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OTHER RAW MATERIALS FOR PRODUCING ETHANOL

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INTRODUCTION

Ethanol may be produced from a wide variety of raw materials, both fossil and renewable. Current commercial fossil sources for ethanol are natural gas, petroleum, and coal, which will not be discussed here. Most of the ethanol is produced from renewable raw materials, which are essentially sources of carbohydrates as sugars (sugarcane, beet, sweet sorghum, Jerusalem artichoke, fruits), starch (corn, wheat, cassava, sweet potato), and lignocellulosic materials. Ethanol production technologies from materials rich in sugars or starches (these are sugar polymers) are called first generation, while ethanol and other biofuels production processes from lignocellulosic materials are named second generation. While first generation technologies are in an advanced degree of commercial maturity, the second generation will still require several years, maybe decades, to become competitive. However, the expectation is that when this happens, they will supersede and replace the first generation processes, for using abundant, varied and cheaper raw materials than those used now. It is important to mention that this expectation is not certain and there is a chance for both technologies to coexist and get pooled together, rendering the production of renewable ethanol even more competitive in comparison to fuels derived from petroleum.

In spite of the large variety of possible raw materials for producing first generation ethanol, over 90% of the current world production is from corn or sugarcane. The interest in cassava (Thailand, Colombia, African countries) and beet (Europe, Egypt, Pakistan, Colombia) is growing and indicates that these raw materials will take a significant role in the future, so they deserve more attention. Sweet potato, in spite of its great potential, lacks some additional technology development in the agricultural end, and also lacks developed varieties to maximize the fermentable material content; this is the reason why it now faces problems with high production costs. Other less-known products, though having a reasonable potential in terms of productivity and production costs, are sweet sorghum and Jerusalem artichoke. These will be the raw materials covered in this chapter, the approach considering two groups, one made up of cultures using developed agricultural production technology, i.e., having the possibility of growing in considerable scale like corn, sorghum, cassava, and sweet potato; and another comprising species that have demonstrated potential for high biological yield at laboratory level, but lacking agricultural production technology adequate to Brazilian conditions.

IMPORTANT RAW MATERIALS

Corn

Corn is nowadays the most utilized raw material, being the US the largest ethanol producer in the world, using almost exclusively this cereal. China, the third largest ethanol producer, after the US and Brazil, also uses mostly corn for the production. Other countries that are large corn producers like Argentina, Australia, and South Africa have seriously considered starting large-scale ethanol production from this cereal. It is important to mention that corn is one of the most cultivated cereals in the world, using an area of 158 million hectares (FAO, 2008), and it is a *commodity* with a strong international market.

DOSON (2001) compares corn with various other raw material options for producing ethanol in the US and the key indexes are shown on Table 1.

These values look rather underrated, as we will see later, but they are interesting as comparison.

Average values of the typical corn composition are shown on Table 2.

Table 2 shows that the content in protein, fatty material and carbohydrates gives corn a high nutritional value, both for human beings and animals. The above 70% content of carbohydrates makes transportation and storage easier and cheaper, allowing its processing into alcohol throughout the whole year.

TABLE 1 Ethanol yield from different raw materials.

Raw material	Fermentable material %	Ethanol yield ($l.t^{-1}$)
Wheat	58.6	356
Corn	57.8	348
Beet	16	92
Sugarcane	11	63
Sweet potato	23.3	129
Potato	15.6	94
Jerusalem artichoke	15.2	82
Pure sugar	100	577

Source: Adapted from DOSON (2001).

TABLE 2 Typical composition of corn.

Component	Content (% m/m)
Moisture	10.93
Protein	9.88
Fatty material	4.17
Carbohydrates	71.95
Fibers	1.71
Ashes	1.36

Source: DOSON (2001).

The great popularity of corn as such a widespread international culture explains its being now the leading raw material for producing ethanol. Nevertheless, its expansion does not seem to be sustainable due to the unattractive energy balance, mediocre productivity and high production costs. On top of requiring subsidies for corn and industrial production, corn ethanol still depends on the sale of its by-products (*Distillers Dried Grain with Solubles* – DDGS in the case of *dry milling*; oil, bran, germ, HFCS in the case of *wet milling*) to be economically feasible. The market for these by-products is limited, and its saturation point doesn't seem too far to be reached.

From the standpoint of area required, corn does not seem to be a good option. Only the US and Argentina have productivity levels that could justify using corn to produce ethanol, as shown on Table 3. The value of 400 $l.t^{-1}$ of corn was used in this table for being a more updated figure than the one presented on Table 1.

From Table 3 it is possible to observe that only the US and Argentina have a productivity level compatible with ethanol production, however much lower than sugarcane.

The technology for converting corn into ethanol is very well developed in the US, which is today the largest ethanol producer in the world. Two processes are used, with relative advantages: *wet milling* and *dry milling* (DOSON, 2001).

The *dry milling* technology is the older and more traditional to produce ethanol from corn. It comprises well characterized steps: grinding, cooking, saccharification (hydrolysis), fermentation, and distillation. Several plants use the simultaneous saccharification and fermentation process – SSF, reducing investment costs and making operation easier.

Grinding is done in mechanical mills, achieving an adequate granulometry for saccharification. The cooking stage's purpose is to gelatinize starch, to allow hydrolysis by enzymes, converting it into

TABLE 3 Corn production in some countries.

Country	Area (1,000 ha)	Production (1,000 tons)	Productivity (t,ha^{-1})	(l,ha^{-1})
US	35,022	332,092	9.48	3,800
Brazil	13,827	51,590	3.73	1,500
India	7,770	16,780	2.16	860
China	28,074	151,970	5.41	2,160
Argentina	2,838	21,755	7,66	3,000

Source: FAO (2008).

sugar. The corn bran that leaves the mills is mixed with water and stillage to reach a solids concentration of 35% before being sent to the pre-cooker, which operates at 60 °C, and with mechanical shaking; the maximum precooking time is 5 minutes. Next, the moist dough is taken to the continuous cooker, which operates under an 11 bar pressure, and 180 °C temperature, where it will stay for approximately 2minutes. The cooked gum is unloaded, by pressure, on the saccharificator, where part of the water evaporates (*flashing*), bringing the temperature down to about 60 °C, when enzyme alpha 1,4-D-glucan hydrolase added in a ratio of 0.025% to 0.050% relative to the starch dry base will act. The pH should be kept between 3 and 5 and the temperature between 30 °C and 65 °C.

Fermentation and distillation processes are similar to those used for sugarcane, discussed in other chapters in this book, except in the SSF process. In this case, the whole process is done in about 40 hours. The main sub-product of the *dry milling* process is called *Distillers Dried Grain with Solubles* – DDGS, which is used as cattle food.

The *wet milling* process is more recent, having been introduced to large scale in the late 1970s, with the accelerated growth of corn ethanol in the US. It was originally designed to produce pure starch, used to produce dishwashing detergent and corn fructose syrup (high fructose corn syrup – HFCS). Its use for producing ethanol was made popular by *Archer Daniels Midland* – ADM, the largest ethanol producer in the US.

The greatest advantage in this technology is the generation of a large number of co-products (HFCS, corn oil, corn germ, dextrose, gluten, and other types of food products for human beings and animals), which contributes to improving the economic viability of ethanol.

Before grinding, corn is immersed in water (*stripping*) to remove the soluble portions and recover the germ, fiber and gluten. After this process, the corn is ground, saccharified, fermented, and the alcohol is distilled in a very similar way to the one used in the *dry milling* process.

Cassava

Cassava is a species that was domesticated by the pre-Columbian populations, with the objective of storing starch in the roots, and being multiplied on its own since 6 to 7 thousand years ago. The selection process was so efficient that cassava became the basic food for various indigenous populations and a supplement to others. Yet nowadays it plays an important socioeconomic role in several tropical countries, mainly in America and Africa. Brazil is the second largest producer in the world, accounting for 10% of the production, after Nigeria (FAO, 2008). Historically, the production of roots in Brazil oscillates between 20 and 25 million tons of roots per year, being the fourth product in volume among the yearly cultures, after sugarcane, soybean and corn.

