Development of a fully mechanized plant to produce syrup from sweet sorghum

Project No.: DST/TDT/AGRO-25/2019 (G)

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1 Objectives

The primary objectives of this project are listed below.

1. Designing, modelling and fabricating a fully mechanized pilot plant for the production of syrup from sweet sorghum.
2. Integration and optimization of all the sub-processes and the respective machinery to produce 150 kg of syrup per day.
3. Standardizing quality of syrup produced and ensuring its marketability so as to create a proper supply chain.
4. Popularizing the syrup production (and thereby, the sweet sorghum cultivation) among the farmers through demonstrating the working of the plant and its socio- economic benefits.

2 Proforma for project completion report

A. SUMMARY SHEET

1. Title of the project: Development of a fully mechanized plant to produce syrup from sweet sorghum.
2. PI and organization: Dr. Anil Kumar Rajvanshi, Nimbkar Agricultural Research Institute, Phaltan-415523.
3. Date of start: September 1, 2020.
4. Total cost of the project:
5. Staff sanctioned: Engineer and technician.
6. Total expenditure:
7. Equipment acquired, if any:
8. Summary of progress made (up to 300 words): According to data of syrup sold at NARI, the demand for sweet sorghum (SS) syrup has been increasing at a steady pace for the last few years. It was felt that there is a need to develop a simple, mechanized and affordable plant that produces about 150 kg SS syrup per day to enable farmers to tap into this growing market and earn more money. During the course of the project, it was realized that some processes are not amenable to *complete* mechanization since it makes the plant substantially more complex and expensive, and thus, it was decided to instead opt for *partial* mechanization wherever needed. Syrup making process involves many steps from harvesting of biomass to storage of syrup, and each of these steps was addressed one by one. NARI had already conceptualized and developed the whole process of SS syrup production in the late 1990s, and accordingly, the processes already in place and not requiring a major overhaul (like stripping of stalks, removal of scum etc) were first optimized and standardized. Then, erstwhile manual processes like mucilage preparation, heating endpoint determination, syrup cooling, etc were fully or partially mechanized. Finally, the subprocesses were integrated so that the plant runs smoothly with minimal human intervention giving syrup of uniform quality. Other major achievements of this work include reduction in labour and losses; enhancement in convenience, safety and hygiene of the plant; and development of a clean and efficient multi-fuel fired furnace of capacity up to 300 kW.

   Efforts were made to popularize the syrup among farmers and start-ups alike by inviting them to our syrup-making sessions, putting up stalls at important events, making banners, etc. Detailed economic analysis was performed which revealed that a farmer can earn up to three times more by growing SS than sugarcane, underpinning the relevance of this work.

B. DETAILED REPORT

1. **Introduction (Need identification, S&T needs, proposed area of intervention) (200 words):** Nimbkar Agricultural Research Institute (NARI) has been producing and selling SS syrup since the 1990s at a small scale. The sale of the syrup made at NARI has been increasing at a linear rate of about 200 kg/year for the last two decades reflecting its growing demand. Thus, it is envisaged that the production of syrup from SS will yield higher returns to the farmers. The

primary aim of this project was to design a small-scale plant (with capacity to produce 50 kg syrup per 8 hours) to mechanize the complete process of syrup production, beginning from crushing of the stalks to bottling of the syrup.

In this work, a semi-mechanized plant with optimal process parameters and requiring minimal human intervention has been designed. Objective criteria have been developed to evaluate and optimize performance through quantification of subjective parameters wherever required. Special emphasis has been laid on keeping the plant simple and affordable: economic analysis reveals that a farmer can earn up to three times in comparison to a sugarcane farmer in the Phaltan region.

2. **Objectives (As approved in the project):**
    a. Designing, modelling and fabricating a fully mechanized pilot plant for the production of syrup from sweet sorghum.
    b. Integration and optimization of all the sub-processes and the respective machinery to produce 150 kg of syrup per day.
    c. Standardizing quality of syrup produced and ensuring its marketability so as to create a proper supply chain.
    d. Popularizing the syrup production (and thereby, the sweet sorghum cultivation) among the farmers through demonstrating the working of the plant and its socio- economic benefits.
3. **Project Area:** N/A.
4. **Community background:** N/A.
5. **Methodology followed (Survey, mobilization, technology, identification, transfer & adoption, demonstration & training component etc.) (500 words):**

The syrup production process from harvesting of biomass to storing of syrup involves many steps, and the first task was to break down this process into four major sections, namely, (a) harvesting of biomass and stripping of stalks, (b) crushing of stalks and settling of juice, (c) heating of juice and (d) cooling and storage of syrup. This helped not only with book-keeping, but also in keeping the whole process in perspective.

In each section, firstly, those tasks which involved maximum human intervention were identified. Through literature study and ad-hoc experiments, it was determined whether their mechanization is possible (within practical constraints). If yes, a systematic plan towards mechanization was sketched and followed. If no, the next best thing was sought: standardization and optimization of process parameters through partial mechanization. The fact that SS syrup was being produced at NARI since the early 1990s, a basic set-up was already in place, which was very useful.

For mechanization, the general approach was as follows: (a) develop an in-house prototype, (b) perform experiments to check its performance, (c) take trials with labourers, (d) make necessary modification based on results and feedback, (e) do a thorough market survey, and (f) purchase the appropriate equipment. The prototypes were designed by using as much of the already available material at NARI as possible. Special emphasis was laid on making *simple* prototypes which are easy to operate and repair. Experiments were done to test and improve the performance of the prototype. Trials were then taken by both researchers and labourers. Some of the labourers had been involved in the process of SS syrup preparation for many years, and their feedback regarding the effect of mechanization was very useful. Once a satisfactory prototype was designed, a thorough market survey was done to find appropriate equipment. In some cases, the prototype that was designed was preferred over purchasing a new equipment from the market.

In this way, processes in each section were mechanized, standardized and optimized. Minor tweaks then had to be made to integrate these processes to make the whole syrup-making process a smooth and continuous exercise with little human intervention. Many large-scale syrup-making sessions were conducted and executed exclusively by labourers, and syrup of uniformly good quality was obtained.

In summary, a plant that requires minimal human intervention, and is convenient, simple, safe and hygienic has been developed.

Farmers were invited to the syrup-making sessions to demonstrate to them the working of the plant and get them interested in making SS syrup. They were impressed with the mechanization, and also appreciated the cleanliness of the plant. For details, see Section 5.5.3.

To popularize SS syrup among the common populace, stalls were put up during the annual pilgrimage to Pandharpur and in a millet-based event organized in Pune. At both these places, people who tasted the syrup liked it very much. In the event in Pune, some entrepreneurs showed interest in marketing of the syrup. Also, a few start-ups that make food products with jaggery showed interest in using SS syrup as an alternative. For details, see Section 5.5.4.

6. **Technical back-up support and linkages established with S&T institutions (200 words):** N/A.

7. **Science and technology component (300-400 words):** Brix data for different SS varieties sown at NARI has been collected during the whole duration of the project, which should serve as an important guide for farmers around the area as regards the sowing and harvesting times of the crop (Section 5.1.1). Preliminary stripping machines have been designed, and in future, dedicated stripping machines for SS may be designed using some of the ideas used (Section 5.1.3). Many experiments to assess the effect of leaf sheath, pest damage and settling of juice on syrup quality have been performed (Sections 5.1.4, 5.1.5 and 5.2.5, respectively). Some of these results could greatly simplify the syrup-making process, and serve as a benchmark for similar analyses on different SS varieties in future. A simple, efficient and clean multifuel-fired furnace of 300 kW capacity and a transient efficiency of up to 25% has been developed (Section 5.3.5). Such furnaces could go a long way in decentralizing food processing industry, and contribute towards solving the critical issue of biomass burning. Objective criteria for determining heating endpoint based on syrup temperature has been developed, obviating human preferences and subjectivity (Section 5.3.4). Taking cue from this, the same approach could also be followed for determining endpoint for other food-products of this class; for example, jaggery. In fact, at NARI even for jaggery a

temperature-based criterion is used nowadays to determine heating endpoint. Curves correlating syrup properties to its other easily measurable physical properties have been developed.

8. **People participation from planning to implementation stage (With emphasis on extent and nature of their involvement in technology generation / modification / transfer / adoption, co-operative formations) (300 words):** In the initial stage of this project, trials of prototypes were conducted with experienced labourers who had known the SS syrup-making process for many years. Their feedback was very important and helpful in designing the final plant. For smooth integration of the developed sub-processes, many syrup-making sessions were carried out, and the experiences of the labourers were recorded, which helped in development of a simple yet non-human-centric plant.
   In the latter stage of the project, farmers were invited to the syrup-making sessions to demonstrate to them the working of the plant and get them interested in making SS syrup. They were impressed with the mechanization, and also appreciated the cleanliness of the plant. To popularize SS syrup among common populace, stalls were put up during the annual pilgrimage to Pandharpur and in a millet-based event organized in Pune. At both these places, people who tasted the syrup liked it very much. In the event in Pune, some entrepreneurs showed interest in marketing of the syrup. Also, a few start-ups that make food products with jaggery showed interest in using SS syrup as an alternative.
9. **Impact analysis with indicators (qualitative & quantitative details, technoeconomic viability, improvement in productivity, quality and quantity / income generation / living standard / skill upgradation & managerial capability / environmental conditions / personnel trained as the case may be) (500 words):**

Economic analysis reveals that a farmer can earn up to three times more than a sugarcane farmer at the current rates by selling his SS biomass to a syrup-making unit. If he produces the syrup in his own unit, the profits go up to about six times. These findings are tabulated below. For details, see Section 5.5.1.

Table 1: Highlights of economic analysis; all comparisons are with a typical sugarcane farmer in Phaltan region.

Scenario 1: farmer grows SS and gives it to a syrup production unit	**Scenario 2: farmer grows SS and produces syrup in his own plant**
For biomass selling price the same as sugarcane (Rs. 2,500/tonne), a farmer can earn up to 33% more profit	Assuming the same biomass yield and syrup selling price as at NARI, profit for a SS farmer is six times more
For biomass selling price of Rs. 5,000/tonne, a farmer can earn three times more, with syrup unit’s annual profit being Rs. 40 lakhs.	

If a farmer sows from February to April, he can earn about Rs. 2.4 lakhs per acre-year (compared to about Rs. 75,000 from sugarcane)	

10. **Special features (New technology generation / innovativeness in terms of low cost / design / environment-friendly etc; replicability potential & multiplier effect in nearby areas) (300 words):**
    A simple, efficient and clean multifuel-fired furnace of 300 kW capacity and a transient efficiency of up to 25% has been developed. Such furnaces could go a long way in decentralizing food processing industry, and contribute towards solving the critical issue of biomass burning. New low-cost method of determining syrup heating endpoint has been developed. With this method, the endpoint could be determined with an inexpensive digital multi-meter (costing about Rs. 200) and a K-type thermocouple wire (available at Rs. 100/meter). Such a method could also be used in traditional jaggery-making units which use highly human-centric criteria (like appearance) to stop heating.
11. **Applying for patent, if any:** No.
12. **Indicators applied for monitoring:** N/A.
13. **Follow up action (Post project) (300 words)**

Many exciting research activities that could not be continued in view of time constraints should be explored further. They are tabulated below, classified according to the sections in the syrup-making process.

Section: harvesting and stripping of stalks
• Improve designs of stripping machines developed during this project.
• Find out effects of incorporating leaf sheath and stalk damaged by pests on syrup quality.
• Improve crushing efficiency of shorter stalk pieces so that the new method of damage detection can be used.
• Devise methods of damage detection which obviate the need to remove leaf sheath.
Section: crushing of stalks and settling of juice
• Develop a simple technique for uniform feeding of stalks at a rate which gives high crushing efficiency and smooth operation.
• Develop crushers more suitable for SS stalks; in particular, stalk feed-rate window for high crushing efficiency with smooth operation should be broad.
• Develop simple and affordable machines for bagasse transport. Conveyor machines and vacuum pumps are two possible ideas.
• Develop a method to recover as much clear juice from the settling tank as possible.
• Explore different shapes for settling tank to enhance settling rate.
Section: heating of juice
• Survey market for a more robust and user-friendly temperature-recording device.
• Design a simple and affordable pan-sealing mechanism to further enhance furnace efficiency.
• Develop compact furnaces with heat output of about 60 kW which could be transported easily.
Section: cooling and storage of syrup
• Explore options for transferring the syrup directly from the heating pan to cold room.
• Explore organic preservatives suitable for SS syrup to increase its shelf-life.
• Use the correlation curve between syrup Brix and its flowability to develop a quicker method for heating endpoint determination.
• Obtain correlation curves (discussed above) for different SS varieties across different seasons.

Section: popularization & dissemination of technology
• More variables should be considered for a more comprehensive economic analysis.
• Data from different regions should be considered to calculate region-specific profits.
• Start-ups making jaggery- and millet-based food products should be encouraged to try SS syrup as an alternative.

14. **Constraints and suggestions (300 words):** It was realized during the course of the project that developing a 'fully' mechanized plant is an unrealistic proposition since there are processes for which there is no simple way of mechanizing. Take for example scum removal process. It is a fairly sophisticated task since the scum needs to be removed gently (lest the scum layer breaks), but promptly (lest it dissolves back into the juice). A machine that does this will be complicated and costly, and for a small furnace such as that developed in this project, it is much simpler and economical to remove the scum manually. Sophisticated mechanization also has the disadvantage that in the event of a breakdown, it is difficult to repair and replace.

    Due to these reasons, activities not amenable to full mechanization were partially mechanized and/or their manual method was improved/standardized (for example, scum removal process was simplified so that only one person can do it now, whereas three were required earlier). Nonetheless, efforts should be continued towards mechanization of such activities in a way that keeps them simple and affordable.

Conclusions: The work done in this project has resulted in a semi-mechanized SS syrup plant with continuous and well-integrated subprocesses. Many processes that were previously carried out manually have been mechanized. Moreover, many existing processes have been kept as they are, but their parameters have been optimized for maximum efficiency. Finally, detailed economic analysis has been performed and steps have been taken to disseminate this technology among rural populace.

This technology is now ready to be taken up for implementation, and future work should focus on its dissemination. It is believed that the newly emerging start-up ecosystem in the country could play a potentially huge role towards that. All the technical know-how of the SS syrup plant as developed in this project including detailed drawings, designs, etc will be provided to start-ups interested in marketing this technology. Moreover, efforts towards reaching out to companies interested in selling SS syrup or using it as raw material for production of confectionaries etc will be continued. A couple of such companies have purchased a total of **2060 kg** SS syrup from NARI since this project started (September 2020) which is a testament to the existence of a burgeoning market for natural sweeteners like the SS syrup.

3 Executive summary

3.1 Introduction

Sweet sorghum (SS) is a sugar-producing crop which can be used for simultaneous production of grain, sugary juice and fodder. Its juice when heated to about 106^{0}C gives syrup. Nimbkar Agricultural Research Institute (NARI) has been producing and selling SS syrup since the 1990s at a small scale. The sale of the syrup made at NARI has been increasing at a linear rate of about 200 kg/year for the last two decades reflecting its growing demand. Thus, it was envisaged that the production of syrup from SS will yield higher returns to the farmers. The primary aim of this project was to design a plant to mechanize the complete process of syrup production, beginning from crushing of the stalks to bottling of the syrup. The production capacity of the plant is 50 kg syrup per 8 hours.

Mechanization of SS syrup-making process is sought for the following reasons:

(a) The process of SS syrup-making is derived largely from that of jaggery making. The traditional jaggery-making units in the country use age-old technologies that are largely human-centric. As a result, the quality of produce (even in the same unit) varies significantly across different jaggery batches. The same was observed with SS syrup production at NARI. It was thus deemed necessary to (i) quantify process parameters to minimize subjectivity and scope for human errors, (ii) optimize these parameters, and (iii) mechanize processes to the extent possible to ensure repeatability. The primary objective of mechanization was to standardize quality of syrup across different syrup-producing units and seasons.

(b) Since the earlier processes were derived from the traditional jaggery-making process, many of them were laborious and inefficient, and at times hazardous. Mechanization was sought to make the syrup-making process convenient, energy-efficient and safe.

(c) Finally, avoidance of human touch ensures hygiene.

However, it was realized during the course of the project that developing a 'fully' mechanized plant is an unrealistic proposition since there are processes for which there is no simple way of mechanizing. Take for example scum removal process. It is a fairly sophisticated task since the scum needs to be removed gently (lest the scum layer breaks), but promptly (lest it dissolves back into the juice). A machine that does this will be complicated and costly, and for a small furnace such as that developed in this project, it is much simpler and economical to remove the scum manually. Sophisticated mechanization also has the disadvantage that in the event of a breakdown, it is difficult to repair and replace.

Due to these reasons, activities not amenable to full mechanization were partially mechanized and/or their manual procedure was improved/standardized (for example, scum removal process was simplified so that only one person can do it now, whereas three were required earlier). In any case, the ultimate aim of developing a **standardized, continuous, efficient** and **fuel self-sufficient** plant was duly achieved.

For ease of bookkeeping, the complete process of syrup-making can be divided into four sections: (a) harvesting and stripping of stalks, (b) crushing of stalks and settling of juice, (c) heating of juice, and (d) cooling and storage of syrup. A drawing of a typical SS syrup production process and a process flow-diagram of the plant developed at NARI are shown in Figure 1 and Figure 2 respectively. A schematic showing the actual layout of NARI SS syrup plant is shown in Figure 3.

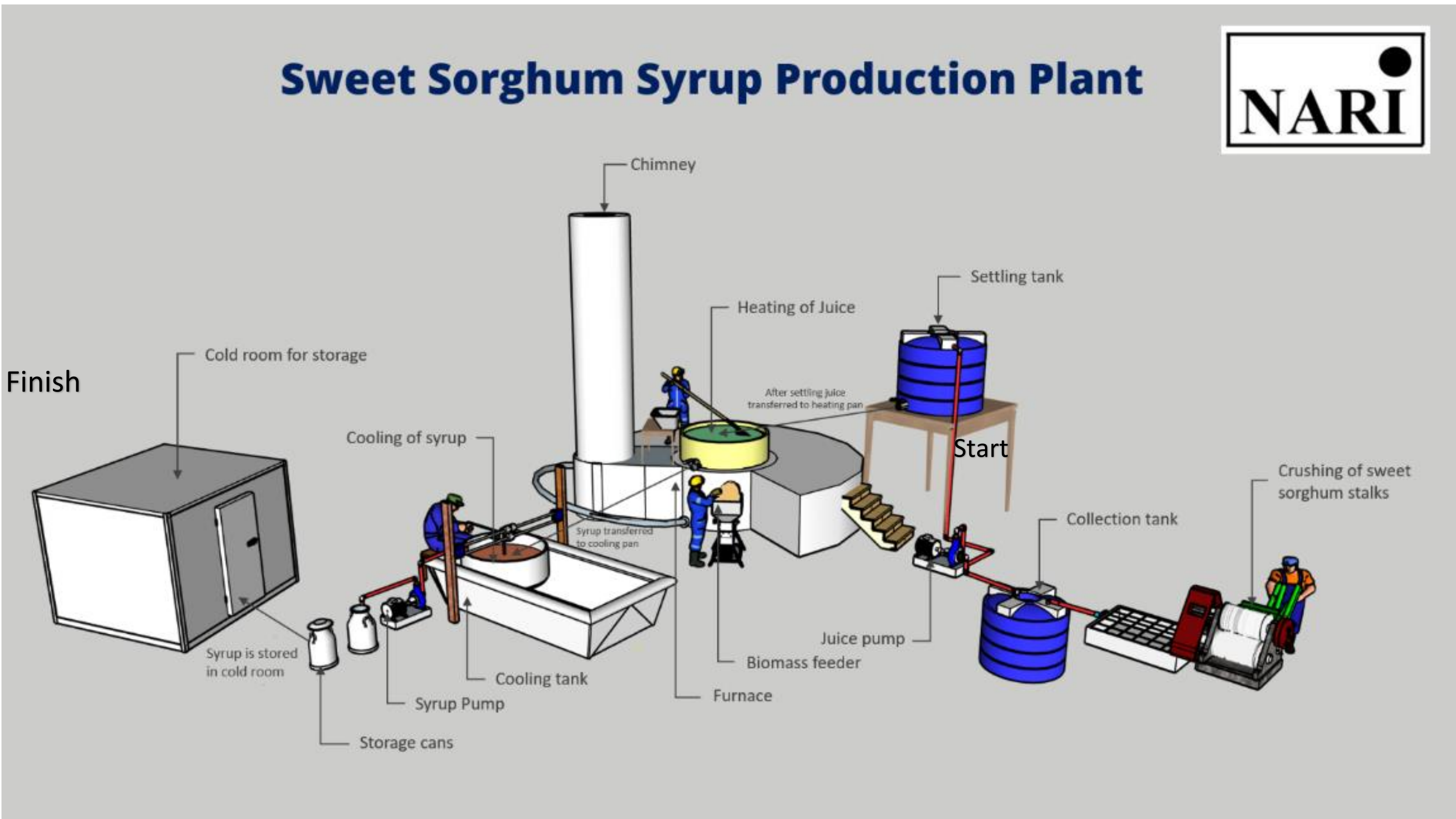


Figure 1: A drawing of NARI SS syrup production plant.

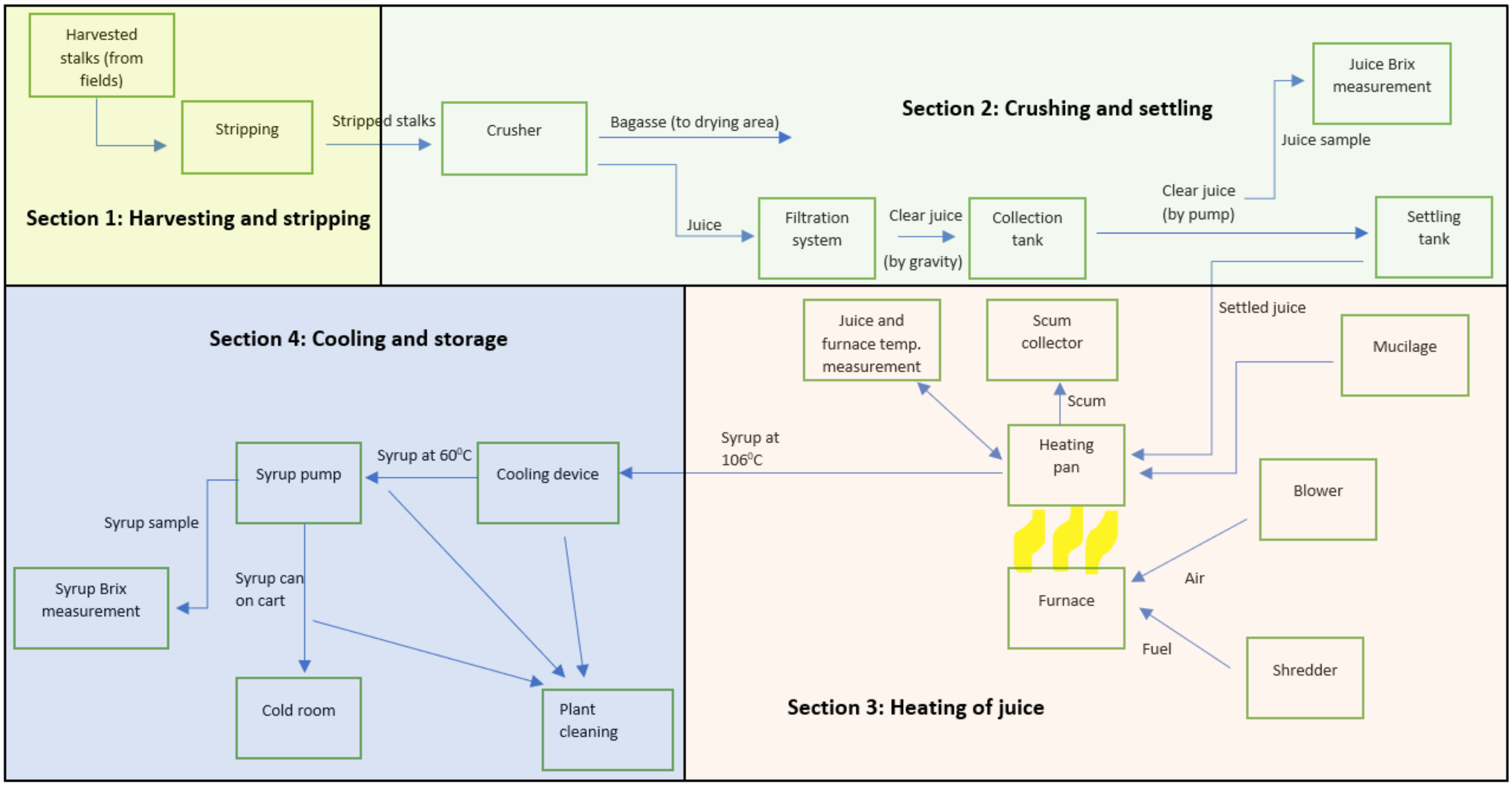


Figure 2: A process flow-diagram of the SS syrup plant at NARI.

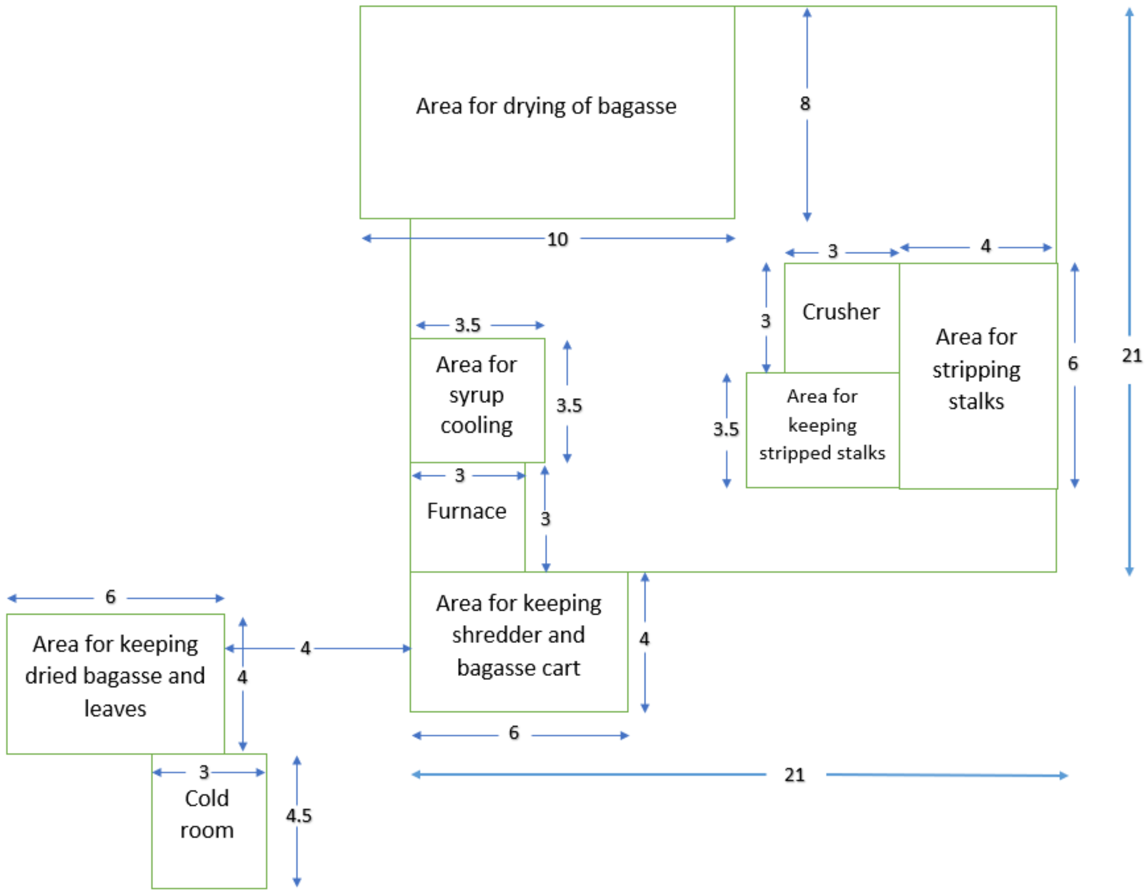


Figure 3: Actual layout of the NARI SS syrup plant. All dimensions are in meters.

