



# The Art and Science of Jaggery Making: A Review

V. Manimozhi Selvi, M. Mathialagan, S. Mohan

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## ABSTRACT

Jaggery is the most popular traditional Indian sweetener produced from sugarcane juice by concentration, without molasses being separated. It is a good source of minerals and nutrients, and has several medicinal values as well. With the increasing demand of this nutritive sweetener, efforts are being made to develop a standard manufacturing package that will increase its productivity besides quality improvement in terms of hygiene, standardization of shape, size and storability. The thermal and overall efficiencies of plants producing jaggery are very small due to the loss of thermal energy through flue gasses and un-designed plant parameters of construction. Storing jaggery is also a major problem. Since, the quality of invert sugars and mineral salts, which are hygroscopic in nature, is greatly affected. This intends us to study the technological upgradations used for the production and preservation of jaggery in order to prioritize the required advancements. This review provides information of the technical upgrading of manufacturing plants for jaggery and the preservation of jaggery using various storage and packaging methods.

**Key words:** Jaggery, Preservation, Sugarcane, Value addition.

## INTRODUCTION

Sugarcane (*Saccharum officinarum*) is a cash crop widely grown for commercial in the world. Besides sugar production, sugarcane is also used for the preparation of jaggery, khandsari. Sugarcane, the prime source of sugar in India, is cultivated in an area of about 5.15 million hectare with a production of about 383 million tonnes (2018-19). Sugar industry, the second largest agro-based industry in India sustains the livelihood of about 12.34 million farmers and farm workers. This industry is meeting about 40% of the total requirement of sweeteners and giving employment to 2.5 millions of people in rural areas with minimum capital investment (Anwar, 1999). Jaggery is an unrefined, non-centrifugal whole cane sugar consumed all over the world. It is a traditional Indian sweetener used in India much prior to arrival of modern sugar making technology. The color of jaggery varies from golden brown to dark brown but from market point of view light golden colored jaggery is very popular. Jaggery is a rich mixture of minerals and vitamins, thus it is the healthiest sugar from the group of sweeteners. The mineral contents in jaggery are approximately 50 times greater than refined sugar and 5 times more than brown sugar by Gopalan *et al.* (1991). Jaggery is a good source of energy (383 kcal/100 g) and has various medicinal values (Ghosh *et al.* 1998; Anonymus, 2014).

### 1. Jaggery market scenario

India has now become the largest producer and consumer of sugar with its production reaching up to 33 MMT for marketing year (MY) 2018-19. As the major producer of Jaggery, the country has recognized as one of the leading traders and exporters of Jaggery to the world. Uttar Pradesh and Maharashtra are the major sugar producing states and as far as Uttar Pradesh is concerned, it is said to be the largest state in sugarcane production in the country. Uttar

Department of Plant Breeding and Genetics, Sugarcane Research Station, Sirugamani, Tricity-639 115, Tamil Nadu, India.

**Corresponding Author:** V. Manimozhi Selvi, Department of Plant Breeding and Genetics, Sugarcane Research Station, Sirugamani, Tricity-639 115, Tamil Nadu, India.

Email: manimozhiagri2005@gmail.com

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Pradesh alone contributes to 42-44% of the country's total sugarcane production and also occupies the top of the list in being the largest sugar producing state with around 107.19 lakh tonnes during the marketing year (MY) 2018-19. It was estimated that about 50% of total sugarcane produced in India is used to manufacture 8–10 million tons of jaggery (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 of sugarcane, sugarcane quality, soil texture, irrigation facilities, time of cane crushing etc., (Narendra Mohan and Anushka Agarwal, 2020). The jaggery has a good demand in domestic and foreign market. The values of nominal protection coefficient and domestic resource cost of jaggery were observed less than unity, which shows that it is a good exportable product and has high export competitiveness (Banakar *et al.* 2012).

