

Research and Development Prospects for Sugarcane Industry in Vietnam

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Abstract Sugarcane is one of the most important industrial crops in Vietnam and covers a total of 127,000 hectares of plantation area. In the season 2020–2021, Vietnam has produced 0.763 million tons of sugar (accounting for 0.34% total world sugar production). A current sugarcane production of 7.498 million tons is being used mainly for sugar production for direct consumption, ethanol production, bio-electricity and fertilization. To ensure crop sustainability, various policies and plans have been implemented. Crop breeding and zoning improvement programme significantly influence sugarcane production

and sugar yield. Over 25 years since the programme “one million ton of sugar” was promoted, Vietnam currently possesses 25 sugar mills with a total capacity of 110,000 tons of sugarcane per day. Major problems of sugarcane industry as well as research and development have been discussed in this review. Recent research and development work focused on the added values of co-products to ensure sustainability of the sugarcane industry. Molasses will be used for ethanol production, and bagasse is used as the biomass for the alternative energy. Sugarcane and sugar would be the main feedstocks for those bio-economy growths in Vietnam. To keep the sustainable development of the sugar industry, and to meet the demand of the food and non-food requirements, it is necessary to upgrade the sugar value chain through the adoption and the development of co-products of the sugar industry.

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Introduction

Vietnam is located in an area of the world that has favourable natural conditions for sugarcane's growth. About 250 years ago, Vietnamese learned to grow sugarcane for producing molasses and sugar. By the nineteenth century, sugarcane farming in Vietnam was considered as an additional occupation beside rice cultivation. At that time, sugar processing was simple and a mainly manual operation. At the end of the nineteenth century, the sugar processing started to mechanize, and the factories were gradually built with the capacity of 350–500 tons of sugarcane per day (TCD).

The development of the Vietnam sugar industry made a significant leap through the “One million tons of sugar programme” introduced by the Vietnam government in 1990, which promotes the production of sugarcane and sugar products (MARD 2017). The aim of this programme is not only for economic development but also for social development, especially in rural areas, hilly and mountainous regions. The current sugarcane yield for Vietnam averages about 65 ton/ha. The extent of mechanization of cane production, harvesting and sugar mills has been increasing. The sugar mills now achieve a capacity up to 12,000 TCD. The sugarcane plantation area covers a total of 127,000 hectares (VSSA 2019b). In the season 2020–2021, Vietnam has produced 0.763 million tons of sugar (accounting for 0.34% total world sugar production) which is used mainly for sugar commodities, fermentation substrates, electricity generation and fertilizers. However, due to many recent factors such as the effectiveness of ASEAN Trade in Good Agreement (ATIGA) and the influence of the COVID-19 pandemic, the number of sugar mills dropped significantly from 38 to 29 in 2019/2020 and finally dropped to 25 in 2020/2021. This is a result of the reorganization of the operating factories and temporary closures of inefficient sugar mills.

To confront this downsizing situation of the sugar industry in Vietnam, we have to learn from the experiences of neighbouring countries such as Thailand, Indonesia and the Philippines, especially the latter two countries which have similar situations to Vietnam’s (VSSA 2019b). Thailand has recently become the third largest producer and second largest exporter of raw sugar in the world due to its excellent geographical location and significant efforts by government, sugar industry and farmers (Sukyai et al. 2016). One of the main focuses of research and development in Thailand is the value-added products, achieving Thailand’s sugar and energy requirements for its food and energy security and contributions to the national economy in terms of income and employment generation. Indonesia is the other neighbouring country to Vietnam, the sugar sector remains highly regulated, with the government controlling imports and domestic market prices and supply chains (USDA 2019). White sugar is mainly produced from sugarcane and is primarily for direct human consumption. Refined sugar is also made from imported raw sugar, which is generally used for processing by the food and beverage industry. The Philippines applies different non-tariff measure and technical barrier to control the sugar market, eliminating the low-prices imported sugar into the country (VSSA 2019b). These countries therefore still keep their stable and sustainable situation after the ATIGA came into effect. The lessons from the other countries require that Vietnam prepares for the regional and international integration in terms of appropriate policy and technology. The

situation requires a review of the whole sugarcane and sugar industries and a discussion on possible extended value chains to achieve sustainable sugarcane production. This review highlights significant aspects of sugarcane production and sugar processing, current trend in research and development for a sustainable sugar value chain in Vietnam.