A summary of this project follows below.

3.2 Summary of the project

The important aspects of this project are presented concisely in this section. Summary of the work done is presented in Table 2. Important statistics of the project are presented in Table 3. Manpower requirement of the developed plant for production of 50 kg syrup is presented in Table 4. Equipment requirement of the developed plant is presented in Table 5.

Table 2: Summary of work done in the project.

Work	Key impact/result
Section: harvesting and stripping of stalks	
Collected Brix data for whole project duration	Determined optimum sowing/harvesting times
Adopted contractual stripping	Reduction of stripping time by half
Developed preliminary stripping machines	Did not yield expected results, needs more R&D in future
Assessed effect of leaf sheath and pest damage on syrup quality	Could ease/do away with stripping of stalks
Devised new method of pest damage detection	Easier, faster damage detection; but less crushing efficiency
Section: crushing of stalks and settling of juice	
Installed new three-roller crusher	Improvement in crushing efficiency from 30% to 50% and rate by six-fold
Modified wet bagasse collection and spreading process	Reduction in people required from 4 to 1, easier handling
Fabricated juice filtration assembly, improved during project	Reduction in scum by 40%, clear syrup, obviation of filter choking
Installed new settling and storage tanks	Easy juice handling
Installed juice transport system	No juice loss due to manual handling
Experimented on effect of settling and its duration on syrup quality	Less scum production during heating
Determined optimum okra mucilage preparation methodology, mechanized it	Enhancement in scum removed and syrup clarity, reduction in time and effort, standardization of mucilage quality

Measured starch in juice, syrup and scum of different SS varieties	Found that starch is less than that in US varieties, so less settling required
Section: heating of juice	
Constructed new furnace	Reduced loss of flue gases, enhanced efficiency; reduction in scum removal effort and people required (from 4 to 1)
Determined optimum furnace design parameters	Enhancement in furnace efficiency
Fabricated a SS304 heating pan	Effective heating, easy handling, food-grade standard
Designed pan lifting and tilting mechanism	Quick and safe operation, reduction in people required (from 4 to 1)
Designed a biomass shredder cum feeder cum air blower	Convenient and uniform feeding of fuel
Determined optimum biomass feeding strategy (continuous feeding rather than batchwise)	Enhancement in fuel efficiency and heating rate, reduced smoke
Fabricated fuel feeding cart	Convenient loose fuel handling and feeding
Designed air-inlet manifold, made modifications in air blower, determined optimum air-flow rate	Enhancement in combustion efficiency, reduced backpressure, safe working conditions
Added obstruction at chimney inlet	Enhancement in efficiency and heating rate, but increase in backpressure
Fabricated scum collector, improved its design; fabricated big scum removing ladles	Reduction in juice loss and people required (from 3 to 1), convenient scum removal
Made design modifications to prevent ash particles from going into juice while heating	Clear syrup
Correlated syrup end-point with its temperature	Objective and easy determination of syrup end-point
Installed digital temperature recorders, explored many temperature sensors for determining syrup end-point	Uniformity in syrup quality, prevention of burning/caramelization
Section: cooling and storage of syrup	
Developed a semi-mechanical cooling mechanism	Better syrup appearance and flowability
Determined viable storage conditions (temperature, air-flow, humidity)	Longer syrup shelf-life

Developed correlation curves between various syrup parameters	Objective evaluation of syrup quality
Installed syrup pump	Safe and convenient syrup transfer to storage can
Installed cleaning pump	Reduction in cleaning effort, saving of water
Installed cold room	Sanitary and controlled syrup storage conditions
Fabricated trolleys for syrup-can transport to cold room	Reduction in manpower (3 to 1 person), more convenient
Carried out floor and shed work of plant	Sanitary work conditions
Section: popularization and dissemination of technology	
Made syrup-making module in English, Hindi & Marathi	Easy for rural farmers to prepare syrup in a correct manner
Demonstrated to farmers syrup-making process	Got farmers interested in planting SS and producing syrup from it
Installed syrup banner in front of the institute	Dissemination of knowledge about SS syrup
Put up stall during annual pilgrimage to Pandharpur in front of the institute	-do-
Carried out cost-benefit analysis of SS syrup production	Justification for producing SS syrup
Did sugarcane v/s SS comparative analysis	-do-
Performed energy consumption analysis	Helps in strategy making

Table 3: Important statistics (Sep 2020 - Aug 2022).

Number of water-boiling tests	60
Number of full-scale syrup-making sessions	20
Syrup produced in full-scale syrup-making sessions	1,211 kg
Total syrup sold	2,220 kg

Table 4: Manpower required for production of 50 kg syrup.

Activity	**Typical number of labourers required**	**Number of hours per labourer**	**Total labour-hours**
Section: harvesting and stripping			
Harvesting, transporting and weighing of biomass	4	4	16
Stripping of stalks	10	8	80
Section: crushing and settling			
Crushing of stalks	4	1	4
Wet bagasse spreading	2	0.25	0.5
Transferring dried bagasse to shed	2	1	2
Mucilage preparation	2	0.25	0.5
Washing of crusher and filtration assembly	1	0.25	0.25
Section: heating			
Collection of 200 kg bagasse in fuel carts	2	0.5	1
Feeding of fuel	1	3.5	3.5
Scum removal	1	3	3
Shifting and tilting of pan for syrup transfer	2	0.1	0.2
Section: cooling and storage			
Cooling of syrup	1	0.1	0.1
Syrup transfer to can	2	0.1	0.2
Can transfer to cold room	2	0.05	0.1

Pressure washing of utensils, equipment and plant	2	0.25	0.5

Table 5: Equipment used in the plant.

Equipment	Power consumption	What it does	Running time (for production of 50 kg syrup)
Section: crushing and settling			
Digital refractometer (also used to measure syrup Brix)	3V DC power	Measures juice Brix	5 mins
Crusher	7.5 hp	Crushes SS stalks to give juice / crushes okra for mucilage preparation	1 hour
Centrifugal pump	1 hp	Pumps juice from collection tank to settling tank	6 mins
Section: heating			
Shredder	3 hp	Shreds and feeds bagasse and leaves mechanically to furnace, provides secondary air for combustion of volatiles	3.5 hours
Air blower	1 hp	Provides air for combustion of fuel	3.5 hours

Digital temperature scanner	10 W	Measures temperature of syrup, chimney inlet and chimney outlet	4 hours
Section: cooling and storage			
Syrup pump	2 hp	Pumps syrup from cooling pan to storage container	1 min
Cold room	0.75 hp	Keeps syrup at 20^0C for long shelf-life	Automatic switch; runs for about 2 mins in every 10 mins (5 hours each day)
Cleaning pump	1 hp	Pressure-washes utensils	15 mins

Table 6: Specifications of the developed plant.

Capital cost (excluding land cost)	11.5 lakh rupees
Land required to set up plant	300 m^2 (3 ares)
Total energy required for production of 50 kg syrup	3,330 MJ
Time required for production of 50 kg syrup (from crushing of stalks to storing of syrup)	8 hours
Number of people required to run the plant	4
Furnace capacity	300 kW

Summary of the work done under each section is now presented.

3.3 Work done

3.3.1 Harvesting and stripping

1. **Brix data collection**: Yearlong data of Brix content (Brix is an indication of the total sugar content) of the SS juice across different varieties, plots and seasons was collected. Using this data, the optimum sowing and harvesting periods of the SS crop were ascertained (details in Section 5.1.1).
2. **Optimizing of the manual stripping process**: Of all the sub-processes, stripping of leaves and sheath from the stalk is the most time-consuming. This removal is done for two reasons: (a) it helps in improving the quality of syrup, and (b) it helps in detection and removal of pest-damaged portions. Several approaches of labour-saving were tried, and it was found out that contractual payment expedites the stripping process by about two times in comparison to the traditional method (traditional method: 7.2 kg/hour/labourer; contractual stripping: 13.6 kg/hour/labourer). This is simpler than developing a stripping machine (number of experiments: 30; details in Section 5.1.2).
3. **Development of stripping machines**: Although mechanization of stripping was not a part of this project, it was still attempted to build simple machines which could at least partially automate the stripping process. Two preliminary stripping machines were developed. The first machine was table-fixed, while the second was handheld. Although marginal improvements were seen with respect to both time and convenience, the amount of time and effort needed to develop a simple yet effective stripping device was deemed excessive. The practice of manual stripping has thus been continued at NARI (number of experiments: 9; details in Section 5.1.3).
4. **Determination of effect of leaf sheath on syrup characteristics**: Experiments were conducted on the effect of leaf sheath on the syrup characteristics. Data showed that sheath does not affect the syrup taste at all, and syrup's clarity is only slightly reduced. However, it adds a brownish hue to the syrup colour. However, more work needs to be done to ascertain short- and long-term effects of sheath on the syrup quality, across all seasons (number of experiments: 8; details in Section 5.1.4).
5. **Determination of effect of damage on syrup characteristics**: The process of damage detection is cumbersome and time-consuming. Experiments indicated that up to 10% damaged stalks (by weight of biomass), if crushed along with the good stalks, do not affect the syrup quality. These findings indicate that damage removal may be skipped in seasons of low damage (number of experiments: 6; details in Section 5.1.5).
6. **Development of a new method for damage detection**: A quicker and more convenient method of damage detection which does not require leaf sheath removal and involves cutting of stalk into smaller pieces was devised. With this method, the damage detection time reduced by about 20%; however, the juice crushing efficiency dipped severely leading to about 70 kg juice loss, or equivalently, about 14 kg syrup loss, in one large scale syrup preparation session. As a result, this method was not pursued further (number of experiments: 8; details in Section 5.1.4).

3.3.2 Crushing and settling

1. **Installation of a new crusher**: A new crusher with three rollers was purchased and installed on a custom-made cement foundation (Figure 4). As a result, for one pass the crushing efficiency improved from about 30% (in the old crusher) to about 50%, and the crushing rate increased six-fold. This has greatly reduced the time and the effort and increased the juice recovery by about 66%, which translates to about 20 kg extra syrup per batch (details in Section 5.2.1).

Figure 4: New three-roller crusher. Left: back view; right: side view.

2. **Modification of wet bagasse collection and spreading process:** Earlier, the bagasse from the crusher outlet was collected in small tarpaulin sheets with holding capacity of 10-15 kg wet bagasse. This was laborious and inconvenient. To solve this issue, it was decided to
(a) modify crusher outlet port's height and use two carts available in-house (with holding capacity of about 65 kg wet bagasse each) for bagasse collection, and
(b) shift bagasse spreading area closer to crusher outlet.
The results of these changes are listed in Table 7. A total of three experiments were performed before finalizing this method; details are presented in Section 5.2.2.

Table 7: Effect of new bagasse collection and spreading system.

Parameter	Earlier	Now
Labourers required	4	1
Number of trips required for spreading	50 (25 per pair)	10
Distance per trip (one way)	30-40 m	5-15 m
Crusher outlet area cleanliness	Slightly unclean	Clean

3. **Fabrication of a juice filtration assembly**: A new juice filtration unit consisting of four filters was assembled after determining optimum filter sizes through experiments (Figure 5). The frames were fabricated in-house. All the filters are made of food-grade stainless steel. With the new filtration assembly, the amount of scum that is later recovered during heating has reduced by about 40% on an average. Later, the finest mesh (~100 microns) in the assembly was shifted from crusher outlet to juice pan to prevent frequent clogging of the assembly (details in Section 5.2.3).

Figure 5: Filtration assembly.

4. **Installation of new collection and settling tanks**: New capacious tanks made of food-grade plastic with capacities of 300 litres and 500 litres, respectively, were purchased for collection and settling of juice (Figure 6) (details in Section 5.2.4).

Figure 6: New collection tank (left) and settling tank (right). Figures not to scale.

5. **<u>Installation of pipes</u>**: Food-grade PVC pipes were installed to transport juice from the crusher to the collection tank and then to the settling tank. This saves about 2-3% juice (i.e., about 6 to 9 litres of juice per batch) which was otherwise lost previously due to manual handling (details in Section 5.2.4).
6. **<u>Determination of effect of settling on syrup characteristics</u>**: It is important to keep the juice still for some time to settle the heavier impurities, especially starch, which in turn reduces scum formation and gives a clearer syrup. By doing both lab and pilot scale experiments, it was determined that a minimum of 1.5 hours of settling is required for optimum results (number of experiments: 10; details in Section 5.2.5).
7. **<u>Determination of mucilage preparation methodology</u>**: Addition of mucilage to the juice facilitates scum formation and removal. Various parameters affecting the mucilage efficacy such as part of okra plant (stem, fruit), type of okra stem/fruit (dried, fresh, powdered), concentration of okra in water, soaking time, proportion of mucilage to be added at different stages of heating etc. were optimized through extensive experimentation. For example, it was observed that mucilage prepared with 1.5% fresh okra fruit (by SS juice weight), soaked in water three times its weight, gives the best results. After finalizing these relative weights, the process of mucilage preparation was mechanized for standardization of mucilage quality and enhancement in convenience (number of experiments: 12; details in Section 5.2.6).
8. **<u>Starch measurement of juice, syrup and scum of different SS varieties:</u>** The extent of sedimentation in the settling process is proportional to the starch content in the juice. In the SS varieties in the US, the starch content is high (about 3700 ppm on average). As a result, typically, more than four hours of settling is required there. Starch content of three varieties grown at NARI was measured and found to be lower than that in the US varieties: e.g., starch content of Madhura-3 juice was found to be about 2600 ppm on average. This justifies the practice of settling

the juice for comparatively shorter time here (number of experiments: 16; details in Section 5.2.7).

3.3.3 Heating

1. **Fabrication of a scum collector and bigger scum removal ladles**: To make the process of scum removal convenient and avoid wastage of juice, it was decided to fabricate a container with provision to filter out scum and drain clear juice back into the pan. Through experiments, a mesh of size 160 holes/inch (~100 microns) was found to be optimum to effectively filter scum. The scum collection container has, in addition to enhancing convenience, led to production of about 4% more syrup for the same amount of juice taken in the pan. To further enhance convenience in scum removal, two bigger scum removal ladles were fabricated. Each ladle spans 156 cm in length, has a bowl diameter of 30 cm and weighs about 1.4 kg, easy for labourers to lift even when full of scum. The ladle is fitted with a 250-micron mesh. It is shown in Figure 7 (number of experiments: 3; details in Section 5.3.1).

Figure 7: Bigger scum removal ladle. Top: close-up view; bottom: while in operation.

2. **Fabrication of a heating pan**: A heating pan with a capacity of 700 litres (to handle 300 litres of juice) and made of food-grade stainless steel was fabricated (details in Section 5.3.2).

3. **Designing and installation of a pan-lifting mechanism**: It is important to stop the heating as soon as the syrup temperature reaches 106 ^{0}C (this temperature was determined by performing experiments; lower and higher temperatures may lead to watery and burnt/caramelized syrups, respectively). A block-and-tackle mechanism was designed and installed for quick, safe and completely mechanical lifting and tilting of the evaporation pan (Figure 8) (number of experiments: 3; details in Section 5.3.2.5).

Figure 8: Block-and-tackle mechanism for lifting evaporation pan.

4. **Designing of a biomass-shredder cum feeder cum air-blower**: A bagasse shredder cum feeder cum air-blower with a capacity for shredding about 150 kg biomass per hour was designed in-house (Figure 9). The shredder has greatly reduced the effort of fuel feeding, which was done manually previously. Moreover, it also distributes the fuel evenly in the furnace, leading to more efficient combustion. It also supplies air at 125 kg/hr for combustion of volatiles, obviating the need for a secondary air inlet that was used earlier (number of experiments: 6; details in Section 5.3.3).

Figure 9: Shredder cum feeder cum air-blower designed in-house.

5. **Correlation of syrup end-point with syrup temperature:** As written above, it is important that syrup heating be stopped at the correct time to prevent the syrup becoming either excessively

thin or viscous. In earlier work at NARI, it was determined that heating of syrup should be stopped when its sugar content reaches 74^0 Brix for good flowability, colour and shelf-life. Since instantaneous Brix measurement is extremely difficult in comparison to measuring temperature, it was decided to correlate syrup Brix with its temperature. It was seen that a nearly one to one correlation exists, and 74^0 Brix corresponds to about 106^0C. Thus, syrup end-point criterion was fixed to 106^0C syrup temperature (number of experiments: 20; details in Section 5.3.4).

6. **Installation of digital temperature recorders and search for temperature sensors**: An 8-channel digital scanner for accurate temperature measurements was installed. Using it, the optimum temperatures at different stages of the heating process have been determined. This is crucial for obtaining syrup with consistent characteristics. For example, a variation of merely 1^0C in the temperature at which the heating is stopped could change the syrup Brix by up to 5 degrees. The scanner also has provision of alarms to sound when the critical temperature is reached. Finally, for accurate temperature measurement of syrup, many different temperature sensors were tried and PT100 sensor was found to be the best among all with regard to accuracy, stability and robustness (number of experiments: 5; details in Section 5.3.4).
7. **Determination of optimum furnace design parameters and construction of new furnace**: One of the most important objectives of this project is to design a self-sufficient furnace, i.e., the bagasse from the biomass should be able to provide sufficient heat to the furnace, and at the required rate. To that end, several modifications in the existing furnace at NARI were made and the optimum values of the following parameters were determined: (a) type of fuel, (b) fuel-feeding rate, (c) air-flow rate, (d) chimney-inlet obstacle height, and (e) furnace height. After finalizing these parameters, a new furnace with these attributes was constructed (number of experiments: 65; details in Sections 5.3.5 and 5.3.7).
8. **Determination of optimum bagasse-feeding strategy**: Earlier in this project, bagasse feeding was done batchwise: 30 kg bagasse was fed at once, every 30 minutes (1 kg /min). This was found to be difficult and inefficient because the bagasse piled up in front of the feeding port and the shredder chute choked frequently. To address this, smaller batch sizes were tried: 6 and 10 kg per batch, respectively. While the average heating rate remained the same, the issues of fuel piling, shredder choking, backpressure and excessive smoke were significantly reduced. It was then decided to feed the bagasse continuously. There were several notable improvements with continuous feeding: (a) the heating rate improved from about 2.15^0C/min to about 3^0C/min (improvement of 40%), (b) backpressure reduced significantly resulting in seamless and convenient operation, (c) furnace efficiency improved, and (d) smoke was cleaner. Finally, the option of shredding bagasse immediately after crushing was also explored, but discontinued because of economic considerations (number of experiments: 5; details in Section 5.3.5.3).
9. **Fabrication of fuel-feeding cart**: To ease the process of continuous fuel feeding, a fuel-feeding cart was fabricated. The cart was designed to hold about 80 kg dry bagasse and its height was chosen so that bagasse could be raked out directly onto the conveyor belt of the shredder. It has significantly reduced the effort required in continuous feeding of bagasse with long pieces in the small-scale water boiling tests since all the bagasse can be filled at once in the cart and easily raked out (Section 5.3.5.3).

10. **Modification in furnace design to increase obstruction to flue gas passage**: To improve the furnace efficiency, the resistance faced by the flue gases in traveling outwards through the chimney was increased so that they give out more heat before escaping. Two methods of doing this were devised: (a) placing an obstacle in front of the chimney inlet, and (b) increasing the obstruction in the chimney. These options were tried independently, as well as in combination. Many designs were tried and tested, and finally an optimum design was arrived at.
It was found that placing a semi-circular obstacle in front of a bigger (by 25% than the previous one in area) chimney gave optimum performance on all four criteria of (a) heating rate, (b) furnace efficiency, (c) convenience and (d) cleanliness of combustion. These four parameters were combined into a single parameter, denoted as *p*, which varies from 0 to 1 as the furnace performance improves. Variation of *p* with time (as many designs were tried and tested) is shown in Figure 10 (number of experiments: 13; details in Section 5.3.5.3).

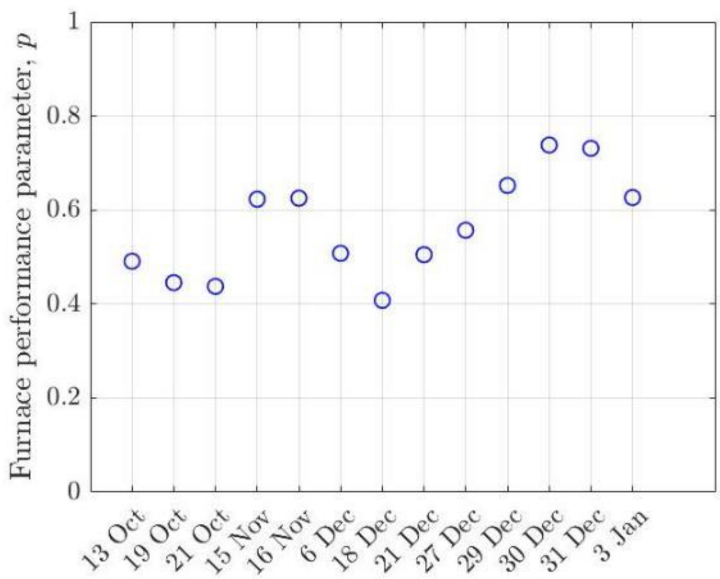


Figure 10: Variation in non-dimensional furnace parameter p with time.

11. **Design modifications for preventing ash particles from going into juice:** Since bagasse and leaves are loose, they go into the juice sometimes during heating, especially when it is windy. Some ash particles also enter the juice through furnace feed-port and chimney. To address this, two modifications were made: (a) a table fan was installed to blow the loose particles away from the juice, and (b) a horizontal sheet was installed over the furnace feed-port. Experiments done towards reducing backpressure also reduced ash particles coming out of the feed-port and entering the juice. Finally, syrup is also filtered while transferring it from the heating pan to cooling pan through a 100-micron mesh to filter out any ash particles and other impurities (number of experiments: 3; details in Section 5.3.7.2).
12. **Designing of an air-inlet manifold and modifications in air-blower design:** Sufficient air access inside furnace is essential for proper combustion. The air-inlet design underwent several changes during this project. The first design involved a primary air-inlet disc at the bottom of the

furnace (throwing air vertically upwards) and a secondary disc at furnace wall (throwing air horizontally). The secondary air-inlet disc was then replaced by a circular ring. Then, the primary air-inlet disc was made bigger so as to cover almost 60% of furnace area (it was 25% earlier), and the secondary ring was removed. Experiments were done at each design stage to determine the optimum air-flow rate. Also, modifications in blower design were done to avoid backflow of flue gases and buckling of connection pipe by attaching a non-return flap and MS pipe, respectively (number of experiments: 10; details in Section 5.3.6).

Overall, the four most important targets of developing a furnace which

(a) is fuel self-sufficient,

(b) provides the required heating rate (so that heating finishes in less than four hours),

(c) is standardized and convenient, and

(d) provides clean combustion,

have been duly achieved.

3.3.4 Cooling and storage

1. **<u>Determination of dominant mode of syrup cooling</u>**: Using a preliminary syrup-cooling device, the relative cooling rates of the following heat transfer mechanisms were determined: (a) conduction through water, (b) natural convection from air, and (c) forced convection from air. The results indicated that conduction through water is the most dominant heat transfer mechanism. The cooling device discussed next was fabricated using this insight (number of experiments: 3; details in Section 5.4.1).
2. **<u>Development of a semi-mechanical cooling system</u>**: A semi-mechanical cooling device consisting of four stainless-steel flaps was fabricated (Figure 11). The flap assembly is connected to a handle, and rotating the latter manually causes vigorous stirring in the syrup leading to faster cooling. The device has reduced the cooling time of 50 kg syrup from about 15 minutes to seven and a half minutes. Moreover, only one person is required to cool the syrup now (whereas two were required earlier) (number of experiments: 7; details in Section 5.4.2).

Figure 11: Semi-mechanical cooling device. Left: while not in operation; right: during syrup-making session.

3. **<u>Determination of optimum conditions for syrup storage</u>**: Experiments were performed to determine the conditions that prolong the shelf-life of the syrup. It was seen that exposure to air reduces shelf-life drastically, whereupon airtight storage containers were purchased (number of experiments: 7; details in Section 5.4.3).
4. **<u>Development of correlation curves between syrup characteristics</u>**: For objective evaluation of syrup quality, two correlation curves were developed: (a) syrup flow versus syrup Brix, and (b) syrup clarity versus light transmittance. One-to-one correlation curves were obtained (number of experiments: 14; details in Sections 5.4.4 and 5.4.5).
5. **<u>Installation of syrup pump, cleaning pump and cold room:</u>** A 2-hp syrup pump with flow rate of about 2 kg syrup/sec was installed to transfer syrup from cooling pan to storage can. A 1-hp pump was installed to clean equipment with the water left in the cooling tank. This served three purposes: (a) saving of water, (b) convenient cleaning of equipment, and (c) saving of time. A half-ton cold room was also installed to store syrup cans for longer shelf-life and convenient storage (details in Section 5.4.6).
6. **<u>Fabrication of trolleys and construction of pathway to carry syrup cans:</u>** Filled syrup cans can weigh up to about 75 kg after large scale syrup preparation. Carrying them to storage area was a laborious and time-consuming process. To this end, the following work was carried out: (a) carts for keeping filled syrup cans were fabricated, (b) ramps were made, and (c) a concrete pathway was made. The last two were done to ensure a continuous path allowing for easy movement of the cart between syrup plant and cold room. With the new arrangement, a single person can easily transport the can/s without needing any lifting (details in Section 5.4.6).
7. **<u>Floor and shed work</u>**: Floor and shed work of the pilot plant at NARI was carried out (details in Section 5.4.7).

3.3.5 Popularization and dissemination of technology

1. **<u>Preparation of syrup manual:</u>** A manual detailing the procedure to be followed for syrup preparation was made in Marathi and English. Care was taken to ensure that the manual instructions were easy to understand and follow, without compromising on technical rigour. The non-technical team at NARI prepared syrup by following the manual to good effect.
2. **<u>Economic analysis of SS syrup production:</u>** A detailed economic analysis considering the following two scenarios of syrup production was performed: (a) farmer grows SS and gives it to a syrup production unit, and (b) farmer grows SS and produces syrup in his own plant. It was seen that in both the scenarios, farmers can earn **three to six times** the profit earned by growing sugarcane, presenting a strong case for the relevance of this work (details in Section 5.5.1).
3. **<u>Energy consumption analysis of the pilot plant</u>**: A detailed analysis of the energy requirements for the SS pilot plant (that produces 50 kg/batch SS syrup) was carried out. The analysis reveals that most (about 97%) of the energy is expended in the heating process (details in Section 5.5.2).
4. **<u>Demonstration of syrup-making process to farmers:</u>** Several farmers were invited to our syrup-making sessions and given a tour of the plant. These visits and the accompanying question-answer sessions were documented (details in Section 5.5.3).