## 2. Nutritional status and importance of jaggery

Jaggery, a product of sugarcane, is such a product which 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 B<sub>1</sub>-0.01 mg, Vitamin B<sub>2</sub>- 0.06 mg, Vitamin B<sub>5</sub>-0.01 mg, Vitamin B<sub>6</sub>-0.01 mg, Vitamin C-7.00 mg, Vitamin D<sub>2</sub>-6.50 mg, Vitamin E-111.30 mg), and protein-280 mg per 100 g of jaggery, which can be made available to the masses to mitigate the problems of malnutrition and under nutrition. The micronutrients present in the jaggery possess antitoxic and anti-carcinogenic properties (Nath *et al.* 2015). The magnesium strengthens the nervous system, helps to relax our muscles, gives relief from fatigue and takes care of our blood vessels. The potassium and low amount of sodium present in jaggery maintain the acid balance in the body cells, and also combat acids and acetone and control our blood pressure. Iron helps to prevent anaemia. It also helps to relieve tension and takes care of asthma, as it has anti-allergic properties. The moderate amount of calcium, phosphorous and zinc helps to maintain optimum health.

## 3. Forms of jaggery

Jaggery is basically available in three forms *viz.*, solid (lumped), liquid and granular jaggery. Of this 80 per cent is in solid lump form while remaining 20 per cent constitute liquid and granular jaggery (Singh *et al.* 2011). The composition of these forms (Table 1) is reported by Said and Pradhan (2013).

### 3.1. Solid jaggery

To prepare solid jaggery the clarified sugarcane juice is boiled at its striking point temperature varying from 116 to 120 °C and then filled in to the molds of different shapes and sizes. The moisture contents of solid jaggery lies in between 5.0% and 7.0% as per the Bureau of India Standard (Anonymous, 1990). The liquid jaggery is semi liquid syrup made by boiling of sugarcane juice below striking point temperature varying from 105 to 108 °C (Nevkar *et al.* 2008).

It contains 30–36% water, 40–46% sucrose, 15–25% invert sugar and 0.30% calcium Wandre and Hasabnis (1995).

### 3.2. Liquid jaggery

It is an intermediate product obtained during concentration of purified sugarcane juice during jaggery making and is semi liquid syrup like product. The quality of liquid jaggery largely depends upon quality and composition of cane juice, type of clarificants used and striking temperature at which concentrating juice is collected. For quality liquid jaggery, the juice concentrate is removed from boiling pan, when it reaches striking point temperature of 103-106°C depending upon the variety and agro-climatic zone. Chemical composition of typical liquid jaggery could be: water 30-36%, sucrose 40-60%, invert sugar 15-25%, calcium 0.30%, iron 8.5-10 mg/100 mg, phosphorus 05/100 mg, protein 0.10/100 mg and vitamin B 14/100 mg (Singh *et al.* 2013).

### 3.3. Granular or powder jaggery

The process of making granular jaggery is similar up to concentration. The concentrating slurry is rubbed with wooden scrapper, for formation of grains. The granular jaggery is then cooled and sieved. Less than 3 mm sized crystals are found to be better for quality granular jaggery. Raising of pH of cane juice with lime up to 6.0-6.2 and striking point temperature of 120°C was found to yield quality granular jaggery with high sucrose content of 88.6%, low moisture of 1.65%, with good colour, friability and crystallinity. Jaggery in the form of granules (sieved to about 3 mm), sun dried and moisture content reduced to less than 2% and packed in polyethylene polyester bags or polyethylene bottles, can be stored for longer time (more than two years), even during monsoon period with little changes in quality. Colour of jaggery powder can range from golden yellow to golden brown dark brown like dark chocolate. The colour is often dependent on base ingredient used to make jaggery powder. It is softer than sugar and also amorphous. This is because vitamins proteins and in gradient of cane are not removed. It is made up of predominantly sucrose mineral salts iron. Hence consumption of jaggery is recommended in case of iron deficiency anaemia. It contains longer chains