Sugar Value Chain in Vietnam

The sugar value chain starts from input supply (sugarcane seeds, fertilizers, pesticides) to sugarcane plantation for sugarcane production. Sugarcane growers receive the support from sugar mills in form of technical assistance and input supplies. After that the cane is harvested and transported to sugar mills for sugar processing to different sugars and co-products. Figure 1 represents the schematic sugar value chain in Vietnam which shows different stages along the chain. In the production and processing stage, through different processing steps, the transformation of sugarcane into raw sugar is carried out. During processing, different by-products are identified such as top and leaves of sugarcane, bagasse, filter cake and molasses. The final products of the sugar value chain are sugars of different types and co-products such as electricity, fertilizers, alcohols, animal feeds. Sugar is also the main feedstock of many other products of the food industry such as soft drink and beverages, candy and bakery products. Large sugar mills can establish close linkage within the value chain which includes different stages such as cane production, processing, distribution of sugar through processing of secondary sugar product or co-products.

Land, Location, and Varieties for Sugarcane Cultivation in Vietnam

In the 2020/2021 season, sugarcane was planted with a total area of 129,000 ha over the country, mainly located in provinces having sugar mills (VSSA 2021). The sugarcane growing areas can be divided into six regions (Table 1). The climate, geography, soil condition and culture are differing from region to region. This influences land availability, yield and the quality of the sugarcane. According to the report of the National Institute of Agricultural Planning and Projection (NIAPP 2015), the area for sugarcane cultivation is composed of 59.2% hilly terrain and 36.1% flat surfaces and 4.7% low-lying land. Gia Lai and Thanh Hoa are the provinces having the largest production areas in the country.

The sugarcane yield in the Southern Vietnam region is the highest (approximately 82 tonnes/ha), whereas in the

