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Jaggery Making Process and Preservation: A Review

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ABSTRACT

Sugarcane is one of the most important crops in India, which meets the sweeteners requirement of people. India is one of the largest sugarcane producers in the world. Jaggery is a conventional sugar that is unrefined and often eaten all over the world. It is regarded as the healthiest sugar in the world because of its mineral and vitamin content as present in sugar cane juice. It is produced in India by the concentration of sugar cane juice, without separating molasses. The Jaggery making plants are placed in decentralized sectors in India. The efficiency of traditional plants producing jaggery is very poor because they are manufactured by local artisans. The use of multi-pan plants with a heat pump based freeze concentration system is found to be a successful approach for efficient jaggery production from the available literature in the manufacture of jaggery manufacturing plants. Due to the presence of inverted sugars and mineral salts that are hygroscopic in nature, the storage of Jaggery is difficult. The storage of jaggery in a whey coated drying cum storage bin is found to be most efficient in preserving the consistency of jaggery. The greenhouse drying of jaggery is an effective way to extract and preserve the moisture content of jaggery for a longer period of time.

Key words: Freeze concentration system, Multiple pan, Single pan, Storage, Two pan.

Sugarcane (*Saccharum officinarum*) is one of the important commercial crops used for the manufacture of sugar, jaggery and other products. Sugarcane is cultivated in India in an area of approximately 5.15 million hectares with production of approximately 383 million tonnes (MY 2018-19). Jaggery provides an alternative market to sugarcane growers. About 26% of the sugarcane produced is diverted for jaggery production. Jaggery is an unrefined, non-centrifugal whole cane sugar eaten across the globe. Jaggery is a rich blend of minerals and vitamins, which makes it the healthiest sugar in the sweetener category (Gopalan *et al.,* 1991). The Jaggery is very widely used not only in individual households but also in many eateries, restaurants, clubs and hostels and it has certain industrial applications as well. Due to its wide applications, the market for jaggery is continuously growing. Presently jaggery is being produced on small scale by traditional method. The jaggery has a good demand in domestic and foreign market (Banakar *et al.,* 2012). The quality and price of jaggery is depends upon its external features like color and texture (Selvi *et al.,* 2022). A best quality jaggery is judged by its features like golden yellow in color, hard in texture, crystalline structure and its unique sweet taste, less in impurities like molasses and some crystals and low in moisture (Shweta *et al.,* 2019). Colour is one of the important criteria determining the grade of gur/ jaggery. Normally jaggery with light colour is preferred for consumption.

Jaggery production and market scenario

India is the world's second largest producer of sugarcane. The production of sugarcane in India stands at 354 million tons. Out of the entire jaggery production in the world, 70% production (approximately 10 million tons) takes place in India alone. Approximately 40% of India's jaggery is exported (Madan *et al.,* 2004). India during the last couple of years has produced more than 300 MMT of sugarcane out of which, about 79.91% is utilized in producing white sugar, 11.29% in producing jaggery and khandsari, 8.80% as cane juice, seed cane for the next harvest *etc*. Sugar recovery for different states in India lies in the range of 8.89 to 11.26% on cane (MY 2018-19), whereas, recovery of jaggery (gur) ranges from 10-13% depending upon the variety, sugarcane quality, soil texture, irrigation facilities, time of cane crushing *etc*. (Narendra Mohan and Anushka Agarwal, 2020).

Nutritional importance of jaggery

The jaggery contains approximately 60-85% sucrose, 5-15% glucose and fructose, 0.4% of protein, 0.1 g of fat. Also it is rich in important minerals *viz.,* magnesium 70-90 mg, potassium 10-56 mg, phosphorus 20-90 mg, sodium 19-30 mg, iron 10-13 mg, manganese 0.2-0.5 mg, zinc 0.2- 0.4 mg, copper 0.1-0.9 mg and chloride 5.3 mg per 100 g of jaggery), vitamins (*viz.,* Vitamin A-3.8 mg, Vitamin B1-0.01 mg, Vitamin B2-0.06 mg, Vitamin B5-0.01 mg, Vitamin B6-0.01 mg, Vitamin C-7.00 mg, Vitamin D2-6.50 mg, Vitamin E-111.30 mg, Vitamin PP-7.00 mg) and protein-280 mg per 100 g of jaggery, which can be made available to the masses to mitigate the problems of mal nutrition and under nutrition. The micronutrients present in the jaggery possess antitoxic

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and anti-carcinogenic properties (Selvi *et al.,* 2022). But, sensing a demand for jaggery from health-conscious consumers, farmers have started constructing jaggery units.

Nowadays, two processes are mainly being followed in India to produce jaggery. One is old indigenous method and the other is modern sulphitation process. A typical Khandsari and Jaggery industry have 1-20 furnaces. The size of the Khandsari sugar units varies between 50-1000- tons of cane crushing capacity per day (Tones Crushed per Day), whereas for Jaggery it ranges 1-15 TCD. The recovery of sugar ranges from 7% (traditional process) to 9% (modern process) whereas recovery for jaggery it is 9% (traditional process) to 13% (modern process) of cane crushed. There is extremely low thermal efficiency of the traditional method of producing jaggery. Since these devices are typically built by local artesian, a large part of the energy is lost into the environment in the form of flue gases. It needs elevated ability and more manual labour due to long heating activity. The conventional method of producing jaggery cannot be used for mass production due to batch processing (Kumar and Kumar, 2018). In India jaggery is produced in the winter and spring seasons and the rest of the year is processed there. In order to preserve the quality of jaggery, the conventional storage methods such as earthen pot, wooden box and metal drum, *etc.* are not very successful. Jaggery storage is a major issue as it absorbs moisture from the air which changes its properties. Conventional storage methods, primarily under all environmental conditions, are not very effective in the rainy season. More than 10% of the $0.6 million worth of jaggery produced in India is estimated to be lost each year due to degradation under normal storage processes (Mandal *et al.,* 2006).