Cassava in Brazil is typically intended for human nutrition, as starch or its derivates, cassava

TABLE 4 Quantity and value of some selected yearly cultures over three years.

Culture	Production (tons)			Value of the production (thousand R$)		
	2003	2004	2005	2003	2004	2005
Sugarcane	396,012,158	415,205,835	422,956,646	12,288,334	12,149,902	13,148,658
Soybeans (grains)	51,919,440	49,549,941	51,182,074	28,584,866	32,627,677	21,750,332
Corn (grains)	48,327,323	41,787,558	35,113,312	13,522,976	11,595,513	9,459,161
Cassava	*21,961,082*	*23,926,553*	*25,872,015*	*4,372,646*	*4,954,660*	*4,081,973*
Rice (with husk)	10,334,603	13,277,008	13,192,863	5,894,739	7,750,355	5,014,251
Wheat (grains)	6,153,500	5,818,846	4,658,790	2,459,688	2,102,426	1,413,409
Potato	3,089,016	3,047,083	3,130,174	1,594,161	1,719,657	1,879,496
Beans (grains)	3,302,038	2,967,007	3,021,641	4,008,884	3,082,348	3,475,946

Source: IBGE (2007).

flour and to a lesser scale, for animal feeding. Throughout Brazil there is a predominance of survival cultures and small-scale production for one's own consumption, and small local and regional markets. In parallel, using 100% Brazilian technology, in the states of Paraná, Mato Grosso do Sul and São Paulo, with some branches in the Santa Catarina state, a vibrant agribusiness developed, connected to the cassava production chain, its technological development being a global benchmark. It produces and processes about five to six million tons of roots per year, apparently half for starch and half for flour. The competitiveness of the cassava in this region is based on the good agricultural performance in comparison to other Brazilian regions: high productivity (Table 5), modern industrial facilities and economy-driven administration throughout the supply chain. Therefore, it is a model region to analyze the feasibility of producing ethanol from cassava. Even in this region, cassava is mostly cultivated by small farmers, though some of them have areas beyond 2,000 ha, in the least fertile soils in the region, rotating with soybean, corn and pasture.

Production of roots

Cassava is a long cycle plant that begins storing starch in the roots 40-60 days after planting, and continues doing so during all the time it is cultivated, as long as there are environmental conditions for photosynthesis. To optimize cost/benefit, cultures intended for flour and starch industries are harvested after 2 cycles (18-24 months); how-

TABLE 5 Production, area and productivity of cassava in Brazil and selected Brazilian states in 2005.

State/Brazil	Production (tons)	Area (ha)	Productivity (t.ha^{-1})
São Paulo	1,144,880	48,643	23.54
Paraná	3,308,000	165,970	19.93
Santa Catarina	589,998	32,165	18.34
Mato Grosso do Sul	538,754	32,492	16.58
Brazil	25,872,015	1,901,535	13.61

Source: IBGE (2007).

ever, there is no technical reason preventing to do it either earlier or later than this period. Harvesting takes place all year round, with a slight reduction in starch content during summer.

Cassava is a species with high yield for producing biomass. The maximum estimated potential under optimum conditions, by means of mathematic growth models, predicts that good genotypes may produce up to 90 t/ha$^{-1/}$year^{1} of roots, or 30 t/ha^{-1}.year^{1} of dry matter. In small plots, 28 t/ha^{-1}/year^{1} of dry matter were obtained at the International Tropical Agriculture Center in Cali, Colombia (COOK, 1985, p. 78). However, it is in stressful conditions that cassava offers advantages in comparison to other cultures by its tolerance to biotic and abiotic factors. Even in regions where performance is better, if analyzed in detail, there are quite different productivity levels, as shown on Table 6.

Overground part production

Cassava is cultivated only to exploit the roots and a small part of the stems as propagation material. About half of the green mass produced is left on the field. This residue may be used to feed animals, as input for power generation or, when abandoned on the field, it has a high nutrient recycling capability. There is consistent information in scientific literature demonstrating the quality and the viability of using it to feed animals, particularly ruminants (CARVALHO, 1983 *et al.*). There is quality and volume to feed a considerable quantity of animals, e.g., 10 ha of cassava produces an overground part sufficient to feed 100 bovines for three months on a fattening program, with minor nutritional supplements. Considering the productivity of 45 t/ha^{-1}, for 18 to 24 months plantations, and the bromatologic compound, it is possible to feed 1,500 bovines per day/ha^{-1} on a fattening program.

Regarding it as an input for power generation, cassava vine is not different from the pattern of other biomasses. The heating value of dry vine was considered as 15.76 MJ.kg^{-1} by CERQUEIRA LEITE (2005) and SILVA, *et al.* (2007). BOOG *et. al.* (2007) estimated that a cassava plantation with approximately 300 days of cultivation in Assis-SP, produces 2.86 t.ha^{-1} of dry mass usable as input for power generation with Higher Heating Value – HHV of 15.1 MJ.kg^{-1} and considering 40% moisture, results in 4.76 t.ha^{-1} of material for combustion with Low Heating Value – LHV of 7.65 MJ.kg^{-1}. Simulations of the power generating potential at various productivity levels observed in the São Paulo state are shown on Table 7. Considering that the energy consumption (industrial + agronomical) of producing ethanol is approximately 82,400 MJ.ha^{-1}, estimating a production of 33 t.ha^{-1} (SALLAS, 2008), using the vine may be decisive for the energy balance of cassava. These figures are simulations obtained from estimated parameters in laboratories and on the field, so they do not comprise transportation costs and other logistic aspects required to the use of the overground part of cassava, because no actual studies were found on this issue.

TABLE 6 Production of roots, dry matter, starch and ethanol from cassava in two regions and some selected producers in the São Paulo state.

Reference	Productivity t.ha^{-1}	Dry Matter %	Starch t.ha^{-1}	Ethanol (99,5° GL)[4] L.ha^{-1}
Mogi-Mirim area[1]	38	38	13	8,000
Assis area[2]	28	38	10	5,900
Selected producers[3]	55	42	18	12,800

[1] Mogi-Mirim (harvested area 2,200 ha.year^{-1}; production 84,000 t.year^{-1}; average 2001-2006).

[2] Assis (harvested area 8,300 ha/year; production 231,000 ton/year; average 2001-2006).

[1,2] Source Cati/IEA, 2007.

[3] Variety IAC 14, 2-cycle harvest (18 to 24 months).

[4] Utilizing parameters obtained by SALLA (2008) (1 ton roots with 330 kg starch + 50 kg fermentable sugars, yielding 210.6 liters of ethanol 99.5° GL).

TABLE 7 Heating value of residues from a cassava plantation (vine + variety) in two regions and some selected producers in the São Paulo state.

Reference	Productivity		Energetic value[4]			
	Roots	Overground part	Based on heating value	Base on LHV	Equivalent in	
	t.ha^{-1}	t.ha^{-1}	MJ.ha^{-1}	MJ.ha^{-1}	kWh[5]	Liters of ethanol
Mogi-mirim[1]	38	25	98,150	82,875	69,063	4,421
Assis [2]	28	20	78,520	66,300	55,250	3,537
Selected producers[3]	55	45	176,670	149,175	124,313	7,958

[1] Mogi-Mirim (harvested area 2,200 ha.year^{-1}; production 84,000 t.year^{-1}; average 2001-2006).
[2] Assis (harvested area 8,300 ha.year^{-1}; production 231,000 t.year^{-1}; average 2001-2006).
[3] Variety IAC 14, 2-cycle harvest (18 to 24 months).
[4] HHV above 15.1 MJ.kg^{-1} and LHV below 7>65 MJ.kg^{-1} at 40% moisture.
[5] An average low-income home uses 250 kWh.month^{-1}, in average.