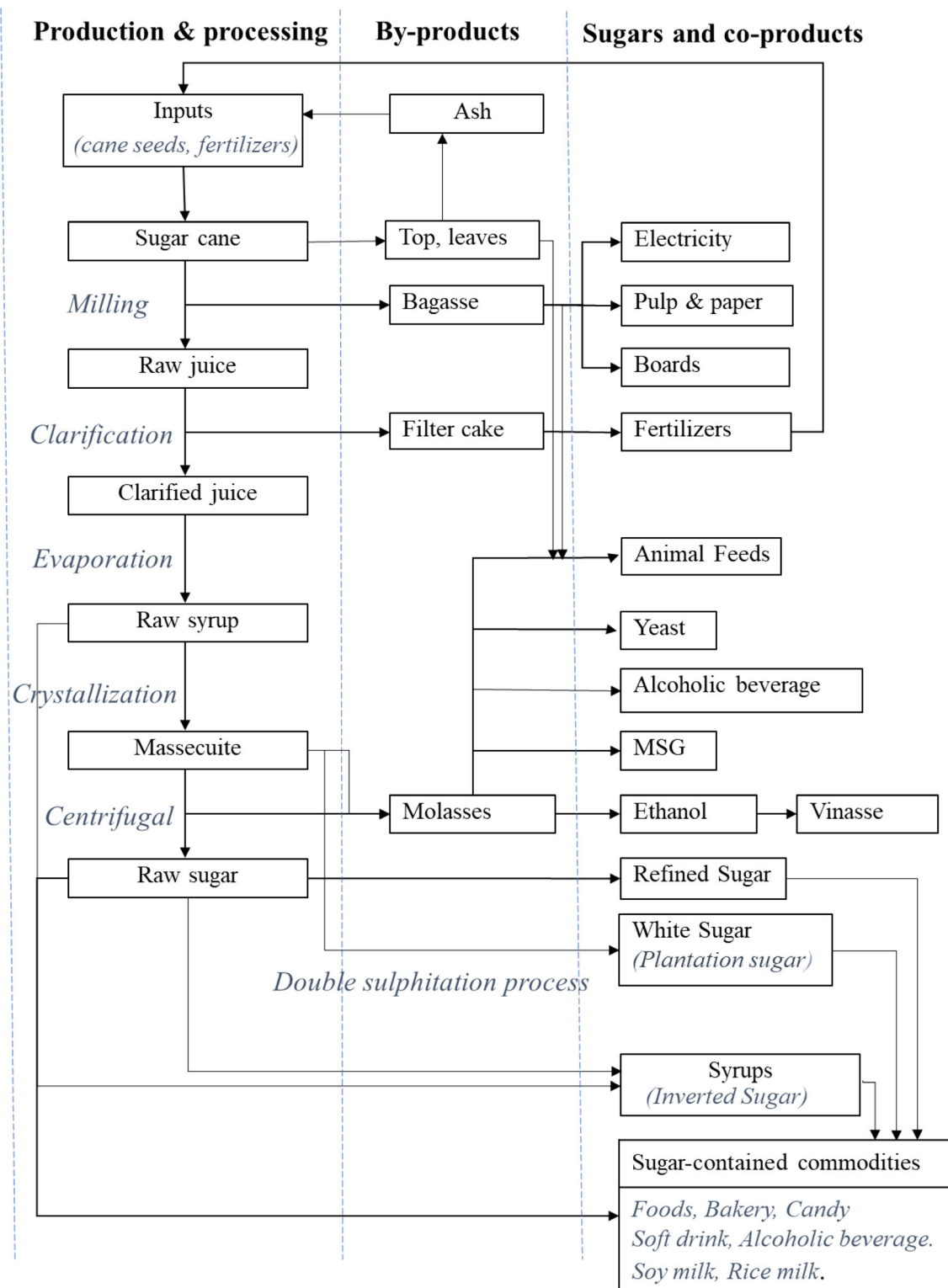


Fig. 1 Schematic sugar value chain in Vietnam

North and Central areas, the sugarcane yield is remarkably lower (58–60 tonnes/ha). However, in terms of quality, the conversion rate of cane into sugar (cane/sugar ratio) in the North was 9.7 which is better than in the South, Centre and

Highlands with ratios of 10.7–10.8. Thanks to the better climate and topography, the irrigation area in the South is larger (13% of total sugarcane areas in this region). In contrast, only 5% of the total sugarcane growing areas in

Table 1 Sugarcane growing regions in Vietnam in 2015 (MARD, 2016b)

Region	Area (10 ³ ha)	Yield (ton/ha)	Production (10 ⁶ ton)	Area with drought/salinity (10 ³ ha)	Irrigated area (10 ³ ha)	No. of sugar mills	Ratio cane/sugar
Over country	284	64	18.3	27	16.7	41	10.5
Provinces (37) without sugar mills	12	49	0.6	–	–		
Provinces (25) with sugar mills	272	65	17.8	–	–		
North	89	60	5.3	14.4	4.4		9.7
Midlands and North Mountain	30	63	1.9		0	5	
North Central	59	58	3.4	14.4	4.4	6	
Centre and Highlands	111	58	6.5	18.6	3.0		10.8
South Central Coast	55	55	3.0	10.6	2.3	10	
Highlands	56	61	3.5	8.0	0.7	5	
South	73	82	6	4.0	9.3		10.7
Western South	24	73	1.7	1.4	9.3	10	
Mekong Delta	49	87	4.3	2.5	0	5	

the North are under irrigation. In the North, land for planting is limited by the mountainous terrain. The average yield in this region is lower in comparison with the South. On the other hand, the dry climate in the North, together with less irrigation, causes the conversion of cane into sugar and the CCS to be higher, and hence the quality is better as mentioned above (Table 1).

The majority of the land belongs to local farmers who own farms of less than one hectare so that the mechanization of sugarcane cultivation is low, resulting in higher sugarcane production costs than those of the world (MARD 2017). Up to the 2014/2015 season, the level of mechanization of sugarcane cultivation was low, for example 59% in soil preparation, 11% in irrigation, 18% in cultivation, and 2% in harvesting (NIAPP 2015). This is low compared to the value of 80–90% in the world's largest sugar producers such as Brazil or Thailand. In general, the cutting, planting and caring of sugarcane are done manually and the irrigation is done by rainfall; thus, the production cost increases while the sugar content and the yield of sugarcane are low. Estimated labour costs paid for harvesting, handling and transportation in Vietnam account for 18–20% of value of sugarcane.

Due to the variations in climate, soil and topography of the cultivation regions, there is no unique variety of cane which can be steadily planted all over the country. Instead, different varieties are required for each region. Most of the current varieties are imported and adapted from other countries such as Thailand (41%), China (12%), Taiwan (22%), France (13%) and Cuba (9%) (MARD 2018). Only 2% of the varieties have been developed by cross-breeding

foreign and local varieties. In the Northern provinces, the cane varieties normally originate from China or Taiwan, for example ROC, QĐ (Guitang), VĐ (Yuetang) and other drought resistant varieties including My55-14, VN84-4137, ROC22/10/16, K84-200, LK92-11, KK3. Most of the varieties cultivated in the Southern provinces are from Thailand, for example K88- 65, K95-156, LK92-11, KK3, Suphanburi7 (MARD 2018).