**Table 1:** Composition of different forms of jaggery.

Composition per 100g	Types of Jaggery		
	Solid	Liquid	Granular
Water (g)	3-10	30-35	1-2
Sucrose (g)	65-85	40-60	80-90
Reducing sugar (g)	9-15	15-25	5-9
Protein (g)	0.4	0.5	0.4
Fat (g)	0.1	0.1	0.1
Total minerals (g)	0.6-1.0	0.75	0.6-1.0
Calcium (mg)	8.0	300	9.0
Phosphorous (mg)	4.0	3.0	4.0
Iron (mg)	11.4	8.5-11	12
Calorific value (Kcal)	383	300	383

Source: Rao *et al.* 2007

of sucrose therefore it is digested slowly and energy release is also slow. Hence energy is provided for a longer period of time and it not harmful for the body.

#### 4. Traditional jaggery manufacturing process

Mechanical and thermal energies are required to prepare jaggery using open earth pan furnace. Mechanical energy is required to crush the sugarcane to produce sugarcane juice, and thermal energy is required to heat the sugarcane juice to prepare jaggery in the furnace. Crushing the sugarcane will produce sugarcane juice and bagasse as a by-product. At the initial moment the moisture content in the bagasse is around 40-50% (Manohar Rao, 1977). The moisture content can be reduced to 8-10% by drying the bagasse in open area and then dry bagasse is used as a raw material to produce heat by combustion in the open earth furnace. It was observed that out of the total energy produced in the combustion process, around 45% is used for jaggery preparation and remaining is lost through flue gases, ash and furnace walls. Sugarcane juice used in preparation of jaggery in the open earth pan consists of three different stages.

The first stage of process begins with supplying sensible heat (around 6% of total energy produced in the combustion process) required to raise the temperature of sugarcane juice from ambient to its boiling point. Measured quantity of additives like bendi, calcium carbonate and phosphoric acid (each at around 30-50 g/100 kg of sugarcane) will be added to the sugarcane juice to maintain the required pH in this stage (Ghosh *et al.* 1998). The second stage consists of removal of water from the sugarcane juice at its saturation/boiling temperature. The amount of heat supplied during this stage (around 39% of the total energy produced in the combustion process) is considered to be latent of vaporization required to convert water to steam. Floating residue known as molasses (around 3-5 kg/390 kg of sugarcane juice) is formed at this point and needs to be removed from the free surface. At the end of the second stage, the sugarcane juice will become rich in concentrated solids as the water is completely removed. In the last stage of jaggery preparation, the heat supplied (around 0.1% of the total energy produced) is utilized to increase the temperature of the sugarcane juice from its boiling point to striking point. The striking point is the temperature at which the sugarcane juice converts to a semi solid paste which slides on the pan surface instead of sticking to the pan. At this stage the sugarcane juice in semi-solid state is removed from the pan and cooled to room temperature to prepare the jaggery. The conventional process of jaggery preparation is represented in (Fig 1 and 2).

#### 5. Exploration of new avenues in jaggery processing

While producing jaggery by traditional process, naturally occurring enzymes and other compounds in sugarcane juice react with each other due to uncontrolled heating and form many dark colored complex compounds. Secondly, due to high heat, sugars in juice caramelize and form dark colored

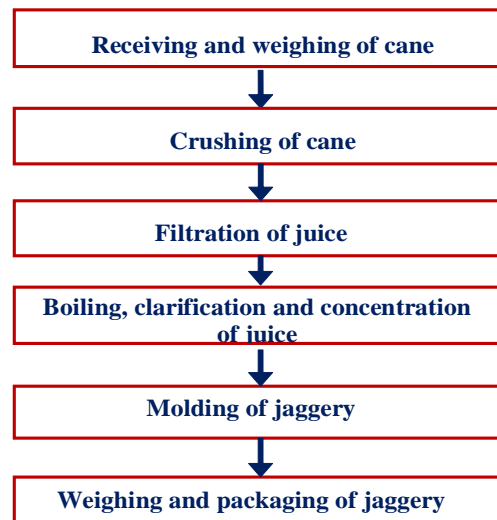


Fig 1: Flow chart of jaggery manufacturing operations Kumar *et al* (2018).

compounds. Finally, excessive use of lime and leaching of iron from pans also result in dark color. Many jaggery producers use surplus sugarcane after supply to sugarcane factories for the production of jaggery. Such sugarcane is not always compliant with the production process and results in lower quality of jaggery.