Source: Cati/IEA (2007); developed by VALLE (IAC) and BIZZO (Unicamp).

The overground part of cassava has a mineral composition similar to other species. Due to the large volume of biomass produced, it is a great nutrients extractor (Table 7). However, in the roots that are extracted from the field, the major components are water and starch. The overground part is richer in diversity and minerals concentration, so cassava is an excellent recycler of nutrients. Cassava extracts more nutrients than sugarcane, however it exports much less (Table 8), which gives it a more favorable profile for environments handled in a sustainable way. Another differentiating feature is the quantity of N required. Though cassava needs more N during the cycle, it exports only 69 kg/ha^{-1}, while sugarcane exports 96 kg/ha^{-1}. Surprisingly, cassava has extremely low needs for nitrogenated fertilization, while sugarcane is very responsive to this fertilizer. The nutrients cycling profile favors producing cassava in self-sustainable handling as well as the energy balance. Nitrogenated fertilizers require great supplies of energy during production, being an unbalancing factor in the energy balance.

Improvement, germplasm, and genetic resources

Cassava is a species about which little techno-scientific knowledge is available, in comparison to other cultivated species. Nevertheless, as it is a native species from Brazil, plenty of empirical

TABLE 8 Nitrogen and other macronutrients extracted, exported and recycled by sugarcane and cassava.

Mode	Sugarcane		Cassava	
	Nitrogen	Other nutrients[1]	Nitrogen	Other nutrients
	kg.ha^{-1}			
Extraction	163 (100%)	383 (100%)	232 (100%)	434 (100%)
Export	96 (59%)	199 (52%)	69 (30%)	150 (35%)
Recycling	67 (41%)	184 (48%)	163 (70%)	284 (65%)

[1] Other macronutrients: P+K+Ca+Mg+S.

Source: SALLA (2008).

knowledge is available, as well as techno-scientific knowledge aimed at the production of cassava flour and starch, which may be used as *input* for energy generation.

Brazil is the largest holder of genetic resources for cassava in the world. This species is cultivated, and has native varieties in all Brazilian ecosystems, from the Amazon, semiarid, down to the sub-tropical region, with mild temperatures. Genetic improvement programs developed in Brazil are few, but having good results. Table 9 shows the progress in productivity and dry matter content obtained in the Agronomic Institute with new more productive varieties, resistant to epidemic diseases and tolerant to low-fertility soils. So far, improvement efforts have focused only in improvements for root production and resistance to diseases; only recently the dry matter content began to be considered an important attribute in trading.

Regarding biotechnology techniques, molecular tracers, sequencing, and structural and functional analysis of the genoma, recently made available for improvement, in cassava, they are practically absent or focused on other objectives, distant from the assisted improvement aimed at starch production or sugars biosynthesis. For ethanol production, theoretically, it is interesting to develop varieties that accumulate directly fermentable sugars in the root, so that the saccharification process will not be necessary. A germplasm with this feature is already known, however there is a need to develop varieties compatible with large-scale production.

Nutrition

Cassava has good performance in fertile soil, however, its performance is also quite satisfactory in poor soil, even with little fertilization, where other cultures would be unviable. Therefore, it is an excellent instrument for exploiting marginal soils without having to resort to oil-based fertilizers. This behavior is explained by the efficient association with mycorrhiza and/or association with other non-Rhizobia nitrogen-setting microorganisms, a mostly unstudied subject, nevertheless proven efficient. (COOK, 1985). The aptitude of cassava for sharing land with other cultures without loss in productivity may be used in conjunction with nitrogen-setting leguminous plants, mostly peanuts. Therefore, it is a species that may collaborate to mitigate nitrifying pollution.

Tolerance to hydric deficit

Cassava seeds have their mass between 30 and 130 g per unit, which gives it good resistance to rainless periods during planting. When the plant is installed, short mini-summers in the winter season may reduce the potential yield, however, in no way it will jeopardize production, as it happens with cereals. Therefore, it is a low-risk culture. This adaptability makes cassava a species very

TABLE 9 Comparison of productive performance and dry matter content of different cassava varieties.

Variety	Production		Dry matter content
	$t.ha^{-1}$	%	%
White from Santa Catarina	20.8	100	39
Fiber	20.8	100	35
Roxinha	21.2	102	36
IAC 12	21.8	105	41
IAC 13	22.6	105	40
IAC 14	26.1	125	43

15 to 22 assessments with one cycle (10 to 14 months).

Source: LORENZI and MONTEIRO (1996).

well adapted to tropical climates where rains are not frequent. This feature is a consequence of the deep root system that exploits a large volume of the soil and physiological mechanisms of rational use of water (COOK, 1985). Therefore, cassava may occupy areas not recommended for sugarcane due to their hydric deficit.

Mechanization

Mechanization of the cassava cultivation has evolved significantly from the 1990s on, and many tasks became fully mechanized, like planting, or partially mechanized, like harvesting. This evolution, associated to the use of herbicides, allowed the increase of cultivated areas in the states of São Paulo, Paraná and Mato Grosso do Sul and is spreading to other states where large projects are being implemented. However, cassava still requires considerable labor, which may limit its cultivation. Machinery for cultivating cassava is typically low cost, in comparison to what is used for cereals and sugarcane, making it affordable for small farmers.

Technology directed to family agriculture

Cassava is a culture whose technological profile matches family agriculture and that in parallel with, or complementary to, sugarcane, may continue to develop technically for large agribusinesses, as well as to integrate family agriculture in energy generation in a way to integrate – and not exclude – social benefits. Therefore, exploiting the features below may be useful in the formulation of public policies, aiming at improving the productive system and minimizing negative socioeconomic impacts.

a) *Low capital demand.* Cassava is a low-risk, low-cost culture. The major disbursement is in harvesting, i.e., close to the income period. Therefore, even producers on a small capital budget can cultivate cassava with low credit needs, with their own capital or even in collaboration with the agro industry receiving the raw material.
b) *Constant cash flow.* Cassava roots are marketed throughout the year, so positive cash flow is constant, making finance management similar to a non-seasonal business, with easy and rational administration for small producers and agro industries.
c) *Business model for small producers.* Currently available techniques allow small producers to obtain a good income, becoming a profitable business model. In the past years, the average cultivated area has increased as a result of the development of agricultural machinery, however, these are expected to remain affordable to small producers.
d) *New varieties.* The most important instruments for obtaining a good profit with cassava are either free or low cost. They are good varieties, good seeds and planting at the right time. Cassava is a vegetative propagation species and the varieties are in the public domain, so it is important that the development of new varieties is not protected, requiring the payment of royalties.
e) *Equipment developed by small producers.* Since the 1990s, there was considerable development in machinery for planting and harvesting, which made working in small areas easier and allowed the expansion of cultivated areas, as they increased the income from the cultivated area. These machines were and are still being developed by technicians with empirical and academic background in the Center-South of Brazil and are manufactured by small and mid-size industries specialized in agricultural machinery. It is a very dynamic industry, and the more professional companies are also developing machines for large projects. In this mix, there are a large number of farmers interacting with small jig and fixture shops that develop, manufacture and improve agricultural machinery for cassava. This employs local talent, adds dynamism to the local and regional economy and to the whole production chain. Though there are many technical innovations, the industry works informally without requesting patents and deserves governmental support to continue the informal innovation process.
f) *Marketing agreements.* The price conflict between farmers and agro industries was

a negative factor in the production chain, but with the introduction of agreements and the publication of trading prices (available at: <www.cetea.esalq.usp.br/mandioca/> and others), the sector became more professional and several problems were mitigated regarding prices and delivery of the agreements. Various conflicts still persist, requiring technical formulations to be equated, mostly by publishing information widely, aiming at reducing unbalanced prices.

g) *Development of jobs, competencies and income.* Since production technologies for cassava are developed locally or regionally by small entrepreneurs and public institutions, this makes local and regional economy stronger and more dynamic. Obviously, the industry will develop faster, more efficiently, and with more innovation if it is supported by public policies made for the industry with this intent.