Figure 12: Demonstration of plant-working to farmers.

5. **<u>Putting up of banner and stall at *Millet Jatra* and NARI main-gate:</u>** A banner was put up in front of the institute main building (on the Lonand-Phaltan highway) to advertise the SS syrup. A stall was put up at *Millet Jatra,* an exhibition to build awareness on millets, in Koregaon Park, Pune (Figure 13). A stall was also put up in front of the main building during the annual pilgrimage to Pandharpur to disseminate knowledge about SS syrup (details in Section 5.5.4).

Figure 13: Stall put up by NARI at 'Millet Jatra'.

3.4 Conclusions

3.4.1 Remarks

The work done in this project has resulted in a semi-mechanized SS syrup plant with continuous and well-integrated subprocesses. The production capacity of the plant is 50 kg syrup per 8 hours. Many processes that were previously carried out manually have been mechanized. Moreover, many existing processes have been kept as is, but their parameters have been optimized for maximum efficiency. Finally, detailed economic analysis has been performed and steps have been taken to disseminate this technology among rural populace.

This technology is now ready to be taken up for implementation, and future work should focus on its dissemination. It is believed that the newly emerging start-up ecosystem in the country could play a potentially huge role towards that. All the technical know-how of the SS syrup plant as developed in this project including detailed drawings, designs, etc will be provided to start-ups interested in marketing this technology. Moreover, efforts towards reaching out to companies interested in selling SS syrup or using it as raw material for other confectionaries will be continued. A couple of such companies have purchased a total of **2060 kg** SS syrup from NARI since this project started (September 2020) which is a testament to the existence of a burgeoning market for natural sweeteners like the SS syrup.

3.4.2 Major achievements

The major achievements of this project are listed below:

- **Reduction in labour and time:** Many of the processes that were tedious and labour-intensive have been made convenient. Maximum number of labourers required at a given time is **four** (during the crushing operation). The following table summarizes the items where labour has been reduced significantly.

Table 8: Reduction in labour achieved during the project. In the notation A x B, A represents the number of labourers and B represents the average time (in hours) taken by each labourer.

Activity	Labour-hours before	Labour-hours now
Stripping of stalks	170 (10 x 17)	90 (10 x 9)
Feeding of stalks in crusher	10 (2 x 5)	4 (4 x 1)
Wet bagasse collection	10 (2 x 5)	1 (1 x 1)
Mucilage preparation	1 (2 x 0.5)	0.5 (2 x 0.25)
Heating of juice	30 (6 x 5)	12 (3 x 4)

Shifting and tilting of pan for syrup transfer	1 (5 x 0.2)	0.2 (2 x 0.1)
Cooling of syrup to 60^{0}C	0.5 (2 x 0.25)	0.1 (1 x 0.1)
Transferring syrup from cooling pan to storage room	2 (4 x 0.5)	0.2 (2 x 0.1)
Preliminary cleaning of utensils, equipment and plant	1 (2 x 0.5)	0.15 (1 x 0.15)

- **Standardization of processes:** A list of activities standardized during this project are listed in Table 9. It has been observed that the syrup quality obtained now is uniformly good across batches.

Table 9: Processes that have been standardized.

Process standardized	Methodology
Juice filtration	Determining optimum filter sizes and sequence
Mucilage preparation	Determining water quantity to be added; mechanization of crushing okra fruit
Mucilage addition	Determining optimum mucilage addition points (in time) and its concentration
Juice settling	Determination of optimum settling time
Heating of juice	Determination of optimum furnace parameters
Scum removal	Determination of optimum filter mesh sizes of ladles and scum storage container
Heating endpoint determination	Developing temperature-based criterion
Syrup storage	Determining optimum storage conditions

- **Improvement in hygiene:** There is no direct human contact with the juice or the syrup at any stage in the process of syrup-making. Only during the second stage of mucilage preparation, the filter pouch containing crushed okra fruits is squished with hands. Overall hygiene of the plant has also substantially improved due to steps like bagasse collection through carts, juice and syrup transport through pumps and pipes, pressure-washing etc.

- **Improvement in safety:** Earlier, processes like lifting of pan at heating endpoint, feeding of fuel in furnace, carrying of hot syrup can to cold-room etc were carried out manually, posing a threat to safety. All such processes have been made extremely safe and convenient through partial mechanization.
- **Reduction in losses:** For the same amount of biomass, about 8% more syrup is obtained now due to introduction of pumps, connecting pipes and scum collector.
- **Development of a clean multifuel-fired furnace:** A good outcome of this project has been the development of a multifuel-fired furnace of about 300 kW capacity which provides clean combustion (Figure 14) and good heating rate for fuels of widely varying densities (Figure 15).

Figure 14: View of the chimney during a syrup-making session. The outgoing smoke through the chimney is transparent, indicating clean combustion.

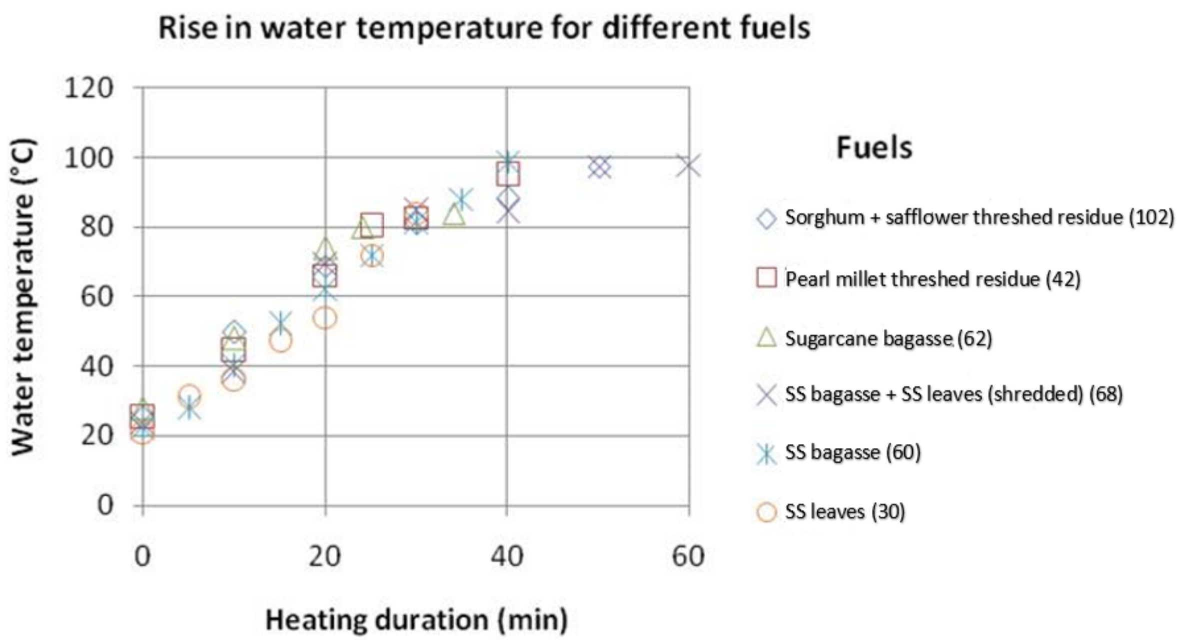


Figure 15: Rise in temperature of 300 kg water with fuels of different densities. The densities (in kg/m^3) are given in brackets.

3.4.3 Economics of sweet sorghum syrup production

Analysis reveals that a farmer can earn **three to six times more** by growing SS in comparison to sugarcane; the corresponding annual turnover of the unit is **25 to 40 lakh rupees**. If the farmer produces syrup in his own syrup unit, then he can earn up to **six-times more** as compared to a sugarcane farmer.

Table 10: Highlights of economic analysis; all comparisons are with profits of a typical sugarcane farmer in Phaltan region.

Scenario 1: farmer grows SS and gives it to a syrup production unit	**Scenario 2: farmer grows SS and produces syrup in his own plant**
For biomass selling price the same as sugarcane (Rs. 2,500/tonne), farmer can earn up to 33% more profit	Assuming the same biomass yield and syrup selling price at NARI, profit for a SS farmer is six times more
For biomass selling price of Rs. 5,000/tonne, farmer can earn thrice more, with syrup unit's annual profit being about Rs. 40 lakhs	
If farmer sows from February to April, he can earn about Rs. 2.4 lakhs per acre-year (compared to about Rs. 75,000 per acre-year from sugarcane)	

3.5 Future work

There are many possibilities which could not be explored further in this project due to lack of time (presented in Table 11), and offer scope for future work both scientifically and economically relevant.

Table 11: Scope for future work.

Section: harvesting and stripping
• Improve designs of stripping machines developed during this project.
• Find out long term effects of incorporating leaf sheath and pest-damaged stalks on syrup quality.
• Improve crushing efficiency of shorter stalk pieces.
• Devise methods of damage detection which obviate the need to remove leaf sheath.
Section: crushing and settling
• Develop an objective but simple technique for uniform feeding of stalks at a rate which gives high crushing efficiency and smooth operation.
• Develop crushers more suitable for SS stalks; in particular, stalk feed-rate window for high crushing efficiency with smooth operation should be broad.
• Develop simple and affordable machines for bagasse transport. Conveyor machines and vacuum pumps are two potential ideas.
• Develop an objective criterion to recover as much clear juice from the settling tank as possible.
• Explore different shapes for settling tank to enhance settling rate.
Section: heating
• Survey market for a more robust and user-friendly temperature-recording device.
• Design a simple and affordable pan-sealing mechanism to further enhance furnace efficiency.
• Develop compact furnaces of heat output of about 70 kW which could be transported easily.
Section: cooling and storage
• Explore options for transferring the syrup from heating pan to cold room directly.

• Explore organic preservatives suitable for SS syrup to increase its shelf-life.
• Use the correlation curve between syrup Brix and its flowability to develop a quicker method for heating endpoint determination.
• Obtain correlation curves (discussed above) for other SS varieties and across different seasons.
Section: popularization and dissemination of technology
• More variables should be considered for a more comprehensive economic analysis.
• Data from different regions should be taken to calculate region-specific profits.
• Start-ups making jaggery- and millet-based food products should be encouraged to try SS syrup as an alternative.

4 Introduction

4.1 Background

Sweet sorghum (SS) was introduced in India in the early 1970s by the Nimbkar Agricultural Research Institute (NARI) by bringing cultivars from various breeding stations in the US. They were then crossed with Indian grain sorghum varieties. The NARI hybrids and varieties contain maximum sugars in the stalk juice at grain maturity. The Brix and purity in the juice of some of these varieties nearly approach those of sugarcane (Rajvanshi & Nimbkar, 2001).

Initially, a complete technology of ethanol production from SS was developed by NARI in the late 1980s (Rajvanshi & Nimbkar, 2001). The ethanol produced was used in specially designed lighting and cooking devices such as lanterns and stoves. However, this ethanol was costly and there were no buyers for it since national policy on biofuels had not been formulated.

Realizing the importance of food over fuel, NARI has since focused its efforts on producing syrup from SS, and today it is the only organization in India producing and selling SS syrup. In the past, NARI had mostly used its hybrid Madhura-1 for syrup production. Recently two new varieties Madhura-2 and Madhura-3 have been successfully used for syrup-making.

A small pilot plant producing syrup from SS has been running for the last two decades at the NARI campus and more than 5 tons of syrup has been sold in bulk till today. This has helped in creating a market for SS syrup in India.

Currently, Indian farmers cultivate SS mostly for fodder and hence its total cultivated area is limited. But, since it is a multi-purpose crop which could be used to make syrup (yielding higher returns), SS has a high potential to replace grain sorghum which is widely grown. The raw produce from the farms of small/marginal farmers yields negligible returns, often not even covering their cultivation costs. But it is a known fact that processed food fetches much higher returns than raw food. The aim is to enable farmers to produce syrup from their own SS crop, which they can directly sell to the big corporations or in the market. To that end, a partially mechanized plant for producing 50 kg syrup in 8 hours has been designed.

4.2 A note on partial (and not full) mechanization

Mechanization of SS syrup-making process is sought for the following reasons:

(a) The process of SS syrup making is derived largely from that of jaggery-making. The traditional jaggery-making units in the country use age-old technologies that are largely human-centric. As a result, the quality of produce (even in the same unit) varies significantly across different jaggery making sessions. The same was observed with SS syrup production at NARI. It is thus deemed necessary to (i) quantify process parameters to minimize subjectivity and scope for human errors, (ii) optimize these parameters, and (iii) mechanize processes to the extent possible to ensure repeatability. The primary objective of mechanization is to standardize quality of syrup across different syrup-producing units and seasons.

(b) Since the earlier procedure was derived from the traditional jaggery-making process, it was laborious and inefficient, and at times hazardous. Mechanization was sought to make the syrup-making process convenient, energy-efficient and safe.

(c) Finally, obviation of human touch ensures hygiene.

However, it was realized during the course of the project that developing a 'fully' mechanized plant is an unrealistic proposition since there are processes for which there is no simple way of mechanizing. Take for example scum removal process. It is a fairly sophisticated task since the scum needs to be removed gently (lest the scum layer breaks), but promptly (lest it dissolves back into the juice). A machine that does this will be complicated and costly, and for a small furnace such as that developed in this project, it is much simpler and economical to remove the scum manually. Sophisticated mechanization also has the disadvantage that in the event of a breakdown, it is difficult to repair and replace.

Due to these reasons, activities not amenable to full mechanization were partially mechanized and/or their manual procedure was improved/standardized (for example, scum removal process was simplified so that only one person can do it now, whereas three were required earlier). In any case, the ultimate aim of developing a **standardized, continuous** and **efficient** plant was duly achieved.

4.3 A summary of the sweet sorghum syrup-making process

For ease of bookkeeping, the complete process of syrup making can be divided into four sections: (a) harvesting and stripping, (b) crushing and settling, (c) heating, and (d) cooling and storage. A sketch of a typical SS syrup production process and a schematic of the plant developed at NARI, clearly depicting these four sections, are shown in Figure 16 and Figure 17, respectively. A schematic showing the actual layout of NARI SS syrup plant is shown in Figure 18.

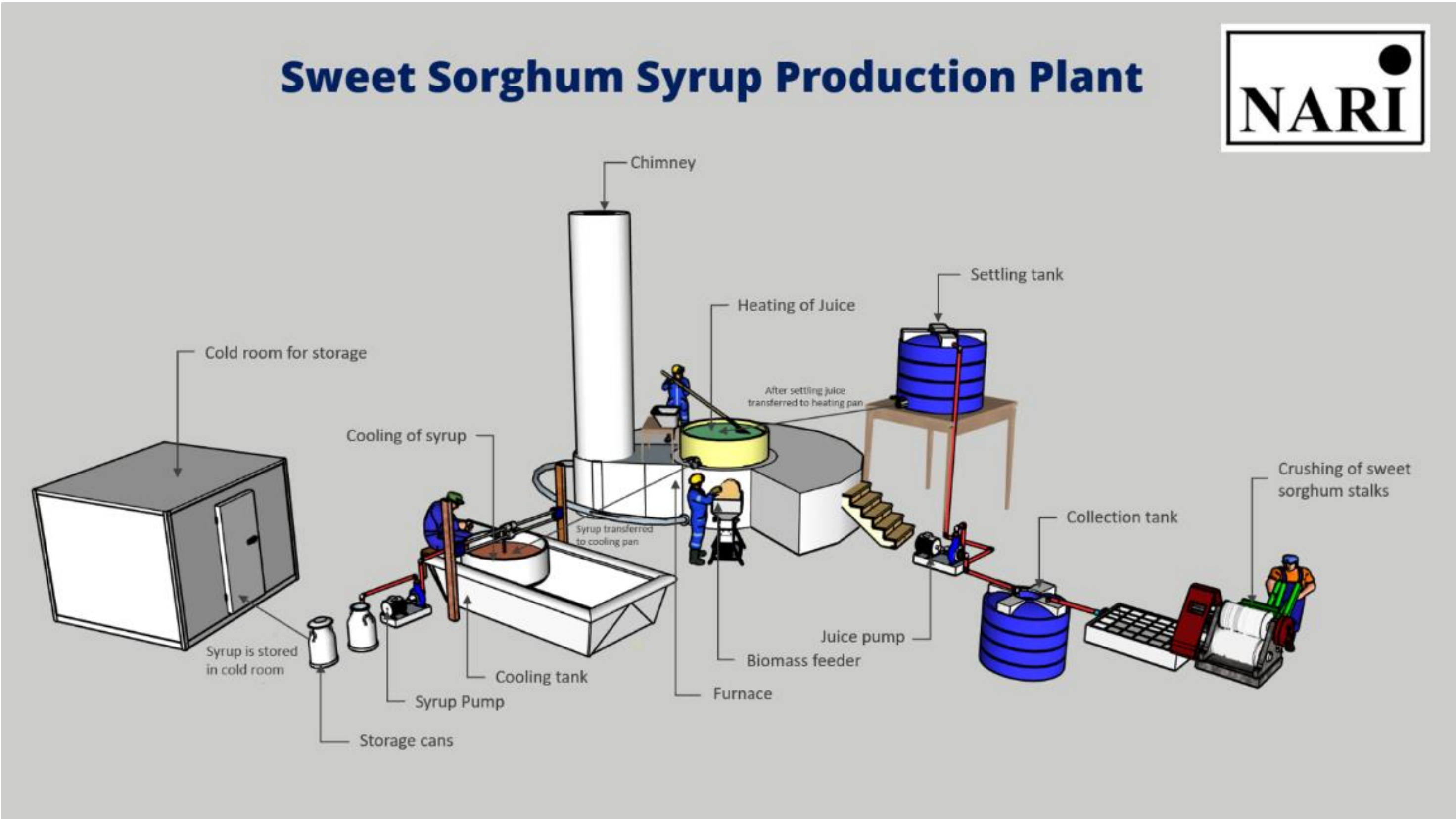


Figure 16: A drawing of NARI SS syrup production plant.

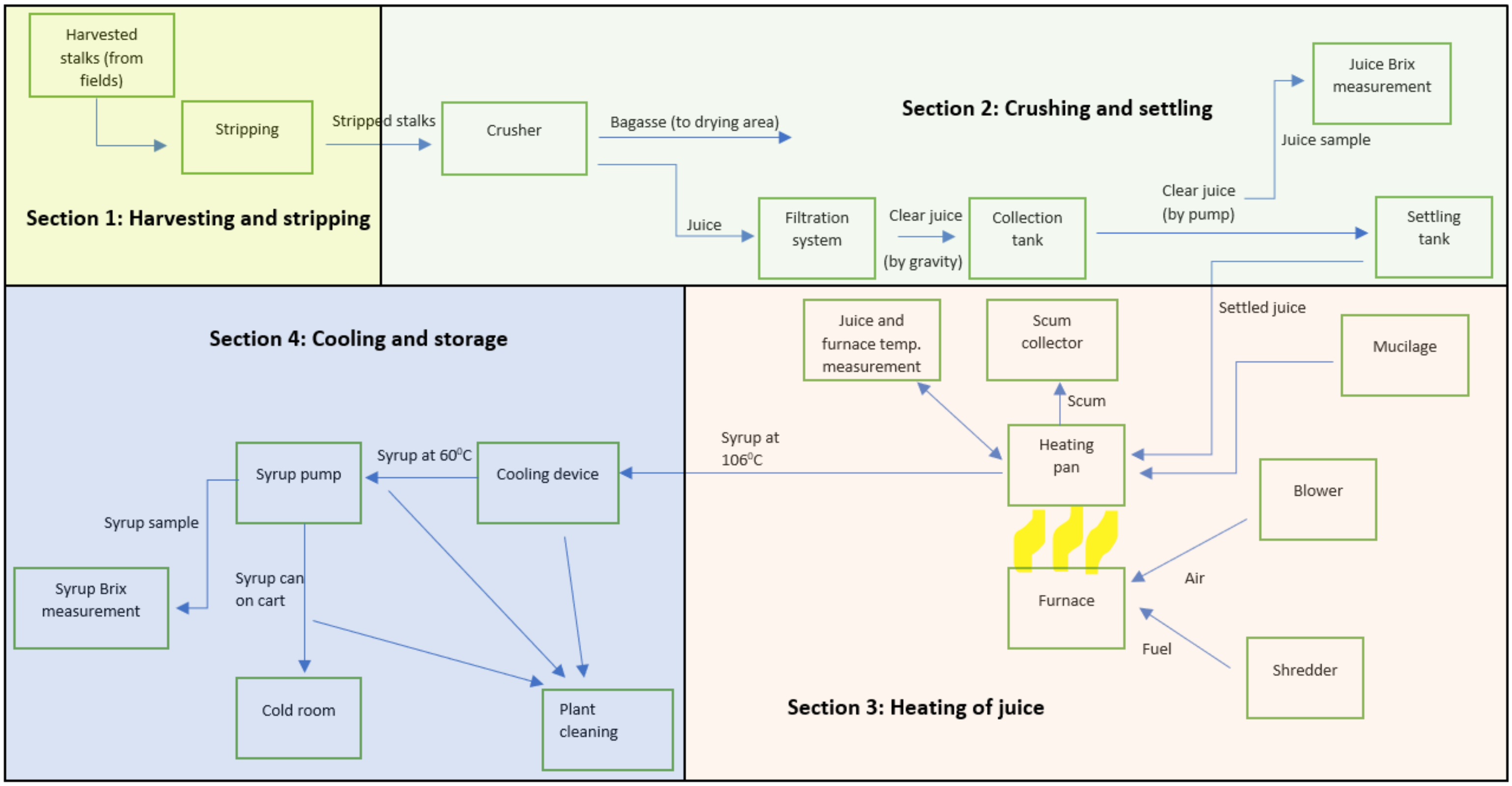


Figure 17: A process-diagram of the SS syrup plant at NARI.

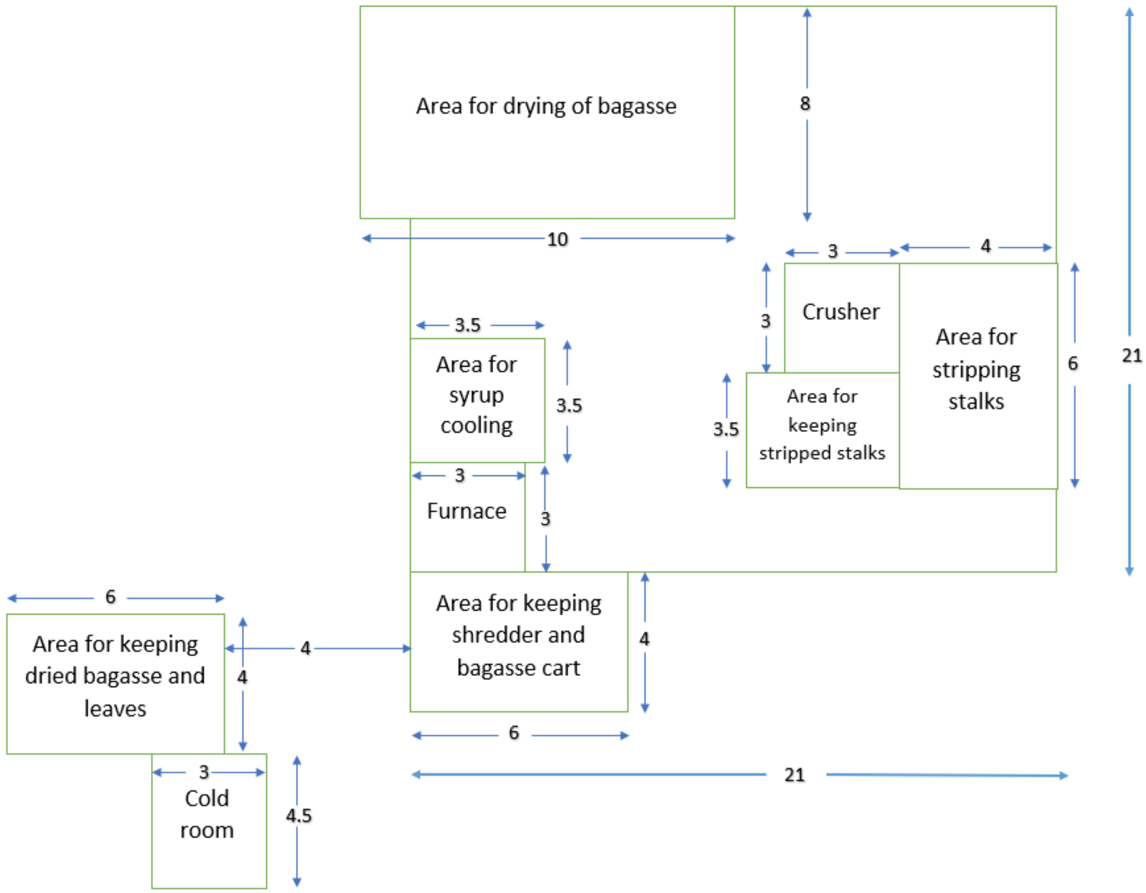


Figure 18: Actual layout of the NARI SS syrup plant. All dimensions are in meters.

A summary of the processes carried out in these four sections is now presented.

4.3.1 Harvesting and stripping

The SS stalks are harvested when the juice Brix (an indicator of total sugar content) is 15 degrees or higher. The harvested biomass is then manually stripped, i.e., leaf laminae and sheaths are removed. The stripping process is carried out for two reasons: firstly, not removing the leaves and the sheath supposedly gives an off taste to the syrup, and secondly, it is required for detection and removal of the part of the stalk damaged by the stem borer. The stripping of SS biomass is a labour-intensive process (15 labourers take 10 hours to strip 1.5 ton of biomass, i.e., 10 kg/biomass/labourer).

4.3.2 Crushing and settling

The stripped stalk is stored for 12-24 hours which helps in inverting the sucrose in the juice. The stalk is then crushed the next day on a 3-roller crusher. The juice is filtered through different sized meshes placed sequentially. Proper filtration is crucial for producing good quality syrup since it removes a significant proportion of the impurities in the initial phase itself. The filtered juice is then settled for 1.5 hours to remove the insoluble matter (mainly starch) from the juice.

4.3.3 Heating

The clear juice is then heated in the evaporation pan. Mucilage prepared from okra fruits or stems is added to the juice to facilitate scum removal. The quality of the syrup produced depends to a large extent upon the amount of scum removed. The heating is continued till the desired syrup consistency is achieved, which is determined from experiments to be at a syrup temperature of around 106^0C.

4.3.4 Cooling and storage

The syrup is cooled rapidly to prevent it from darkening. Finally, it is poured into airtight containers for storage, which are then put in an air-conditioned room.

4.4 Objectives

- Designing, modelling and fabricating a fully mechanized pilot plant for the production of syrup from SS.
- Integration and optimization of all the sub-processes and the respective machinery to produce 150 kg of syrup per day.
- Standardizing quality of syrup produced and ensuring its marketability so as to create a proper supply chain.
- Popularizing the syrup production (and thereby, the SS cultivation) among the farmers through demonstrating the working of the plant and its socio-economic benefits.