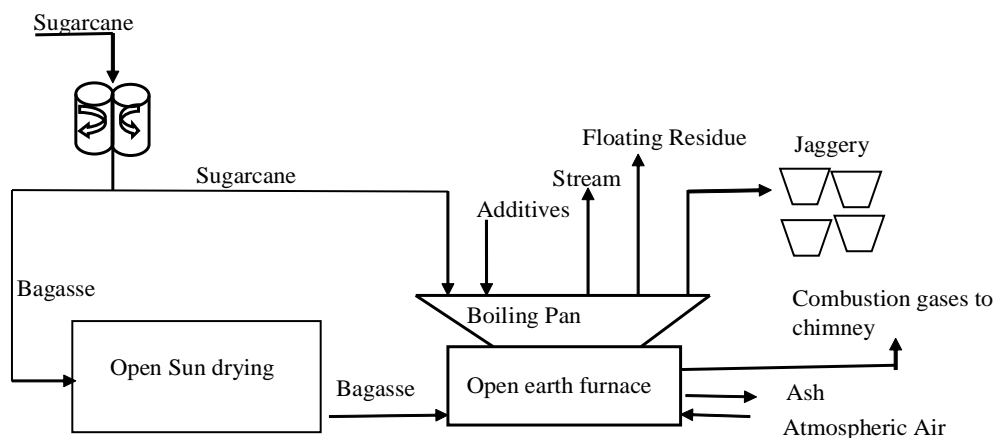
There are several jaggery units which are on the verge of closure as a result of traditional technologies, low market price for jaggery in comparison to fair remunerative Price (FRP) /State Advised Price (SAP) for sugarcane. Traditional process involves manual labor and involves long hours of production. 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.

With the advent of modernization and introduction of new technologies while quality of sugar has improved to a greater extend in order to cater to the sector specific requirements of the market, jaggery production is still confined to small scale cottage industry usually for local consumption, using traditional technologies necessitating measures to be taken for quality improvement (Shahi, 1999). With the passage of time although the jaggery industry has witnessed growth in many folds, but sadly there isnt any significant improvement in its performance, technical efficiency and recovery. Few reasons as to why old technologies are still in practice for jaggery manufacturing are:

- (a) Lack of government policy support
- (b) Dis-organized micro and small scale sector
- (c) Lack of will and financial constrains to adopt new technologies
- (d) Poor education of craftsmen involved in jaggery processing

#### 5.1. Technological advancements in jaggery processing

Conventionally jaggery is produced by evaporation of water in open pan/s. Furnace is fired using bagasse, which is residue of sugarcane, obtained during juice extraction. Furnace heat utilization efficiency is very low, which is ~15% for single (Sharon *et al.* 2014), ~30% for two (Anwar, 2010),



**Fig 2:** Conventional Process of Jaggery preparation.

and 50 to 60% for four pans (Shiralkar *et al.* 2014). It also depends on number of parameters like sizes of pan, furnace and chimney, flue gas flow patterns, orientation and air inlets, bagasse firing practices, etc. In addition to this, these units are mainly designed and developed through past experiences. Saving of bagasse gives additional revenues to the farmers. Chemicals like lime, phosphoric acid and hydros powder are used by jaggery makers to clarify juice (Singh *et al.* 2013; Sardeshpande *et al.* 2010; Bhardwaj and Singh, 2013). Traces of these chemicals in the jaggery are harmful for human health. This problem was overcome by the use of two pan; three or four-pan could be used so as to consume maximum thermal energy of the hot flue gasses. Several research is being carried out to enhance the performance of jaggery plant. The research study includes the use of juice pre-heaters, energy boosters, economizers, heat pump based freeze concentration system of sugarcane juice etc. Among all the above mentioned suggestions, the use of multiple pan plant with heat pump based freeze concentration system of sugarcane juice seems to be a promising approach for efficient jaggery production. These key issues are addressed by Energy Efficient Freeze Pre-concentration Process.