Summarizing, one can state that cassava has a large utilization potential for ethanol production due to biological features that may significantly contribute to mitigate social and environmental impacts derived from the production of this commodity. However, this potential is scarcely explored because its technological development has undergone slow improvements, and to a much lesser extent than needed. Its current status may be considered as resembling sugarcane in the 1970s. Its natural potential will only be exploited if there is intense governmental support to qualify human resources, develop technology and transfer it to the production sector.

Sweet potato

Sweet potato is originated from the tropical regions of the Central and South America. It is a species with high economic and nutritional value (Table 10), being one of the sources of food safety of countless populations, mostly those located in poor regions. It is a rustic culture, adapted to tropical and sub-tropical conditions, with great potential for technology development.

Currently China stands out as the world's largest producer, having over 4.7 million hectares cultivated with sweet potato, and reaching an average productivity level of 21.3 $t.ha^{-1}$ of roots (FAO, 2008). The African continent is second, however with low average root productivity (4.4 tons/ha). Still in Africa, the leading producer is Nigeria, with over 1 million hectares cultivated with sweet potato, however, presenting only 3.4 t/ha^{-1} in average root productivity (Table 11).

Among developed countries, Japan stands out with the highest average root productivity (24.2 $t.ha^{-1}$), above the level achieved in the US (21.0 $t.ha^{-1}$). Still considering Japan, historically, sweet potato was used as raw material for producing ethanol during Word War II, as reported by Mr. Ryoichi Nakagawa, which was used as fuel for aircrafts and other vehicles (NEELY, 1997), (AKIHIKO ANDO, personal communication)[1].

In Brazil, sweet potato is cultivated practically everywhere, and mostly as a culture to guarantee food in small rustic properties. In 2006, IBGE data showed the Northeast (19,381 ha), the South (18,768 ha) and the Southeast (5,635 ha) as the regions having the largest areas producing sweet potato (Table 12).

In the Southeast region, the São Paulo state stands out with the largest cultivated area with this tuber (3,114 ha) which is scattered all over the state (Figure 1). Three large production areas, however, should be highlighted, represented by the cities of Sorocaba, Dracena and Presidente Prudente, where areas larger than 250, 300 and 2,000 hectares, respectively, are cultivated (Figure 2).

Processing of amylaceous raw materials for ethanol

The starch present in the roots, tubers and cereals has to be converted into sugar, to be fermented by yeasts. Hydrolysis or saccharification of starch may be done by acid or enzymatic way

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[1] ANDO, Akihiko. Personal comunication (2007). Escola Superior de Agricultura Luiz de Queiroz – Esalq/USP – Centro de Energia Nuclear na Agricultura (Cena); Piracicaba-SP.

TABLE 10 Average nutritional composition of sweet potato *(Ipomoea batatas)*, taro *(Colocasia esculenta)* and yam *(Dioscorea alata)*.

Composition	Sweet potato	Taro	Yam
	Ipomoea batatas	***Colocasia esculenta***	***Dioscorea alata***
Moisture (%)	71.1	69.1	77.3
Energy (kJ 100g^{-1})	438	480	347
Protein (%)	1.43	1.12	2.15
Starch (%)	20.1	24.5	16.7
Sugar (%)	2.38	1.01	1.03
Fiber (%)	1.64	1.46	1.88
Minerals (mg 100g^{-1})			
Calcium	29	32	8.2
Phosphorus	51	70	38
Magnesium	26	115	17
Sodium	52	1.8	3.3
Potassium	260	448	318
Sulphur	13	8.5	12
Iron	0.49	0.43	0.60
Copper	0.17	0.18	0.15
Zinc	0.59	3.80	0.39
Manganese	0.11	0.35	0.04
Boron	0.10	0.09	0.09
Vitamins (mg 100g^{-1})			
Vitamin A (ret. β-carotene)	0.011	0.007	0.018
Thiamine	0.086	0.032	0.047
Riboflavin	0.031	0.025	0.030
Nicotinic acid	0.60	0.76	0.38
Vitamin C	24	15	28

Source: BRADBURY (1988).

TABLE 11 Planted area, total production and productivity for sweet potato in the world and its leading producers (2006).

Countries	Planted area (ha)	Total production (ton)	Root productivity (kg.ha^{-1})
World	8,661,288	127,228,146	14.7
China	4,708,503	100,222,120	21.3
Africa	2,559,223	11,326,628	4.4
Nigeria	1,021,000	3,462,000	3.4
Cuba	47,123	303,000	6.4
Japan	40,800	988,900	24.2
United States	35,130	737,000	21.0

Source: FAO (2008).

TABLE 12 Planted and harvested areas, total production, productivity and total value of production of sweet potato, divided by geographic regions and states (2006).

Regions/States	Planted area (ha)	Harvested area (ha)	Total production (ton)	Roots productivity (kg/ha)	Value
Brazil	44,406	44,357	518,541	11,690	230,768
North	382	366	866	2,366	227
Acre	10	10	88	8,800	50
Amazonas	342	326	628	1,926	103
Pará	30	30	150	5,000	75
Northeast	19,381	19,378	181,470	9,364	65,605
Maranhão	16	16	25	1,562	5
Piauí	98	98	507	5,173	268
Ceará	1,221	1,221	9,306	7,621	3,934
Rio Grande do Norte	2,198	2,197	18,753	8,535	7,461
Paraíba	5,796	5,796	51,225	8,837	18,616
Pernambuco	2,054	2,054	19,051	9,275	9,068
Alagoas	2,031	2,031	18,509	9,113	6,538
Sergipe	3,143	3,143	34,532	10,986	7,226
Bahia	2,824	2,822	29,562	10,475	12,490
Southeast	5,635	5,605	83,800	14,950	31,930
Minas Gerais	1,198	1,198	16,064	13,409	7,194
Espírito Santo	186	186	4,220	22,688	1,688
Rio de Janeiro	1,107	1,107	19,144	17,293	6,385
São Paulo	3,144	3,114	44,372	14,249	16,663
South	18,768	18,768	250,013	13,321	131,919
Paraná	2,997	2,997	49,755	16,601	22,597
Santa Catarina	2,877	2,877	44,931	15,617	15,006
Rio Grande do Sul	12,894	12,894	155,327	12,046	94,316
Center-West	240	240	2,392	9,966	1,086
Mato Grosso do Sul	6	6	90	15,000	32
Mato Grosso	30	30	180	6,000	63
Goiás	120	120	660	5,500	299
Distrito Federal	84	84	1,462	17,404	693

Source: IBGE (2008).

(Figure 3), in continuous or discontinuous processes. Acid hydrolysis reduces the time required for starch saccharification, however, it has a host of restrictions, such as equipment corrosion, the need to correct the pH of the sugar solution, partial destruction of sugars and the formation of non-fermentable sugars. Enzymatic hydrolysis takes place in reactors where enzymes of vegetal or microbial origin, especially the enzymes α-amylase and amyloglucosidase (VENTURINI FILHO *et al*., 2003).