4.5 Structure of the report

This report is structured as follows. In Chapter 5, the work that has been done is described. In Chapter 6, conclusions and scope for future work are presented.

5 Work done

In this chapter, the work done in the project, and its implications, are presented. The work is categorized according to the four section-heads mentioned in the previous chapter: (a) harvesting and stripping, (b) crushing and settling, (c) heating, and (d) cooling and storage. Besides, work done towards popularization and dissemination of this technology is also presented.

5.1 Harvesting and stripping

The first step in the syrup-making process is harvesting of the SS stalks when the Brix of juice from them reaches at least 15^0. These are then stripped off their leaf laminae and sheath. A schematic depicting the processes in this section is shown in Figure 19.

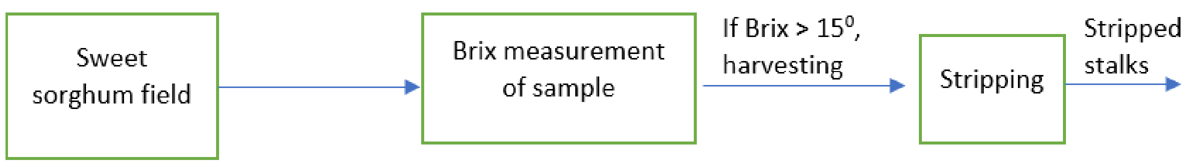


Figure 19: Schematic of processes carried out in 'harvesting and stripping' section.

The work done in this section is listed below:

1. Brix data collection.
2. Optimization of the manual stripping process.
3. Development of a stripping machine.
4. Determination of effect of leaf sheath on syrup characteristics.
5. Determination of effect of pest damage on syrup characteristics.
6. Development of a new method for damage detection.

We now present the details of this work.

5.1.1 Brix data collection

5.1.1.1 Introduction

Brix is used in the food industry for measuring the approximate sugar content. Note that it only measures the total content of the soluble solids in a sample and not the individual sugar types. A Hanna HI96801 digital refractometer is used to measure the Brix at NARI.

Data of the Brix measurements of juice across different varieties, plots and seasons was collected for the whole duration of this project. The chief objective of Brix data collection is to identify the dates appropriate for sowing and harvesting of the SS crop.

The complete procedure of Brix analysis from sampling to measurement is presented in Appendix A.

5.1.1.2 Demonstration of data collection

For demonstration, the variation in Brix content in juice with 'the number of days from sowing' for Plot 16A, which was sown in January 2021, is shown in Figure 20. It is seen from the figure that the Madhura-3 (M3) cultivar has the highest juice Brix content among all the varieties. Its Brix level reached the desired value of 15^0 between 71 and 82 days from the day of sowing and remained steady until it was harvested at 105 days from sowing. Generally, the Brix content of juice reaches a maximum at the physiological maturity of the grain. This is also seen in Figure 20 for all the cultivars. Hence, it is important to harvest the crop during the three-week window with the highest juice Brix content.

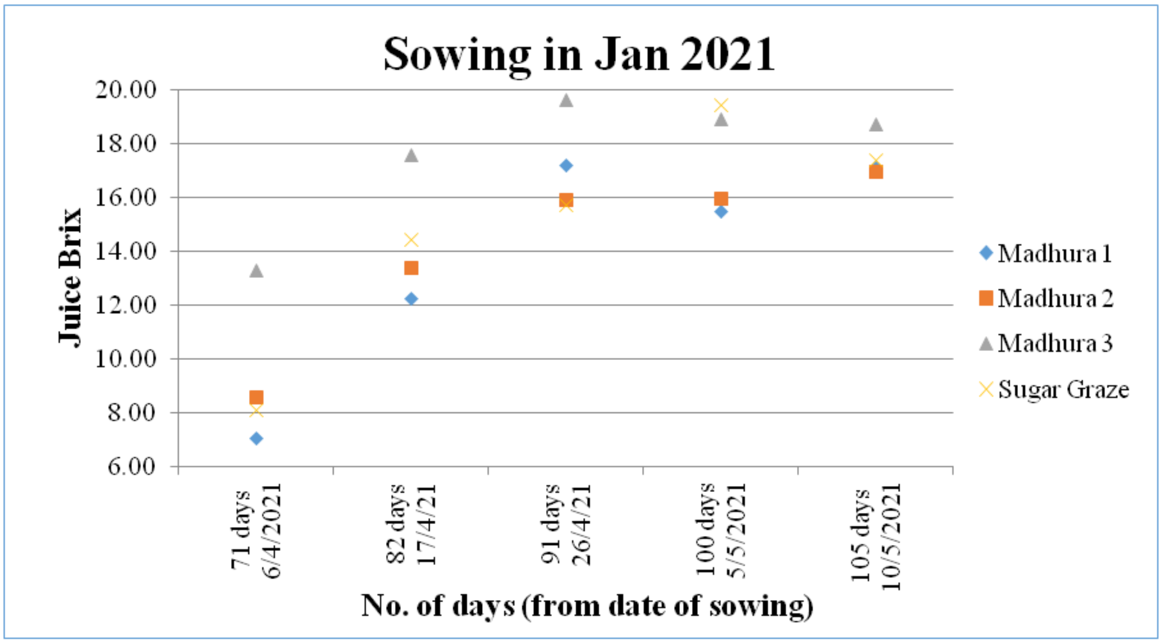


Figure 20: Juice Brix variation with time in SS varieties sown in Plot 16A in January 2021.

As another illustration, the variation in the juice Brix content of the Madhura-3 cultivar sown at different times of the year is shown in Figure 21. Except for the ones sown in June and August, all the crops reached the desired level of 15^0 Brix.

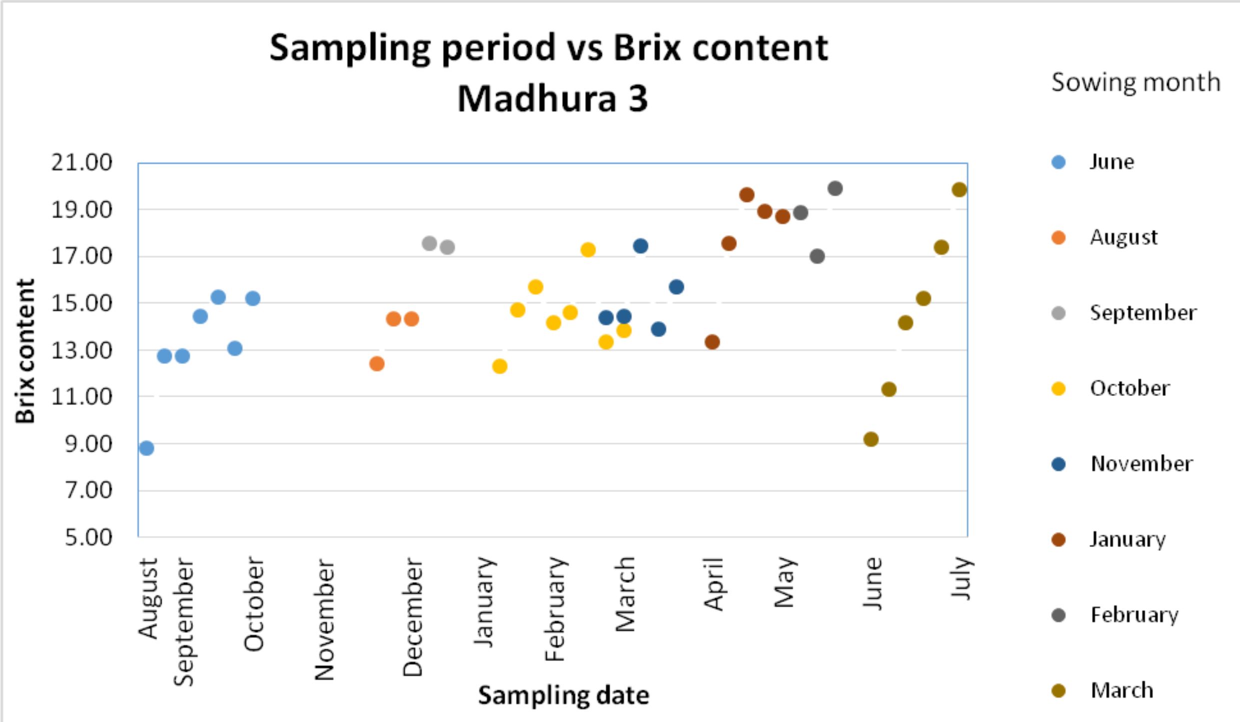


Figure 21: Seasonal juice Brix variation in Madhura 3 from August 2020 to July 2021.

Note that Figure 20 and Figure 21 are presented here as examples. Similar figures corresponding to different cultivars, sowing dates and plots have been generated and analyzed for policy-framing.

5.1.1.3 Conclusions

After analyzing all the juice Brix data (corresponding to different cultivars and seasons), the following conclusions were drawn:

1. The crop should be harvested only if its juice Brix content is 15^0 or above.
2. Among all the cultivars, Madhura-3 has the highest juice Brix content on an average which is also maintained over the longest period.
3. In all the cultivars, the Brix content increases, reaches a maximum, and then decreases. The harvesting should be done in a window of about three weeks near the maximum.
4. Except for the crops sown in the months of June and August, all the crops of the Madhura-3 cultivar (which is the best-performing cultivar) reached the desired level of 15^0 Brix between 80 to 90 days.

5.1.2 Optimization of the manual stripping process

5.1.2.1 Introduction

SS biomass when harvested has green leaves attached to the stalk. Leaves are strongly attached to the stem, unlike those of sugarcane which are dry and easily removed from the stalk. Leaf stripping of SS is done manually and is a very labour-intensive process. Figure 22 shows the processes involved in the stripping operation. The aim was to maximize the manual stripping rate, to which end, several labour management methodologies were tried. Some of them are presented below.

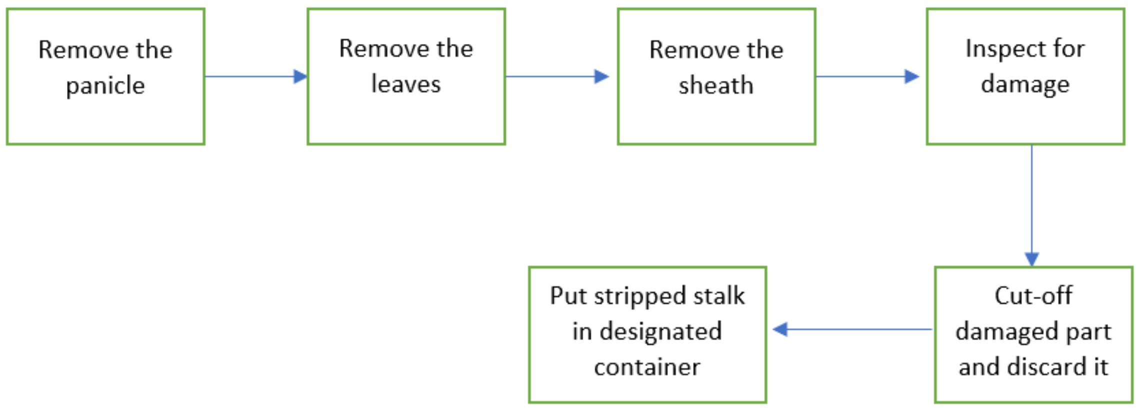


Figure 22: Schematic representation of stripping operation of SS.

5.1.2.2 Conventional stripping

The first task was to determine the stripping rate with the method that has been conventionally employed at NARI. Many experiments were done, whose results are presented in Table 48. To make sure that the data is free of any biases due to the physical characteristics of the crop, the physiological data of the crop was recorded. Analysis of this data showed that on an average, about 167 labour-hours are required to strip 1.2 ton of SS biomass (which yields 50 kg syrup), that is, the conventional stripping rate is about 7.2 kg biomass/hour/labourer. The complete data for this exercise is presented in Appendix B.

5.1.2.3 Contractual stripping

The following small change in the management made a significant difference in the stripping rate: the labourers were now paid based on the amount of stalk they stripped. The data from these experiments is recorded in Table 12. The table shows that the stripping efficiency with contractual payment improves to around 13.6 kg/hour/labourer (almost double of the conventional stripping rate), which translates to about 88 labour-hours for producing 50 kg syrup.

Table 12: Experimental data of contractual stripping of SS.

Variety	Date of harvesting	Biomass weight (kg)	Stripping efficiency (kg biomass/labour-hr)
Madhura-3	07-Jun-21	1315.00	14.97
Madhura-3	20-Apr-21	643.6	12.24
Madhura-3	19-Apr-21	649.4	12.35
Madhura-3	30-Mar-21	1040.00	14.75
Average			13.6

5.1.2.4 Conclusions

Stripping of leaves and sheath from the stalk is one of the most time-intensive processes in the SS syrup-making process. Upon changing the payment basis from per hour to per kg, it was observed that the stripping rate almost doubled.

5.1.3 Development of stripping machines

5.1.3.1 Introduction

As mentioned above, stripping of leaves and sheath from the stalk is one of the most time-intensive procedures in the SS syrup-making process. Although mechanization of stripping was not a part of this project, it was still attempted to build simple machines which could at least partially automate the stripping process, possibly reducing time and effort. Two semi-mechanical stripping machines were developed, as discussed below.

5.1.3.2 Table-mounted stripping machine

The first machine is table-mounted and consists of four blades each spanning a quarter of the stalk circumference. Two persons, one for feeding and one for pulling out the stalk at the other end, are required. Figure 23 shows the machine while in operation (see Appendix C for details of the stripping machine).

Figure 23: Stripping machine during operation.

Complete leaf removal and about three-fourths sheath removal was achieved with the machine (Figure 24). A comparison of the time taken by the machine and manual stripping is provided in Figure 25. It is seen in the figure that the machine is about 1.3 times faster than manual stripping. However, the machine had the following drawbacks:

- It was difficult to feed the stalk in due to small opening.
- For stalks with greater thickness variation along their length, the jerk action required was large.
- Shearing action of the machine rapidly deteriorated with accumulation of scrap biomass on the insides of the blades, requiring frequent cleaning.

Figure 24: Left: unstripped stalks; right: stalks after stripping with machine.

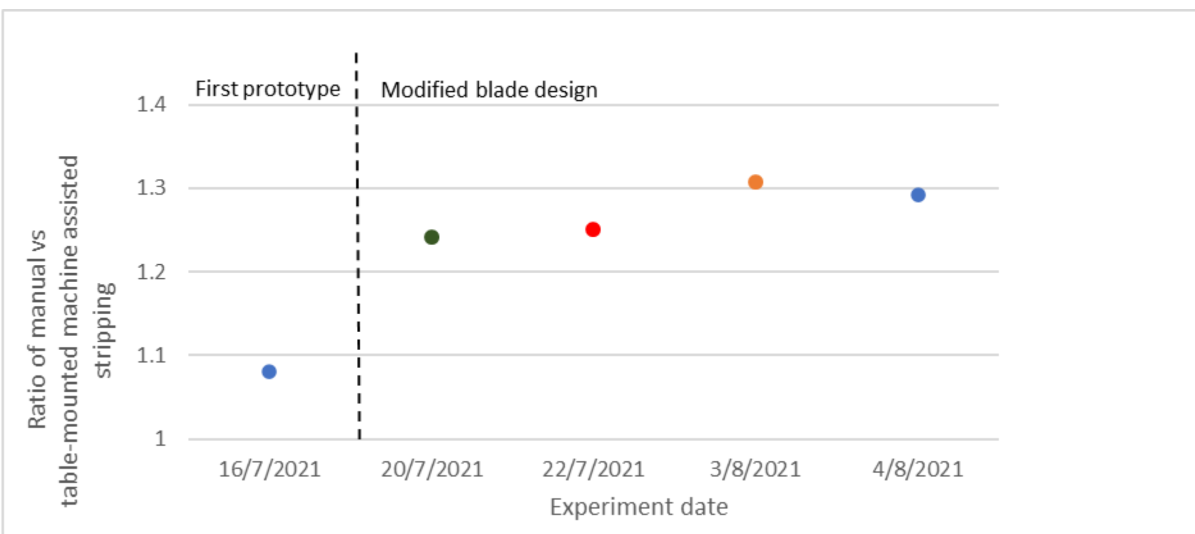


Figure 25: A comparison of time taken for manual and machine-assisted stripping.

5.1.3.3 Handheld stripping machine

The second stripping machine was a handheld one. Unlike the first machine where the spring mechanism adjusts blade opening to provide effective shearing action throughout the length of the stalks, here this adjustment is provided by a human hand tucked-in loosely in the handles provided in the machine. Figure 26 shows a picture of this handheld stripping machine.

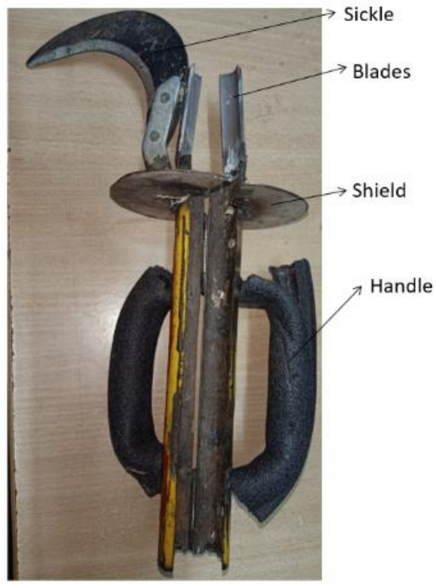


Figure 26: Handheld stripping machine.

Four experiments were performed to note the time required with the handheld stripping machine. The average stripping rates (biomass stripped per unit time) for manual and machine-assisted stripping for these four experiments came out to be 0.45 and 0.54 kg/min, respectively. That is, machine-assisted stripping was found to be 1.2 times faster than manual on average. See Appendix C for complete data of these experiments.

However, the handheld stripping machine too had its drawbacks:

- The left hand (weaker hand) starts paining after a while due to frequent changes in the orientation required owing to variable stalk characteristics.
- At times, the soft fleshy part of palm gets wedged between the semi-circular tubes to which the handles are attached. This may lead to sores on long usage.
- The machine weighs about 350 g without the sickle, which is a bit heavy.

5.1.3.4 Conclusions

Although marginally higher stripping rates were obtained with the machines, they suffered from serious drawbacks. The amount of research work required to make these machine considerably faster than manual stripping, and yet more convenient and inexpensive to use was deemed excessive. In view of this, further development of these machines was discontinued and the practice of manual stripping has been continued.

5.1.3.5 Future work

- Handheld stripping machines already exist for sugarcane. However, sugarcane's sheath is loose and the stalk is uniformly thick along the length. On the other hand, SS sheath is tightly attached to the stalk, and the latter's thickness varies a lot along its length. Future work should address this obstacle while designing stripping machines.

5.1.4 Determination of effect of leaf sheath on syrup characteristics

5.1.4.1 Introduction

Leaf sheath removal in SS is a long and tedious process since, unlike sugarcane, the sheath is tightly attached to the stem. It is the activity that requires the maximum human intervention and time in the whole syrup-making process. Sheath removal has been part of the SS syrup making process for two apparent reasons: (a) it is essential to detect the pest-damaged stalk, and (b) the sheath gives a bad taste and appearance to the syrup. To test if these are indeed true, eight experiments were performed, in each of which SS syrup was prepared from juice squeezed from stalks *both with or without sheath*.

5.1.4.2 Experiment details

A new method was devised to remove parts of stalk damaged by borer while keeping the sheath on: the stalks (after removing the panicle) were cut near the nodes to visually inspect for damage, and the damaged portions were discarded. In this way, each stalk was cut into about 8 pieces. The details of this method of damage detection are presented in Appendix D.

In each experiment, the biomass was split into two batches. One batch was stripped in the conventional way. The other batch whose sheath was not removed was subjected to the treatment described in the previous paragraph and Appendix D. Organoleptic assessment of the syrups prepared with these batches was conducted on the following five criteria: colour, clarity, flow, smell and taste.

5.1.4.3 Results

The assessment indicated that sheath does not affect the syrup clarity, flow, smell and most importantly, taste. It adds a brownish hue to the usually reddish tinge of SS syrup, which was in fact liked by the evaluators. However, the new method of damage detection discussed above suffered from a serious flaw: the crushing efficiency of the shorter stalk pieces was poor: about 28% as against about 40% for that of the usual uncut stripped stalks (sheath has no effect on crushing efficiency; this was determined in a separate set of experiments). This translates to production of about 10 kg less syrup on pilot scale. Since this is a considerable reduction and a significant amount of R&D was deemed necessary to improve crushing efficiency of short pieces, the new method of damage detection was not pursued further.

The details of the experiments and the organoleptic assessment, and their results, are provided in Appendix D.

5.1.4.4 Conclusions

It was found out that leaf sheath does not affect syrup clarity, flow, smell and taste, but adds a brownish hue to it. However, its removal is important for damage detection, and it was decided to continue with the practice of sheath removal until a method of spotting damage which does not require removing the sheath is devised.

5.1.4.5 Future work

1. Use the stripping machine (described in the previous section), which removes leaf sheaths only partially, but enough to expose a significant amount of pest damage and does not require chopping of the stalk into shorter pieces. The above experiments show that 100% sheath removal is not necessary.
2. Cut the stalks into longer pieces than the ones in this trial. Ad hoc experiments suggest that increasing the length of stalk pieces increases crushing efficiency. Also, currents experiments have indicated that complete damage removal is not necessary in any case. In view of this, an optimum length to which stalk pieces are cut needs to be found so that the extraction is high and the damage low.
3. Focus on understanding the mechanics of crushing and come up with a simple theory as to why shorter pieces do not get crushed that well. With this understanding, (a) modify the roller design, (b) modify the feeding mechanism, (c) pre-treat the cut stalks.
4. Devise other strategies to detect pest-damage from outside.
5. Assess the long-term effect, if any, of including the leaf sheath on syrup quality.

5.1.5 Determination of effect of pest damage on syrup characteristics

5.1.5.1 Introduction

Continuing with the theme of getting round the process of leaf sheath removal, experiments were conducted on the effect of pest damage on the syrup characteristics. The primary motivation was the following: if the results indicate that damage does not affect the chief features of the syrup, especially the taste, the process of sheath removal could be completely done away with.

5.1.5.2 Experiment methodology

The quantity ‘damage % with respect to biomass’ was considered as the primary variable in these experiments. Six experiments were performed, for the values 0, 2, 4, 6, 8 and 10 of this variable. Another minor point to note is that when the value of this variable is 0, it is not implied that there is absolutely no damage present in the crushed stalks. What is meant is that all the damage *that is easily detected* has been removed. Similarly, for the 2% case, what is implied is that pest-damaged stalk amounting to 2% by weight of the biomass is deliberately added, and so on.

In the crop used for these experiments, when no pest-damaged stalks were intentionally crushed, the damage % with respect to biomass was about 18. So, the typical domain of the primary variable was 0-18.

One final point to note is that in earlier experiments, it had already been ascertained that a high proportion of damage spoils the taste of the syrup. So, it was decided to vary the values of the primary variable from 0-10, in steps of two, for the experiments.

5.1.5.3 Organoleptic assessment

Organoleptic assessment of syrup prepared in each of the six experiments was conducted one day after the experiment was performed. Nine participants each took part in the first four assessments, whereas 11 participated in assessments for Experiments 5 and 6. The participants were asked to rate the syrups on five criteria: color, clarity, flow, smell and taste, on a scale of 1 (worst) to 5 (best). The average ratings are plotted in Figure 28. Here are a few highlights.

1. Damage does not seem to be affecting the colour, clarity, flow and smell of the syrup.

2. As far as the all-important criterion of taste is concerned, it is seen that while all the syrups have got a decent rating, there is a clear preference for syrups with least damage (with 0 and 2% damaged stalk contents). While subsequent increase in proportion of damaged stalk does adversely affect syrup taste, the ratings indicate that this effect is not very much.

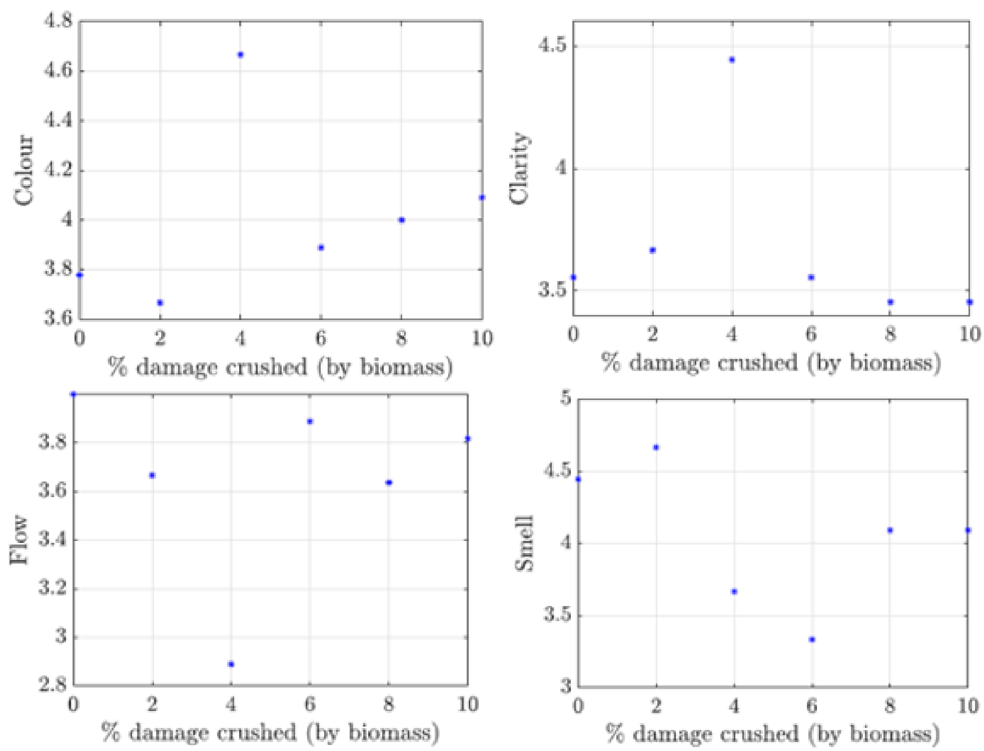


Figure 27: Effect of pest damage on organoleptic properties except taste (rated on a scale of 1 to 5). It is seen that there is no clear trend.

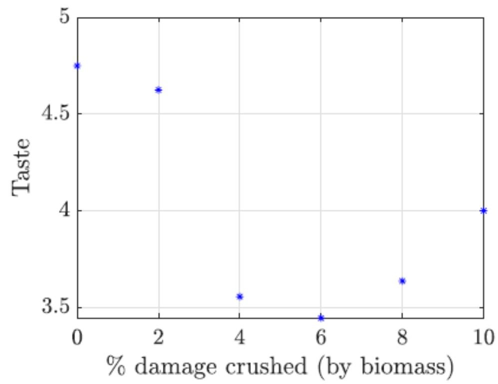


Figure 28: Effect of pest damage on syrup taste (rated on a scale of 1 to 5). It is seen that no or little pest damage gives the best syrup taste.

5.1.5.4 Conclusions

Addition of damaged stalk at least to an extent of up to 10% of biomass by weight does not affect the organoleptic quantities, except for taste. While damage does add a slightly bitter aftertaste to the syrup, it is not excessively troubling.