Although the Jaggery industry has grown several folds over the decades, there has been no organized effort to improve its performance, efficiency and recovery. Hence, this review paper explain the traditional method of jaggery making plants and storage, their constraints and to overcome problems associated with traditional methods of jaggery making, advanced modified method of jaaggery making process and storage was summarized here.

Traditional jaggery manufacturing process

Jaggery manufacturing is a continuous cycle of heat and mass transfer in which the fresh sugarcane juice are used; bagasses are used as raw material for fuel. The progressive heating and stirring of sugarcane juice in an open pan changes the sugarcane juice from liquid to semi-solid, which further becomes solid after cooling. The traditional jaggery manufacturing process involves a number of operations that are performed by skilled and semi-skilled persons (Kumar and Kumar, 2018). Depending on the type of canes used, sugarcane juice varies in colour from grey dark green to light yellow (Rao *et al.,* 2007). In addition to this molasses is also a valuable byproduct of the jaggery manufacturing process that also serves as fuel. Thus this industry does not depend on additional fossil fuel for its production. Clarificants are the organic and inorganic components used in the process of making jaggery to clarify the raw sugarcane juice (Carter, 1954).

The traditional Jaggery manufacturing process involves a number of operations which are shown in Fig 1.

Classical jaggery production operations and equipments

The first step in the manufacturing of jaggery is the weighing of the cane and then transferred by crushing it in a crusher to extract sugarcane juice (Kelhua). In order to crush canes, vertical or horizontal crushers with three rollers are typically used. Conventionally, a couple of bullocks run a crusher. Now the bullocks are replaced by a diesel engine for a day. The performance of vertical and horizontal crusher juice recovery ranges from 50-55 per cent and 55-60 per cent respectively. The crushing efficiency can be increased from 27 per cent to 80 per cent using multiple crusher and hot water. This method is not possible in conventional method tiny jaggery making unit (Rao *et al.,* 2007). The schematic views of different sugarcane crushers are shown in Fig 2 (Kumar and Kumar, 2018).

In the masonry settling tank, crushed sugarcane juice is stored for some time to isolate the heavier impurities due to sedimentation process. There clear juice is transferred to boiling pan with continuous stirring action and juice will be heated in boiling pan. The juice will be boiled using bagasse as a fuel. The time required for boiling of juice is normally depends on workers engaged in the process. After boiling the juice will be allowed for clarifications in which

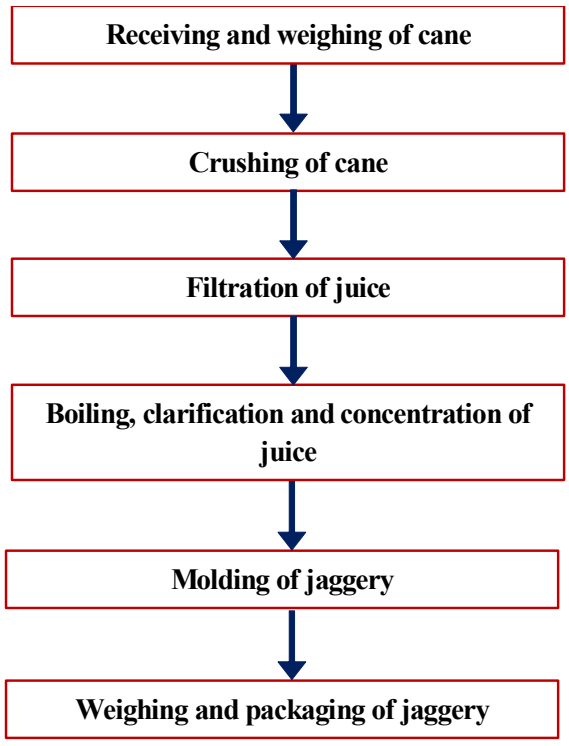

Fig 1: Flow chart of jaggery manufacturing operations (Selvi *et al.,* 2021).

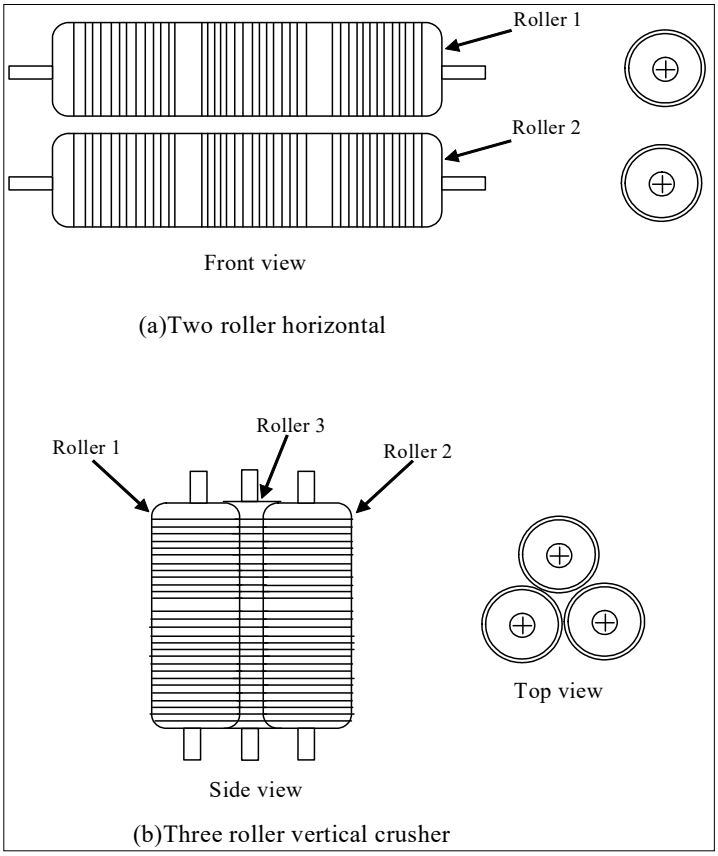

Fig 2: Schematic views of different sugarcane crusher.

impurities will be removed. The quality of jaggery depends on clarifier used in the process (Narian, 2002; Asokan and Rupa, 2008).