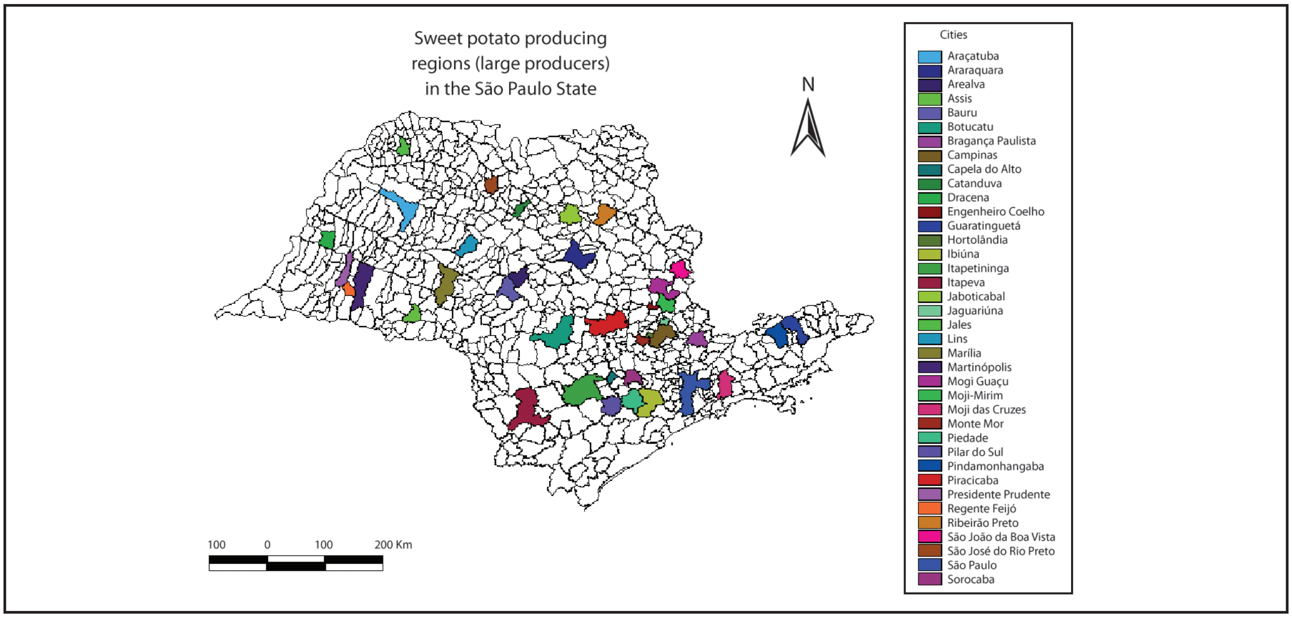
The issue of using amylaceous raw materials, with emphasis on sweet potato, for producing biofuels is not new. In 1909 a study was published assessing the key parameters (productivity and dry matter content in roots) for ethanol yield, suggesting that root productivity would be the major factor (KEITT, 1909). However, when genotypes have different starch content, it is observed that starch plays a larger role in ethanol yield (BOSWELL, 1944). Ethanol produced from sweet potato was used as fuel by Japan in World War II (NEELY, 1997).

In late 1970s, ARAÚJO *et al*. (1979) used sweet potato as raw material for ethanol production, achieving an average yield of 158 liters per ton of roots. However, they observed that the low root productivity (11 to 13 t/ha^{-1}) was the restraining factor for recommending it as alternative source for producing ethanol in Brazil.

In the 1980s, SACKS (1980) pointed out the need to replace the use of grains such as corn to produce ethanol through fermentative processes. According to this author, among the various alternative raw materials for producing ethanol, sweet potato stood out as adequate for this purpose. However, the sweet potato yield of starch per hectare should be higher than grain and plantations should have high starch content.

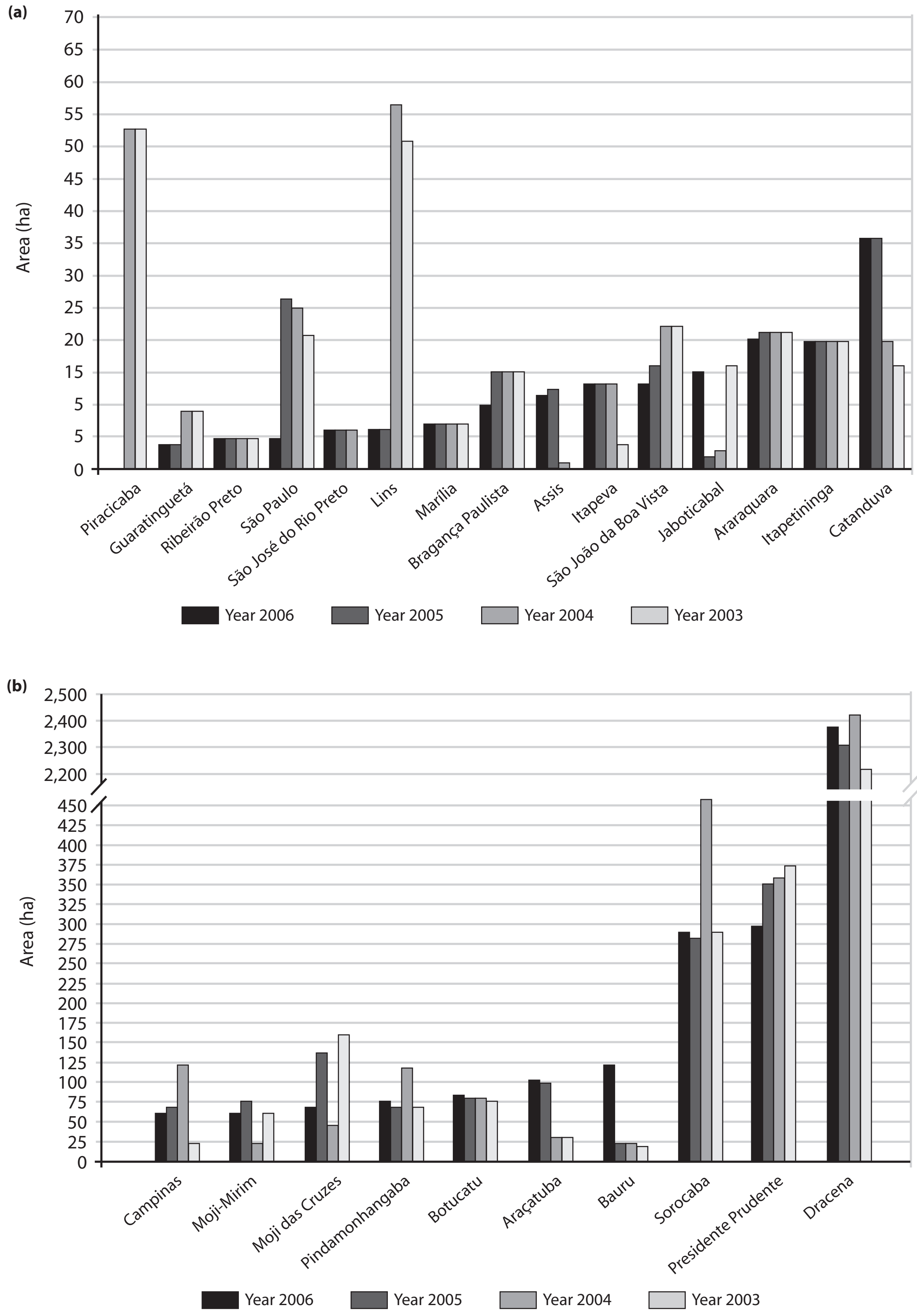
MCARDLE and BOUWKAMP (1982) assessed the sweet potato's potential for producing ethanol, using sweet potato varieties with high starch content in the roots. They found productivities higher than 5.8 t.ha^{-1} of starch in a productive system using little agricultural inputs and a conversion into ethanol higher than 76%. These authors pointed out that roots storage and transportation costs may be limiting factors for the implementation of ethanol processing plants in the US.