## 5.2. Jaggery making using freeze pre-concentration of sugarcane juice

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° Brix. 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.

The number of open pan/s used for concentrating juice depends on severity of bagasse use. Some cane varieties are sugar rich while some are fibre rich. Single pan jaggery making with sugarcane having low fibre and high sugar content may require additional fuel other than bagasse. This

issue was addressed by increasing number of pan for preheating and concentration. Two, three and four pan furnaces are reported in literature. It shows that furnace heat utilization efficiency increases with number of pans. Initial investment also increases with increase in number of operators. Quality of jaggery is still being questioned, as chemical clarificants are used to enhance colour of juice and hence colour of jaggery. Organic sugarcane cultivation and crushing same sugarcane for organic jaggery making using only vegetative clarificant showing huge potential in Indian market as well as for export. India exported 3,41,155.34 MT of jaggery and confectionery products to the world for the worth of Rs. 1,633.22 crores/ 227.90 USD Millions during the year 2019-20 (APEDA, 2020). This huge opportunity can be met by continuous and automated operation of small jaggery units. It will offer addition employment and help to improve status of debt ridden sugarcane farmers. These issues are addressed by Energy Efficient Freeze Pre-concentration of Sugarcane Juice using a Reversible Heat Pump.

## 5.3. Advantages of fpcs are as follows

- Low specific power consumption 9 to 11 kWh/m<sup>3</sup> water removal
- Saving of bagasse upto 77% of produced bagasse. It gives additional revenue to farmers
- Reduction in area required for jaggery making unit by 60%
- Quality of jaggery gets improved. Colour of jaggery gets improved without using chemicals
- Reduction in pan size, which is required for boiling of concentrated juice
- Operation of system is also possible using solar photo-voltaic cells
- Automated operation reduces number of workers required to handle boiling process

## 6. Storage and packaging

The storage life of jaggery is mainly depends upon the atmospheric humidity and temperature. 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 monsoon 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, the humidity content of jaggery should not exceed 6 percent 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.* 2012). The pretreatment with nitric oxide of sugar cane 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. Studies on the handling, packaging and solar drying of jaggery under various environmental conditions have been addressed in this document. 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 first national seminar on jaggery manufacturing, its quality and storage was organized in 1985 at Indian Institute of Sugarcane Research, Lucknow (Baboo and Ghosh, 1985). The prepared jaggery, can be kept at low temperature for up to eight months (Uppal and Sharma, 2002). Jaggery can be stored without any physical changes for duration of 20 months at a temperature range of 7-9° C (Uppal, 2002). Excessive use of sulfite as a clarifier can impact jaggery colour during storage (Perez-Gago *et al.* 2002). Excessive microbial growths during jaggery