Recent technologies in jaggery manufacturing process

Three kinds of jaggery manufacturing plants are historically used in India, namely, single-pan, two-pan and multi-pan (three or four pan) jaggery manufacturing plants. In typical jaggery production plants, pans used are typically rectangular with a flat surface or hemispherical or cone shaped. Several modifications have been done in the pan type used in the units in order to increase the thermal efficiency. They are shown in Table 1. The schematic view of temporary single pan jaggery making plant is shown in Fig 3a.

In case of two pan jaaggery making plants, two pans are fitted at the top of the furnace. First pan is the gutter pan fixed as first pan in which sugarcane juice will be boiled. The second is boiling pan, the juice will be heated at desired temperature level. The schematic view of two-pan jaggery making furnace is shown in Fig 3b. In addition, to boiling and gutter pans, one or two more pans will be fitted in a series manner in multi pan jaggery system. The sugarcane juice will be pre heated in first two pans. Then pre heated juice will be moved to the boiling pan for actual heating. In the plants, direction of juice conversion is opposite to the direction of movement of hot thermal energy. The other structural features of three or four pan model are similar to that of two pan jaggery making model. Performance of the jaggery making plant is more in three and four pan model due to more heat generation. But, the use of three or four pan type does not indicate a noticeable change of increase of thermal efficiency and a decrease in the consumption of bagasse. The schematic view of four-pan jaggery making plant is illustrated in Fig 3c.

Anwar (2014) developed an efficiency booster, at the bottom of the single pan jaggery manufacturing plant. The schematic view of efficiency booster used in jaggery manufacturing plant is shown in Fig 4.

Anwar (2010) increased the heat utilization efficiency of two-pan jaggery making plant by using fins at the bottom of boiling and gutter pans along with the saving of bagasse. The schematic views of fins at the bottom of boiling and gutter pans used in jaggery manufacturing plant is shown in Fig 5.

From the above discussion, it is noted that, the efficiency of traditional plants producing jaggery is very poor because they are manufactured by local artisans. In order to improve the efficiency of jaggery making following method has been used.

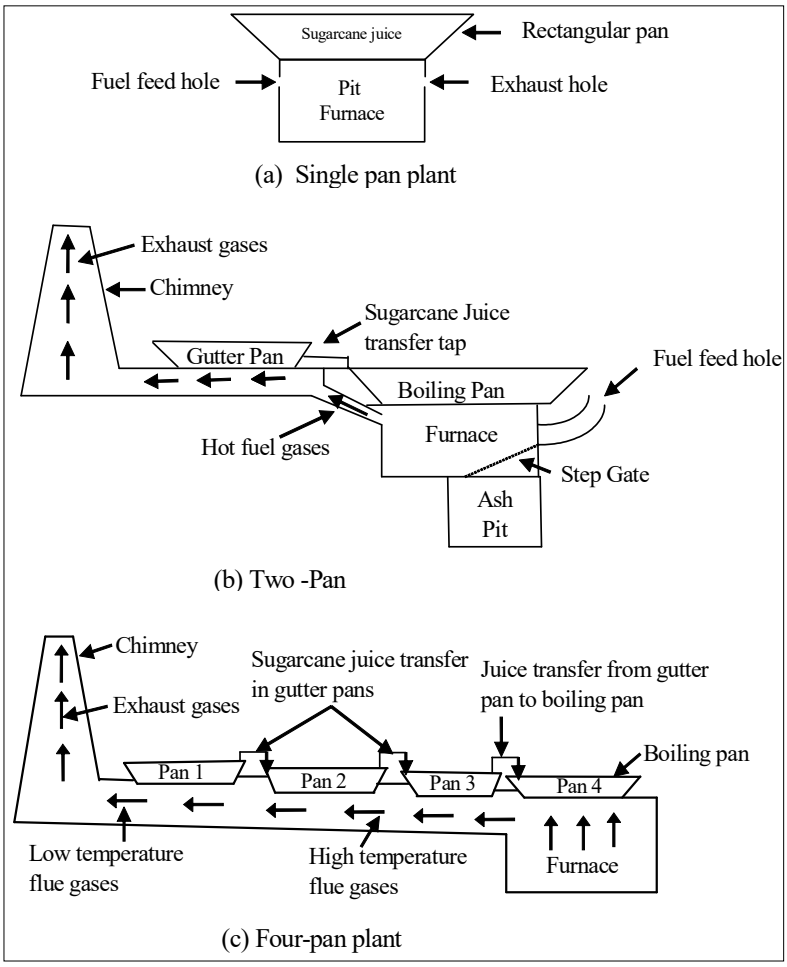

Fig 3: Schematic views of different jaggery making plants.

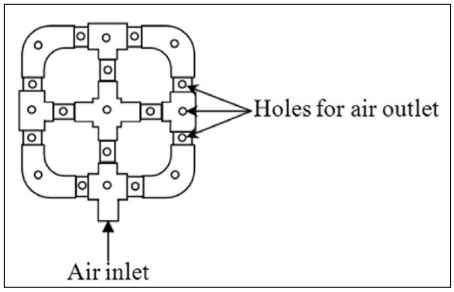

Fig 4: Schematics of efficiency booster.

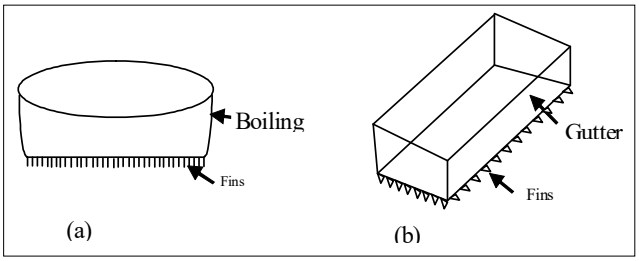

Fig 5: Schematic views of fins at the bottom of boiling and gutter pan.