Efficiency of the fermentation processes of the sweet potato mash varies between 87% and 93%, depending on the variety and the roots' dry matter content (WU, 1988), which are close to



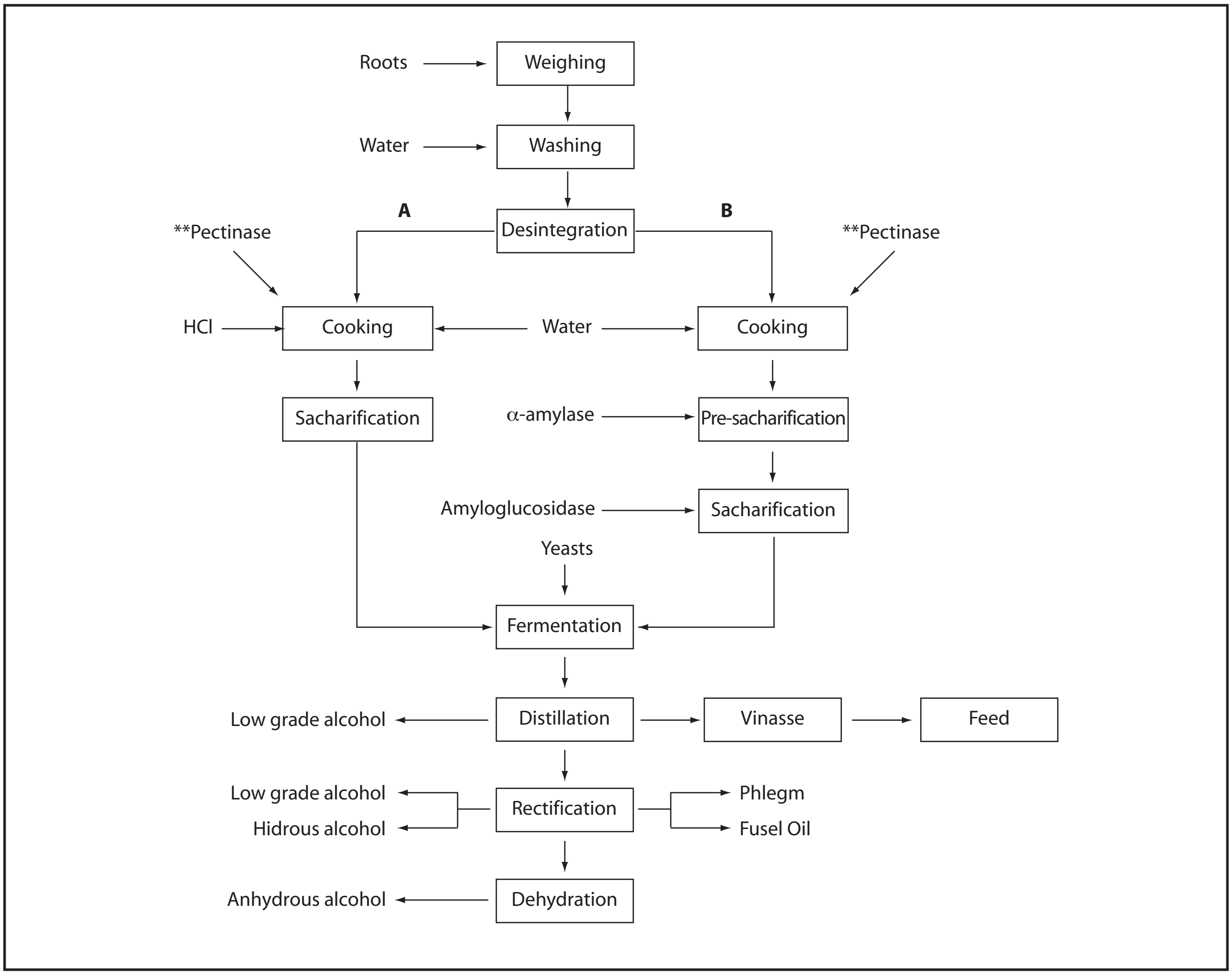
Source: adapted from IEA (2007).

FIGURE 1 Areas where the largest sweet potato producers in the São Paulo state are concentrated.



Source: Adapted from IEA (2007).

FIGURE 2 Major sweet potato producers in the São Paulo state. Areas under 60 hectares (a) and areas over 60 hectares (b).



Source: Adapted from VENTURINI FILHO *et al.* (2003), according to WU (1988).

FIGURE 3 Flowsheet of acid (A) and enzymatic (B) hydrolysis processes modified by the addition of pectinases.

the 88% obtained in the corn fermenting process (WALL *et al.*, 1983).

JONES *et al.* (1983) assessed the sweet potato's capacity to produce ethanol, using the *Jewel* and *Hi-Dry* varieties, obtaining respectively between 5,332 to 7,109 l/ha^{-1}, and between 6,660 and 10,663 l/ha^{-1} of ethanol. Nevertheless, these authors recommend the adoption of varieties with higher dry matter content and the improvement of fermentation methods to increase ethanol yield.

Other cultures may be alternative sources of raw material for producing ethanol. Along this line, TALBERT *et al.* (1983) evaluated the productive potential of eight commercial crops (corn, barley, rye, wheat, grain sorghum, sorghum bicolor, Jerusalem artichokes and sweet potato) in the South-east region of the United States. Best results were obtained with corn, sweet potato and Jerusalem artichoke. From these, the sweet potato was the most viable for producing ethanol, obtaining 1,780 liters of ethanol per hectare, with possibilities of reaching 2,806 L.ha^{-1}, its cost varying from US 42¢ to US$ 2.01 per liter. Yield levels were close to those obtained for corn (2,132 L.ha^{-1}), like production costs between US 42¢ to 54¢ per liter of ethanol. Jerusalem artichoke's yield was lower than 1,700 L.ha^{-1}, and high production cost, at least US 94¢ per liter. These authors pointed the sweet potato as a potential culture for the production of ethanol, and observed that production costs may be lowered by using higher yield varieties and by optimizing fermentation processes.

COLLINS (1984) assessed the dry matter and protein content and the ethanol yield of nine sweet potato genotypes in North Carolina, US. In a harvest made at 5½ months, yield obtained was between 31.4 and 58.6 $t.ha^{-1}$ of roots. The *Pelican Processor* and *Jewel* varieties were the most productive, with 58.6 and 50.2 t/ha^{-1} of roots, respectively. Between these, the *Pelican Processor* stood out for its higher dry matter per hectare yield (18.3 t/ha^{-1}) and ethanol (8,597 L/ha^{-1}), with a ratio of 0.1467 liters of ethanol per kg of roots. It was also ascertained that the roots' dry matter content had a positive correlation with ethanol efficiency ($r = 0.96$ and $p< = 0.01$) and a negative correlation with the protein content ($r = -0.66$ and $p< = 0.05$). Therefore, this author suggested that sweet potato improvement programs should first select high-yield root genotypes and, secondly, select them by the roots' dry matter content.

KIM and HAMDY (1985) obtained for the sweet potato variety *Georgia Red* (23.6% ± 1.2 of dry matter and 21.4% ± 0.6 of starch) a 30.8 $t.ha^{-1}$ roots productivity, which corresponds to 4,032 liters of ethanol per hectare.

In Brazil, specifically in the Tocantins state, Tocantins Federal University (Universidade Federal de Tocantins – UFT) has been carrying out a sweet potato improvement program, initiated in 1997, specifically focused on energy (SILVEIRA, 2008). In this program, high-yield and high starch content genotypes, with were evaluated for five years in Tocantins regarding root yield, dry matter and starch content, and ethanol yield. Varieties that stood out were Duda (65.5 t/ha^{-1} of roots, 40.4% of dry matter and 24.4% of starch), Beatriz (43 $t.ha^{-1}$ of roots, 33.2% of dry matter and 26.2% starch), Ana Clara (45.7 $t.ha^{-1}$ of roots, 35.4% of dry matter and 23.4% of starch), Amanda (46.7 $t.ha^{-1}$ of roots, 32.4% of dry matter and 21.4% of starch) and Julia (40.6 $t.ha^{-1}$ of roots, 37.4% of dry matter and 24.6% of starch), with 10,467, 7,436, 7,058, 6,595 and 6,585 $L.ha^{-1}$ of ethanol, respectively. Regarding production costs, this author reported an average cost of R$ 0.42 per liter of ethanol produced.