5.1.5.5 Future work

1. Although the experiments indicate that presence of as much as half of the total observable damaged stalk (by weight) when included does not affect the syrup characteristics much, **the long-term effects of inclusion of damaged stalk should still be checked in future work**. For example, does inclusion of damaged stalk result in unusually high settled mass upon in syrup stored for longer duration.
2. If it is established more firmly in future work that presence of some amount of damage does not adversely affect the syrup characteristics, it will have a huge bearing upon the efficiency of the whole process. These results could be used to simplify the process of removing the damaged part of the stalks and save a lot of time and effort.

5.1.6 Summary of harvesting and stripping section

Table 13: Summary of work done in harvesting and stripping section. Number of experiments done (wherever applicable) are given in brackets.

Work	Key impact/result
Collected juice Brix data for whole project duration	Determined optimum sowing/harvesting dates
Adopted contractual stripping (30)	Reduction of stripping time by half
Developed preliminary stripping machines (9)	Did not yield expected results, needs more R&D in future
Assessed effect of leaf sheath and borer-damaged stalks on syrup quality (14)	Could ease/obviate stripping of stalks
Devised new method of stem borer damage detection (8)	Easier, faster damage detection; but less crushing efficiency

Table 14: Manpower consumption in harvesting and stripping section for 50 kg syrup production.

Activity	Typical number of labourers	Number of hours per labourer	Total labour-hours
Harvesting, transporting and weighing of biomass	4	4	16
Stripping of stalks	10	8	80

Table 15: Equipment used in harvesting and stripping section.

Equipment	Power consumption	What it does
Digital refractometer (also used to measure syrup Brix)	3V DC power	Measures juice Brix

Table 16: Scope for future work in harvesting and stripping section.

1. Improve designs of stripping machines developed during this project.
2. Find out long-term effects of incorporating leaf sheath and pest-damaged stalk on syrup.
3. Improve crushing efficiency of shorter stalk pieces.
4. Devise methods of pest damage detection which obviate the need to remove sheath.

This concludes the work done in the section ‘Harvesting and stripping’. Next, the work done with regard to the crushing and settling processes is presented.

5.2 Crushing and settling

After the SS stalks have been stripped and the pest-damaged portions removed, they are crushed to obtain juice. This juice contains many impurities, composed mainly of starch. If it is heated directly without removing the impurities, a lot of scum is produced, and the resulting syrup has a cloudy and foamy appearance. Hence, the juice is filtered and settled before heating it since much of the impurities are heavier than the juice. Also, mucilage is prepared using okra fruits/stems (to be added to the juice while heating) to enhance scum formation. A schematic of the processes carried out under this section is presented in Figure 29.

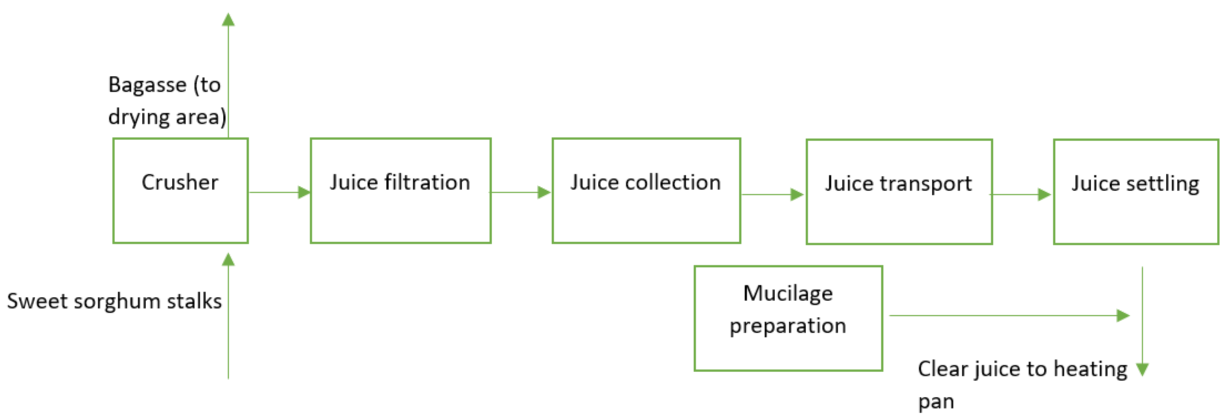


Figure 29: A schematic of the processes under the section 'Crushing and settling'.

The major work done in this section is listed below.

1. Installation of a new crusher.
2. Modification of process of wet bagasse collection and its spreading.
3. Fabrication of a new filtration assembly and its modification.
4. Installation of new storage tank, settling tank and pipe.
5. Determination of effect of settling and its duration on syrup characteristics.
6. Determination of mucilage preparation methodology.
7. Measurement of starch in SS juice, syrup and scum.

The description of this work is presented below.

5.2.1 Installation of a new crusher

5.2.1.1 Introduction

Previously, a 3-roller crusher of Kirloskar (Sharad no. 2) driven by a 10 hp motor was used for crushing the SS stalks. Since it was purchased in the 1980s, due to wear and tear, it had a low crushing rate of 100 to 150 kg of SS stalk per hour. It took five hours to get 300 kg of SS juice (for 50 kg syrup production).

Moreover, its efficiency was low: even with multiple passes (3 to 4) of the SS stalks through the crusher, only 30 to 40% (based on weight of the stripped stalks) juice extraction was obtained. Hence, a new crusher to reduce the crushing time and increase the efficiency was purchased.

5.2.1.2 New 3-roller crusher

A 3-roller crusher, Jagdish no.4, was purchased from Shree Vishwakarma Engineering works, Rajkot, Gujarat. It was supposed to have a crushing capacity of 1100 kg per hour and is driven by a 7.3 hp motor. Although the crusher is designed for sugarcane, it has a lower clearance between the rollers, making it suitable for SS stalks (since SS stalks have smaller diameters than those of sugarcane).

Pictures showing the processes carried out from the construction of the foundation to installation of the crusher are compiled in Figure 104 in Appendix E.

5.2.1.3 Performance of the new crusher

Many trials were taken on the new crusher; its average crushing capacity was found to be around 650 kg (stripped stalk)/hr. In comparison, the old crusher had a capacity of 100 to 150 kg/hr. So, the crushing time has reduced to about 1/5th. Also, the extraction of juice, defined as the percent weight of the juice per unit mass of the SS stalks crushed, has improved significantly: earlier, a maximum of 40% extraction was achieved with three to four passes of the stalks; the new crusher gives an extraction of about 45% in a single pass, greatly reducing the effort, time and electrical power. Due to higher extraction, syrup recovery has also increased in the same proportion.

Pictures of crusher while in operation are shown in Figure 30. A comparison of the old and the new crushers is provided in Table 17. It can be seen from the table that the manpower requirement is more for the new crusher as the crushing is so fast that one person is required to feed the stalks, two persons are required to collect the stalks and hand them over to the person doing the feeding, and one person is required to collect the wet bagasse.

Figure 30: Operation on the new crusher. Left: back view; right: side view.

Table 17: Comparison of parameters for old and new crushers for making 50 kg syrup.

Parameter	New crusher	Old crusher
Motor rating (hp)	7.3	10
Crushing rate	650 kg/hr	125 kg/hr
No. of passes needed	1	3 to 4
Juice extraction (% of stripped stalk)	40 to 50	30 to 40
Operation time (hours)	1	5
People required for juice extraction	4	2
Total electrical energy consumed (kWh)	5.5	37.5

5.2.1.4 Conclusion

The new 3-roller crusher has significantly reduced the time, effort and power expended in the crushing operation. As a result, the crushing time for producing 50 kg syrup has reduced from 5 hours to just one hour. Moreover, it has also increased the syrup production by about 33% (for the same amount of SS stalks crushed).

5.2.1.5 Future work

If the stalk feed rate is low, crushing efficiency is less. If it is high, then there is a possibility of the crusher getting choked. Thus, there is a window of feeding rate for which the crushing efficiency is good and the operation is smooth (no choking). This window for the purchased crusher is *quite narrow*. This task becomes all the more difficult due to high variation in stalk thickness along its length, and also due to variation in average thickness of stalk across different varieties and seasons. It is only with experience that one learns to feed at the correct rate. Future work should focus on:

(a) Developing an objective but simple technique of uniform feeding of stalks at a rate which gives high crushing rate and smooth operation.
(b) Developing crushers that take into account the high variation in stalk thickness of SS and provide a broader window of feed rate for which the extraction is high.

5.2.2 Modification of wet bagasse collection and spreading

5.2.2.1 Introduction

Earlier, the bagasse from crusher outlet was collected in small tarpaulin sheets with holding capacity of 10-15 kg wet bagasse. This was laborious and inconvenient. To solve this issue, it was decided to

(a) modify crusher outlet port and use old NARI carts (with holding capacity of about 65 kg wet bagasse) for bagasse collection, and
(b) shift bagasse-spreading area closer to crusher outlet.

5.2.2.2 Results

The results of these changes are tabulated in Table 18.

Table 18: Effect of new bagasse collection and spreading system.

Parameter	Earlier	Now
Labourers required	4	1
Number of trips required for spreading	50 (25 per pair)	10
Distance per trip (one way)	5-15 m	30-40 m
Crusher outlet area cleanliness	Slightly unclean	Clean

Figure 31 shows the new method of bagasse collection. Figure 32 shows the bagasse-drying area and shed for dried bagasse.

Figure 31: New method of wet bagasse collection.

Figure 32: Bagasse drying system. Top-left: bagasse drying area; top-right: bagasse drying area as viewed from crusher; bottom-left: tent for protecting bagasse from rain while allowing air passage; bottom-right: shed for dried bagasse and leaves.

5.2.2.3 Future work

The task of (both wet and dry) bagasse transport could be mechanized through usage of conveyors or vacuums. Both these options were considered in this project but not undertaken because of the following reasons:

(a) Commercially available conveyor machines are expensive. Developing a conveyor machine from scratch would have taken a lot of time.
(b) Two well-known companies were called to demonstrate their litter picker-type vacuum machines and it was observed that due to highly variable length of bagasse particles and their loose nature, the vacuum collectors were not able to transport bagasse satisfactorily.

Future work should focus on developing simple and affordable machines for bagasse transport.

5.2.3 Fabrication of a filtration assembly

5.2.3.1 Introduction

There are many impurities in the juice obtained from the crusher, many of which are heavier than the pure juice. As mentioned earlier, it is crucial that these impurities be removed before the heating process to obtain less scum (which is more difficult to remove) and clearer syrup. Two methods to remove the impurities were employed: filtering and settling (in that order).

Filtering was employed to remove the impurities. Previously, coarse stainless-steel meshes mounted on small (area-wise) frames were used for juice filtration; consequently, (a) a lot of impurities were not removed during filtration, and (b) meshes choked frequently. Hence, fine meshes of stainless-steel as well as of nylon were purchased. Frames were fabricated at the institute to hold the meshes in place. Stainless-steel meshes were found to be rugged, and thus were preferred over nylon ones despite higher costs.

5.2.3.2 Fabrication of frames for the filters

As mentioned above, earlier, small stainless-steel screens were used for juice filtration (Figure 33). Due to small cross-sectional areas of these circular frames, clogging of the screens was frequent. Hence, new frames having more cross-sectional area and fitted with food-grade stainless-steel meshes were fabricated at NARI. They were arranged from coarse at the beginning to fine at the end to prevent clogging of the juice, which flowed in from the crusher by gravity into the filtration unit (Figure 34 and Figure 105). The sizes of these screens, and the sequence in which they were placed is reported in Table 19. Detailed pictures of these meshes are shown in Appendix F.

It was noted that the filtration assembly still choked at times, especially when the crushing was good, due to choking of the finest filter of 100-microns size. To address that, it was decided to use the 100-microns filter while transferring the juice from settling tank to heating pan.

Figure 33: Smaller circular meshes used for juice filtration earlier.

Figure 34: New stainless-steel juice filtration unit. In this picture, the first three filters of this unit of sizes 2500, 750 and 250 microns, respectively, are seen. The fourth mesh of 100-microns size is used while transferring the juice from settling tank to heating pan.

5.2.3.3 Performance of the filtration unit

With the new filtration unit, about 40% of the total impurities are removed in the filtering process itself, thus lowering the amount of impurities which are later removed as scum while heating. This has reduced the efforts expended in the removal of scum during the heating process. A comparison between the old and the new filtration units is shown in Table 19.

Table 19: Comparison of old and new juice filtration units.

	Old juice filtration unit	**New juice filtration unit**
Mesh size of the first screen (micron)	2000	2500
Mesh size of the second screen (micron)	1000	750
Mesh size of the third screen (micron)	500	250
Mesh size of the fourth screen (micron)	_	100
Scum obtained (% weight of juice)	9.6	5.5

5.2.3.4 Conclusions

The quality of syrup is directly related to the amount of scum removed. Since scum is removed manually (during heating), its removal varies from person to person. This results in a variable syrup quality. Since the aim is to standardize the quality of the syrup, it is desired that as many of the impurities as possible are removed before the heating process. To that end, a new filtration unit has been developed containing four stainless-steel screens arranged sequentially size-wise. The new unit has led to reduction in the scum quantity by about 40%, thus improving and standardizing the quality of the syrup, and reducing the effort in the scum removal process.

5.2.4 Installation of new collection tank, settling tank and pipe

5.2.4.1 Introduction

To hold the juice from the crusher after filtration (till all the stripped stalks are crushed), a collection tank is needed. This tank is kept at a lower height in comparison to the crusher outlet so that the juice could flow in by action of gravity (through the filtration assembly). Once all the stalks are crushed and all the juice is collected, the juice is pumped to the settling tank kept at a greater height. After allowing the heavier impurities to settle for some time, the clear juice is taken out of the tank through a tap in the settling tank. The tap is placed judiciously so as to recover as much of the clear juice as possible without disturbing the settled impurities.

5.2.4.2 Purchasing of new tanks

Previously, a rectangular stainless-steel tank of 120 litres capacity was used to collect the juice from the filtration unit. This tank was not sufficient to hold 300 litres juice required for pilot scale syrup production (that is, 50 kg syrup in one batch). Hence, an existing underground cement tank of 650 litres capacity was first utilized for juice collection (Figure 35). However, cement particles were found in the juice when it was pumped to the evaporation pan for heating. Also, it was difficult to clean the cement tank since it was underground. To that end, a 300-litre capacity food-grade PVC tank was purchased. Similarly, a new food-grade PVC settling tank of capacity 500 litres was purchased since the capacity of the old one was just 60 litres (Figure 36).

Care was taken to ensure that the designs of these tanks (a) allow for easy cleaning, and (b) provide a good height to diameter ratio (determined in separate experiments). Also, it was found that after settling, the clear juice should not be pumped to the evaporation pan since it disturbs the settled mass and mixes it back into the clear juice. Instead, it should be brought to the pan by the action of gravity. So, the settling tank was kept at an elevation such that its drain was just above the evaporation pan.

Figure 35: Left: previously used 650 L cement collection tank; right: new 300 L plastic collection tank.

Figure 36: Left: new 500 L plastic settling tank; right: previously used 60 L stainless steel settling tank.

5.2.4.3 Performance of juice collection and settling tanks

With the 300 litres plastic collection tank, the issues faced with the cement tank were resolved. Once the juice is pumped out, the tank is taken out and cleaned with water.

With the 1 hp pump in place, it takes 6 minutes to pump the juice from the collection tank to the settling tank. The pipe connecting the collection and the settling tanks is cleaned before and after each usage by pumping water through it.

5.2.4.4 Installation of new pipes

A PVC pipe of 2.5 cm diameter has been purchased to transfer the juice from the collection tank into the settling tank via a 1 hp centrifugal pump. By using pipes, about 3% juice which was previously wasted due to manual handling was saved.

5.2.4.5 Conclusions

New collection and settling tanks of 300 and 500 litres, respectively, have been purchased and installed. Moreover, a pump and a pipe to transfer the juice from the collection tank to the settling tank have been installed. The new set-up is compact and convenient, and it has led to enhanced syrup recovery because no juice is lost during handling.

5.2.4.6 Future work

Amount of settled mass varies a lot with season, and so does the height of the settled mass in the tank. Accordingly, there is no *one* fixed location at which the tap for draining clear juice from the settling tank can be installed. Instead, the tap has been installed just above the *maximum* expected settled mass height (determined by looking at data of different seasons).

Generally, to recover as much clear juice as possible, what is done is the following: after all the clear juice up to the tap height has flown to the heating pan by gravity, the settling tank is tilted gently to drain out as much clear juice as possible; as soon as the white settled mass appears (adjudged by looking from the top), the tap is closed. This method is simple, but contains an element of subjectiveness. Future work should focus on development of an objective criterion for the same.

5.2.5 Determination of effect of settling on syrup characteristics

5.2.5.1 Introduction

In the conventional SS syrup making process employed at NARI, the filtered juice is kept still for about 90 minutes to settle the heavier impurities (consisting mostly of starch). It was decided to perform experiments to determine if settling is indeed required, and if yes, what the effect of settling on syrup characteristics is.

Accordingly, many small-scale experiments were performed in which two batches of syrup were made. For the first batch, the juice was directly heated without settling (unsettled). For the second batch, the conventional method was employed, i.e., the juice was settled for 90 minutes. All other parameters were kept the same in the two batches.

5.2.5.2 Experiment results

If the impurities are not removed before the heating process (by filtering, as seen in the previous section, and by settling), they later appear as scum while heating. So, quite expectedly, it was observed that more scum was obtained for the 'unsettled' batch on an average. This is attested to by the plot of the scum obtained (by weight of the juice heated) for all the experiments (Figure 37). Moreover, it was observed that on storing the syrup from the 'unsettled' batch, a settled mass appeared in the bottle after about one week (Figure 38), which is undesirable; although no change in any other characteristics of the syrup was noted.

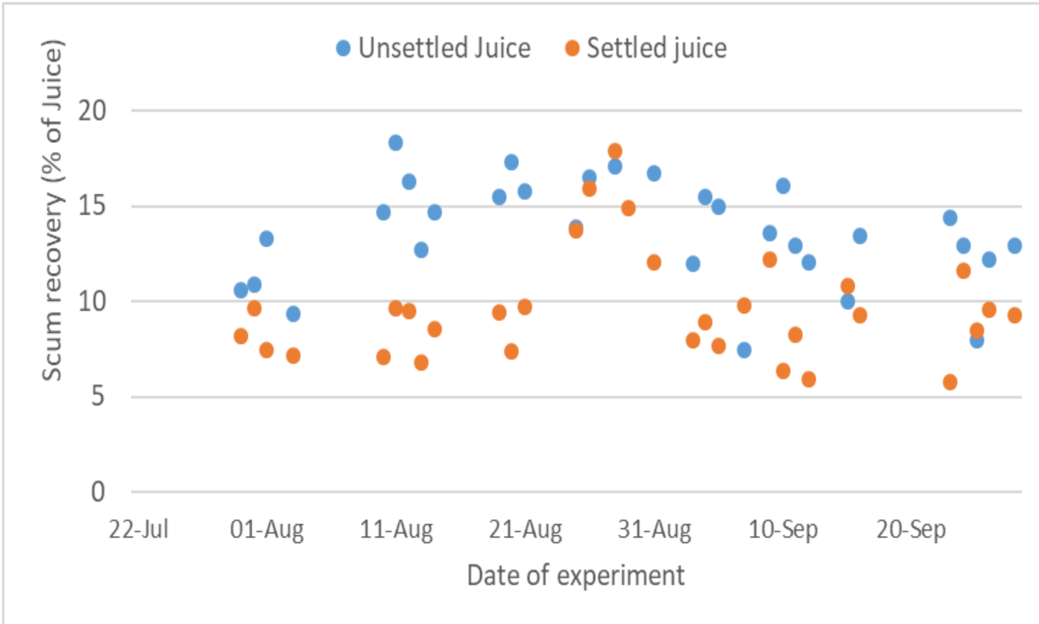


Figure 37: Scum obtained with unsettled and settled juice.

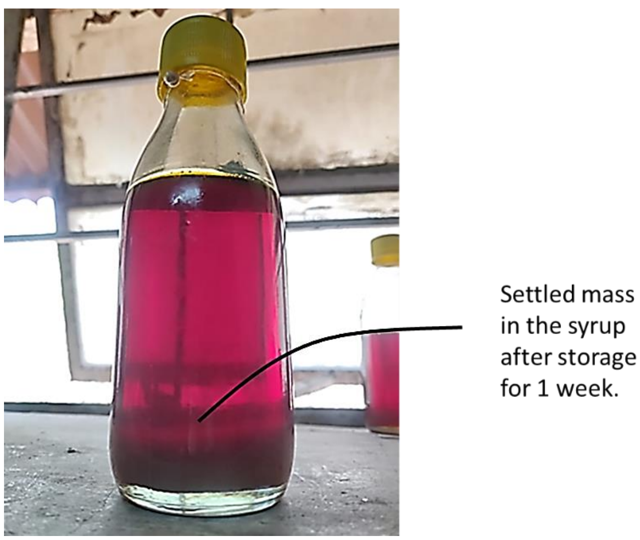


Figure 38: Settled mass appeared in the 'unsettled' batch syrup after one week.

5.2.5.3 Organoleptic assessment

Organoleptic assessment for syrup from all the experiments were carried out to see if the users discerned any difference in the syrups. In each assessment, five participants were asked to rate the syrups on a scale of 1 (worst) to 3 (best) based on the following three characteristics: taste, colour and clarity. The (averaged out) results of the tests are given in Table 20.

Table 20: Results of organoleptic surveys for settled and unsettled juice.

Taste		Colour		Clarity	
Unsettled juice	Settled juice	Unsettled juice	Settled juice	Unsettled juice	Settled juice
3	3	2.8	2.9	2.8	3

The major findings of the assessments can be summarized as follows.

1. No significant difference was found between the tastes of the two syrups.
2. The appearance of the 'settled' syrup is slightly better than that of the 'unsettled' syrup (Figure 39).

Figure 39: Syrups prepared from settled (left) and unsettled (right) juices.

5.2.5.4 Experiments on settling time required

Experiments were also conducted on minimum settling time required and optimum aspect ratio of the settling tank. Juice was settled in transparent glass bottles and their photos were taken; the white starch layer deposited at the bottom clearly revealed the amount of settled mass. These experiments indicated that the layer accrued mass for about 90 minutes, across all the three varieties tested, after which it changed little. Also, the aspect ratio of the juice column did not make much difference in the settling rate. The details of these experiments are presented in Appendix G.

5.2.5.5 Conclusions

Organoleptic testing indicated that not settling the juice prior to heating does not affect the taste of the syrup, and only marginally affects its appearance (adversely). However, settled mass appears in it if stored for one week or more. Therefore, it was decided to continue with the practice of settling the juice before heating. It was also found that a settling time of 90 minutes is optimum, and that the aspect ratio of the juice column does not make much difference so far as settling rate is considered.

5.2.5.6 Future work

Settling tanks of different shapes should be explored to see if they reduce the settling time. Ad-hoc experiments carried out during this project suggested that the settling rate is more in conical containers (tapering upwards) than cylindrical ones.

5.2.6 Determination of mucilage preparation strategy

5.2.6.1 Introduction

Mucilage is a gelatinous substance extracted from plants. It removes the suspended impurities from the juice by coagulating them, which then precipitate out as a layer suspended atop the juice.

To determine the mucilage to be used, the following aspects of mucilage preparation were experimented with: (a) type of okra fruit to be used, (b) amount of water to be added, and (c) amounts of mucilage to be added at different heating stages.

5.2.6.2 Type and form of okra plant parts to be used

Mucilage extracted from different okra plant parts in various forms was tried: dried okra fruit powder, dried okra fruit pieces, fresh okra stem and fresh okra fruits. Although the performance of all these alternatives, as far as scum generation is considered, was at par, fresh okra fruit was preferred because of the following reasons.

1. The syrup with dried okra fruit powder has suspended powder particles in it giving it a bad appearance. Moreover, the mucilage preparation is tedious and time consuming.
2. The mucilage prepared with dried okra fruit pieces lacks stickiness. This necessitates use of higher amounts per unit mass of SS juice.
3. It is not economically feasible to use fresh okra stem since cutting the stem mandates replantation. However, once the fruit production ceases the stems can be used for mucilage preparation.

Fresh okra fruit does not suffer from any of the above shortcomings and gives good mucilage. Note that this mucilage was prepared by soaking the fresh okra fruit pieces in three times the water (by weight of fresh okra fruit pieces) for about one hour and then mashing them by hand.

5.2.6.3 Concentration of fresh okra fruit pieces

After settling upon fresh okra fruits, experiments on the quantity of okra fruit to be added (for a given amount of SS juice) were performed. The results of these experiments are shown in Figure 40, where the scum obtained with different mucilage concentrations (defined as percent of fresh okra fruit used by the juice weight) is plotted. It is seen that in the experiments in which the juice was (a) settled (but not preheated), and (b) not settled at all, the highest scum quantity was obtained for 1.5% mucilage concentration. In the experiment in which the juice was preheated (to about 75^{0}C) *and* settled, the highest scum was obtained for 2% mucilage concentration.

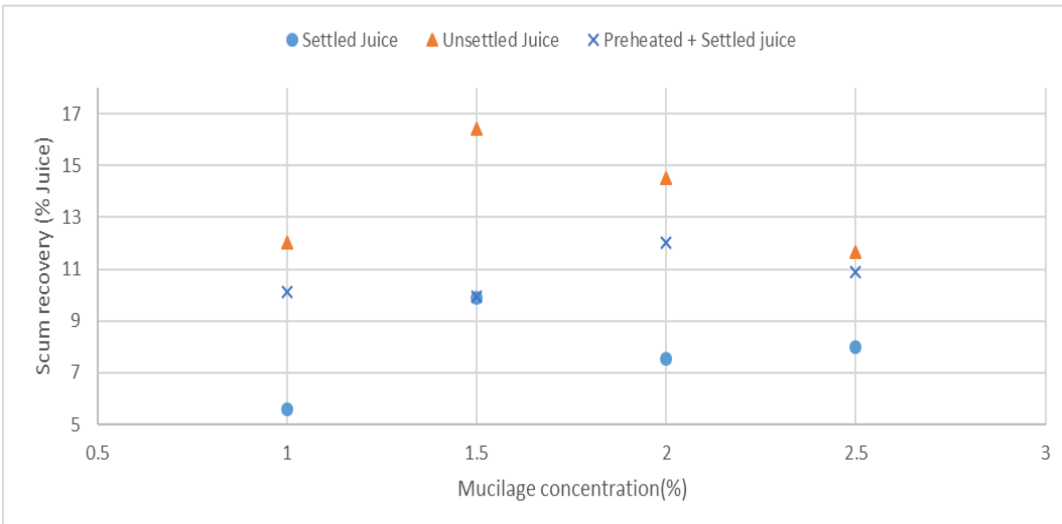


Figure 40: Scum obtained for different mucilage concentrations.

5.2.6.4 Proportion of mucilage to be added at different stages

Experiments were then performed to determine the proportion of mucilage to be added to the juice at different stages of the heating process. The following strategies of mucilage addition were tried.

1. No mucilage is added initially, and the first layer of scum can form on its own. This layer is removed, and 50% of the mucilage is then added. After removal of another scum layer, the remaining 50% of the mucilage is added.

2. 50% of the mucilage is added prior to heating and the remaining 50% after removal of the first scum layer.