Jaggery making using freeze pre-concentration of sugarcane juice

Rane and Jabade (2005) proposed a new idea of the heat pump dependent freeze concentration system (FCS) for the concentration of sugarcane juice in a jaggery method. In this method water is extracted from sugarcane juice by selective freezing in the form of ice.

The schematic view of freeze concentration system used in jaggery manufacturing plant is shown in Fig 6. In this process, water is selectively freezed and separated from juice to form ice and concentrated juice. Freezing point of juice changes from -1.5 to -4.6°C (Mathlouthi and Reiser, 1995) for 20 to 40 minutes. During this initial 63% water removal, bagasse is saved and that can be recycled in field for composting. Concentrated juice is obtained at low temperature. This juice is further concentrated using steam jacketed pan with vegetative clarificants. Altogether, it improves colour of jaggery from dark brown to golden yellow which has higher market value.

Storage of jaggery

The quality and storability of jaggery depends on varieties

Table 1: Recent technologies in jaggery manufacturing process.

Specification	Benefits	Reference
Developed an automated process for jaggery preparation using PLC and monitored by IIOT.	Jaggery preparation process is automated. Thus, a hygienic and fully automatic PLC based jaggery production system with fault detection capability is developed.	Jayanthi *et al.* (2019)
Analyzed the CFD model of double pan and Four pan Jaggery plant furnace.	Improved the overall performance of Jaggery plant by modification in construction of furnace pan, chimney which resulted in saving in fuel and energy.	Meshram *et al.* (2018)
Using a boiler, net separator and PLC controller for the automation of jaggery packaging.	A water tube boiler and PLC controller could be used to make the process continuous and automatic.	Magade *et al.* (2017)
Using modified pan having fins at the bottom in traditional single pan jaggery making plant.	Increased by 9.15% and decreased the bagasse consumption by 28.19%.	Madanrao (2017)
Installed a CFD simulation module in pans of jaggery making plant.	CFD could be a good simulation tool to simulate the various operating parameters of jaggery making process by using various boundary conditions.	Madrid *et al.* (2016)
Using freeze pre-concentration process in a traditional jaggery making plant.	Freeze pre-concentration could be an efficient jaggery making process but it increases the sugar lost in inclusion and the cost of the system.	Rane and Uphade (2016)
Employed a juice pre-heater and economizer for the utilization of exhaust heat in a traditional two-pan jaggery making plant.	Increased thermal efficiency (50.74 per cent) and a decrease of 1.2 kg/kg of jaggery produced in bagasse consumption was observed.	Manjare and Hole (2016)
Using bottom of the pan fins in the conventional single pan jaggery plant.	Increased thermal efficiency by 9.44% and fuel/energy savings by 31.34%.	Agalave (2015)
Installation of automatic sugarcane feeding system in the jaggery making plant.	Facilitate easy and quick feeding and less labour consuming.	Kavatkar *et al.* (2015)
Installation of booster by increase the turbulence within the furnace in a single pan jaggery plant.	Improved thermal efficiency (35 per cent), fuel savings (26 per cent) and time spent during the process (30 per cent).	Anwar (2014)
Installation of pre-heater and economizer to use exhausted heat in a single pan model.	Increase in thermal efficiency from 16.16% to 24.36% and decrease in the consumption of bagasse by 1.2 kg/kg of jaggery produced.	Manjare and Hole (2013)
Fins at the bottom of boiling and gutter pans in a furnace in the two pan model.	Increase of heat use efficiency about 9.44 per cent.	Anwar (2010)

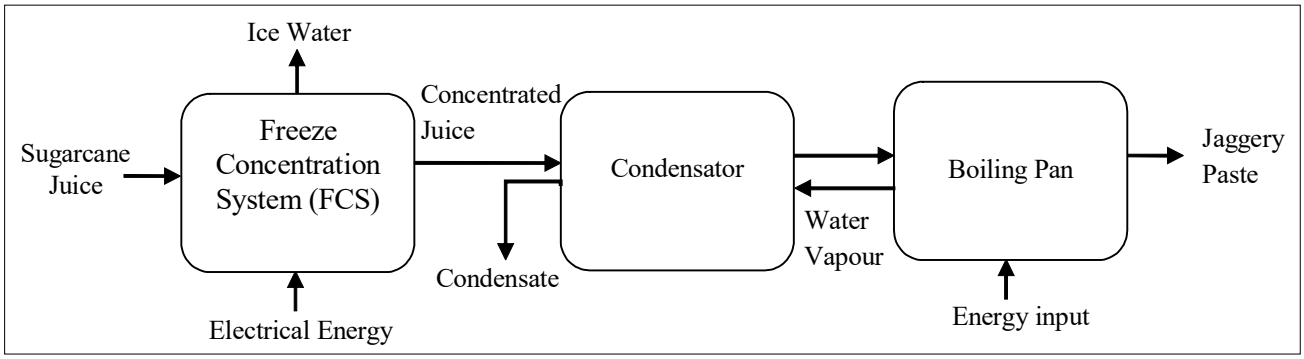

Fig 6: Schematic view of freeze concentration system.

used for cultivation, quality and quantity of inputs used in the jaggery making plant. The major problem associated with jaggery storage is the presence of inverts of sugars and mineral salts, which, being hygroscopic in nature, absorb moisture particularly during the moonsoon season when the ambient humidity is high leads to spoilage of the jaggery materials. It was estimated that during monsoon season more than 10% of total jaggery produced in India of value 0.6 million US $ is lost annually (Mandal *et al.,* 2006). For good consistency and should be kept at 43-61 per cent relative humidity. The storage of jaggery is a significant function for its preservation under adverse environmental conditions. Jaggery production begins in the month of September/October in India and continues until March/April and is processed for the rest of the year. It has been estimated that every year between one third and one half of the total output of jaggery is stored (Kumar *et al.,* 2013b). The pretreatment with nitric oxide of sugarcane juice provides better colour and sucrose amount, which helps increase the shelf life of jaggery (Hussain *et al.,* 2012).