storage are very harmful to human body (Singh *et al.* 2009). The shape and sizes of jaggery particles also affect the storage life time of jaggery powder. Jaggery powder of coarse grade (0.5-0.708 mm) was found to be more suitable than medium (0.351-0.420 mm) and fine (0.211-0.296 mm) in 100 gauge polyethylene bags for a period of six months in terms of its chemical properties and organoleptic properties (Unde *et al.* 2011). An improved drying cum-storage bin (100 kg capacity) and a six-ton capacity godown were built by IISR, which was found suitable for almost all regions in India (Anwar, 1999). In the jaggery cum storage bin, the change in quality characteristics during storage such as moisture content, colour, sucrose and sugar reduction was found to be more successful than the open pan and polyethylene bag for a period of six months (Chand *et al.* 2011). Jaggery storage in the IISR bin was also found to be more effective under hilly climatic conditions than the polythene bag and open storage. For a longer time than jute bags, the PET film with 100% nitrogen can be used to store jaggery (Chand *et al.* 2014). The storage of jaggery in drying cum storage bin with edible coating of whey protein was found to be good as compared to uncoated jaggery. Patil and Anekar (2014) observed the storage of jaggery in a pre sterilized PET bottle at refrigeration temperature (7° C) was found more efficient than at room temperature (27° C) and high temperature (37° C). Mishra *et al.* (2016) utilized the carboxy methyl cellulose and whey protein to maintain the moisture content of jaggery or storage of jaggery for some time. Shweta *et al.* (2019) suggested that solid jaggery can be kept for more than one year at low temperature. Quality and colour are the significant characteristics that decide the acceptability of customers towards jaggery. In the case of jaggery stored at low temperatures, the consistency and colour of solid jaggery stored at room temperature are good and appropriate. The various studies carried out on storage and packaging of jaggery is listed in (Table 2 and Table 3) respectively.

**Table 2:** Studies on the affects of storage materials on the shelf life of jaggery

Storage material / conditions	Description	Pros/cons	References
Low temperature	Studied the storage life of jaggery at low temperature	Could be stored for a period of eight months	Uppal and Sharma, 2002
Low temperature	Calculated the storage time of jaggery at 7-9° C temperature	Could be stored for a period of 20 months	Uppal, 2002
Airtight container	studied the physico- chemical properties of stored jaggery	Maintaining the quality of jaggery with respect to sucrose content	Ramya <i>et al.</i> (2010)
Jaggery cum storage bin	Compared the storage life of jaggery in jaggery cum storage bin with open and polyethylene bags	Jaggery could be stored for a period of six months in jaggery cum storage bin	Chand <i>et al.</i> (2011)
Low temperature Room temperature and pre sterilized PET bottles	Studied the storage life of liquid jaggery at room temperature, refrigeration temperature and pre sterilized PET bottles	liquid jaggery could be stored for a period of 90 days in refrigerator	Patil and Anekar, 2014

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

Storage material	Description / Remarks	Pros/cons	References
Nitrogen packaging	Investigated the packaging behavior of jaggery with vacuum and nitrogen environments	The nitrogen packaging of solid jaggery maintained its freshness for a longer period	Gupta <i>et al</i> (2002)
Painted earthen pot, heat sealed packet of LDPE and PET jar	Compared commonly used packaging materials for keeping quality of jaggery during monsoon season	Painted earthen pot, heat sealed packet of LDPE and PET jar with airtight lid were the best jaggery packaging method in monsoon season	Mandal <i>et al</i> (2006)
LLDPE, PP, LD/HD/LLD, BOPP and PET	Conducted a study to compare the effects of different packaging materials on keeping quality of jaggery	Three ply packaging material was observed as the best packaging material due to high strength, low water vapour trans-mission rate and least oxygen transmission rate	Singh, 2008
100 gauge polyethylene bag at room temperature	Studied the effect of different particle sizes on storability of jaggery powder	Particle size of coarse grade (0.5-0.708 mm) can be stored for a period of six months	Unde <i>et al</i> (2011)
Low density polyethylene pouch and paper bags	Studied the effect of packaging material and irradiation (3 kGy, 5 kGy and 7 kGy) on storage stability of jaggery	Low-density polyethylene pouch and paper bags subjected to medium dose irradiation at 7 kGy were found best	Sankhla <i>et al</i> (2011)
PET film with 100% Nitrogen	Observed the effect of modified atmosphere packaging on keeping quality of jaggery	PET film with 100% Nitrogen could be used for longer duration.	Kumar <i>et al</i> (2012)
Whey	Evaluated the effect of edible coating and packaging materials on microbiological characteristics of jaggery	Use of whey as a coating and packaging material was very effective to preserve jiggery for longer time	Shukla, 2012
Nitrogen	Studied the shelf life of jaggery under modified environmental conditions	Packaging of jaggery with nitrogen was found very effective to maintain all the physicochemical, microbial and overall parameters than vacuum, polythene bags and airtight containers at room temperature	Singh <i>et al</i> (2012)
PET film	Analyzed the effect on color of jaggery cube under modified atmospheric conditions packed in a plastic film	PET film was the best jaggery packaging method than LDPE, PP and laminated aluminum film under modified atmospheric packaging conditions	Kumar <i>et al</i> (2013a)
PET film under 100% nitrogen	Studied the effect of modified atmospheric packaging conditions on keeping quality of jaggery	Packaging of jaggery in PET film under 100% nitrogen showed less reduction in quality storage than parameters during LDPE and PP films	Kumar <i>et al</i> (2013b)
Triple layered vacuum packaging	Investigated the processing, packaging and storage of jaggery in different layered and vacuum packaging materials	Packaging of jaggery in a triple layered vacuum packaging material for the change in color, sucrose content, hardness, reducing sugar, moisture content, porosity and microbial load was found very effective	Kumar <i>et al</i> (2013c)
Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE) plastics, plastic and glass containers, aluminum pouch and open storage.	Evaluated the microbial, physicochemical and shelf life of muscovado sugar under various packaging materials and storage time	Packaging of muscovado in glass container, aluminum pouch and HDPE plastic was found very effective	Karen Luz <i>et al</i> (2013)