Production and Processing

Of the agricultural crops cultivated in Vietnam, sugarcane is the most closely linked between farmers and processing enterprises through investment contracts and product sales. Table 2 highlights the changes of the industry over the last three seasons. Cane yield per hectare and CCS % cane have not changed but cane and sugar tonnages were reduced. There is significant reduction in the number of operating sugar mills that led to decreases in sugarcane production, and total sugar produced in the last few seasons. The main reasons are the effectiveness of ATIGA and the import of low-price sugar from neighbouring countries which compete with the high production cost for most of the sugar mills in Vietnam. This trade agreement was effective since January 1, 2020 for Vietnam. The ATIGA comprises several new elements to ensure the realization of free flow of goods within ASEAN, including the following: tariff liberalization, removal of non-tariff barriers, rules of origin, trade facilitation, customs, standards and conformance, and sanitary and phytosanitary measures (Invest in

Table 2 The production activity of recent seasons in Vietnam

	2017/2018	2018/2019	2019/2020
Sugarcane production area (ha)	241,407	192,386	150,689
Cane crushed (tonnes)	15,430,648	12,201,667	7,662,235
Yield of cane/hectare	63.9	63.4	53.39
CCS (%)	9.70	9.70	10.15
Sugar produced (tonnes)	1,476,499	1,173,933	767,954
Cane/sugar ratio	10.45	10.39	9.98
Tonnes sugar/hectare	6.12	6.10	5.09

(VSSA 2020)

ASEAN 2021). This is an encouraging trend which facilitates diversification by creating more co-products alongside of the main products of sugar industry.

Regarding the production cost, Vietnam costs are higher than those of other countries in the world. Specifically, the price of sugar in Vietnam is 45% higher than in Thailand and 72% than in Brazil (VSSA 2019a). This is due to three main reasons: (1) High cost of cane production, (2) The cost of the conversion rate of sugarcane into sugar is also higher and (3) The price of the raw material accounts for 76% of the total production cost for sugar processing factories. The high production cost leads to the low competitiveness of the sugar industry, which is caused by internal difficulties of the industry:

- The sugarcane production area is small, and it is difficult to apply mechanization.
- The growing areas of the country have not been reasonably allocated.
- The research and application of sugarcane varieties suitable for each locality are limited.
- The percentage area of irrigated sugarcane is low.
- The cane growing areas are mostly close to rural locations; this makes the installation of irrigation systems difficult.
- The technical education levels of sugarcane farmers are low. This causes improper soil preparation; low fertilizer investment; poor and untimely applications of fertilizers.
- Post-harvest management is inadequate, resulting in poor recoveries at the mills.

The cost of producing sugarcane is very high in Vietnam. This is a serious problem which needs to be addressed by the industry and Government. The large sugar mills such as LLS and TTC are using Information Technology for harvesting planning to reduce post-harvest lost caused by prolonged waiting time before cane crushing.

Blanco Directo Sugar and the Double Sulphitation process are applied for producing plantation white sugar in

Vietnam. However, Blanco Directo Sugar is becoming more widely used and gradually replacing sugar from the Double Sulphitation process. During the last 10 years, sugar factories in Vietnam used technology and equipment imported from China. Recently, many factories upgraded production and capacity by using newer technology and more efficient equipment. The new investments focus mainly on milling tandems, diffusers, continuous vacuum pans and high-pressure boilers. This results in increasing recoveries and energy savings.

By-products

Beside sugars, sugar industry produces a large amount of by-product (bagasse, molasses, filter cake), which could be further processed to added value co-products. These products contribute to reduce the production costs, thus reduce sugar price, and ultimately enhance competitive capacity of sugar industry. Table 3 shows the survey of Ministry of Agriculture and Rural Development (MARD) on the by-products in Vietnam sugar industry in the period 2005–2014 (MARD 2016a). This survey indicates the low percentage of by-products using for processing secondary products or co-products.

Bagasse: Bagasse accounts for about 30% of the total crushed cane weight, which is equivalent to about 4 million tonnes bagasse per season in recent years.

Final molasses: Sugar processing released final molasses at a ratio estimated of about 4% cane crushed, which is equivalent to 0.5 million tonnes of molasses discharged annually by the sugar industry.

Filter cake and ash: these by-products account for about 3% of the total crushed cane weight, which is equivalent to about 0.4 million tonnes filter cake and ash.

Table 3 By-products converted to co-products in sugar industry in Vietnam over the period 2005–2014

Season	By-product (tonnes)				Converted (%)			
	2005/2006	2010/2011	2012/2013	2013/2014	2005/2006	2010/2011	2011/2012	2013/2014
Bagasse	1,641,696	2,849,806	3,605,086	3,421,676	72.2	72.2	73.9	73.3
Molasses	150,536	302,704	358,157	331,505	43.5	49.2	48.2	48.0
Filter cake, ash	134,464	308,166	359,469	383,285	44.6	54.6	53.1	58.3

Sugar and Sugar Co-products

The types of sugar produced in Vietnam include RS Sugar (Refined Standard), RE Sugar (Refined Extra), and Raw Sugar. Currently, only nine companies can produce RE sugar. The production of RE sugar accounts for approximately 50% of the total national sugar output; it is supplied mainly to industrial customers, thus leading to high demand, less volatile prices and less competition from smuggled RS and Raw sugar.