The researchers used various conventional and enhanced methods to increase the shelf life of jaggery. For jaggery storage, which varies from region to region, usually earthen pot, wood box and metal drums are used. Jaggery is stored in the shape of a heap in some areas and filled with cane garbage, bagasse, wheat straw, cottonseed, furnace ash, palmyra leaf mat, rice husk, *etc.* to protect it from direct contact with moist air (Rai and Paul, 2007). The various studies carried out on storage and packaging of jaggery is listed in Table 2 and Table 3, respectively.

It is observed that from the above discussion the jaggery is stored in traditional method and modern scientific methods *viz.,* tin, painted earthen pot, low temperature storage, drying cum storage bin, nitrogen PET film and whey coatings. The storage of jaggery in a whey coated drying cum storage bin is found to be most efficient in preserving the consistency of jaggery. The greenhouse drying of jaggery is an effective way to extract and preserve the moisture content of jaggery for a longer period of time.

Varieties suitable for jaggery making

Varieties having high sucrose content, low reducing sugars, high purity, low colloids, low organic non sugars such as nitrogen, phenols, amino acids, starch , gums and high level of phosphate should be chosen for jaggery production. The varieties suitable for jaggery making are always found to be equally suitable for sugar. The quality of cane is a main genetic factor also many other factors like climate, soil type, crop management *etc* affect the jaggery production. The sugarcane variety suitable for jaggery should have specific characters like early maturity, less fibre content, high purity of juice *etc.* Some of the Tamil Nadu sugarcane varieties are specifically suitable for jaggery making CoG 6, CO 0212, CO 06022 and CO 11015 (Atulya).

The greenhouse drying of jaggery is an effective way to extract and preserve the moisture content of jaggery for a longer period of time. The various studies carried out on solar drying of jaggery are listed in Table 4. The schematic views of natural and forced convection greenhouse jaggery dryers are shown in Fig 7a and b.

Summary

Traditional jaggery making process involves consumption of more manual source and long hours of operation for the production. Also, during the traditional method of operation, the flue gas emanating from direct fire under the pan releases harmful chemicals in the boiling house which are hazardous and cause respiratory problems to workers. In order to solve this problem, two-pan, three-pan and four-

Table 2: Studies on the effect of storage materials on self life of jaggery.

Storage material	Advantages	References
Low temperature, room temperature and pre sterilized PET bottles	Liquid jaggery could be stored for a period of 90 days in refrigerator.	Patil and Anekar (2014)
Jaggery cum storage bin	In jaggery cum storage bin, jaggery could be stored for a period of six months.	Chand *et al.* (2011)
Airtight container	Quality of jaggery could be maintained.	Ramya *et al.* (2010)
Low temperature	Jaggery could be stored for a period of 20 months.	Uppal (2002)
Low temperature	Stored for a period of eight months.	Uppal and Sharma (2002)
Airtight container	Physico-chemical properties of jaggery (like color and sweetness) were not affected.	Uppal and Sharma (1999)
Painted and unpainted earthen pot	In painted earthen pot, had less increase in reducing sugars.	Singh (1998)
Painted and unpainted earthen pot	Jaggery could be stored for a longer period in painted earthen pot.	Baboo and Shukla (1987)
Godown storage with controlled relative humidity.	Jaggery could be stored in long time with 40-45% relative humidity.	Gunjal and Galakatu (1986)

Table 3: Studies on the effect of packaging materials on shelf life of jiggery.

Storage material	Advantages	Researchers
Low temperature.	Solid jaggery could be stored at low temperature for a period of 1 year.	Shweta *et al.* (2019)
Moisture absorber, edible coating of CMC, HPMC and high density polyethylene bags.	In controlled conditions of temperature and relative humidity, physical, chemical and microbiological deterioration was very less.	Chand and Kumar (2018)
CMC and hydroxyl propyl methyl cellulose (HPMC).	The storage life of jaggery was increased up to 225 days.	Kumar *et al.* (2017)
Carboxy methylcellulose (CMC) and whey protein (WP).	Maintained the quality of jaggery.	Mishra *et al.* (2016)
Vitamin C enriched.	Storage life was not changed.	Anwar *et al.* (2015)
Pre sterilized PET bottle.	More efficient storage.	Patil and Anekar (2014)
Edible coating.	Stored for longer duration in terms of physiochemical and shelf life.	Chand *et al.* (2014)
Low density polyethylene (LDPE), high density polyethylene (HDPE) plastics, plastic and glass containers, aluminum pouch andopen storage.	Very effective method.	Karen Luz *et al.* (2013)
Triple layered vacuum packaging.	Color, sucrose content, hardness, reducing sugar, moisture content, porosity changed and microbial load was found very effective.	Kumar *et al.* 2013(c)
PET film under 100% nitrogen.	Less reduction in quality parameters during storage.	Kumar *et al.* 2013(b)
PET film.	PET film was the best jaggery packaging method than LDPE, PP and laminated aluminum film.	Kumar *et al.* 2013(a)
Nitrogen.	Packaging of jaggery with nitrogen was found very effective to maintain all the physicochemical, microbial and overall parameters at room temperature.	Singh *et al.* (2012)
Whey.	Very effective to preserve jaggery for longer time.	Shukla (2012)
PET film with 100% nitrogen.	PET film with 100% nitrogen could be used for longer duration.	Kumar *et al.* (2012)
Low density polyethene pouch and paper bags.	Low-density polyethene pouch and paper bags subjected to medium dose irradiation at 7 kGy were found best.	Sankhla *et al.* (2011)
100 gauge polyethylene bag at room temperature.	Particle size of coarse grade (0.5-0.708 mm) can be stored for a period of six months.	Unde *et al.* (2011)
LLDPE, PP, LD/HD/LLD, BOPP and PET.	Best packaging material due to high strength, low water vapour transmission rate and least oxygen transmission rate.	Singh (2008)
Three ply packaging materials.	For solid jaggery the three ply packaging materials were stated more suitable as quality packaging material.	Singh and Singh (2008)
Earthen pot, wooden box and metal drum.	Avoid anaerobic respiration.	Rai and Paul (2007)
Painted earthen pot, heat sealed packetof LDPE and PET jar.	Best jaggery packaging method in monsoon season.	Mandal *et al.* (2006)
Nitrogen packaging.	Solid jaggery maintained its freshness for a longer period.	Gupta *et al.* (2002)

