement of NCS by refined sugar and other sweeteners (principally corn syrups) is still going on, as shown in Figure 1. In 1961 NCS represented 16% of total per capita sweetener consumption worldwide. For 2009 this share fell to 3%. Today it is a marginal food on the world market, but still important in some of the producing countries (Jaffé 2012).

Figure 1



Based on FAOSTAT data, own calculations

However, whilst production of non-centrifugal sugars has been declining in Asia, it has been rising, even if only slowly, in Latin America (International Sugar Organization 2013). Non-centrifugal sugar production in Latin America reached an all-time high in 2011, surpassing the 2 mln tonne level for the first time. This compares to around 1.6 mln tonnes 20 years ago. In Colombia the share of sugarcane allocated to production of non-centrifugal sugars is now the highest worldwide, at 40%. In Brazil, output rose from an estimated 280 thousand tonnes in 2005 to 470 thousand tonnes in 2011 (International Sugar Organization 2013). In Latin America, there are growing efforts to increasingly market non-centrifugal sugar alongside other types of niche market sugars overcoming the negative view that the traditional sugar industry has had of non-centrifugal sugars (International Sugar Organization 2013).

This displacement of NCS by refined sugar has economic, technological and cultural reasons. “Pure”, refined, cheaply mass-produced products (mainly flours, oils and fats and sweeteners), adapted to the requirements of urban, small family life have profoundly changed the diets in all developed countries, with important negative health consequences. The recognition of these effects by significant proportions of the consumers in these countries are behind the increasing importance of natural, organic or low processed foods in many markets. This offers a crucial opportunity for increasing the consumption and production of NCS, if the reasons that led to its displacement are overcome.

The objectives of this paper are to identify the technological changes needed to make NCS competitive with refined sugar and other caloric sweeteners as well as diversify its use. First, the requirements for the increase in NCS consumption will be analyzed, followed by a description of the typical NCS production processes and its required technological advances.

2. Requirements for the increase in world panela consumption

World panela consumption can be schematically divided into four different main markets. The largest is the consumption by the rural, small town and large-city rural migrant populations of the main panela producing countries, principally India, Colombia, Pakistan, China, Brazil, Bangladesh, Myanmar and the Philippines. This consumption has been falling in all countries. Colombia still presents the largest yearly per capita consumption with around 10 Kg for 2009, followed by Myanmar with around 7 Kg/year/capita. The consumption of panela of the other listed countries is in the range of 4 – 2 Kg/year/capita (Jaffé 2013).

The second largest market is probably the use of panela for the production of alcoholic beverages and in other fermentation industries, both in the producing countries and in export markets. Outstanding examples are rum worldwide, shochu in Japan and cachaza in Brazil. No quantification of this market is known.

The third market is the household consumption by middle and high income consumers, both in panela producing countries and export markets. This market is growing, particularly of organic panela in export markets (International Sugar Organization 2013). Finally, a small, still incipient, market of panela as a food industry ingredient exists in the developed countries, as well as in some countries with a long tradition of panela production, like Colombia. Main industries using panela as an ingredient are the beverage, confectionery, bakeries and sauces industries.

The development of the NCS world consumption depends then on increasing its competitiveness as a sweetener and ingredient vis-à-vis its competitors, that is, in the direct household markets, the food-ingredient markets and in other industrial markets. This competitiveness will be determined by the diversity and convenience of its presentations, its safety and quality, and its cost.

The traditional NCS presentation in most countries is in solid form, in different shapes as, for example, blocks or cones. Some countries also have traditional granulated presentation, like for example, gur in India, azucar mascabo in Brazil and muscovado in the Philippines. The relatively recent introduction of granulated presentations is an important advance in most Latin America as it is much more convenient in its use, principally because of its higher solubility and better shelf life. Another presentation, important in some domestic and industrial markets, is in concentrated liquid form.