TABLE 13 Composition in percentages of residues (moist and dry) of the sweet potato fermentation process.

Component	Moist residue	Dry residue
	(%)	(55 °C/72 h)
Raw protein	611	14.5
Ethereal extract	0.97	2.92
Raw fiber	7	39.04
Non-nitrogenated extract	22.45	38.6
Ashes	8.98	14.02
Moisture	42	12

Source: SILVEIRA (2008).

Besides the high ethanol production capacity, mainly with varieties having high starch content in the roots, the by-products derived from the fermentation process have characteristics that make them adequate for animal feeding (Table 13), thus being able to improve the economic result of processing plants. The ethanol production rate is about 1:6.4, i.e., for the production of one kg of ethanol, 6.4 liters of stillage are obtained and the solid content in the liquid residue is between 4% and 6% (WU, 1988). However, using a mixture of 40% of ground cassava roots and 60% of macerated corn grain, the ethanol production ratio was 1:14, and the residues from the fermentation featured these physicochemical characteristics: 94.36% of moisture, 4.29% of carbohydrates, 0.93% of protein and 20.88 kcal $100g^{-1}$ for heating value (VIEIRA[2]). In addition to these, sensorial features presented good palatability to cattle.

Currently, interest in using sweet potato as raw material by China and other countries has drawn growing interest, as well as other environmental projects.

Sweet potato processing

Using sweet potato as raw material for producing ethanol causes some problems in the fermentation process, mostly related to the mash viscosity (presence of pectines), interfering in ethanol yield and in the filtering and residue concentration processes. In view of this problem, research was made to stabilize the mash and neutralize the viscosity

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[2] VIEIRA, Jonas Arantes. Agroindustrial Tarumã Ltda. São Pedro do Turvo-SP. 2008.

effect in the process. CHUA *et al.* (1984) determined that the addition of depolymerase pectine to the sweet potato mash increased the release of glucose, however, the use of heating in the saccharification of starch was essential to reduce the process total time. The addition of pectinases to the sweet potato mash increased the ethanol yield, the percentage of solids and proteins in the filter pie (WU and BAGDY, 1987). Regarding the filter cake characteristics, these authors observed an increase in the amino acids content, as they were higher than those present in the filter cake obtained in cereal fermentation processes. Furthermore, the residues of sweet potato fermentation for producing ethanol, especially if concentrated as a filter cake may be used as raw material for the food industry, which contributes to the distillery economic results.

Nowadays, the processing cost of amylaceous raw materials for producing ethanol has been high, which renders ethanol from starch non-competitive in comparison to ethanol produced from sugarcane. However the adoption of varieties with high dry matter content and high root yield, plus adjustments of the fermentation process, such as the use of more efficient or genetically modified enzymes may allow better economic results, like those by SILVEIRA (2008). Nevertheless, it is crucial to add value to the by-products from the sweet potato fermentation process, which may be used for human consumption (WU, 1987) or for animal feed.

Sweet sorghum

This gramineous plant has drawn a lot of attention worldwide as a high potential raw material for producing ethanol, often compared to sugarcane. Its main reported advantages are high resistance to drought, adaptability to less fertile soil (alkaline and salted), undefined production cycle (allows planting at various periods of the year, being capable of offering two harvest seasons or sharing land with other cultures), and being more tolerant to temperature variations, as long as no freezing occurs. On the disadvantage side, the following points were observed: fast deterioration after harvest, difficulties in transportation, more difficult sugar crystallization, low juice purity and lower sugar content than sugarcane.

Because of its less stringent requirements in terms of soil and climate, sorghum has been recently considered for ethanol production in some regions of Africa, China, India, and even Europe (Italy, Greece and Romania). A large project was set up by ETA Florence in Italy (ETA FLORENCE, 2002), using resources from the European Committee to assess the techno-economic feasibility of producing ethanol from sweet sorghum in large agro industrial complexes; three locations were pre-selected: one in Southern Italy (Basilicata area) and two in China (Dongying region in the Shandong province and Huhhot in the Inner Mongolia province), all of them with colder weather, low pluviometric precipitation climates and with irrigation possibilities.

The following agricultural practices were determined for field tests, which are generally independent from the local climate:

- *Planting:* with seeds, immediately after the previous harvest; allows a ratoon, and alternation with wheat or another cereal is recommended, in two-year cycles. There are European, Chinese, and American suppliers of selected seeds at a price ranging from US$ 6 to 10 per kg^{-1}.
- *Density:* lines spread apart 70 cm, and maximum density 10 plants.m^{-2} to prevent them from tipping.
- *Varieties:* several selected varieties having good yield, of the precocious, normal and late types.
- *Fertilizers:* though it is not demanding on soil fertility, sweet sorghum responds well to fertilization, 90 to 120 kg N.ha^{-1} being recommended.
- *Herbicides:* preferably use them in advance of the emergency and select the type carefully if it is to be applied after sprouting.
- *Fitosanitary conditions:* it is important to treat the seeds before planting and to use varieties resistant to pests and diseases.
- *Harvest:* the harvest period is selected by a compromise between maximum productivity and the extension of the harvest period

(2 to 4 months); with adequate planning, up to two harvests per year are possible.

- *Energy demand:* it is strongly dependent on the location and the volume of irrigation water; in the Italian project, the estimate value was 21 MJ.ha^{-1}, while in the Huhhut (China) one, the estimate value was 0.38 MJ.ha^{-1}, reflecting the lower mechanization level and the absence of irrigation.

The energy complexes studied considered 7,000 ha in Italy, 19,000 ha in Dongying, and 20,000 ha in Huhhut. Ethanol productivities per year was estimated as 6,000 L.ha^{-1}.year^{1} for Italy and Dongying and 5,000 L.ha^{-1}.year^{1} for Huhhut, using both stalks and grains as raw material. Mechanized harvest with grain, trash and (chopped) stalks separation done in the harvest equipment.

Production costs were estimated around US\$ 250 m^{-3}, considering the sale of surplus electricity and pelletized bagasse.

Energy balance showed estimated results between 0.52 kWh.L^{-1} of ethanol (Italy) and 0.39 kWh.L^{-1} of ethanol (Dongying).

The Indian company Praj Industries Ltd. (PRAJ, 2005) selected 14 varieties for a three-year test period (2001-2003) in West India. In this process, they also developed agricultural practices, including controlled and measured irrigation; samples were periodically analyzed to measure sugar and fiber content, biomass of leaves and purity of the juice. In terms of fertilization level, it was around 150 N/100 P/100 K kg.ha^{-1}, and irrigation was about 175 m^{3}.ha^{-}1.year^{1}.

Key results were: total fermentable sugars – TFS between 10.5% and 11%, 42 to 50 t.ha^{-1}.cycle^{-1}, 105 to 115 days cycle. Major pests and diseases were assessed and proper fitosanitary actions were suggested.

Several decades ago, SACHS (1980) analyzed raw material alternatives for producing ethanol in California; for sweet sorghum he used experiments in Texas and Louisiana, where some 4,700 L.ha^{-1} of ethanol had been obtained in 110 to 130 days cultivation cycles, being, in this aspect, a better option than corn. In addition to ethanol, 13 tons of fiber (dry basis) were obtained by hectare.

In Brazil, sweet sorghum was intensely studied since the outset of Proalcool. Still in the 1970s, INT (ARAÚJO *et al.*, 1977) thoroughly assessed sweet sorghum for the production of ethanol. Three varieties were provided by the National Corn and Sorghum Research Center of Embrapa, located in Sete Lagoas – Minas Gerais, with two different maturation cycles: 90 and 105 days. Both the stalks and the grains were analyzed for the production of ethanol, while saccharification, fermentation and stillage characterization tests were carried out. Results are shown in this reference. It is worth noting that the Brix of the juices was between 14.67% and 17.87%, in the average of the varieties, quite similar to the values found for sugarcane. Fermentation tests were carried out without any problem, showing good efficiency in laboratory conditions.