At present, the revenue from co-products (electricity, fertilizers, alcohol, MSG, animal feeds) from sugar factories contributes 6.4–9.6% of the total revenue of sugar industry; this is an important factor in the production and business of sugar mills. The quantity of materials from which co-products could be developed by sugar mills is currently very large (Table 3). In addition, the level of utilization of secondary materials is not high: about 83% of the bagasse, 48% of the molasses and 61% of the filter cake are converted into co-products. The amounts of secondary materials that are not consumed are often sold or released into the environment. Previously, 80% of the bagasse was used in the sugar factories boilers; the remaining 20% was used to produce plywood. Molasses was fermented to produce alcohol, MSG (monosodium glutamate) and animal feeds. Recently, more sugar mills have invested in technologies to develop co-products from by-products in sugar processing which means to convert the available by-products beside the main products as sugars of different qualities. The benefit of co-products is that their production reduces the impact of reject streams discharged in the environment.

Cogeneration from cane bagasse for electricity: One tonne of cane can provide 0.3 tonnes of bagasse that produce 100–120 kWh of electricity (MARD 2016a). The sugar miller using this source of electricity can export 50–60 kWh to the national grid. In 2016–2017, the sugarcane industry had about 200 MW of generating capacity for export to the national electricity grid. Large sugar mills, such as Lam Son, Cam Ranh, TTC Tay Ninh, Quang Ngai and An Khe, with high capacities have invested in large generators for electricity production. However, due to the unfavourable price of electricity, those millers could not

invest in high efficiency boilers and generators. For the 2017–2018 season, 28 power plants in Vietnam have invested in technology to utilize bagasse to improve the efficiency of sugar production and trading with total capacity of 351.6 MW and producing 186.3 GWh of electricity.

Animal feeds: Beside the usage in power generators, bagasse is also a good feedstock for animal feeds, especially for buffalo and cattle raising. The survey results showed that bagasse was sold by sugar factories in Nghe An, Dak Lak, Hau Giang to livestock businesses with an output of 23,784 tons, accounting for 0.89% of total bagasse processed in the surveyed provinces. In Nghe An, the bagasse of Nghe An Sugar Company was sold to TH Dairy Company for processing as cow feed. In Hau Giang, a Japanese company has invested in animal feed processing factory using fermented bagasse with a capacity of about 20,000 tons of raw materials/year. Currently, bagasse is naturally fermented, and pressed and purchased by Japanese and Korean businesses at a price of 500,000 VND/ton (approximately USD 22/ton).

Fertilizers: Filter cake (mud) and ash are often used to produce biofertilizers, most sugar mills often provide to sugarcane growers or sell to collectors in need. In 2015–2016, there were 19 sugar mills having a complete fertilizer production line from filter cake to supply fertilizers to its sugarcane growers. The total ratio of using filter cake and ash to produce fertilizer is summarized in Table 4. The percentage of filter cake converted to produce fertilizers was 59.1 in the season 2013/2014. Survey results at 10 factories with production lines of microbiological fertilizers from filter cake and ash show that the output of mud and kiln ash put into the production of compost is 188,564 tons, accounting for 43.61% of the total production of sludge and ash generated in sugar processing. The obtained products are mainly invested in the sugarcane material areas of the power plants.

Monosodium glutamate: there is about 0.5 million tonnes of molasses annually provided to monosodium glutamate production.

Alcohol: Molasses products have very low financial margins (less than 1%), while ethanol production can yield up to 30%. Refined alcohol products are made from

Table 4 Statistics of the number of sugar mills producing fertilizers from filter cake in Vietnam over the period 2005–2014

Season	Percentage of filter cake/ash converted to fertilizer (%)			
	2005/2006	2010/2011	2012/2013	2013/2014
Whole industry	65.8	68.6	68.3	59.1

molasses by fermentation followed by distillation. In 2016, only 6 of the 41 sugar mills produce alcohol from molasses. The volume of molasses used in alcohol production varied from 13 to 32% of the total amount produced (Table 5). The excess amount of molasses is sold or mixed with bagasse as animal feeds. The production of ethanol from molasses is not yet common in Vietnam mainly due to economic and competitive reasons. However, the price of ethanol is currently high and varies according to market's trend. If more sugar mills adopt ethanol production technology, the increased revenue can compensate for the higher production cost of sugar. Under the current low sugar price, sugar plants that can also produce ethanol from sugarcane will be effective in production and business.