Table 4: Recent Technologies on solar drying jaggery.

Researchers	Year	Description	Pros/cons
Tiwari *et al.*	2004	Greenhouse drying of jaggery under natural convection mode (Fig 7a).	It was observed that for a given size of greenhouse CMTC is a strong function of mass of jaggery, temperature and relative humidity.
Kumar and Tiwari	2006 (a)	Greenhouse drying of jaggery under forced and natural convection modes (Fig 7a and 7b).	It was observed that the shape and size of jaggery samples play an important role in the variation of the values of CMTC.
Kumar and Tiwari	2006 (b)	Thermal model for the greenhouse drying of jaggery with thin layer under natural convection mode (Fig 7a).	The present model was stated very effective to design a greenhouse dryer for a thin layer and given mass of jaggery.
Kumar and Tiwari	2006 (c)	Thermal model for the greenhouse drying of jaggery under forced convection mode (Fig 7b).	The number of air charges per hour, relative humidity and the surface area of jaggery were stated to be the most effective parameters in greenhouse drying of jaggery.
Parkash and Kumar	2014	Artificial neural network (ANN) model under natural convection mode (Fig 7a).	ANN model is a computer program designed to predict the hourly mass of jaggery during its drying under natural convection mode by detecting the patterns from the experimental data.
Jakkamputi and Mundauti	2016	Jaggery making unit using solar collector and solar drier.	Around 2360.44 kJ of heat energy and 0.23604 kg of dry bagasse could be saved per kg of jaggery preparation.

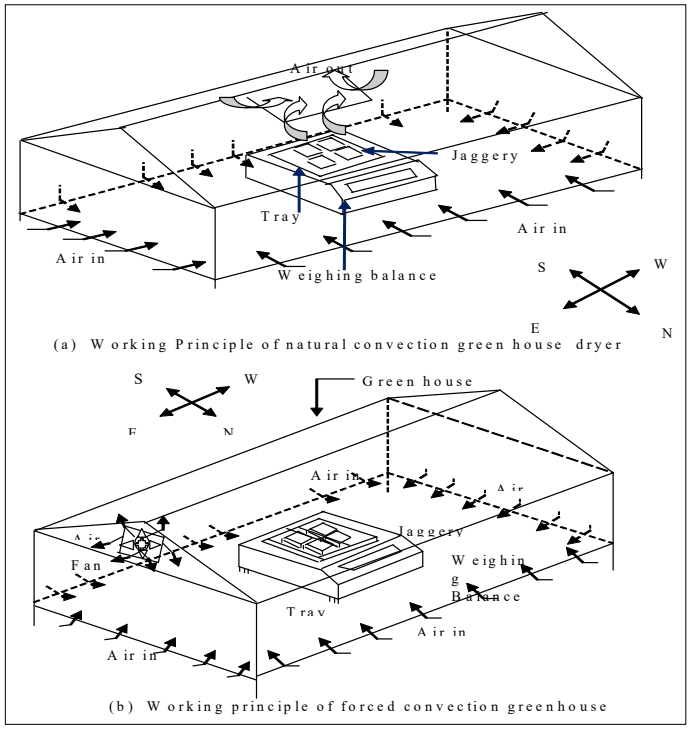

Fig 7(a and b): Schematic view of greenhouse jaggery dryers.

pan plants are used to absorb hot flue gases with optimum thermal capacity. In this way, many researches have been carried out to increase the efficiency of the jaggery making plant. Among the methods studied, multi-pan plants with a heat pump based freeze concentration system is found to be a good approach for the efficient production of jaggery. Since, storage is also a major concern; the conventional method of jaggery storage is not very successful to maintain the quality. Compare all the storage methods, whey coated drying cum storage bin is most efficient in maintaining the consistency of jaggery for a longer time. So, the key challenge before the researchers is the optimization of jaggery manufacturing processes, improvement in conventional jaggery manufacturing plants and preservation of jaggery.

Way forward

The Scientists/researchers have to work more effectively in the production and storage of jaggery to meet these challenges in the future. To make the jaggery manufacturing process eco-friendly, the government and researchers should encourage the farmers to use solar energy in heating sugarcane juice.

Conflict of interest

All authors declared that there is no conflict of interest.

REFERENCES

Agalave, G.B. (2015). Performance improvement of a single pan traditional jaggery making furnace by using fins and baffle. International Journal of Advance Research in Science and Engineering. 4(4): 85-89.

Anonymous (2019). Per capita consumption of sugar, gur and khandsari. Co-operative Sugar. Oct. 2019. 51(2): 55.

Anonymous (2019). Utilization of sugarcane for different purposes. Cooperative Sugar. 51(2): 37.

Anwar, S.I., Singh, R.D., Pandey, V.K. and Pandey, P.R. (2015). Storage studies of natural vitamin C enriched jaggery. Agricultural Engineering Today. 39(1): 8-10.