3. Same as the above, except that the percentages in the two stages are 75% and 25%, respectively.

4. All the mucilage is added prior to heating.

Although quantitatively (that is, by the amount of scum obtained), there was little to separate these four approaches, the second approach resulted in faster scum formation and slightly better syrup appearance.

Hence, the strategy of adding 50% of the mucilage prior to heating and the remaining 50% after removal of the first scum layer was adopted.

5.2.6.5 Overall efficacy of the mucilage

To assess the overall efficacy of the mucilage, prepared and added using the methodology described above (that is, mucilage prepared with 1.5% fresh okra fruit pieces soaked in three times water for about one hour, half of which is added before heating and the other half after removing the first scum layer), the following experiments were done. In each experiment, two batches of syrup were prepared: in the first, no mucilage was added; in the second, mucilage was added using the foregoing strategy. The following quantities were measured: (a) scum obtained during heating, (b) clarity of syrup, (c) starch content in juice, syrup and scum. It was seen that mucilage addition leads to marginal enhancement in scum quantity, reasonable enhancement in syrup clarity, and reduction in syrup scum-content. The complete data of these experiments is presented in Appendix H.

5.2.6.6 Mechanization of mucilage preparation method

Earlier, the mucilage was obtained by squishing the soaked okra by hands. This added an element of subjectivity since the force applied during squishing varies from person to person. Moreover, it was noted that even when the labourers with above average strength did the squishing, a lot of mucilage was still left behind in the pulp. To address this, it was decided to use the SS stalk crusher for crushing okra too. The methodology for mucilage preparation that was decided after experimentation is presented in Appendix H.

Figure 41 shows that mucilage prepared using this method is clear and the discarded solid pulp hardly contains any mucilage. Also, the process is now standardized, convenient and takes about one-third the time taken for earlier manual process.


Figure 41: Left: discarded solid okra pulp; right: final mucilage.

5.2.6.7 Conclusions

Many experiments were performed to determine the best mucilage preparation methodology for maximum scum removal. To that end, the following aspects were looked at: form of okra to be used (fruit, stem, dried, fresh), quantity of okra fruit used by juice weight, amount of water to be added, time for which the okra pieces are to be soaked and proportion of mucilage to be added at different heating stages. It was concluded that mucilage prepared with 1.5% fresh okra fruit pieces soaked in three times water for about one hour, half of which is added before heating and the other half after removing the first scum layer, gives the best results. It was also seen that mucilage addition (desirably) reduces the starch content in the syrup.

The process of obtaining mucilage by squeezing the soaked okra pieces by hand involved a degree of uncertainty, since the force applied for squeezing varies from person to person. Accordingly, the concentration of mucilage varied, even when the quantity of okra fruit pieces taken to begin with was the same. To address that, process of squeezing the soaked okra fruit pieces was mechanized leading to both convenience and uniformity in quantity and quality of mucilage.

5.2.7 Measurement of starch

Introduction

The extent of sedimentation in the settling process is proportional to the starch content in the juice. In the SS varieties in the US, the starch content is high (Sherwood, 1923) (Table 21). As a result, typically, more than four hours of settling is required there. It is reported in literature from the US that if settling is not done for the requisite time, the sediments remaining in the juice will cause the juice to burn and stick to the pan. But here at NARI, burning of syrup was not observed even when the juice was not settled at all. It was speculated that this is perhaps due to low starch content of the juice in varieties grown at NARI. To that end, starch content in the juice, syrup and scum from three varieties grown at NARI was measured.

Table 21: Juice starch content data from 15 SS varieties in the US.

Average (of 15 readings)	3660 ppm
Minimum	1420 ppm
Maximum	8520 ppm

Results

The starch contents obtained are reported in Table 22. It is seen that settled juice has less starch content than unsettled juice, justifying the practice of settling. It is also seen that mucilage helps reduce the starch content in the syrup since it leads to formation of more scum.

Table 22: Starch content in SS varieties grown at NARI.

Variety	Starch content (ppm)					
	Juice		Syrup		Scum	
	Unsettled	Settled	Without mucilage	With mucilage	Without mucilage	With mucilage
Sugargraze	2620	2217	8503	5126	1954	2388
Madhura-2	1830	1056	3447	2244	3466	6647
Madhura-3	2676	1370	1376	720	5209	4452

5.2.8 Summary of crushing and settling section

Table 23: Summary of work done in crushing and settling section. Number of experiments done (wherever applicable) are given in brackets.

Work	Key impact/result
Installed new three-roller crusher	Improvement in crushing efficiency from 30% to 50% and rate by six-fold
Modified wet bagasse collection and spreading process (3)	Reduction in people reqd. from 4 to 1, easier handling
Fabricated juice filtration assembly, improved during project	Reduction in scum by 40%, clear syrup, obviation of filter choking
Installed new settling and storage tanks	Easy juice handling
Installed juice transport system	No juice loss due to manual handling
Experimented on effect of settling & its time on syrup quality (10)	Less scum during heating
Determined optimum mucilage preparation methodology, mechanized it (12)	Enhancement in scum and syrup clarity, reduction in time and effort, standardization of mucilage quality
Measured starch of juice, syrup & scum of different SS varieties (16)	Found that starch is less than US counterparts, so less settling required

Table 24: Manpower consumption in crushing and settling section for 50 kg syrup production.

Activity	**Required number of labourers**	**Number of hours per labourer**	**Total labour-hours**
Crushing of stalks	4	1	4
Wet bagasse spreading	2	0.25	0.5
Transferring dried bagasse to shed	2	1	2
Mucilage preparation	2	0.25	0.5
Washing of crusher and filtration assembly	1	0.25	0.25

Table 25: Equipment used in crushing and settling section.

Equipment	Power consumption	What it does
Crusher	7.5 hp	Crushes SS stalks to give juice / crushes okra for mucilage preparation
Centrifugal pump	1 hp	Pumps juice from collection tank to settling tank

Table 26: Scope for future work in crushing and settling section.

1. Develop an objective but simple technique of uniform feeding of stalks at a rate which gives high crushing efficiency and smooth operation.
2. Develop crushers more suitable for SS stalks; in particular, stalk feed-rate window for high crushing efficiency with smooth operation should be broad.
3. Develop simple and affordable mechanisms for bagasse transport. Conveyor machines and vacuum devices are two possible avenues.
4. Develop an objective criterion to recover as much clear juice from the settling tank as possible.
5. Explore different shapes for settling tank to enhance settling rate.

5.3 Heating

After settling, the clear juice flows by gravity through pipes to the heating pan kept over the furnace. The furnace is lit using the bagasse and leaves obtained from the previous SS harvest. The juice is heated till about 80 ^{0}C (measured with a digital thermometer); thereupon, the heating is stopped for half an hour to allow formation of a healthy scum layer atop the juice. This layer is subsequently removed, and the furnace is re-ignited. Post that, any scum, as soon as it appears, is removed swiftly but carefully. Finally, when the syrup temperature reaches 106^{0}C, the heating pan is promptly lifted through a mechanical lifter, and the syrup is poured into the cooling tank. A schematic of the heating process is shown in Figure 42.

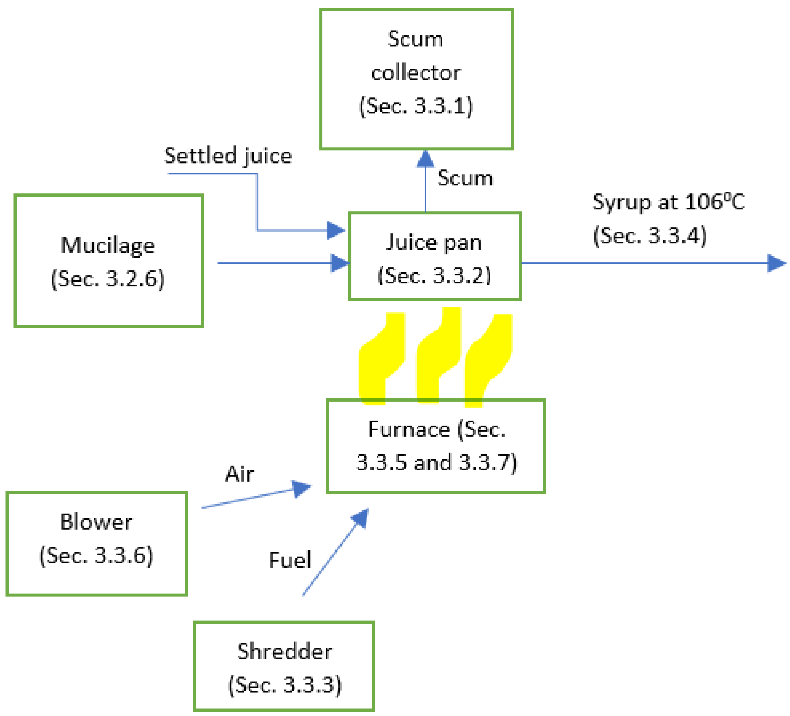


Figure 42: Schematic of the heating process.

The following major activities were carried out in the heating section:

1. Fabrication of scum collector and scum-removing ladles.
2. Designing of a heating pan.
3. Designing and fabrication of a bagasse shredder.
4. Correlating heating endpoint with syrup temperature.
5. Improvement of the old furnace.
6. Designing of optimum air-inlet mechanism.
7. Construction of new furnace and its improvement.

The details of each of these activities are presented below.

5.3.1 Fabrication of scum collector and scum-removing ladles

5.3.1.1 Introduction

Proper scum removal is crucial to obtain clear syrup. To that end it is important to simplify the scum removal process as much as possible.

Earlier, the scum-removing ladles were fitted with a stainless-steel mesh of size about 160 holes/inch (i.e., about 100 microns). This mesh size was chosen because for a finer mesh, a lot of clear juice would also be scooped out leading to wastage; and for a coarser mesh, scum removal would not be proper leading to cloudy syrup. However, even with mesh of size 100 microns, as the scum is scooped out with the ladle, some juice also accompanies it. The labourer then has to hold the ladle (or shake it gently) above the pan for about 10 seconds to allow clear juice to drip back in the pan; the filtered-out scum is then put in the waste bin. This process was found to be ineffective for the following reasons:

(a) It is tedious.
(b) At temperatures above 90^{0}C, the scum formation rate is high, and it is required to remove it quickly lest it dissolves back into the juice.
(c) As the syrup-making session proceeds, the ladle mesh pores get clogged and the dripping of juice back into the pan becomes even slower.
(d) Even so, some clear juice is always wasted in this process.

To get around this issue, it was decided to fabricate a scum collector with a provision to filter out scum and drain clear juice back into the pan. The scum collector is shown in Figure 43.

Figure 43: Scum collector. Top-row: usage during syrup-making; bottom: while not in use.

5.3.1.2 Determination of mesh size for scum collector

An experiment was performed to determine the optimum mesh size to be used in the scum collector. A mesh which allows clear juice to pass through but stops the scum over a time-order of a couple of hours was sought. A mesh of 100 microns was found to give optimum performance. The details of the experiment are given in Appendix I.

5.3.1.3 Scum-removing ladle

To further facilitate the scum-removal process, bigger scum removal ladles were fabricated. Each ladle spans 156 cm in length, has a bowl diameter of 30 cm and weighs about 1.4 kg (without scum), which is easy for the labourers to lift even when full of scum. It is shown in Figure 44. The ladle was fitted with a coarser mesh of 250 microns since it was found through experiments that over a time-order of a few seconds (which is what the ladle is supposed to hold the juice for), the ladle does not let any scum through.

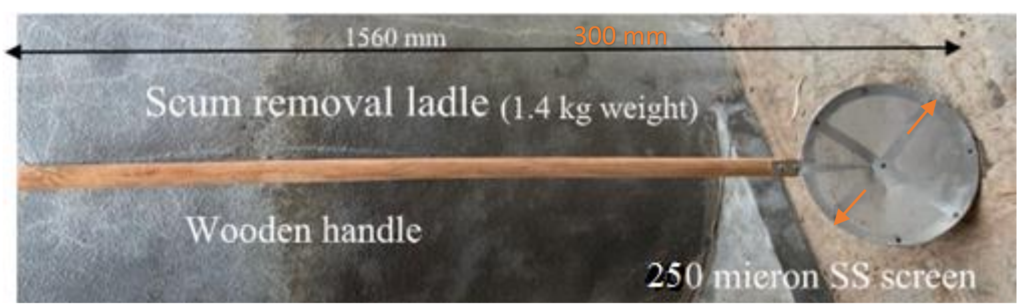


Figure 44: Bigger scum removal ladles. Top: close-up view; bottom: while in operation.

5.3.1.4 Conclusions

1. Scum-removal process has been significantly simplified. Earlier, at least three persons used to sit atop benches to remove scum. This restricted mobility and was uncomfortable, especially when the steam is dense. With a raised platform and the bigger scum removal ladle, only one person can easily remove the scum now (new furnace design is discussed in detail on Page 124).
2. Scum scooped out with a ladle is now immediately put in the scum collector without waiting for clear juice to drip out (as was the case earlier). This leads to faster, more convenient and more effective scum removal. Newly designed lightweight scum-removing ladles have further enhanced convenience.
3. About 10 kg juice that was earlier lost in a large-scale syrup-making session is recovered from the scum collector. This implies production of about 4% (2 kg) more syrup than before.

5.3.2 Fabrication of a heating pan

5.3.2.1 Introduction

For 50 kg syrup production per batch, approximately 300 litres of SS juice is needed. Furthermore, through bench-scale experiments, it was found that on heating the juice, its volume almost doubles. Hence, a pan with volume of 600 to 700 litres was sought. The cross-section of the pan was decided based on the height of the syrup at 106 ^{0}C: if the syrup height is too low, it can get caramelized even with a slight delay in lifting the pan.

Few trials were taken on the pan designed for sugarcane jaggery production at NARI since it had a 700 litres capacity. It was slightly tapered (from top to bottom) which facilitated scum removal.

5.3.2.2 Pan details

The specifications of the evaporation pan are provided in Table 27.

Table 27: Specifications of the evaporation pan.

Parameter	Value
Bottom diameter (mm)	1400
Top diameter (mm)	1500
Height (mm)	450
Thickness (mm)	1.3
Material	Stainless-steel 304
Capacity (litres)	700

To facilitate the complete drainage of the syrup from the pan, a tap of 37.5 mm diameter was installed near the bottom of the pan to rapidly drain as much of the syrup as possible (Figure 45). Four mild steel rings were fitted to lift the pan promptly when the heating operation was over.

Figure 45: Development of the evaporation pan. Left: drain near the bottom; right: zoomed out view of the pan.

5.3.2.3 Calibration of the pan

It is critical to correctly measure the amount of juice/water in the evaporation pan for accurate assessment of the performance of the set-up. For example, in water boiling tests, the furnace efficiency depends on the initial and the final volumes of water in the pan, which must thus be measured accurately.

Previosly, these volumes were estimated by assuming them to be conical frustums, which was not really the correct approach since the bottom of the pan is slighly curved. Hence, the evaporation pan was calibrated by adding known quantity of water and measuring the corresponding water level (Figure 46). For water level measurement, a detachable assembly consisting of a stainless steel scale has been fabricated (Figure 47).

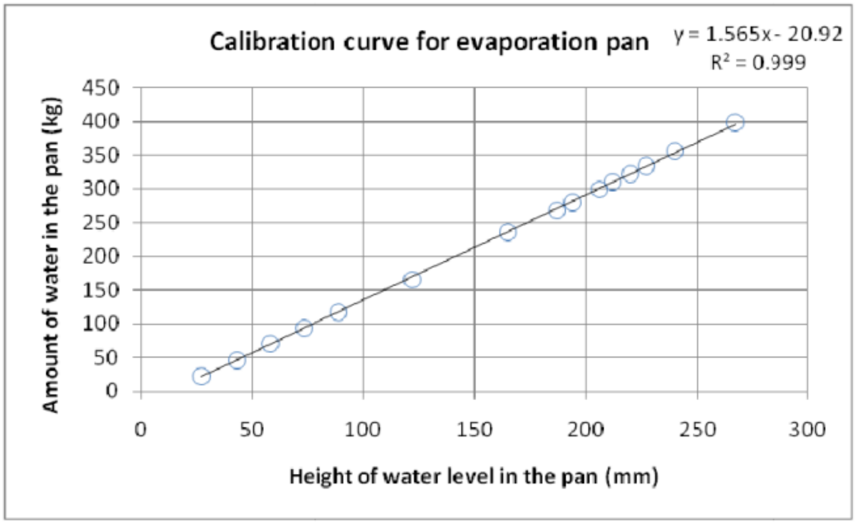


Figure 46: Calibration curve for the pan.

Figure 47: Stainless-steel scale for measuring juice level in heating pan.

5.3.2.4 Performance of the pan

Firstly, it has been observed that the volume and the cross-section of the pan are ideal for 50 kg SS syrup production. The juice does not spill over during heating, and the final syrup layer at the end of the heating process is about 2.5 cm, sufficient to prevent caramelization. Moreover, the design of the pan allows for convenient scum removal. After heating, the syrup drains easily and rapidly from the pan. A pan lifting mechanism (discussed below) ensures that the pan can be tilted as much as needed to drain out all the syrup.

5.3.2.5 Designing and installation of a pan-lifting mechanism

As mentioned before, it is crucial to lift the evaporation pan immediately after the temperature of the syrup reaches about 106^{0}C to prevent burning and caramelization of the syrup. Previously, the evaporation pan was lifted manually by four to six people by inserting two long wooden poles in the 4 rings on the periphery of the pan. This process was both cumbersome and perilous. Moreover, the chances of burning of syrup were high. To address these issues, a block-and-tackle mechanism has been installed to simplify lifting of the pan.

A description of how this mechanism was improved gradually is given in Appendix J. Photos of the mechanism are given in Figure 48. With this mechanism, a single person can easily complete the process of (a) fitting the frame in the O-rings of the pan, (b) lifting the pan, (c) shifting it sideways and (d) tilting it for syrup drainage, in about 4 minutes.

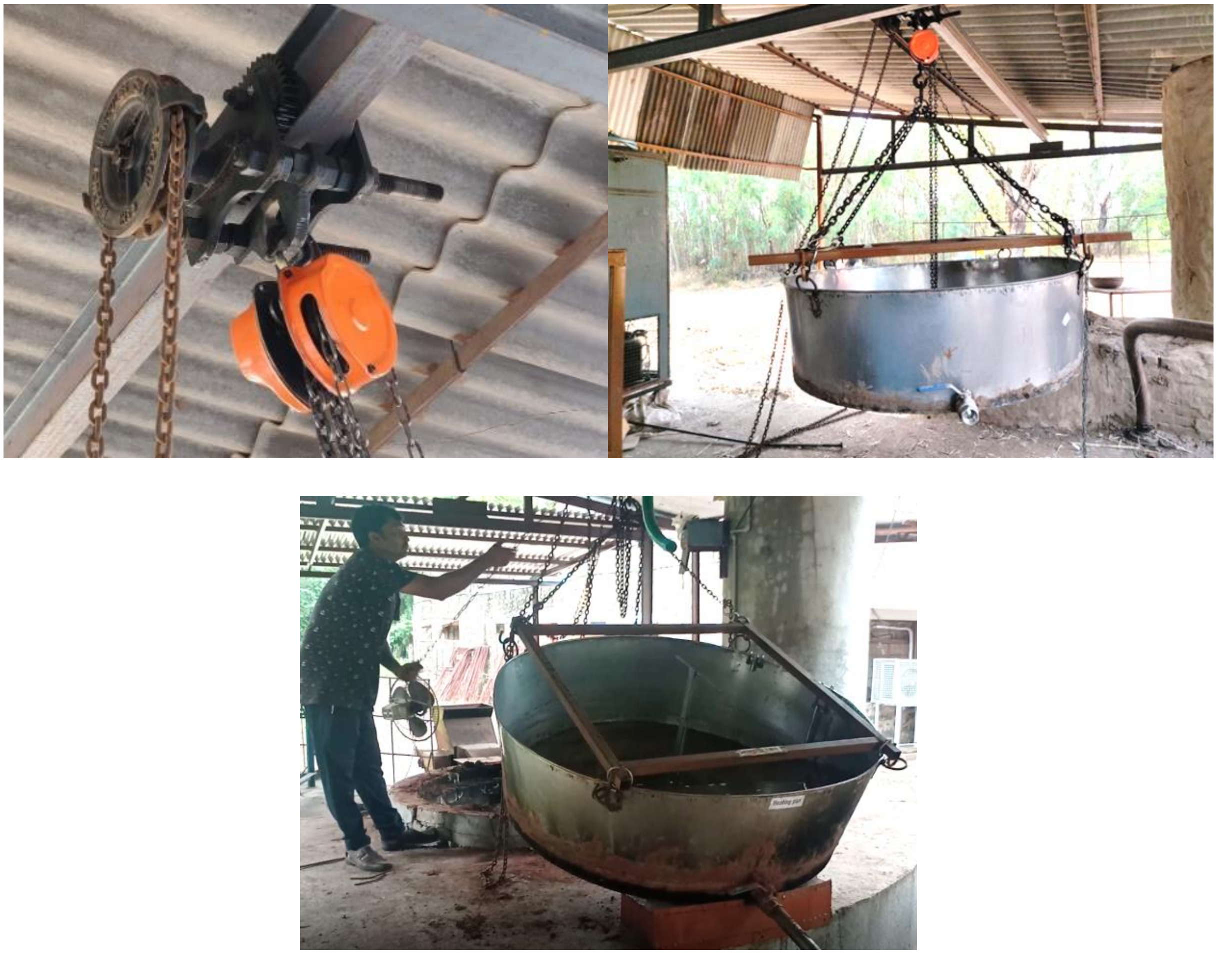


Figure 48: Top-left: new chain block; top-right: demonstration of lifting; bottom: tilting of pan for syrup drainage.

5.3.2.6 Conclusions

A 700-litres stainless steel evaporation pan has been designed. Its dimensions are well-suited for preparation of 50 kg syrup. Several features like large-diameter tap near the bottom for rapid syrup drainage, four mild steel rings for convenient lifting, tapered side walls to facilitate scum removal and a ruler for juice volume determination have been provided to make the heating process trouble-free.

To enable quick, safe and effortless lifting of the evaporation pan upon completion of heating, a block and tackle lifting mechanism was installed. As soon as the temperature scanner displays 106^{0}C, the pan is promptly lifted and the syrup is transferred, resulting in perfectly cooked syrup each time.

5.3.3 Designing of a bagasse shredder

5.3.3.1 Introduction

Previously, dried loose bagasse and leaves were fed as fuel to the furnace which was cumbersome because of the difficulty faced in handling loose mass. So, it was decided to shred the bagasse and leaves before putting them into the furnace. Even after shredding, manual feeding was found to be cumbersome. Options for mechanical feeding of the fuel were then explored.

There is a dearth of small-scale automatic bagasse feeders in the market. Also, they are expensive which makes them uneconomical for the pilot plant of the scale envisaged for this project. To that end, it was decided to develop a fuel feeder from scratch.

5.3.3.2 Fuel feeding strategies tried

Multiple feeding strategies were explored: (a) manual feeding using a drum and a guideway, (b) semi-mechanical feeding using a blower and a hopper, and (c) semi-mechanical feeding with a modified biomass shredder. These three designs are shown in Figure 49. Option (c) was finalized since it was found to be most convenient and effective. However, since the biomass shredder was primarily meant for chopping long green leaves for animals, several modifications had to be done for our purpose: its chute was modified and the rollers gaps were reduced. The details of these modifications, as well as the other feeding strategies that were explored are given in Appendix K. The specifications of the shredder are given in Table 28.

Figure 49: Fuel-feeding strategies tried. Top-left: a drum and guideway, top-right: a blower and a hopper, bottom: modified shredder (modified shredder was finalized).

Table 28: Specifications of the modified shredder.

Parameter	Value
Motor capacity	2.2 kW (3 HP), 3 phase
Biomass	All low density agricultural residues
Biomass feeding capacity	150- 180 kg/hr (biomass with shorter pieces) 120 – 150 kg/hr (biomass with longer pieces)
Air flow rate	120 kg/hr
Operators required	1

5.3.3.3 Performance

As mentioned in Table 28, the shredder can feed biomass at a rate of 120-180 kg/hr depending on whether it is composed of short or long pieces. Moreover, it also helps in uniform distribution of the fuel in furnace

(Figure 50). Finally, the shredder also provides air at the rate of 120 kg/hr, thus acting as a substitute air-blower for the combustion of volatiles and obviating the need for a secondary air-inlet.

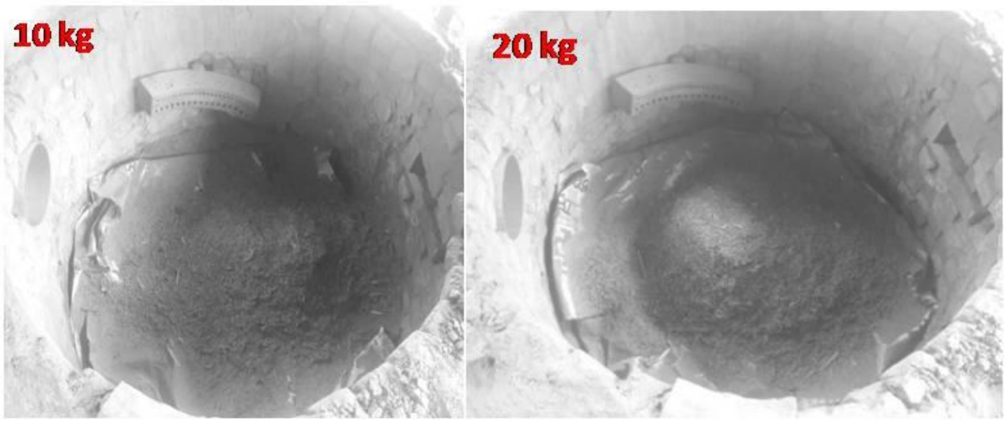


Figure 50: Distribution of shredded fuel in the furnace. Left: 10 kg batch; right: 20 kg batch.

5.3.3.4 Some other details

(a) While feeding through the shredder, care should be taken to ensure that the biomass is free of metal parts, rocks and wood to avoid damage to the blades.
(b) The biomass is fed manually into the hopper. A preliminary automatic conveyor feeder for this purpose was developed, but given the additional costs, this idea was not pursued further.

5.3.3.5 Conclusions

The shredder was modified to also feed the fuel into the furnace. To that end, its shute was modified, and an inlet was designed using a hopper. The shredder cum feeder has made the fuel handling extremely convenient and fast in comparison to the manual techniques employed previously.

5.3.4 Correlating heating end-point with syrup temperature

5.3.4.1 Introduction

To prevent caramelization, determination of a criterion at which the heating should be stopped is critical. Earlier at NARI, this criterion was syrup Brix (an indication of the total amount of soluble solids): it was found in separate experiments that a syrup with a Brix of at least 74^0 has the least chance of fungal infection on storage; moreover, the flowability of the syrup is good at this Brix. So, it was decided to stop the heating as soon as the syrup Brix reached 74^0 (Brix rises steadily once the temperature of the syrup crosses 100 ^{0}C).

However, it takes a few minutes to measure the Brix value of the syrup, which is excessive. For this reason, it was decided to correlate the Brix of the syrup with its temperature.