One important element for the increase in NCS world consumption is the guaranty of a high and even quality. Factors such as humidity, colour, granulometry and purity need to be tailored for each specific use and market. This guaranty has to extend to the presence of legally established levels of possible contaminants and toxics, such as acryl amide, pesticide residues and polycyclic aromatic hydrocarbons (PHA´s).

The cost of production of NCS is generally higher than that of refined sugar because of its much smaller scale of production, both in the production of the cane to be processed and in its manufacturing process. The efficiency of energy use is generally much lower, as is the extraction rate of the sugarcane juice, because of the technology used and the lack of economies of scale.

But perhaps the most important obstacle to the increase of NCS consumption is the unawareness, by both food industry professionals and the larger public, of its health and potential environmental advantages. This is due to the confusion caused by the different names given to NCS in many countries as well as to lack of information. A negative image of NCS in the sugar industry, which thinks of it as a primitive, low quality, poor-people product, is also a problem to overcome.

3. NCS manufacturing technology: Process and unit operations

3.1. Historical outline

Sugar manufacturing technology originated 3500 years ago in India as the way to conserve, transport and use sugarcane juice. Ancient Buddhists writings describe the process of extraction of sugarcane juice with machinery quite similar to the still used "kolhu", a system of mortar and pestle driven by oxes (Kew 2014). The juice obtained was boiled down to solid "guda", today jaggery, and also to obtain "khand", a partially centrifuged sugar, which today is khandsary, (Kew 2014) still a quite important industry in South Asia. Advances in this technology are recorded in Persia by 700 AD, in the form of improved machinery to shred and crush the canes (Kew 2014). Further improvement of the extraction of the juice was done by the Arabs which created the three roller mill, moved by animal or water power. (Fraginals 1976). It is now clear that the roller mill was used in the first sugar plantations in the Americas established in the early sixteenth century, brought from the Canary Islands, Madeira and Andalusia (Steven-Acevedo 2013).

The development of the modern sugar processing technology started with the creation of a large scale sugar export industry in the West Indies. By the nineteenth century the use of iron and steel to build the mills, the introduction of the steam engine and later electricity and fuel oil, and the placing of several consecutive mills permitted a huge increase in the extraction efficiency of the process, which reached 85% compared to an estimated 20% in the past (Reheder 1999; Fraginals 1976).

The most significant innovations in the sugar industry have been those directed at energy use and consumption. Until well into the twentieth century, wood was the chief source of energy, both to boil the syrups and run the mills. The introduction of steam-power added fuel demands of the mill to those of the boiling house. Brazilian, Caribbean and Louisiana industries emerged during a time when wood was used both as a building material and as fuel and the use of wood in the sugar industry compounded the pressure on wood supplies. This led to innovations to increase the energy efficiency of the process (Vaughan 2002).

In 1813 the British chemist Edward Charles Howard invented a method of refining sugar that involved boiling the cane juice not in an open kettle, but in a closed vessel heated by steam and held under partial vacuum. Further gains in fuel-efficiency came from the multiple-effect evaporator, designed by Norbert Rillieux in Louisiana (perhaps as early as the 1820s, although the first working model dates from 1845). This system consisted of a series of vacuum pans, each held at a lower pressure than the previous one. The vapours from each pan served to heat the next, with minimal heat wasted (Vaughan 2002).

3.2. Scale of production of NCS industries

With the advent of the new technologies to produce and refine sugar on a large scale starting in the seventeenth century, NCS production was progressively confined to small on-farm cottage industries for local consumption, based on traditional technology. The basic process of refined sugar manufacture has essentially the same unit operations as the one for NCS production. What is known as front-end processes, that is cane preparation and juice extraction, are the same, and of the sugar-end processes they share juice preparation/concentration and crystallization.

The determining factor for choice of technologies in these processes is the scale of production. The parameters used to measure scale are cane crushing/milling per day and NCS production per hour. Some surveys use also total employees per factory. The scale of NCS production is, compared to refined sugar production, still small, as classifications by size of NCS factories shows (Table 1).