Yeast production and other co-products: Beside the above-mentioned co-products in sugar mills, there is product development in producing yeast from molasses. The Vietnam-Taiwan Sugar Company has recently invested in food-grade yeast production line. In addition, bagasse can be used as a medium for mushroom production which is also cost-effective. These special, smaller, less development cost, but profitable co-products are very important contribution to the added value of sugarcane. They introduce the concept of developing simple co-products and financially attractive. This model will eventually expand to larger developments and gradually improve financial issues of the industry.

Sugar-containing commodities: Sugar is a main raw material for confectionary, candy, beverage, and soft drinks. These products have recently been developed by sugar millers, according to the market demand and the availability of sugar. A good example is the Quang Ngai sugar factory with well-known brand products such as soymilk, beer, candy, biscuits and mineral water. In the period of 2012–2016, the total income of the company increased 22% each year, reaching 8,223 billion VND (i.e. 360 million US dollars), in which the income from sugar

was only 20% of the total. This is an excellent example of a diversification project which used sugar directly for an important and lucrative market.

Current Trends of Research and Development for Sugarcane Value Chain Development

Major Research and Development Thrusts for Diversification

The research and development (R & D) activities in the sugar industry need to be strengthened through collaboration with research institutions to improve the sugarcane value chain. Presently, the Institute of Sugarcane Research is the main institution carrying out R & D and transferring technology for sugarcane at agricultural production. In 2018 season, the Institute has implemented 90 hybrid pairs, 18 hybrid seedlings and continued to develop pre-selection steps. However, the R & D of using by-products to convert into co-product is still underestimated. New ideas, capacity and effective technological transfer are needed to increase the value of co-products.

Diversification Through Development of Added Value Co-products

In order to gain more value from sugarcane, several factories are starting to focus on different added value products from sugars such as polyols, inverted sugar, and fructose oligosaccharides. In a recent study, Hanoi University of Science and technology (HUST) used cane juices, syrup and sugar from a sugar mill to produce invert sugar syrups, using a commercial invertase enzyme. At pilot scale and under reasonable experimental conditions, the yields were 95–98%. The syrup with low residual sucrose has been successful applied for the production of

Table 5 Statistics of the number of sugar mills producing alcohol from molasses in Vietnam over the period 2005–2014

Season	Percentage of final molasses converted to produce alcohol (%)			
	2005/2006	2010/2011	2012/2013	2013/2014
Whole industry	25.0	31.8	31.7	13.3

jams with different tropical fruits (Figs. 2, 3). In addition, there are also other research activities regarding to the use of by-products in R&D institutions in Vietnam. High-test molasses (HTM) is a co-product obtained by the concentration of clarified cane juice to approximately 85°Bx, followed by a partially inversion of sucrose using invertase or acid. The HTM production uses sucrose thus reducing the tonnage of sugar produced. Financial implications must therefore be studied to ensure profitability. HTM can be an interesting added value co-product for the sugarcane industry.

At smaller scale, Fructose oligosaccharide (FOS) can be produced by the degradation of inulin or by the transfructosylation action of a β -fructosidase on sucrose. The resulting mixture has the general formula of (GF)_n, with *n* ranging from 1 to 5. FOS, especially from sucrose, has been paid attention for two decades. However, due to the lack of commercial enzymes, this co-product was not considered. Recently, the availability of commercial enzymes has restarted the consideration on this co-product by R & D teams from several sugar mills in Vietnam. Recently, several “blended” co-products have been created including cane sugar and different components having the functional characteristics of compounds such as oligosaccharide prebiotics, fruit juice concentrates (for colour), natural flavours. This can be a potential option for sugar factories to increase the value of sugar products.

Molasses, another by-product of the sugar processing, has been used for animal feeding in Vietnam. It is added directly to the animal feed to increase energy for cattle (Nguyen and Bui 2016; Cuong et al. 2010), and for black tiger shrimp (Chau et al. 2017). Molasses can be mixed with shrimp heads, a waste stream from the shrimp industry,



Fig. 3 Inverted sugar, syrup and jam developed by HUST

at a ratio of 1: 3. This co-product has a protein content of up to 35% and is rich in N-glucosamine. Ducks meals supplemented with 17% of this co-product were recommended. (Phan and Pham 2004). Recently, sugarcane molasses was used as nutrient for carotenoids or beta-carotene production. The carotenoid was accumulated up to 1100 mg/g of *Rhototorula mucilaginosa* using sugarcane molasses (Pham Thi Ly 2018).