5.3.4.2 Determination of correct temperature at which to stop the heating

Several experiments were performed to obtain a correlation between the Brix of the syrup and its temperature (Figure 51). It is seen that the syrup Brix varies up to 5^0 for a given temperature. This is partially attributable to the absence of a perfectly one-to-one correlation between the two quantities, and partially to the low precision of the thermometer that was used in these experiments (the thermometer had a least count of 1^0C).

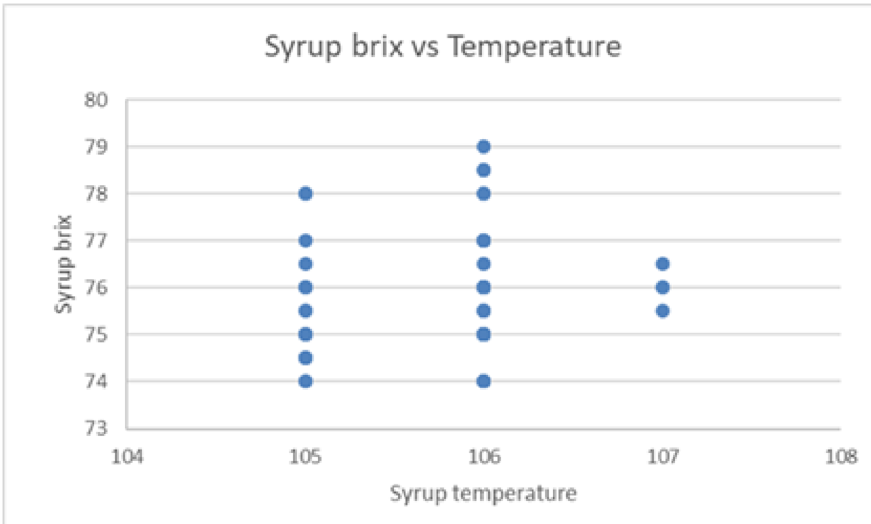


Figure 51: Variation in syrup Brix with temperature.

In another set of experiments, syrup samples at different temperatures were taken out from the heating pan (as the syrup was being heated) and their Brix values were measured. Figure 52 shows the data of one such experiment.

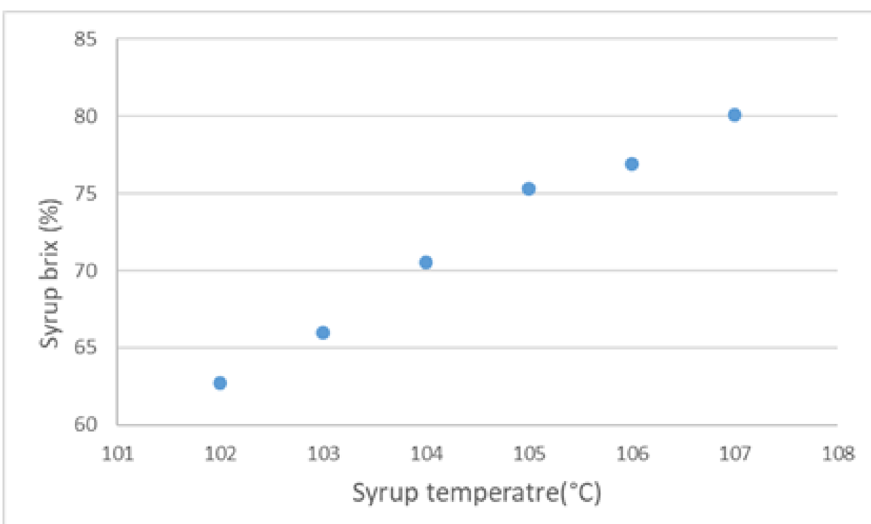


Figure 52: Variation of Brix with temperature for the same syrup.

Finally, multiple experiments were carried out where heating was stopped when syrup attained 105, 106, and 107^{0}C, and it was found that the resulting syrup had a favourable appearance, flowability and Brix content. Accordingly, the criterion for stopping the heating was fixed to be a syrup temperature of 106 ^{0}C.

Once the temperature criterion was fixed, focus was set on convenient and accurate measurement of syrup temperature. To that end, a digital temperature scanner was purchased. Also, many different temperature sensors were tried and finally PT100 sensor was finalized. Details follow below.

5.3.4.3 Digital temperature scanner

An eight-channel temperature scanner was purchased to monitor the temperatures at different locations in the furnace and the evaporation pan (Figure 53). Currently, four channels out of the eight available are used. Channel 1 and 2 are used to monitor juice temperatures at two different locations in the evaporation pan. Channel 3 measures temperature of the flue gases at the chimney inlet while Channel 4 measures temperature of the flue gases at the chimney outlet. K-type temperature probes and stainless-steel coated thermocouple wires were purchased along with the scanner.

Figure 53: Top: eight channel digital scanner (courtesy: Protek Instruments, Pune); bottom-left: K-type thermocouple probe; bottom-right: K-type thermocouple wire.

The scanner has a least count of 0.1^{0}C and has digital display to show the temperature readings. It has an auto as well as a manual scan mode making it easy for the user to see the temperature of the points of interest. The scanner has provision for setting alarms for critical temperatures (when the temperature exceeds the set value, the alarm beeps). For example, an alarm of 106^{0}C is set in Channel-1 to indicate heating endpoint. Similarly, an alarm has been set in Channel-3 to whenever chimney inlet temperature either drops below 400^{0}C or exceeds 800^{0}C for monitoring of fuel feeding rate. The scanner also has provision to connect different types of temperature sensors: thermocouple type-K, thermocouple type-T, RTD, etc.

However, the device suffers from the following shortcomings:

(a) Its wire (both electrical and temperature sensor) input mecahnism design is poor and requires the user to manually strip the wire-ends and insert them in closely-spaced tiny holes. This results in frequent short-circuits and loose connections.
(b) It is very sensitive to the signal from the K-type thermocouple sensor, showing highly oscillatory readings especially around heating endpoint.
(c) The procedure for adding an alarm is very complicated. Moreover, the tiny holes for wire insertions make adding an alarm in parallel an excruciating task.
(d) The procedure for changing the input sensor type is too complicated for a rural farmer to follow.

5.3.4.4 Determination of correct sensor for syrup temperature measurement

As mentioned in the previous subsection, it is extremely important that the heating of syrup be stopped at the right time, which through experiments was determined to be when the syrup temperature reaches about 106^{0}C. In that light, it is important that the sensor used to measure syrup temperature satisfies the following important criteria: (a) it measures the correct syrup temperature, (b) the measurement is steady and not fluctuating over a wide range, and (c) the sensor is robust (to handle required temperatures), food-grade and not excessively expensive.

During the course of this project, many different temperature sensors were tested. These trials are presented below in the order they were carried out.

1. Firstly, K-type thermocouple wires were tried. Though cheap, rugged and easily available, these sensors are highly sensitive to temperature change. This is an issue near heating endpoint since the syrup is very foamy, and the thermocouple tip is surrounded by ever-forming and collapsing air pockets, leading to a highly varying display temperature (the variation being up to 2^{0}C at times).
2. To address this, the thermal mass of the sensor was increased by coating the thermocouple tip with silicon glue (note that silicon is non-reactive). Although the noise in the signal reduced, variations of up to 1^{0}C were still observed.
3. Another method of increasing the thermal mass was tried: the thermocouple tip was dipped in oil (almond, safflower and lubrication) housed in a thin stainless-steel tube which was in contact with the syrup. This reduced the fluctuations significantly, but the response time of the sensor

increased so much that a lag of up to 10^{0}C from the actual temperature at typical juice heating rates occurred.

4. A Hanna *Checktemp1* thermistor consisting of an RTD sensor was then tried. Its performance was good, both in terms of stability and responsiveness. However, it was expensive (about Rs. 3,500), and not meant for rugged environments.
5. Finally, a Teflon-coated PT-100 sensor probe connected to the temperature scanner was finalized. Its performance was good in all respects.

Figure 54: Teflon-coated PT100 sensor used for measuring juice temperature.

5.3.4.5 Conclusions

Determination of a robust heating endpoint criterion is perhaps one of the most important steps towards standardizing syrup quality, since even a slight haste or delay in stopping of heating may lead to significant variation in syrup properties. To that end, the following steps were taken: (a) an optimum syrup Brix value was determined, (b) syrup Brix was correlated with its temperature to determine the temperature at which the heating must be stopped, and (c) an accurate digital temperature measurement system was installed. Unlike in traditional jaggery-making units where heating endpoint is determined by human judgement (e.g., in one of the methods, a small amount of jaggery is taken and dipped in water for rapid cooling, the resulting crystallized mass is then thrown against a metal sheet and if the resulting sound is metallic enough, the heating is stopped), this is an objective criterion.

5.3.4.6 Future work

The temperature scanner is poorly designed with regard to provision for connection of wires, adding alarms and changing input-sensor type. A more user-friendly device should be selected in future.

5.3.5 Furnace work: old furnace

5.3.5.1 Introduction

Previously, liquid petroleum gas (LPG) was used to make syrup from the SS juice. Approximately half kg gas is needed to make 1 kg syrup. For 50 kg syrup production, it requires 25 kg of gas which costs roughly Rs. 1400. Due to such high costs, use of LPG for heating was found to be uneconomical.

As is customary in the sugar industry, it was decided to carry out the heating on a furnace that uses SS bagasse, a by-product of the syrup making process, as the primary fuel. The following objectives were outlined towards building of the furnace:

A. Furnace should be fuel self-sufficient (the by-products of the syrup production process should provide enough heat energy). Also, furnace should work on agricultural residues commonly available in rural settings.
B. Furnace should provide the desired heating rate such that the heating process in the SS syrup-making finishes in at least four hours.
C. The furnace should be efficient and optimized for least pollution.
D. The furnace should be simple in design and easy to construct from locally available material.

5.3.5.2 Renovation of the old furnace

NARI had already developed a direct combustion, multi-fuel furnace to produce SS syrup (Rajvanshi & Nimbkar, 2001). The same furnace was also used to make jaggery from sugarcane. Before working on the optimization of the heating process parameters, it was decided to renovate this furnace by (a) plastering it with mud, (b) making provisions for air inlet and thermocouple wire connections, and (c) fabricating stands for scum removal. The details of the renovation are presented in Appendix L. A photograph of the renovated furnace is shown in Figure 55.

Figure 55: Old furnace, after renovation.

5.3.5.3 Determination of optimum furnace parameters

5.3.5.3.1 Introduction

Heating rate plays a crucial role in determining the syrup quality. A cursory look at the heating process reveals why. Initially, the juice is heated at a moderate rate: very slow heating leads to currents not strong enough for scum formation; rapid heating breaks the delicate scum layer which re-dissolves in the juice. When the temperature reaches 80 ^{0}C, it is maintained there for half an hour for maximum scum removal. Once most of the scum is removed, the juice is heated rapidly till the temperature is in the range 101-102^{0}C, whereupon it is heated slowly to avoid caramelization and darkening of the syrup. When the temperature reaches about 106 ^{0}C, the heating pan is promptly lifted off the furnace.

In bench scale experiments, where LPG is used, it is relatively easy to control the heat input rate (by simply turning the knobs of the heating devices used), and hence the juice temperature. However, on a pilot scale, where loose biomass is used as fuel, the heating rate must be controlled by varying parameters like the fuel-feeding rate and the airflow rate. Multiple experiments were carried out to determine the optimum values of these rates for production of good quality syrup.

Since it is uneconomical to produce syrup every time an experiment has to be done, water boiling tests (of equal scale) were performed to evaluate the furnace efficiency and optimize the heating parameters. Temperature was recorded with the help of a built-in digital thermocouple for computing the heating rate and the efficiency of the furnace. The details of these experiments are given below.

5.3.5.3.2 Determination of the fuel to be used

The first task was to choose an appropriate fuel for the furnace. Water boiling tests were carried out to test the performance of the following fuels: SS plus safflower threshed residues, pearl millet (bajra) threshed residue, sugarcane bagasse, SS bagasse plus SS leaves, shredded SS bagasse and SS leaves. In each test 270 kg of water was taken and its temperature was recorded. An equal fuel feed rate of 60 kg/hr was chosen for all the cases (densities of the tested fuels are given in Table 29). The resulting temperature-time curves are shown in Figure 56. It is seen that for all the fuels, roughly the same heating trend was obtained.

Table 29: Densities of the fuels tested.

Fuel	Density (kg/m^3)
SS bagasse	60
SS leaves	33
Mixture of shredded bagasse and leaves of SS	68
Sugarcane bagasse	62
Pearl millet (threshed residue)	42
SS plus safflower (threshed residue)	102

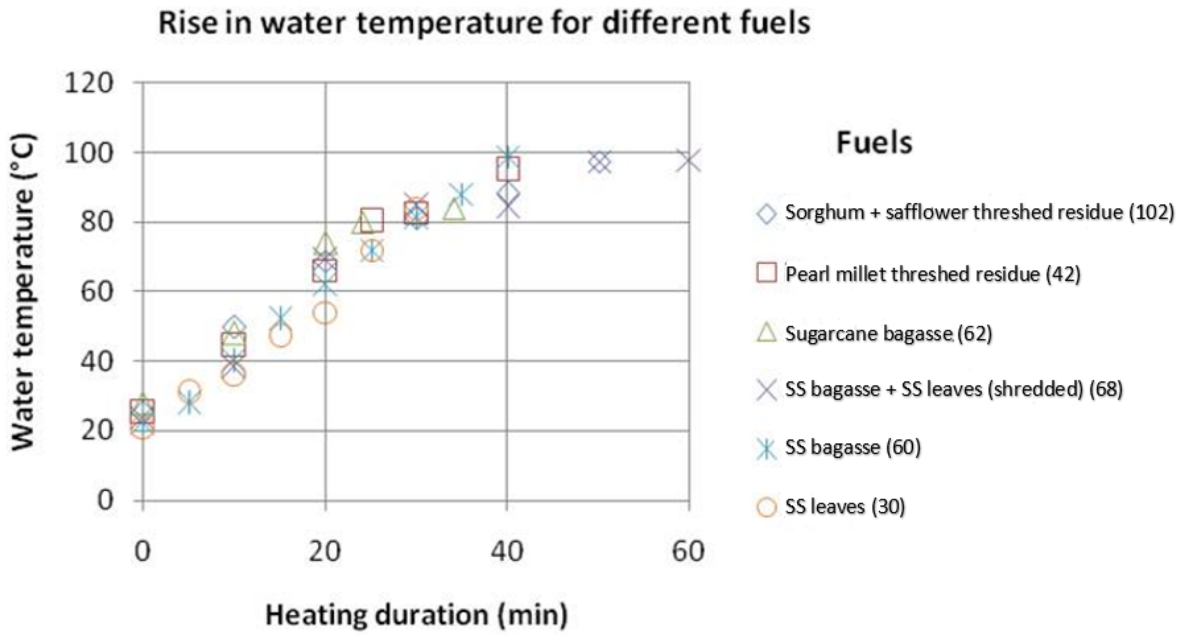


Figure 56: Rise in temperature with time for different fuels.

As stated earlier, one of the aims of this work is to develop a self-sufficient furnace. So, it was decided to use SS bagasse as the primary fuel. Also, the option pre-shredding of bagasse and leaves was discarded since it did not result in improved heating characteristics. Finally, since SS leaves due to their loose nature are difficult to handle, and thus, they were not an automatic choice for fuel if the bagasse was in short supply.

5.3.5.3.3 Determination of bagasse supplement

For pilot-scale experiments, the bagasse obtained from 1.2 tonnes SS biomass (needed to prepare 50 kg SS syrup) was sun-dried for better performance. As a result, its moisture content reduced from about 60% to 10%. After drying, the bagasse weight was found to be about 130 kg (or 120 kg on dry-basis; see the material flow diagram in Figure 57). Through separate experiments on furnace efficiency, it was found that about 180 kg bagasse (on dry basis) was needed to make 50 kg of syrup, implying that the furnace was not self-sufficient. It was decided to use other fuels to supplement the bagasse as it was more economical than diesel. The various supplements that were tried are: (a) wood, (b) diesel, and (c) SS leaves. Through experiments, it was concluded that leaves are a good supplement because (a) using them is in line of our objective of self-sufficiency, (b) they are cheap, and (c) they provide a desirable temperature-time profile. The details of these experiments are given in Appendix M.

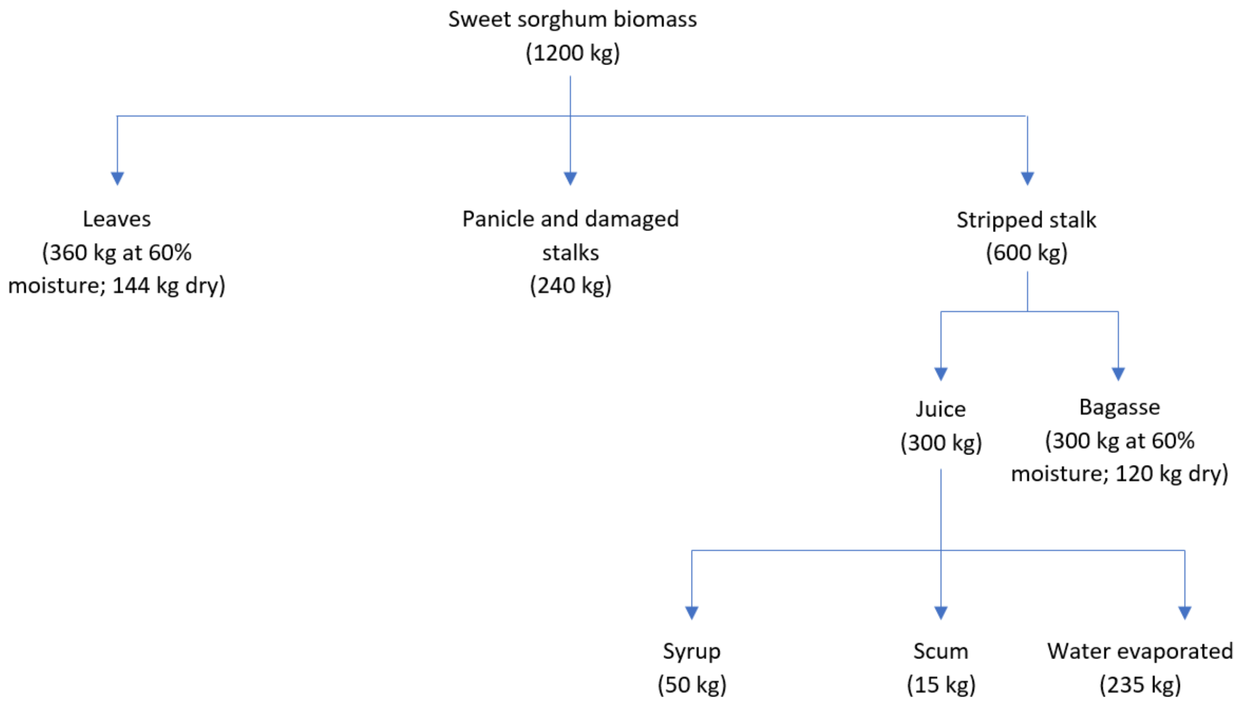


Figure 57: Material flow diagram for SS syrup plant.

<u>A note on use of bagasse-leaves combination with regards to furnace self-sufficiency</u>

After fixing the primary and the secondary (supplement) fuel, a detailed analysis of fuel self-sufficiency was carried out. The highlights of this analysis are presented below.

From the material flow diagram (Figure 57), it was found that 300 kg of juice needs to be boiled to get 50 kg syrup, i.e., about 250 kg water needs to be evaporated. This means that about 650 MJ energy needs to be supplied to the furnace. Since the gross calorific value of SS bagasse is 18 MJ/kg (dry) (Rajvanshi & Nimbkar, 2001), the amount of bagasse needed for fuel self-sufficiency, assuming a furnace efficiency of 20%, comes to 180 kg (dry). However, from the material flow diagram (Figure 57), only 120 kg dry bagasse is available. Hence with bagasse alone fuel self-sufficiency cannot be achieved (to achieve fuel self-sufficiency with bagasse alone, furnace should be 30% efficient). As seen in the previous section, usage of SS leaves (from the same biomass) made up for this shortage. If the calorific value of SS leaves is also assumed to be 18 MJ/kg on dry basis, then 180 kg bagasse plus leaves are needed with furnace efficiency of 20%; whereas from Figure 57 it is seen that a total of 264 kg bagasse plus leaves on dry basis are obtained. This can also be seen this way: if furnace efficiency is about 14%, then the furnace will be *barely* self-sufficient. In addition, panicles and damaged stalk can also be used as fuel, and if they are also included in the analysis, then a furnace efficiency of about 11% is enough for achieving fuel self-sufficiency.

A note on use of bagasse-leaves combination with regard to heating rate

As regards to the heating rate obtained with the bagasse-leaves combination, it is seen in Figure 56 that a temperature rise of almost 2^{0}C/min is obtained. This corresponds to a power input of about 42 kW. To produce 50 kg SS syrup in 8 hours (that is, 150 kg syrup per day), heating operation should finish in 4 hours' time (Figure 58).

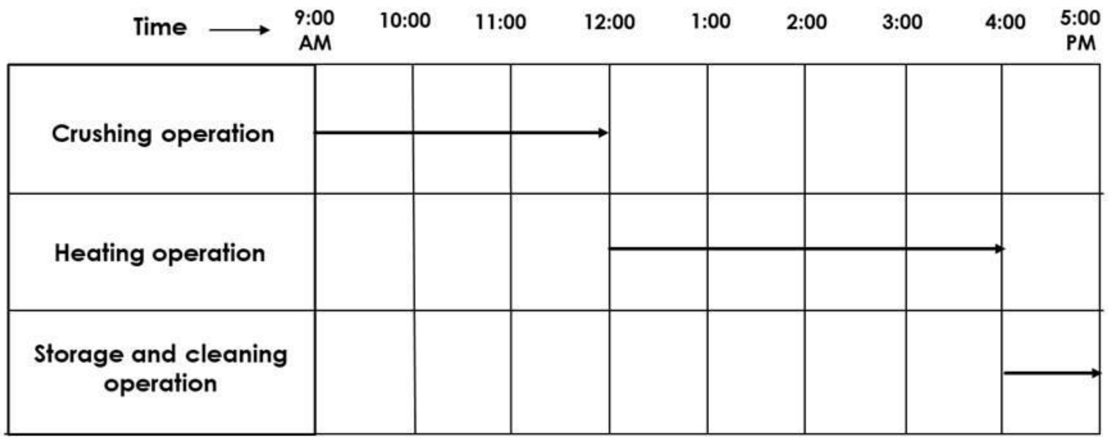


Figure 58: Time distribution for different processes to make 50 kg syrup in eight hours.

To boil 250 kg water in 4 hours (as discussed above), the furnace should have an average heating rate of about 45 kW. That is, at the time of the experiments in Figure 56, the heating was just below the required level. With improvement in furnace performance (discussed later), this issue was also resolved.

Finally, four more pilot-scale water boiling tests were conducted to check for fuel self-sufficiency, and it was found that the furnace was self-sufficient. Details of these experiments are given in Appendix N.

5.3.5.3.4 Determination of optimum fuel-feeding rate

It was seen above that the total amount of dry bagasse needed for the heating process is 180 kg. Since the time of heating for a batch is 4 hours, the required fuel-consumption rate comes to 45 kg/hr (dry). To check if this rate gives the optimum results, water-boiling tests were performed with different fuel-feed rates. The temperature-time curves in the initial stage of the heating obtained in these tests are plotted in Figure 59. From the figure, it is concluded that 60 kg/hr feed rate gives the most rapid temperature rise. Note that a further increase in fuel-feed rate will give so rapid an increase in water temperature that its boiling point cannot be controlled. Most importantly, it is concluded from Figure 59 that a fuel-feeding rate of about 45 kg/hr gives comparatively good results.

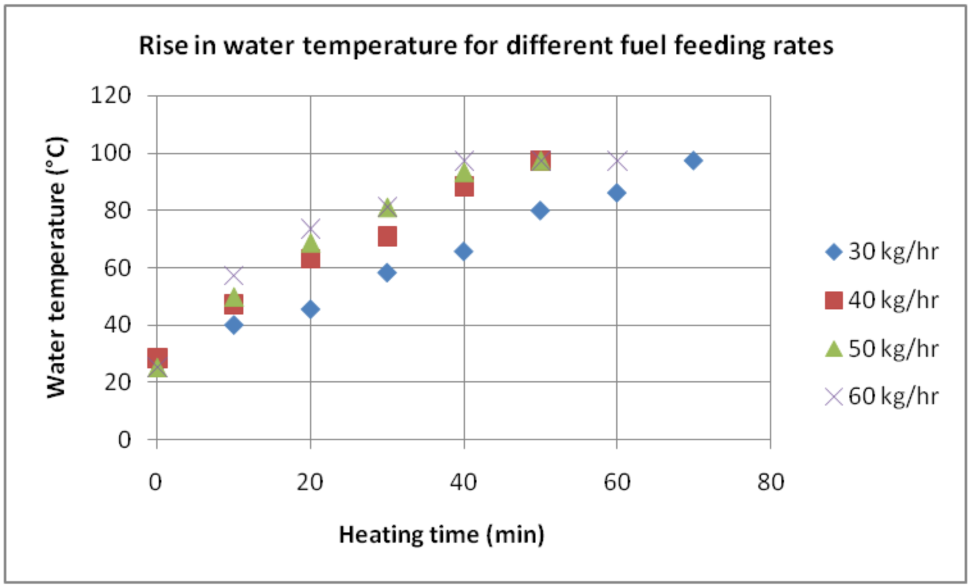


Figure 59: Temperature-time curves for different fuel-feed rates. 300 kg water was taken in the pan.

5.3.5.3.5 Determination of optimum biomass-feeding strategy

Introduction

Apart from fuel self-sufficiency, it is also envisaged that the feeding be convenient, the heating rate be fast and the smoke be minimal. The manner of bagasse feeding (batchwise versus continuous) plays an important role towards achieving these goals, as shall be seen below.

Earlier, during syrup preparation, the bagasse was fed in a batchwise manner. Thirty kg of bagasse was fed at once every 30 minutes, i.e., an average of 1 kg bagasse per minute (this rate was fixed through earlier experiments). Though furnace had achieved self-sufficiency, feeding 30 kg bagasse at once was found to be difficult and inefficient for the following reasons:

(a) The bagasse used to pile up in front of the feeding port (Figure 60), choking up the shredder chute and resulting in excessive backpressure through the feeding port.