Table 1 – Classification of NCS factories according to scale of production

Size	Colombia		India		International	
	Cane crushing	NCS production	Cane crushing	NCS production	Cane crushing	NCS production
	Tons/day	Kg/hour	Tons/day	Kg/hour	Tons/day	Kg/hour
Small		< 100	< 10	< 125	< 50	
Medium		100 - 250	10 - 20	125 – 250	50 - 500	
Large		> 250	> 20	> 250	> 500	
Ref.		MADR 2006	Dwivedi 2010		Practical Action 2010	

Compared to the typical sugar factory these capacities are only a fraction of the typical milling capacities in the refined sugar industry. For example, a recently proposed categorization according to technological level of the sugar industry (Pippo & Luengo 2013), the Very Low Technology Development category establishes milling capacity of less than 3000 tons cane/day, and for State of the Art Technology factories of 7000 tons cane/day. The defining parameters of the category of large factories in Table 1 is then less than 20% of the measure for Very Low Technology, and less than 10% for State of the Art Technology.

No comprehensive industrial surveys are known to exist in any of the NCS producing countries. But some evidence points to the conclusion that of the total NCS factories only a small percentage falls into the "Large" category. For example, it is estimated that in Colombia there are around 23.000 NCS mills or "trapiches". Of these 83% were classified as small, 15% as medium and 2% as large (MADR 2006). This was confirmed by the general annual manufacturing survey for 2001, which only includes factories with 10 or more employees. Only 11 NCS factories were surveyed, producing 1,3% of the total NCS (Panela) production of the country (Espinal et al. 2005). For India, all identified surveys, which are limited to some state or region, reach the same conclusion (Lal Das 2001; Dwivedi 2010; Suryavanshi & Patel 2012).

The typical, and dominant, NCS producing facility is then a small-scale cottage industry. The technology used will be described next, with special emphasis on the modernization efforts to increase the scale of production.

3.3. Current NCS technology

To characterize the NCS technology currently in use, the more than 700 documents available in the Panela Monitor data base were analyzed to identify any relevant content. The typical unit operations of the NCS manufacturing process will be described, when possible identifying regional or national variations.

3.3.1. Cane preparation

NCS manufacture starts with the harvesting and conditioning of the sugar cane stalks for processing. Few descriptions of this unit operation have been found. Generally, the harvested cane is cleaned manually as preparation for the juice extraction, removing leaves and dirt by hand, rarely using water. The stalks are generally fed whole into the mill. Only one description of NCS manufacturing in the Northwest of Brazil mentions that the harvested canes are downloaded manually or mechanically, and that the better equipped units have mechanism to cut the canes before milling, the simpler ones milling directly the whole cane stalks (Azeredo et al. 2009; Da Silva 2010) These authors report that the use of cut canes can improve the extraction rate for juice, from approx. 500 kg juice per ton of milled cane in the case of whole canes to up to 650 kg per ton when using cut canes.

3.3.2. Juice extraction

Juice extraction can be achieved in principle by compression of whole or cut sugar cane stalks or by diffusion of the juice from ruptured tissues and cells of the stalks (Bagasse) by repeated and through contact of bagasse with juice of progressively decreasing concentration. Practically all NCS production described in the publications examined for this survey is achieved through milling. Only one case of use of diffusion in NCS production has been identified.

In India, both vertical and horizontal roller mills are common. The sugarcane crushers using vertical rollers, known as “kohlus”, are mechanically less efficient than horizontal ones, with low juice yield and high power load, down-times and wear-and-tear. Despite repeatedly passing the cane through the crusher, only about 70% juice is extracted. This loss of juice is mainly due to mechanical inefficiency of the vertically affixed rollers. The locally fabricated rollers are usually made of nonstandard steel, although wooden rollers can still be found, and they need to be frequently repaired and re-grooved resulting in loss of production time during the season (Bhupinder et al. 2006). The smaller mills are double roller crushers, three roller crushers (vertical/horizontal) being more common, the horizontal mills being more efficient (85 – 60%) than the verticals (50 – 55%) (Jagunnadha Rao et al. 2007). The crushers are powered by bullocks or by electric or diesel motors (MOFPI 2005; Jagunnadha Rao et al. 2007). Multiple crushing and hot water as means to increase the juice extraction efficiency are not used, due to its higher energy requirements (Jagunnadha Rao et al. 2007)