Table 3: Continue.....

Table 3: Continue.....

Edible coating	Studied the effect of edible coating on quality parameters of jaggery	Drying cum bin with edible coating of whey protein could be used to store for longer duration in terms of physiochemical and shelf life	Chand <i>et al</i> (2014)
Pre sterilized PET bottle	Studied the effect of parameters and storage conditions on quality of jaggery	More efficient storage in presterilized PET bottle and 7°C temperature	Patil and Anekar, (2014)
Carboxy methylcellulose (CMC)	Studied the effect of CMC and WP on quality of jaggery during storage	Could be used to maintain the quality of jaggery for some time	Mishra <i>et al</i> (2016)
and whey protein (WP)	Evaluated the storage life of jaggery under different edible coating materials	Reported that use of CMC and HPMC as an edible coating material may improve the storage life of jaggery up to 225 days	Kumar <i>et al</i> (2017)
CMC and hydroxyl propyl methyl cellulose (HPMC)	Evaluated the storage life of solid jaggery at low temperature and room temperature	Solid jaggery could be stored at low temperature for a period of 1 year	Shweta Deotale <i>et al</i> (2019)
Low temperature			

## SUMMARY

The thermal and overall efficiencies of the production plants for jaggery are very limited, depending on the number of variables. Design and construction specifications of the plant, bagasse combustion, the use of hot flue gas thermal energy and the draught produced by the furnace are some of the major factors that need due attention. All these parameters are directly related to the efficiencies of the plant that makes jaggery. The researchers also face major challenges with low juice recovery quality, low productivity and elevated operating time of conventional jaggery plants. In order to solve this problem, two-pan, three-pan and four-pan plants are used to absorb hot flue gases with optimum thermal capacity. The use of multi-pan plants with a heat pump based freeze concentration system is found to be a good approach for the efficient production of jaggery from sugarcane juice from the available literature on improvements for the production of jaggery production plants.

Jaggery storage is also a major concern. 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. Edible coating, PET film, drying cum storage bin, low temperature storage, PET film with 100 % nitrogen is used as packaging materials for keeping quality of jaggery. The storage of jaggery in the whey coated drying cum storage bin is most efficient in maintaining the consistency of jaggery for a longer time. Some of the researchers' current research activities are improving the efficiency of heat utilization, preheating of juice, using the freeze concentration technique, automating various processes and maintaining the consistency of jaggery for a longer period under all environmental conditions. In short, 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 sugar cane juice.

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