Sugarcane bagasse, beside using for boilers and cogeneration, was also considered to yield glucose for bioethanol production. A fast pyrolysis system was first investigated in 2019 for bio-oil production from sugarcane bagasse in Vietnam. The obtained bio-oil co-product met the US standards for fast pyrolysis fuel oils (ASTM-DT544-12) (Nguyen et al. 2019). Bagasse can be used to produce a bio-char which adsorbs heavy metal ions in wastewater. Charcoal from bagasse was used to adsorb Cu²⁺ and Ni²⁺ with the adsorption capacities reaching 50.0 mg/g and 44.8 mg/g of Cu²⁺ and Ni²⁺, respectively (Le and Hua 2018). Ho and Phuong (2015) used bagasse to



Fig. 2 Production of inverted sugar at pilot scale at HUST

form composite materials; the highest mechanical composite (100 kg/cm^2) was achieved by mixing 50% bagasse and 50% polypropylene at $180 \text{ }^\circ\text{C}$ for 15 min. Another composite with 25% bagasse and 75% rice straw was made and used in vegetable farms (Vo and Thi 2017).

Sugarcane bagasse is considered as an alternative industrial feedstock to produce bioethanol. Bagasse usually contains from 40 to 45% cellulose and therefore can be used as feedstock for ethanol production. One of challenges is to have a hydrolysate with high concentrations of glucose. Different fractionation processes were investigated for remove of lignin and hemicellulose, in results to yielded cellulose contents of 85% to 90% were developed. (Le et al. 2015; Ngo et al. 2015, 2016a, b). The ethanol fermentation of these hydrolysates was not inhibited and gave a achieved a fermentation yield $91.08 \pm 2.02\%$, comparable to that with glucose fermentation (Ngo et al. 2016a). A simultaneous hydrolysis and fermentation to convert the pre-treated bagasse to ethanol was performed giving an ethanol content of $82.46 \pm 3.42 \text{ g/L}$. The fermentation process time was shortened to 4 instead of 7 days (Ngo et al. 2016a). Bagasse was also hydrolyzed with sulfuric acid for glucose recovery; the residual bagasse was used to grow *Yarrowia lipolytica* yeast to produce lipids (Ho et al. 2013).

Sugarcane bagasse was used in the production of the erosion control blanket (ECB) in mixture with agricultural by-products due to the research done by The Agricultural Genetics Institute of Vietnam in cooperated with TU Bergakademie, Freiberg Germany. ECB is biodegradable and prevents erosion. Soils were tested in open field at a construction site of TU Bergakademie (Fig. 4). During the pilot phase (1.5 years), ECB helped protect the slopes against erosion and improved water retention in the soil.

Trials in Vietnam support the results. These natural mats are already used to combat erosion and enrich the nutrients in soil in the province Thanh Hoa, Vietnam (Katja et al. 2020).

Bagasse has also been considered in a first trial to produce geotextile, a type of biodegradable cover film, preventing erosion and leaching in soils. This research was also conducted by the Agricultural Genetics Institute, and the film was primarily applied to the slopping areas in Lam son, Thanh Hoa province. Recently, small applications of bagasse have been considered for the production of fibre-board (Fig. 5), biodegradation straw (Fig. 6) Food and beverage (F&B) containers (Fig. 7). In addition, the bagasse is used in animal feed as an important source of fibre (Fig. 8) and biomaterials for shrimp pond treatment (Fig. 9).

Cellulose from bagasse can also be a feedstock for the development of cellulose-based materials namely microcrystalline cellulose (MCC) and nanocellulose (NC) production. These micro-/nanosized materials are potentially widely applied in medicine, food and polymer industries (Sofla et al. 2016). However, these research findings are not yet applied at the industrial scale since a pilot production is required for industrial applications.

Future Prospects for the Sugarcane Industry in Vietnam

The sugarcane industry of Vietnam needs to meet the demands for domestic consumption and export. It is estimated by MARD that this basic production is 2.0 million tons of sugar in 2020 (+ 62% compared to 2016), and 2.7 million tons in 2030 (+ 35% compared to 2020). In the

Fig. 4 ECBs from Vietnam sugarcane bagasse and agricultural by-products during the trial at construction site at TU Bergakademie Freiberg (2017–2018) (Katja et al. 2020)





Fig. 5 Fibreboard from sugarcane bagasse



Fig. 8 Animal feed from sugarcane bagasse



Fig. 6 Straw from sugarcane bagasse



Fig. 9 Cellulose from bagasse using in shrimp pond treatment

2016–2020 period, the industry was forecasted to grow at a compound annual growth rate of 12.8%/year. MARD also predicted that from 2020 to 2030, the total area under sugarcane will increase by 6%. In addition, the cane yield per hectare should rise above 80 tonnes, with a higher sugarcane CCS of 10.6% (MARD 2016b). Rearrangements and organizations of larger cane growing areas, facilitating mechanization, irrigation and fertilization are the main drivers for these developments in Vietnam (Table 6).