In Latin America, wooden rollers have been mostly substituted by metallic, generally cast iron, three roller mills, powered by electric or diesel motors, as more commercially oriented producers seek to increment production and productivity. Remaining traditional vertical mills are powered by animals and horizontal ones by diesel motors (Almengor 1998). Animal power can still be found in Guatemala, El Salvador, Colombia and the Brazilian Northeast (Almengor 1998; Lopez Guido et al.2010; Rodriguez et al. 2005; Rodrigues Lima & Lira Cavalcanti 2001;). Extraction efficiency, that is, mass of extracted juice per mass of crushed cane, of 58 – 63% are reached with three-roller mills in the region, but artisanal producers will never extract more than 50 kg of juice per 100 kg of cane, because of limits in the resistance of the equipment as well as of power consumption (Diaz & Iglesias 2012).

In the Philippines wooden roller mills are also rare, having been widely substituted by small two- to three-roller cast iron mills, powered by animals or diesel engines (Aquinas University Foundation 2010). A description of kokuto manufacture in Okinawa, the only place in Japan were NCS is produced, mentions a roller mill, as well as the custom to double press each cane batch to increase the juice extraction rate (Shimbo 2013)

3.3.3. Juice cleaning and clarification

The juice obtained from pressing the canes is first strained through a piece of cloth or other filter for removing the particles of bagasse and any other material suspended into it. Then it is collected in settling tanks for a pre-cleaning through the physical settling of coarse and heavy impurities, as described in India and Colombia (Jagunnadha Rao et al. 2007; Rodriguez et al. 2005). But processes without any settling step are still used as mentions from El Salvador and Colombia show (Lopez Guido et al. 2010).

The typical NCS production process includes a juice clarification step. This can involve physical means (gravity and/or heating), changing the chemical parameters of the juice (pH) and/or the use of synthetic or natural clarificants/flocculants to coagulate and trap proteins, fats, waxes and gums in the juice. These particles float on the surface as scum or precipitate during boiling. The scum is then removed using long handled fine-mesh ladles or by passing a fine cotton cloth through the juice. The combinations and sequence of use of these operations varies between countries and regions.

In India *sajji* (crude sodium carbonate), soda, ash, sodium hydrosulphate, sodium carbonate and super phosphate etc. are the chemical clarificants used in jaggery and gur making process. They are generally dissolved in a small quantity of water and added in the cooling pan just before final stringing of the mass. These clarificants are sometimes added twice. After clarification with some vegetable clarificant, the process is repeated again in the cooling pan. As regards lime, it is always used before the boiling has started and never in the cooling pan. (Bhupinder et al. 2006). Natural clarificants used in India are bark from the following plants: *Hibiscus figulneus*, *Hibiscus esculentus*, *Bombus malbaricum*, *Kydia calycina*, among the most important. These barks are soaked in water and the resulting solution added to the juice just before boiling commences. Approximately 10 to 15% of non-sugars can be removed using this method (Practical Action 2010).

In Latin America, clarification is generally carried out in a heated receiving pan, at 50 – 55 ^{o}C, were the chemical or natural clarificants are added. For Ecuador and Colombia the following chemicals are reported to be commonly used: Calcium oxide (Lime), calcium carbonate, sodium hydrosulfite and sodium bisulfates (which are prohibited) (Quezada Moreno 2007). In Brazil lime is reportedly commonly used to adjust the pH of the juice to a value of 6,5 - 7,0, a practice also common in the rest of Latin America (Mendonça do Nascimento 2007; Azeredo & Da Silva 2009). Natural flocculants are obtained from locally available plants, the most important being *Heliocarpus appendiculatus* ("*Burrio"*), *Heliocarpus americanus*, *H. popayanensis*, *Triunpheta lappula ("Cadillo"), Gauzuma ulmifoliase ("Guacimo)*, *Pavonia sepium ("Balso")* among others, in Central America and Andean countries, and *Ricinus communis and Guazuma ulmifolia* in Brazil (FUNACH-ASCAPAM 2002; Quezada Moreno 2007; Ortiz G. et al. 2011; Mendonça do Nascimento 2007). The bark of these plants is pounded with water to extract the mucilage which is used in the process (FUNACH-ASCAPAM 2002).