A study on sweet sorghum carried out by Esalq in an attempt to combine the culture of sweet sorghum with sugarcane, aiming at having the plant operating all year round, the sorghum would be planted in the sugarcane field renewal area, and several requirements were pointed out as necessary for sorghum to be adequate for such practice, the major ones being: having a short cycle, being sterile (not generating seeds in the field), good sugar content in the period, having resistance to major pests and diseases of both sugarcane and sorghum. In one analysis of the varieties of sweet sorghum provided by Embrapa Corn and Sorghum, some problems were identified that would compromise the sugarcane/sorghum alternation as intended, mostly because of the negative interaction between the two cultures from a pest and diseases control standpoint. A warning was made about the problems resulting from soil compactation, due to sorghum harvesting in the months from January to March, when rainfall is more intense in the Center-South.

Overall, it may be said that some business experience is lacking in the use of sweet sorghum as raw material for ethanol production, both in the agricultural and distillery areas, which might give some reassurance to ethanol producers to try this option.

Jerusalem artichoke

The Jerusalem artichoke (*Helianthus tuberosus L.*), is a plant of the family of the hickory, with tubercles that are a source of inulin, oligosaccharides and fructose. The enzymatic hydrolysis of inulin produces fructooligosaccharides (FOS) with low molecular weight, polymerization degree from 1 to 10, in addition to fructose and glucose. It has an immense range of applications in the food industry and may be used as a substrate for ethanol fermentation.

It is a culture of tropical countries, widely cultivated in Europe, Canada, US, and Latin America (Brazil and Peru). It matures in around 130 days, with the overground part reaching 1.50 to 2.10 m in height; it seems to be resistant to pests and diseases and tolerates droughts well.

The agricultural aspects of growing Jerusalem artichoke were exhaustively studied by PAULA and CARIOCA (2000), motivated by works carried out in Canada, Spain, France and Germany, aiming at obtaining inulin and fructose.

In France, 37 varieties were tested, presenting carbohydrates content in a range from 55% to 75% of dry mass. In Germany, field tests showed values for dry matter between 11.5 to 14.0 $t.ha^{-1}$.

In Brazil, 27 varieties of Jerusalem artichoke were tested in the Northeast by PAULA and CARIOCA (2000), with very promising agronomical results. Dry matter yield varied from 4.6 to 19.7 $t.ha^{-1}$, being inulin between 70% and 85% of dry mass. The two most productive varieties, MFW and Columbia, produced between 19 and 20 $t.ha^{-1}$ of dry matter; these same varieties also produced above 6 $t.ha^{-1}$ of green biomass (overground part), and more than 1 $t.ha^{-1}$ of protein. Considering that two or three harvests are possible in one year, these figures become very significant when considering the production of ethanol.

Fermentation may be carried out directly with inulin, using microorganisms like *Kluyveromices maxianus*, or after inulin hydrolysis into fructose and glucose, when it will be possible to use *Saccharomyces cerevisiae*.

In SACHS' (1980) study, irrigated Jerusalem artichokes in California produced 30 $t.ha^{-1}$ in average, on a 110-day cycle and noticed that the pulp may contain as much as 15% in protein, which confers it a high nutritional value.

Sugar beet

Sugar beets are cultivated mostly in mild climate countries to produce sugar, corresponding to almost one-fourth of the world's production. It is seldom produced outside Europe and the US, however, there are some exceptions, as shown on Table 14.

Though it does not appear on Table 14, it is worth mentioning that beet productivity in Chile was 79 $t.ha^{-1}$ in that same year (2007).

It is easy to draw the conclusion that beet, in terms of productivity in liters of ethanol per area

TABLE 14 Sugar beet production worldwide.

Country	Area (1,000 ha)	Production (1,000 tons)	Productivity (tons/ha)	$L.ha^{-1}$
France	393	32,338	82.28	7,700
Germany	406	26,114	64.32	6,000
US	504	31,912	63.24	5,900
Turkey	330	14,800	44.85	4,200
Iran	160	5,300	33.12	3,100
Morocco	60	3,000	50.00	4,700

Source: FAO (2008).

unit is a good option for many countries, In fact, with the change in the European sugar regime, a large portion of the beets, that won't be used for the production of sugar any longer, is being diverted for the production of ethanol, sharing with wheat the preference for this use.

A few years ago, Syngenta Seeds (CHATIN *et al*,, 2004) concluded a seven-year project to develop sugar beet varieties adapted to warmer climates, with the objective of competing with sugarcane in tropical countries, The noted advantages would be: six-month cultivation cycle; adaptability to alkaline and salted soils, plus lower irrigation demand; Syngenta states that productivity levels between 60 and 80 $t.ha^{-1}$ with saccharose contents from 15% to 19% are obtained with an irrigation of only 10,000 $m^3.ha^{-1}$, A sugar mill using this input was scheduled to start operation in 2004 in India and another one in 2005 in Colombia. The same source estimates that half of the processing plant would be the same for either sugarcane or beet; only the front-end of the process would have to be modified: washing the tubers, slicing, diffusion, drying and pulp pelletizing.

More information on the commercial use of this raw material for producing sugar and ethanol is needed before an opinion can be drawn on its use in Brazil. However, the potential productivity is something that arouses interest. The alternative to be researched is the possible shift between beet and sugarcane, to extend the harvest. There are four plants in Pakistan and one in Egypt operating with these two raw materials.

FINAL CONSIDERATIONS

The options for raw materials for the production of ethanol are many and varied, however few reached a significant proportion as commercial alternatives. It is estimated that about 90% of the world's production of ethanol is from sugarcane or corn. Nevertheless, with the growing world production and the entrance of new countries into production, other raw materials become possibilities, mostly beet, wheat and cassava.

It is interesting to notice that the producing countries so far have always sought for an alternative among the cultures they mastered, like Brazil with sugarcane, the US and China with corn, Europe with wheat and beet, Colombia with sugarcane, and so on. This is explained by the immediate availability to start producing ethanol, technical advances in the selected culture (lower cost and risk) and cultural aspects of working with a well-known agricultural product. Thus, several promising raw material options, like sweet sorghum and Jerusalem artichoke, failed to advance due to the lack of familiarity of the prospective producers with these cultures. The lack of interest leads to a shortage of investments in developing these cultures, which on their turn remain out of the ethanol production chain, and the loop is perpetuated. Table 15 below shows some of these points.

It may be noticed that the cultures that advanced the most in terms of production – sugarcane and corn – had significant gains over the last

TABLE 15 Raw materials for the production of ethanol.

Raw material	Brazilian production (millions of tons)		Productivity ($t.ha^{-1}.year^{-1}$)		Yield in ethanol ($L.ha^{-1}.year^{-1}$)	
	1980	2005	1980	2005	1980	2005
Sugarcane	120	410	45	72	3,015	6,000
Cassava	26	27	12	13.8	2,160	2,750
Sweet sorghum	–	–	35	50[1]	1,925	6,000[2]
Sweet potato	1.6	0.54	10	11.2	1,250	1,770
Corn	16	34.9	1.5	3	580	1,200

Source: MENEZES, 1980; (1) PRAJ, 2005; (2) ETA FLORENCE, 2002.

25 years, while cassava and sweet potato remained stationary regarding production and productivity. Cassava seems to deserve more attention due to the importance of its culture in Brazil and by the potential it has to improve productivity if more effort is put toward genetic improvement and agricultural practices modernization; sweet potato seems to have some potential, but its high production costs place it in the background. Both sweet sorghum and Jerusalem artichoke deserve more attention, however they would still have a long way to go to build confidence in farmers and investors; these two plus cassava may eventually become important options for areas inadequate for sugarcane, however, having other positive features for the production of biofuels, either by their privileged geographic location for exports or for social reasons.

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