By 2030, the Vietnam sugarcane industry should produce the following annually:

- A sugar production of 2.7 million tonnes, of which refined sugar is 1.6 million tonnes, basically meets domestic demand.
- The use of bagasse should allow an output of 2.4 million MWh. About 1.2 million MWh would be supplied to the national grid.
- Ethanol production would reach 150 million litres/year.
- The output of filter cake fertilizer reaches 500,000 tons.

The 10 year-period will include technical and financial activities to develop technically simpler co-product processes. This may also involve input from growers, millers, research institutes, universities, and government. The following co-products fall into this category:



Fig. 7 Biodegradable F&B containers

Table 6 Sugarcane industry proposal by MARD towards 2020 under vision 2030

Parameters	2016	2020	2030
Area under cane (10 ³ ha)	284	300	300
Yield (tonnes cane/ha)	64	72	80–84
Cane crushed (10 ⁶ tonnes)	18.3	21.6	24–25
Conversion rate from cane to sugar ratio	9.6	10.5	10.6
Sugar production (10 ⁶ ton)	1.2	2.0	2.7

- The manufacture of invert liquors and syrups. These are well established commercially elsewhere in the world.
- The production of special sugars, both refined and raw. There are markets for these in the European Union.
- The production of high-test molasses. This product is used in the food and animal feed industries.
- The use of juices and/or molasses as raw materials for the production of shrimp and fish feeds.
- Using scrubber fly ash to make a product similar to activated carbon.
- Investigating the commercialization of cane wax.

The production of these co-products can be trialled, depending on the commercial situations. They do not require expensive plant modifications or raw materials. The technologies are well established and can be applied readily by existing factory staff. As usual with co-products, their success in the sugarcane industry depends principally on financial issues and marketing.

The quantities of bagasse, filter cake, molasses and other internal streams will also increase allowing more co-products to be manufactured. This expansion of the sugarcane industry will help lowering the production costs of sugarcane. A reduction in the sugar price should follow, opening the prospect of exporting Vietnamese sugar to countries in the region.

Future Direction for Research and Development in the Sugarcane Industry

Extending value chain for sugarcane and the sugar industry and opening new markets will be the crucial directions to develop this industry as a biorefinery:

- Manage the crushing of different sugarcane varieties to benefit from early/late maturing varieties; to extend the length of the crushing season; to produce more sugar during the high sucrose peak, but more invert syrups during high total sugars (sucrose + fructose + glucose) peak. High fibre (> 20%) sugarcane has been developed; this offers the advantage of extending the crushing season by producing bagasse for cogeneration

and of producing lower purity juices which could be added to stored final molasses for the production of ethanol.

- The relevance of biotechnology in the sugarcane industry is now well established. This may well offer many future possibilities for the industry in Vietnam. However, the techniques, procedures and developments are still often at very early stages. It should be more effective in Vietnam to concentrate on improving the industry as proposed here rather than to consider research and developments in biotechnology. This does not imply that biotechnology should not be considered by universities and other advanced technological institutions. In fact, this type of research should be encouraged and supported by the State.

In the view of sustainable production, the sugar industry will develop the goods from both main and waste streams. Circulating the feedstock values from the waste stream back to the industry helps reducing the input (water, energy, fertilizer, packaging materials, etc.) and improves the value chain. Besides that, recovery of the values and biogas from wastewater also contributes to reduce the energy input to the factory, and to produce biomass fertilizer as well. Those developments will be the first steps towards the circular economy applied in the sugar industry.

Conclusions

The sugarcane industry in Vietnam has faced many difficulties over the last few years even though the government has recognized the importance of this crop and initiated multiple policies which helped. These include crop zoning policies, the development of varietal improvement programmes and an attempt to standardize the crop price. The sugar industry in Vietnam suffered very strong competition from neighbouring countries. Many attempts from the government and the Vietnam Sugarcane and Sugar Association have tried to strengthen the competitiveness of both growers and millers. Research and development in Vietnam is currently focusing on breeding programmes and the improvement of plantation practices as well as the development of added value co-products from sugar and factory streams to stay competitive with other crop and with foreign imports.

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