An alkaline mixture of limestone and water is used to adjust pH to 7,2 and clarify the cane juice in kokuto production in Okinawa (Shimbo 2013).

3.3.4. Concentration of juice

After the conditioning of the juice, the next operation is its concentration. The typical operation worldwide is the use of open pan boiling techniques, either in a single or in a series of open pans that are located above a furnace. A furnace has two parts: a combustion chamber and a process zone where the juice evaporates. In the combustion chamber the fuel used reacts with air to obtain thermal energy in the form of hot gases and ashes. The heating is through contact of the hot gases with the bottom of the pans (Velasquez et al. 2005) Evaporation is open because the pans are exposed to atmospheric pressure and the heating is direct. During the evaporation process solids still present in the juice in suspended form agglomerate and float to the surface, permitting its manual removal (Velasquez et al. 2005).

The boiling pans can be round or rectangular depending on furnace design and local tradition (Environmental Information System India 2005). The transfer of the concentrating juice is generally done manually. Boiling of juice to the proper consistency requires great skill on the part of the boiler as slight over-boiling results in caramelization and consequent damage to the colour and flavor of the NCS (Bhupinder et al. 2006).

In all cases fuel is provided by bagasse from the crushing operation, with differing humidity, but frequently additional fuel, such as wood, may be required to complete the boiling in the more traditional and inefficient facilities (Environmental Information System India 2005r). Furnaces of different designs can be found in all countries seeking better energy use and efficiency through combustion chambers designed for better combustion, improving air flow, fuel feeding and removal of ashes. Other design changes are directed towards increasing the heat transfer from the hot gases to the juice, through the placement of the pans on the gases stream or the optimization of the bottoms of the pans and the control of the air draft and gases draft through the whole system. Some designs use this draft to reduce the humidity of the bagasse and so increase the combustion efficiency.

The more advanced processes substitute the combustion chamber with a steam boiler, the energy for evaporation being applied through heat exchangers to the juice in closed vacuum pans. Closed multiple-effect evaporator steam-driven systems are being used in some few more advanced NCS production facilities in India, Colombia, Brazil and Costa Rica (Suryavanshi & Patel 2012; Velasquez Arredondo et al. 2004; Personal communication). These systems offer important advantages in energy use efficiency and in process control, principally the possibility to control overheating of the product so to avoid undesirable colour and taste changes as well as the generation of toxins.

In India single pan furnaces are generally used in the states of Punjab and Andra Pradesh, though double or multiple pan furnaces are not an uncommon sight, two and three pans are common in Rayalaseema and Telangana, both regions in Andra Pradesh state**.** (Bhupinder et al. 2006; Jagunnadha Rao et al. 2007)). The single pan process is known as the Kolhapur type (after a district in Maharashtra state), and the four-pan one UP (after Uttar Pradesh state) type (Suryavanshi & Patel 2012). In Karnataka state, high-income producers use triple pan process, but the majority use double pans due to lower investment and skill required (Ravindra et al. 2004). A survey in Maharashtra state found that the three-pan process was preferred (Jadhao et al. 2008). This was also found for Madhepura, Bihar state (Lal Das 2001)

A typical NCS making furnace in India consists of fuel feeding, opening, grate, fire place, chimney and ash chamber. It is constructed with brick and mud below the ground level. The smoke produced during combustion is made to go out through a chimney of the oven. The bagasse is fed manually at regular interval of time (Sada Riva Rao 2003). The main difficulty with most of common furnaces is their excessive fuel consumption and low rate of boiling

(Bhupinder et al. 2006). The thermal efficiency of one typical furnace was found to be a lowly 14.75%. The bagasse used was 3.85 kg/kg of jaggery manufactured.(Sada Riva Rao 2003).