Anwar, S.I. (2014). Improving thermal efficiency of open pan jaggery furnaces-A novel concept. Indian Journal of Sugarcane Technology. 29(1): 32-34.

Anwar, S.I. (2010). Fuel and Energy Saving in open pan furnace used in jaggery making through modified juice boiling concentrating pans. Journal of Energy Conversation and Management. 51: 360-364.

Asokan, S. and Rupa, T.R. (2008). Sugarcane Chemistry Including Sugar and Gur Technology. Coimbatore: Directorate of Open and Distance Learning, Tamil Nadu Agricultural University.

Baboo, B. and Shukla, A. (1987). Improved techniques for domestic storage of gur in earthen pots. Indian Journal of Sugarcane Technology. 41(1): 27-30.

Banakar, B., Sandesh, K.C. and Ashoka, N. (2012). Export competitiveness of sugarcane jaggery in Karnataka-A comparative analysis. Indian Journal of Sugarcane Technology. 27(01): 1-3.

Carter, R.A. (1954). White Sugar Manufacture at Entumeni Mill. Proc South African Sugar Technol Association. 28: 122-127.

Chand, K., Shahi, N.C., Lohani, U.C. and Garg, S.K. (2011). Effect of storage conditions on keeping qualities of jaggery. Sugar Tech. 13(1): 81-85.

Chand, K., Verma, A.K., Kumar, A. and Shahi, N.C. (2014). Effect of edible coating on quality parameters of jaggery during storage. Sugar Tech. 16(1): 80-85.

Chand, K. and Kumar, S. (2018). Effect of moisture absorber and packaging materials on quality parameters of Jaggery cubes. International Journal of Chemical Studies. 6(2): 1398-1404.

Gopalan, C., Shastri, B.V.R. and Balasubramanian, S.C. (1991). Nutritive value of Indian foods. National Institute of Nutrition Hyderabad, ICMR.

Gunjal, B.B., Galakatu, P.D. (1986). Water vapor adsorption by jaggery. Journal of Indian Sugar. pp 633-636.

Gupta, R., Singh, P. and Suman, A. (2002). In: An Investigation on Packaging of Jaggery in Vacuum and Nitrogen Environment. [Singh Jaswant, (eds)]. Processing of National Seminar on Status, Problems and Prospects of Jaggery and Khandsari. Lucknow, IISR: pp 193-196.

Hussain, Z., Islam, M., Mohammad, Z., Khan, K.M., Preveen, S. and Afzal, M. (2012). The effect of pretreatment of juice on the properties and composition of jaggery. Sugar Tech. 14(3): 291-294.

Jakkamputi, L.P. and Mundauti, M.J.K. (2016). Improving the performance of jaggery making unit using solar energy. Perspectives on Science. pp 1-7.

Jayanthi, G., Aaradhika, S., Swathy, S. and Mathumitha, N. (2019). Automation using Plc and IIOT Monitoring in Jaggery Preparation. International Journal of Innovative Technology and Exploring Engineering. 9: 1.

Karen Luz, Y., Teves Erlinda, I., Dizon Jovita, L., Movillon and Aldwin, M. Teves (2013). Microbial, Physicochemical and Shelf-life Evaluation of Muscovado in Different Packaging Materials at Various Storage Time. International Proceedings of Chemical, Biological and Environmental Engineering, IACSIT Press, Singapore.

Kavatkar, A., Rajmane, A. and Dandage, R. (2015). Developing a sugarcane feeding system for jaggery making plants for rural India. International Journal of Science Technology and Management. 04: 225-228.

Kumar, A. and Tiwari, G.N. (2006a). Effect of shape and size on convective mass transfer coefficient during greenhouse drying (GHD) of jaggery. Journal of Food Engineering. 73: 121-134.

Kumar, A. and Tiwari, G.N. (2006b). Thermal modeling of a natural convection greenhouse drying system for jaggery: An experimental validation. Solar Energy. 80: 1135-1144.

Kumar, A. and Tiwari, G.N. (2006c). Thermal modeling and parametric study of a forced convection greenhouse drying system for jaggery: An experimental validation. International Journal of Agricultural Research. 1(3): 265-279.

Kumar, A., Chand, K., Shahi, N.C., Kumar, A. and Verma, A.K. (2017). Optimization of coating materialson jaggery for augmentation of storage quality. Indian Journal of Agricultural Science. 87(10): 1391-1397.

Kumar, D., Singh, J., Rai, D.R., Bhatia, S., Singh, A.K. and Kumar, M. (2013a). Colour changes in jaggery cubes under modified atmosphere packaging in plastic film packages. Agrotechnology. 1-5. https://doi.org/10.4172/2168-9881.S11-005.

Kumar, D., Singh, J., Rai, D.R., Kumar, M. and Bhatia, S. (2013b). Effect of modified atmosphere packaging on keeping quality of jaggery. Sugar Tech. 15(2): 203-8.

Kumar, P.A., Kailappan, R. and Nirmala, R. (2012). Effect of different clarifying agents on the quality of jaggery. Mysore Journal of Agricultural Sciences. 46(4): 784-789.

Kumar, P.A., Nirmala, R. and Bhavya, E.P. (2013c). Processing packaging and storage of jaggery from sugarcane. International Journal of Processing and Post Harvest Technology. 4(1): 7-12.

Kumar, R. and Kumar, M. (2018). Upgradation of jaggery production and preservation technologies. Renewable and Sustainable Energy Reviews. 96: 167-180.

Madan, H.K., Jaiswal, U.K., Kumar, S. and Khanna, S.K. (2004). Improvement in gur (jaggery) making plant for rural areas. Journal of Rural Technology. 4: 194-196.

Madanrao, R.K. (2017). Experimentation on single pan jaggery making furnace for performance improvement. International Journal of Innovations in Engineering Research and Technology. 4(2): 22-26.