Multiple pan processes are typical in Latin America. Only the very small, household processing of NCS uses one or two pans, as the example from Guatemala, where 80% of the producers surveyed in a 1998 study used one pan, the rest using two pans (Almengor 1998). Four to eight concentrations pans are reported for Colombia, three to four in El Salvador, three for Brazil, two for Ecuador (Rodriguez et al. 2005; Lopez Guido et al. 2010; Mendonça do Nascimento 2007; Quezada Moreno 2007)

Traditional furnaces in Latin America are generally of the parallel-flow type, that is, the hot gases and the juice flow in the same direction, the more advanced ones being of counter-flow design (the flow of the hot gases is opposite to the direction to the flow of the juice) (Velasquez Arredondo et al. 2005). Another improvement used by larger-scale NCS producers, particularly in Colombia, is a Ward type furnace with an additional chamber for drying the bagasse, known as CIMPA type named for its developer, a Colombian NCS research institute (Rodriguez & Gottret 2002)

3.3.5. Crystallization of NCS

When the boiling has sufficiently advanced, that is, around 90% of water has been evaporated, the mass is stirred frequently by means of a wooden stirrer in order to avoid caramelization due to excessive local heating. At this stage, a small quantity of anti-frothing and anti-adherents agents are generally added, which are vegetable oils from locally available sources. Mustard, coconut and castor oils are mentioned for India and *Laurus nobilis, Ricinus communis* and *Olea europaea* in Colombia (FUNACH-ASCAPAM 2002).

The "striking point", that is, when the NCS begins to crystallize, is reached when the boiling mass attains a temperature between 115^{0}C to 120^{0}C. An experienced juice boiler can judge accurately when the mass has to be stuck out of the boiling pan judged by eye-estimation or simple tests as, for example, the pouring of some syrup into water, and rarely by thermometer. (Bhupinder et al. 2006). The heavy syrup is placed unto special wooden or metallic curing troughs or tubs with continuous stirring before being poured into mostly wooden or clay forms to obtain solid, lump presentations. Granulated presentations are obtained by additional vigorous stirring, to incorporate air for the separation of the crystals (FUNACH-ASCAPAM 2002).

Solid lump of various forms (tablets or bricks, cones, round) are the dominant presentations world-wide, generally used by the smaller, more artisanal producer. In India approx. 80% of total jaggery production is presented in solid form, the rest in liquid or granulated form (Jagunnadha Rao et al. 2007. Similarly for Brazil it is reported that only 17% of producers have presentations different from the solid form (Rodrigues Lima & Lira Cavalcanti 2001). Solid forms are reported also to be dominant in Guatemala, El Salvador (Almengor 1998; Lopez Guido et al 2010). Granulated presentations are generally produced by larger, technologically more advanced producers. The smaller, less advanced of them obtain it by manual stirring, in others crystallization is achieved by mechanical stirring using mixers. Only a few exceptional cases of use of special vacuum crystallization pans are reported (Personal communication).

3.3.6. Conditioning and packaging

Most of NCS production is traded in local markets with low marketing requirements. Lump NCS is generally not wrapped individually and only packed in suitable containers, like wooden or carton boxes. Production for more demanding markets is wrapped individually in paper, cellophane or plastic.

In the case of granular NCS production, some factories include a final drying step to reduce the humidity to less than 1%, which improves the shelf live and handling characteristic of the product. A sieving step is also carried out by some producers, first to separate larger lumps, which are reprocessed, from the smaller grains, but also in the more advanced facilities to obtain different presentation according to grain sizes, with different functionalities. Granular NCS is generally packed in plastic bags.