Madrid, R.L., Marcelo, D., Orbegoso, E.M. and Saavedra, R. (2016). Heat transfer study on open heat exchangers used in jaggery production modules-computational fluid dynamics simulation and field data assessment. Energy Conversion and Management. 125: 107-20.

Magade, P.B., Dhavale, V.M., Bhate, V.G., Thorat, V.P. and Zende, R.K. (2017). Design and manufacture prototype of jaggery plant. International Research Journal of Engineering and Technology. 4(3): 1583-1585.

Mandal, D., Tudu, S., Mitra, S.R. and De, G.C. (2006). Effect of common packaging materials on keeping quality of sugarcane jaggery during monsoon season. Sugar Technology. 8(23): 137-142.

Manjare, A. and Hole, J. (2013). Exhaust heat recovery of jaggery making furnace. International Journal of Science and Research. 5(4): 1349-1351.

Manjare, A. and Hole, J. (2016). Exhaust heat recovery and performance improvement of jaggery making furnace. International Journal of Current Engineering and Technology. 5: 165-70.

Mathlouthi, M. and Reiser, P. (1995). "Sucrose: Properties and Applications", Chapman and Hall Publication, London. pp. 107-111.

Meshram, V.A. and Deepti, A.D. (2018). The Review on Jaggery Making Process and Preparing CFD Model to Analyse Heat Transfer. International Journal on Theoretical and Applied Research in Mechanical Engineering. 7: 1.

Mishra, R., Omore, P.K., Chand, K., Kumar, S. and Bist, A.S. (2016). Efficiency of a coating composed of carboxymethyl cellulose and whey protein concentrate to control the quality of jaggery. International Journal of Engineering Science Research and Technolgy. 385-98.

Narendra Mohan and Anushka Agarwal. (2020). New ventures of value-addition in jaggery processing for a dynamic sugar industry. International Journal of Engineering Research and Technology. 9(1). DOI : 10.17577/IJERTV9IS010179.

Narian, S.H. (2002). Jaggery and khandsari industry in India. Indian Farming. pp 57-68.

Parkash, O. and Kumar, A. (2014). ANFIS modeling of a natural convection greenhouse drying system for jaggery: An experimental validation. International Journal of Sustainable Energy. 33(2): 316-335.

Patil, S.D. and Anekar, S.V. (2014). Effect of different parameters and storage conditions on liquid jiggery without adding preservatives. International Journal of Research in Engineering and Technology. 03(12): 280-283.

Rai, D.R. and Paul, S. (2007). Packaging requirements of highly respiring produce under modified atmosphere packaging: A review. Journal of Food Science and Technology. 44: 10-15.

Ramya, H.N., Chowde Gowda, M., Jayamala, G.B., Krishnamma, P.N. and Shreedevi, M.S. (2010). Effect of ambient atmospheric conditions on change in physico-chemical properties of stored jaggery. International Journal of Applied Agricultural Research. 5(1): 9-18.

Rane, M.V. and Jabade, S.K. (2005). Freeze concentration of sugarcane juice in a jaggery making process. Applied Thermal Engineering. 25(14-15): 2122-2137.

Rane, M.V. and Uphade, D.B. (2016). Energy efficient jaggery making using freeze pre-concentration of sugarcane juice. Energy Procedia. 90: 370-81.

Rao, P.V.K.J., Das, M. and Das, S.K. (2007). Jaggery-a traditional Indian sweetener. Indian Journal of Traditional Knowledge. 6(1): 95-102.

Sankhla, S., Chaturvedi, A., Kuna, A. and Shreedhar, M. (2011). Studies on effect of packaging material and irradiation on storage stability of jaggery. Sugar Tech. 13(3): 229-235.

Selvi, V.M., Mathialagan, M. and Mohan, S. (2022). The art and science of jaggery making: A review. Agricultural Review. 43(4): 401-409. DOI: 10.18805/ag.R-2138.

Shukla, P. (2012). Effect of edible coating and packaging on microbiological characteristics of jaggery. Prime Journal of Microbiology Research. 2(4): 121-125.

Shweta Deotale, M.G. Bhotmange Prabodh Halde and M. Chitale (2019). Study of traditional Indian sweetener 'Jaggery' and its storage behavior. International Journal of Chemical Studies. 7(3): 411-412.

Singh, J. and Singh, R.D. (2008). Processing, handling and storage of sugarcane jaggery. Lucknow: Indian Institute of Sugarcane Research. pp 158.

Singh, J. (2008). Grading Packaging and Storage of Jaggery. In: Processing, Handling and Storage of Sugarcane Jaggery. [Singh Jaswant, Singh, R.D. (eds)]. Lucknow: IISR. 111-4.

Singh, K. (1998). Packaging in jaggery and khandsari. Research Digest. Lucknow: IISR. pp 87.

Singh, P., Suman, A., Arya, N., Gupta, R. and Rai, R.K. (2012). Evaluation of sugarcane jaggery shelf life under modified environments: Influence on physico-chemical and microbial properties. Indian Journal of Sugarcane Technology. 2(1): 32-36.

Tiwari, G.N., Kumar, S. and Praksh, O. (2004). Evaluation of convective mass transfer coefficient during drying of jaggery. Journal of Food Engineering. 63: 219-227.

Unde, P.A., Adagale, P.V., Hashmi, S.I. and Raheem, A. (2011). Effect of different particle sizes of jaggery powder on storability. World Journal of Agricultural Science. 7(2): 157-160.

Uppal, S.K. and Sharma, S. (1999). Evaluation of new sugarcane varieties for jaggery (gur) quality and their shelf life in airtight containers during rainy season. Indian Sugar. 49(9): 701-704.

Uppal, S.K. and Sharma, S. (2002). Effect of storage temperatures on jaggery (gur) quality of sugarcane varieties. Journal of Food Science and Technology. 39(5): 549-551.

Uppal, S.K. (2002). Storage of Jaggery under low temperature for longer duration. Sugar Tech. 4(34): 177-178.