4. Innovations in NCS technology

NCS technology is a special case of sugar technology. As stated before, both NCS and refined sugar production basically share all unit operations, except refining. Therefore innovations in both industries have a similar dynamic and directions. Sugar production is a mature industry characterized by wide variations in their degree of technological development, even in the same country. In the last thirty years, the typically slow pace of innovation in this industry has accelerated, as important changes with respect to energy conservation, diversification and environmental factors have been introduced (Magalhaes 2010). Brazil is today the world's leader in this field (Pippo & Luengo 2013). These changes have been driven by concerns about the emission of CO_2 and global warming, the rise of oil price in the international market, and other geopolitical factors associated with oil supply instability (Pippo & Luengo 2013).

The spread of mechanized sugarcane harvesting combined with the rise of the efficiency in energy use have led to a better appreciation of the value of bagasse as a key resource. 66% of the residues of sugarcane, that is, bagasse and sugarcane agriculture residues (sugarcane leaves (green and dry) and cane tops) are lignocellulosic. The modern sugar mill has become a multipurpose, highly efficient factory producing food (sugar, others), energy (steam and electricity), and biofuels (ethanol), with low greenhouse emissions. The key cause of these changes is the use of sugarcane agro-industrial residues as feedstock for energy cogeneration and biofuel production (Pippo & Luengo 2013)

However, bioethanol from sugarcane juice competes with the production of sugar and other food products. This fact should, as foreseen by some authors, impulse a new phase of sugarcane technology development, which would use sugarcane agriculture residues for cogeneration, reserving bagasse for biofuel production (Pippo & Luengo 2013). The use of lignocellulosic materials as feed stock for biofuel production has been pursued for at least a decade and, according to newspaper reports, is close to commercialization in several countries. A startup company in Italy has been producing cellulosic ethanol in 2013, and four other are planning to initiate production in 2014. One of them will use bagasse as integral part of a sugar and ethanol production complex in Brazil (The Economist 2013).

4.1. Technological change in NCS production

The differences and variations present in NCS production processes can be attributed to historical, cultural, economical and geographical factors. Each factory follows a production model which determines and constrains the technology used. Three production models can be identified, which are the cottage industry, the industrial production and the organic production model.

4.1.1. Cottage industry

Technological change in the NCS cottage industry can be characterized by several lines of technological development. A first is the progressive change of its most important machine, the mill. Natural materials, such as wood, have been substituted by industrial ones in its construction. Also human or animal power have been substituted by internal combustion or electrical motors for the drive of the mill, and mills with better juice extraction efficiencies have been introduced, the original two-roller mill been substituted with now dominant three-roller mills. This line has been developing for centuries, carried out mainly by NCS producers and equipment manufacturers.

Another line of technological change has been the progressive increase in the efficiency of evaporation of the sugarcane juice. The materials used to build the heating pans have changed, stronger and better heat-transmitting materials like steel substituting the traditional use of iron or cooper; the form and number of pans has increased; and the design of furnace and heat transfer systems has changed to facilitate the combustion and heat transfer. This last change has been accelerated since the nine-teen-eighties by government, academic and international cooperation programs, particularly in Colombia.

Another, more recent and still limited, development has been the diversification of the presentations of NCS, principally with the introduction of the granular product to complement the still dominant solid presentation. This technological advance is being complemented with new operations like drying, sieving and packing the product.

4.1.2. Industrial production

The increase in scale of production of some entrepreneurial cottage producers has led to the development of an industrial production model for NCS, which first was based on the refitting and adjustment of the traditional process, but which more recently has permitted the design of brand new facilities. The industrial NCS manufacturing process is basically an adaptation of various technologies commonly used in the sugar industry for the unitary operations shared by both industries, like conditioning of cane, juice extraction and concentration. The sugar industry is a traditional agro-industry characterized by wide variations in its scale of operations and the degree of modernization of the technology used. The industrial production of NCS is comparable to sugar factories on the lower range of scales of production and of less advanced technologies.

The technological changes in the industrial NCS production have been characterized by the introduction of technologies for higher juice extraction efficiency, with mechanical handling of the harvested canes, its reduction in size by cutters and the mechanical feeding of the cut canes to larger and more efficient mills or trains of them. The juice is collected in pre-cleaning tanks and then pumped to heating pans, to be clarified with the addition of suitable chemicals. The evaporation of the water in the juice is achieved by using steam, generally generated in biomass fired boilers. The more traditional factories still have open pans, which are being slowly substituted by closed vacuum multiple effect evaporators. Both solid and granulated presentations can be produced. The crystallization for the granular presentations is obtained by mechanical mixers and the product is further dried and sieved, before being packed.

4.1.3. Organic production

The past two decades have seen the development of a small export market for organic NCS in Europe, North America and Japan, supplied by organized groups of small scale producers and some industrial scale producers. The constrains that the certification of organic products establishes are mainly for the agronomic part of the NCS production, except for the use of chemicals in the manufacturing process, and may warrant the establishment of this special production model.

4.2. Scenarios of NCS innovation

What could possibly happen in NCS innovation in the future? Where is NCS technology heading? The identification of the drivers of innovation in each NCS production model and the analysis of the possible alternative outcomes is one way of trying to answer these questions.

In the case of the cottage industry production model the following drivers can be identified. The most important one is the need to increase the economic returns for the cottage producer, which means increasing the efficiency of the production process. The most important factor to increase this efficiency is a more efficient energy use, but increasing the extraction rate of sugarcane juice and reducing manual labour are also important. The aim is making the production unit energy self sustaining, which means an efficient use of all the lignocellulosic residues generated, and producing bagasse for sale. A second driver is the need to adapt the production process to environmental and quality requirements established by environmental, sanitary and food quality regulations and consumer markets.

The most direct way of achieving these aims is to increase the scale of production so to incorporate the already available technologies used in the sugar industry. But this implies the change to the industrial production model. The real challenge for innovation here is to develop small scale, efficient and relatively cheap processes and equipment, to permit the production of a traditional product with high quality and good economic returns. The small scale production of local varieties of cheese, meat products, jams, etc. in many countries, protected by denominations of origin, is an example to be followed. NCS has quality attributes (chemical composition, taste, colour) defined by local factors, such as sugarcane varieties, soil types and climate that could be exploited towards this end.

In the case of the industrial model of NCS production the most important drivers of technological change are the need to increase productivity and diversification for the displacement of refined sugar on a significant scale. This implies an increase of the scale of production to take advantage of economies of scale, through the adoption and, eventually, adaptation of the sugar processing advances of recent decades. A crucial factor for the success of this strategy will be the development of competitive advantages based on the nutritional and health effects of NCS, that is, to turn NCS into a mass-market functional food. This can be achieved with the incorporation of NCS in the formulation of beverages, soft drinks, sweets, bakery and many other foods for nutritional and health purposes.

A logical extension of the exploitation of these properties of NCS is the development of nutraceuticals and drugs derived from it. Extracts of NCS can be prepared to more precisely target health and nutritional advantages for human and veterinary use, taking advantage of its constituent antioxidants, minerals, complex sugars, etc. A prerequisite for this strategy is a more complete and profound scientific knowledge of NCS composition and health effects. But this lack has not inhibited Japanese and Australian companies to already position themselves for these possibilities by obtaining broad patents on this use of NCS. For example, Mitsui Sugar Co. from Japan has obtained several U.S. patents on NCS and extracts from it since the late nineteen seventies (Shimizu & Hashizume 1978; Mizutani et al. 1999; Kawai et al. 2003; Araki et al. 2006) and other inventors and companies have applied for similar ones more recently (Chou 2003; Kannar & Kitchen 2010).

The large scale use of NCS as a functional food and as a source of drugs or nutraceuticals will require tighter controls of current production processes. Also industrial scale extraction and preparation processes have to be developed. The effect of heath exposure, final humidity, storing, type of presentation, etc. on the different properties of NCS and its extracts and components has to be understood, as well as the effects of agronomical variables (soils, cane variety, cane maturity, climate, etc.) on them. All of this calls for an ambitious R&D agenda.

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