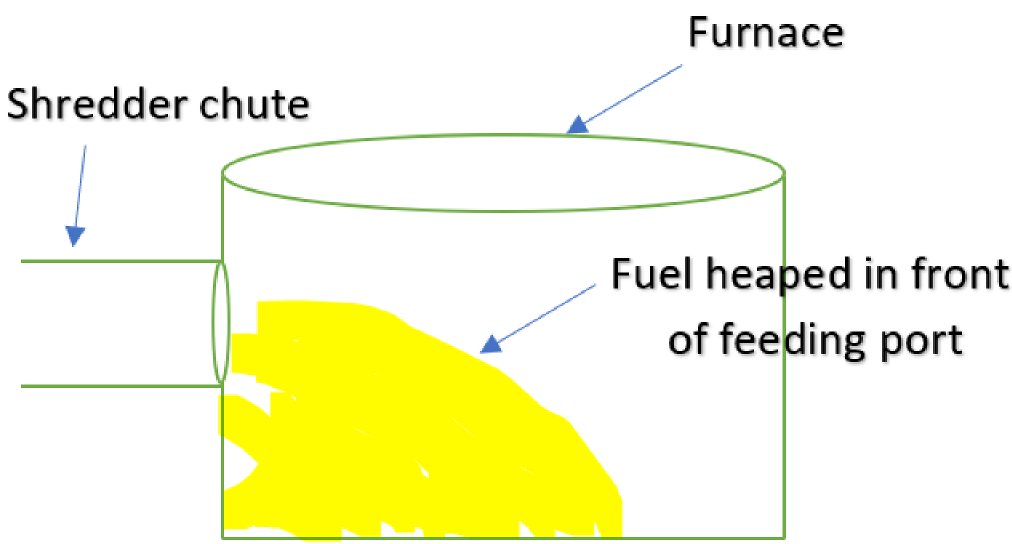


Figure 60: Fuel heaping in the front of the feeding port.

(b) The shredder hopper/conveyor also choked frequently due to excessive bagasse being fed at once.
(c) Piling up of bagasse led to its non-uniform combustion, leading to variable heating rate and intermittent heavy black smoke.
(d) The air blower had to be turned off during fuel feeding, leading to inefficient combustion.

To address these issues, water-boiling tests were performed with smaller batch sizes of bagasse, keeping the average feeding rate the same: 1 kg per minute. Two smaller batch sizes were experimented with: 6 kg per batch and 10 kg per batch. It was seen that while the average heating rate remained the same as with 30 kg batch-size (Figure 61), the other issues such as choking up of shredder and excessive smoke were significantly reduced.

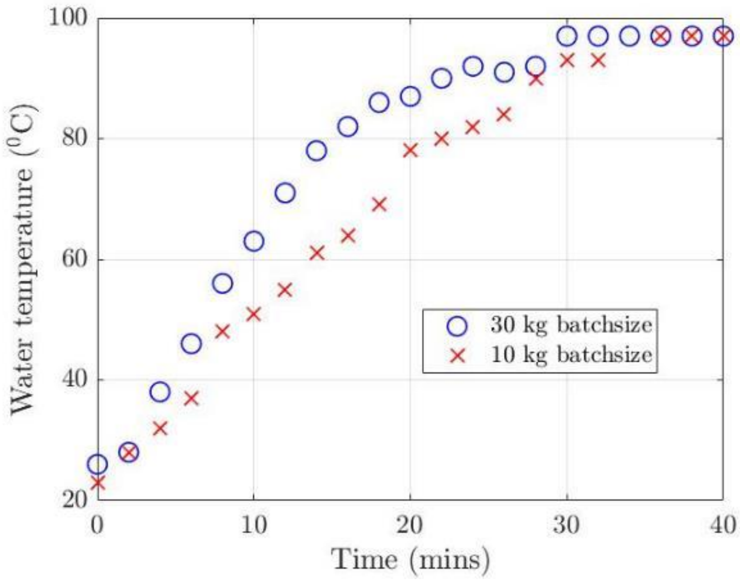


Figure 61: Heating rates with 30 kg and 10 kg fuel batches, with all other parameters being the same. It is seen that the rates are the same on an average. Note that in these experiments, the secondary air inlet ring was kept 150 mm above the primary air inlet manifold.

However, following drawbacks of smaller batch sizes were observed:

(a) Due to backpressure, the air blower had to be turned off while the bagasse was being fed. Since the feeding was done every 6 or 10 minutes, as the case may be, this meant that the blower was off for a significant amount of time. This resulted in shortage of air in the furnace, leading to incomplete combustion.

(b) Since feeding occupied a significant proportion of the total heating time, the feeding port was almost always open. This resulted in a lot of black smoke coming out through the feeding port, causing the feeder a lot of inconvenience.

Nevertheless, encouraged by the results of the shorter batch sizes, it was decided to feed the bagasse *continuously*.

Strategy for continuous feeding

For continuous feeding, it was decided to feed the bagasse in tiny amounts (of order of a few fistfuls). When to feed it was decided on the basis of the *chimney inlet temperature* (indicative of how hot the furnace is). If this temperature dropped below a threshold value T_a, the bagasse was fed. If the temperature went above a threshold value T_b, the feeding was momentarily stopped until the temperature dropped back sufficiently below T_b. Through ad-hoc experiments and experience, T_a and T_b were chosen to be 600^{0}C and 800^{0}C, respectively.

Moreover, it was decided to remove the secondary air inlet ring since it was causing a lot of back-pressure through the feeding port. This was happening because (a) the holes in the ring were oriented horizontally (Figure 62), (b) the ring was fitted at the level of the feeding port. This resulted in a lot of air, along with flue gases, escaping through the feeding port leading to backpressure.

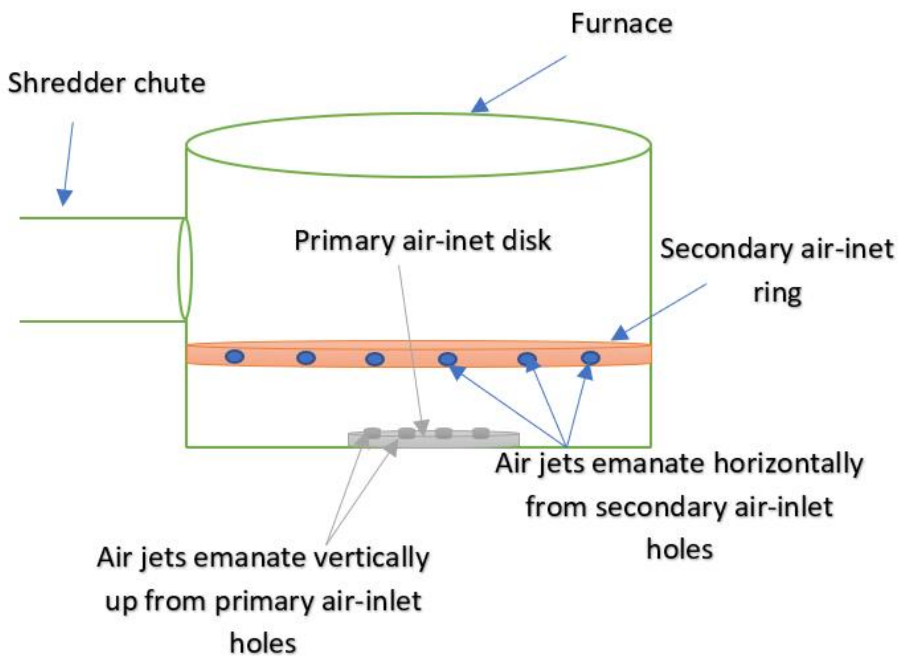


Figure 62: A sketch depicting direction of air jets emanating from primary and secondary air inlets. The secondary air inlet holes throw air jets in the horizontal plane which leads to backpressure build-up at feeding port choking the shredder chute.

Observations from water-boiling tests with continuous feeding

There were several notable improvements with continuous feeding, as listed below:

(a) The heating rate improved significantly. With batchwise feeding, it took about 35 mins on an average to heat 270 kg water from room temperature to boiling point; with continuous feeding, it took about 25 mins (Figure 63). Moreover, the heating rate remained constant through the experiment because of uniform and complete combustion.

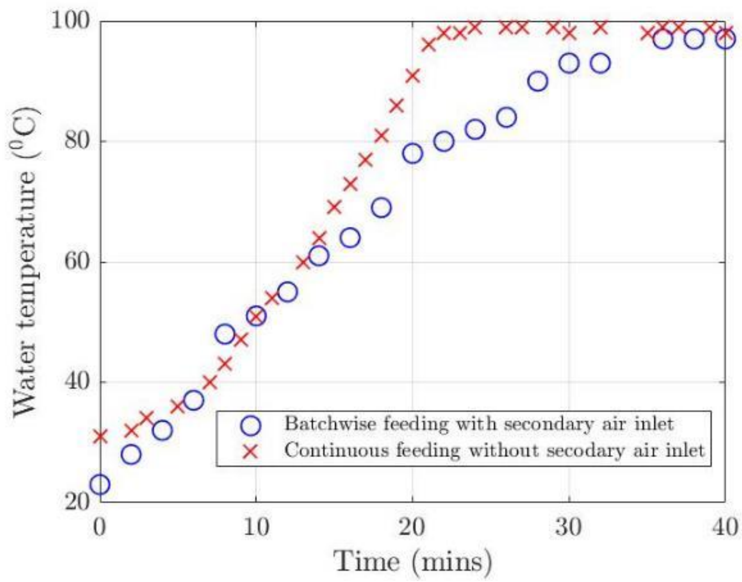


Figure 63: An illustration of heating rates with batchwise (30 kg batches) and continuous feeding. In the former, the secondary air inlet ring was used. The corresponding transient furnace efficiencies were 12.7% and 13.93%.

(b) The backpressure through the feeding port was reduced significantly since no fuel heaping occurred.
(c) The air blower did not need to be switched off or turned down at any time since the tiny bits of fed bagasse burn immediately leading to uniform dissipation of pressure through the chimney (unlike batchwise feeding where rapid combustion during feeding led to excessive backpressure).
(d) The shredder chute and the hopper did not choke.
(e) Again, due to excellent and uniform combustion, the smoke was transparent and clean.
(f) Finally, the transient furnace efficiency, defined as percentage of input energy utilized for heating of water, improved.

However, continuous feeding of bagasse is labour-intensive and engages at least one labourer continuously (whereas in batchwise mode, the labourer is engaged for about 5 minutes every 30 minutes, for instance). To ease the process of continuous feeding, the following work was done:

(a) a fuel-feeding cart was fabricated (details below),
(b) a preliminary conveyor system was developed, but not pursued further, and
(c) the option of shredding the bagasse immediately after crushing was also explored since shredded bagasse dries faster and is convenient to handle, but this was found to be economically impractical.

Fuel-feeding cart

To ease the process of continuous fuel feeding, a fuel-feeding cart was fabricated. The cart was designed to hold about 80 kg dry bagasse and its height was such that the bagasse could be directly raked out onto the conveyor belt of the shredder. To keep the cart light, 0.5 mm galvanized iron sheet was used in its fabrication.

Figure 64: Cart for storing bagasse and leaves during feeding.

The cart has significantly reduced the effort required in continuous feeding of bagasse with long pieces since about half the bagasse needed to make syrup can be filled at once in the cart and easily raked out. If bagasse particles are small, they cannot be raked out (since it needs to fed through shredder hopper) like the long bagasse pieces; nevertheless, the hand motion required to feed short bagasse pieces has also reduced significantly.

Conclusions

The feeding mode of bagasse was switched from batchwise to continuous. This has improved the heating rate, reduced the smoke, enhanced the furnace efficiency and made feeding more convenient. Further, a fuel-feeding cart was fabricated to make the process of continuous feeding convenient.

5.3.5.3.6 Determination of optimum furnace height

Introduction

Water-boiling tests were carried out to determine the optimum furnace height. Heights considered for these experiments were 60, 70, 90 and 110 cm (with 110 cm being the maximum achievable height due to infrastructural constraints). In terms of furnace volume, the four tests corresponded to 55, 64, 82 and

100% of maximum furnace volume achievable, respectively. The height of the furnace was varied by filling it up with ash to the desirable level. All other parameters were kept the same.

Observations from water boiling tests

Four criteria considered for judging the optimum height were: (a) heating rate, (b) smoke, (c) furnace efficiency, (d) convenience. The first three are plotted in Figure 65 below. Note that smoke is rated on a scale of 0 (clear smoke) to 3 (dense smoke) and the percentages of readings corresponding to each rating are plotted.

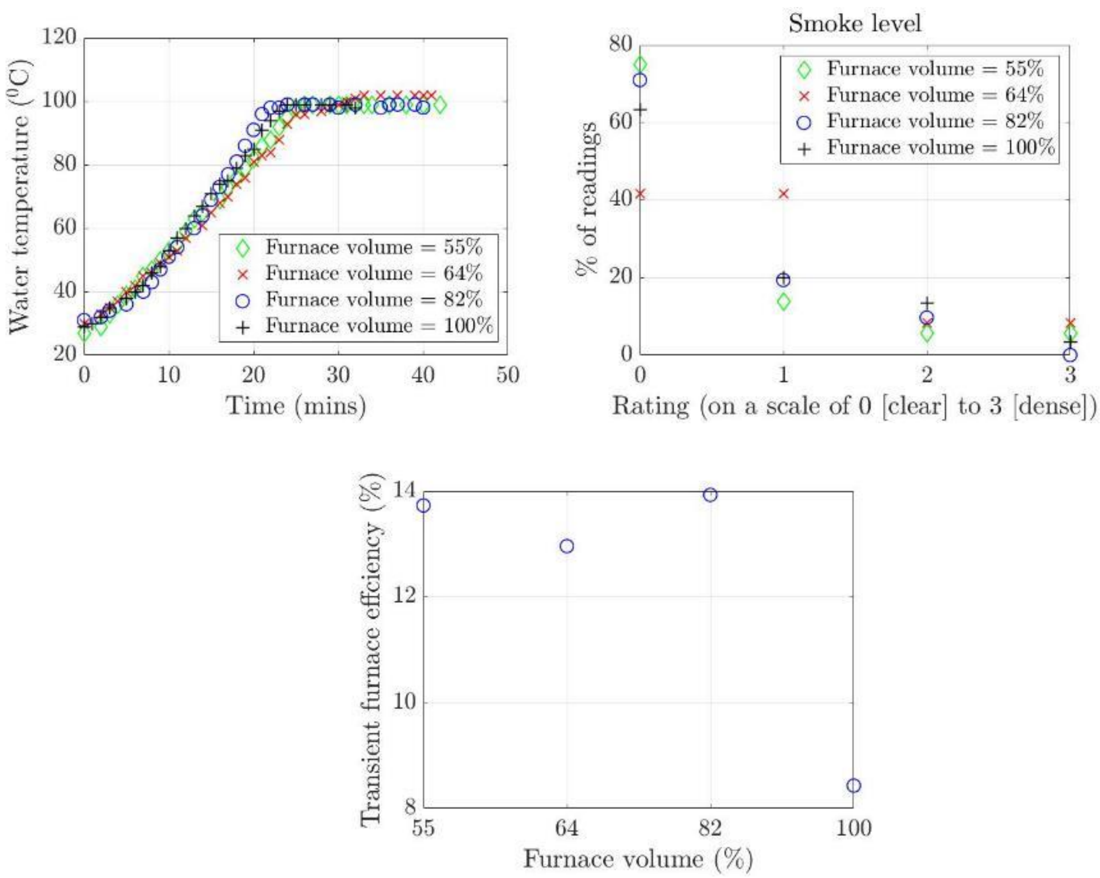


Figure 65: Comparison between different furnace heights. Top-left: water temperature versus time; it is seen that good heating rates are obtained in all cases with little to differentiate between them. Top-right: percentage of readings corresponding to smoke ratings on a scale of 0 (clear) to 3 (dense); it is seen that furnace volumes of 55% and 82% correspond to cleanest combustion. Bottom: transient furnace efficiency versus furnace volume (as percentage of maximum furnace volume); it is seen that the efficiency is good for all volumes except 100%.

Moreover, the following points were noted:

(a) At 55% furnace volume, the bagasse was heaping in front of the feeding port. It was having to be stoked continuously to make way for new bagasse, making it inconvenient.

(b) At 100% furnace volume, more bagasse per unit time had to be fed to maintain the desired chimney inlet temperature. This resulted in shorter experiment time and poorer transient furnace efficiency.
(c) Excellent turbulent fire was observed visually for 64 and 82% furnace volumes indicating that intermediate furnace heights are best for sustaining strong convection currents.

Furnace volume of 82% performed well on all four criteria. Accordingly, 90 cm was finalized as the furnace height.

Conclusions

Water boiling tests were done to compare four different furnace heights on four different criteria: (a) heating rate, (b) smoke, (c) furnace efficiency, (d) convenience. It was seen that the furnace height of 90 cm performed well on all four criteria and was finalized.

5.3.5.3.7 Determination of optimum obstruction at chimney inlet

Introduction

With introduction of continuous-bagasse feeding, although the heating rate and the combustion quality had significantly improved, the furnace efficiency improved only slightly. It was felt that this was because the flue gases escaped far too easily through the chimney instead of contributing towards heating of the pan. This was also observed visually: the flue gases seemed to be escaping through the chimney without seeing the pan. To resolve this issue, it was decided to increase the resistance faced by the flue gases in traveling outwards through the chimney. Two methods of doing this were devised:

(a) Placing an obstacle in front of the chimney inlet, and
(b) Increasing the obstruction inside the chimney pipe.

The above options were tried independently, as well as in combination. Many designs were tried and tested, and slowly an optimum design was arrived at. Nine water-boiling tests (WBTs) were done as different designs were tried. A flow-chart showing the chronological design evolution schematically is shown in Figure 66. The designs were evaluated on the following four parameters: (a) heating rate, (b) furnace efficiency, (c) average backpressure, and (d) average smoke. The details of these designs, and the experiments to test their performance, are given in Appendix O.

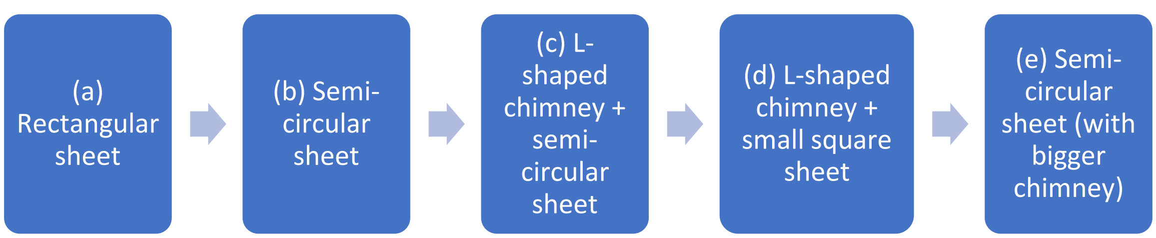


Figure 66: The chimney-obstruction designs evolved roughly in the manner shown above.

Results

It was seen that putting a semi-circular obstacle in front of the chimney inlet and increasing the radius of the chimney inlet from 8 to 10 inches (tried in WBTs 7 and 8) gave the best results. This is also noted from Figure 67 where it is seen that all the four evaluated parameters have desirable values for WBT 7 and WBT 8.

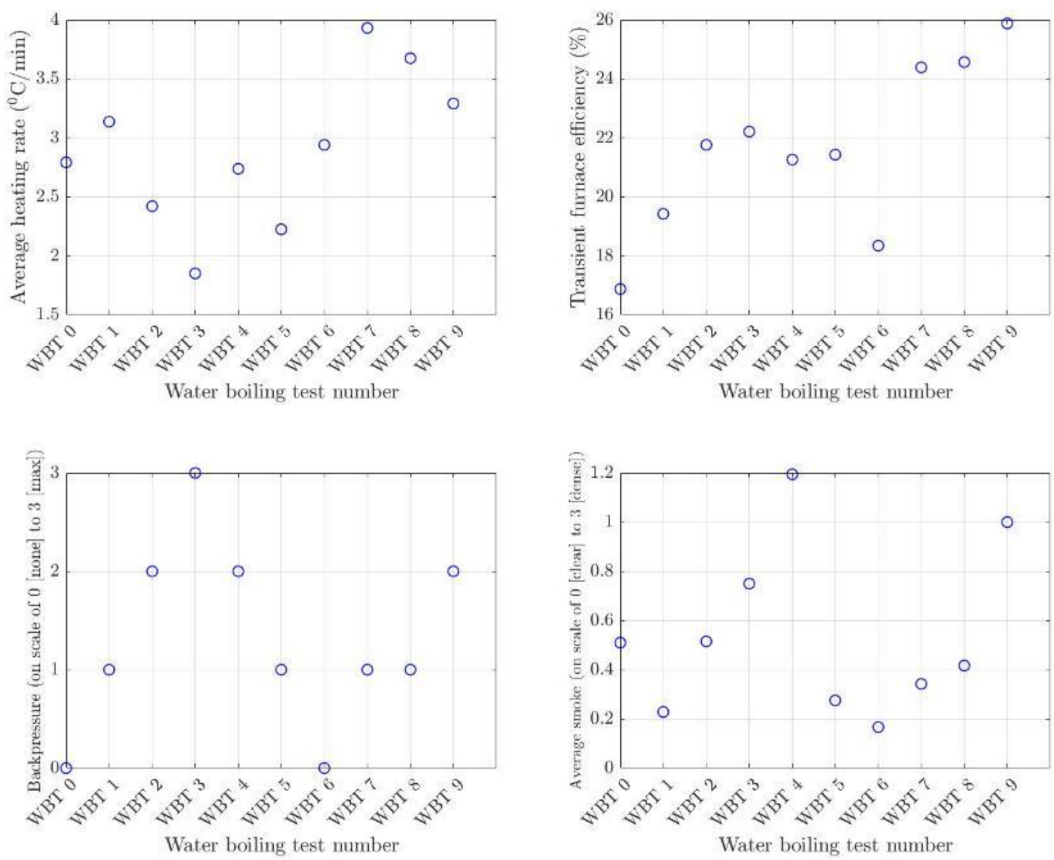


Figure 67: All the four parameters have desirable values for water-boiling test (WBT) 7 and WBT 8, corresponding to semi-circular sheet with 5 and 10 cm gaps between the pan-bottom and the obstacle top respectively, plus bigger chimney of 10 inches.

A non-dimensional parameter for evaluating furnace performance

The above four parameters: heating rate, furnace efficiency, backpressure and smoke level were combined into one single non-dimensional parameter to depict overall furnace performance. This parameter, called 'furnace performance parameter', p is designed to vary from 0 to 1 as furnace performance improves. Details on how p is calculated are presented in Appendix P. This parameter is plotted below in Figure 68. It is seen that p improved from 0.55 in mid-November (WBT 0) to 0.7 at December-end (WBTs 7 and 8).

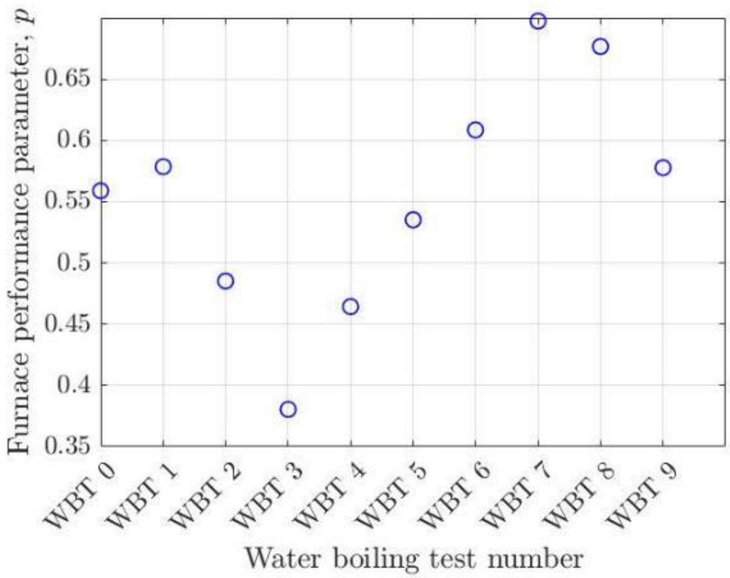


Figure 68: Variation of furnace performance parameter p with WBTs. It is seen that p has improved from 0.55 on November 15 (WBT 0) to 0.7 at December-end (WBTs 7 and 8).

Conclusions

Obstruction was added in the chimney inlet to prevent the flue gases from escaping the furnace via chimney too easily. This was done using two methods: (a) placing a barrier in front of the chimney inlet and (b) increasing the obstruction in the chimney by making it L-shaped. Water boiling tests with 270 kg water in pan were done to determine a design that performs well on the following four parameters: (a) heating rate, (b) furnace efficiency, (c) backpressure and (d) smoke. A non-dimensional parameter varying from 0 to 1 was defined to evaluate performance of each design. It was seen that this parameter improved from 0.55 with the original design to 0.7 with a semi-circular sheet placed in front of a bigger chimney inlet.

5.3.5.3.8 Determination of optimum feeding port location

A new feeding port which is at 90 degrees with respect to the chimney was tried and compared with the original port at 180 degrees. It was seen that the two locations gave similar results, and the feeding port at 90^0 was finalized owing to its convenience with regard to fuel-feeding. The details of the experiments performed are presented in Appendix Q.

5.3.5.3.9 Conclusions

Based on the experiments conducted on the already existing furnace, a small furnace of about kW capacity which satisfied the following four properties was designed:

(a) it is fuel self-sufficient,
(b) it provides the required heating rate (so that heating finishes in less than four hours),

(c) it is standardized and convenient, and
(d) it gives clean smoke.

5.3.5.3.10 Future work

1. A small amount of smoke comes out through the tiny spaces between the pan and the furnace, especially when the pressure inside the furnace is high. Preliminary pan-sealing mechanisms were designed and experiments were done to test their efficacy (Appendix R), but this work was not followed to the end due to large amount of time and effort needed. In future, affordable pan sealing designs can be investigated to further enhance furnace efficiency.
2. It is envisaged that furnaces of similar capacity, but even more compact size should be designed so that they can be manufactured at a central location and transported through cargo trucks. This will help in standardization of heating process, and also reduce furnace cost and construction effort.

5.3.6 Design of optimum air inlet mechanism

5.3.6.1 Theoretical estimation of air required

The air-flow rate is calculated based on the biomass-consumption rate of the furnace. Stoichiometric calculations showed that the amount of air required (with no excess air) for complete combustion is 4.9 kg/kg of dry bagasse. Since the bagasse consumption rate is 45 kg/hr (as shown previously), the theoretical air-flow rate required for complete combustion comes out to be 221 kg/hr.

Biomass fuels contain about 75% volatiles and hence most of the combustion occurs above the fire bed (Rajvanshi & Nimbkar, 2001). It is for this reason that two air inlets were provided: primary port for combustion of fixed carbon and secondary port for combustion of volatiles. The incoming air is split into the same ratio as that of the fixed carbon and the volatiles (18:76 or roughly, 1:4). Finally, it is widely reported in the literature that excess air should be used for increasing the efficiency of the combustion (Table 30). With an assumption of 50% excess air, the primary and the secondary air-flow rates are calculated to be 66 kg/hr and 266 kg/hr, respectively. The corresponding air-inlet settings were then determined using the corresponding calibration curves (Figure 155 and Figure 156).

Table 30: Excess air percentages reported in literature.

Sr. No.	Amount of excess air	Reference
1	0-200%	Tariq, A.S., Reupke, P. and Sarwar, G. (1994) Biomass combustion systems, Natural Resources Institute, Chatham, UK. ISBN 0-85954-385-4
2	5-50%	Sammy Sadaka, "Biomass Combustion", University of Arkansas, FS 1056.
3	38% (for fuel with 50% moisture)	C. Gopala rao et al., "Effect of air-fuel ratio on bagasse fired boiler performace", Energy management, Vol 17/1, Mar 1993, pp. 29-38.
4	50%	Biomass energy for heating and hot water supply in Belrus, UNDP, 17 Jun 2005.
5	25% (for fuel with 30% moisture)	Chapter 6, "Boiler efficiency", Introduction to boiler operation, University of Pune.

5.3.6.2 Installation of blower

A blower driven by a 3 hp motor and 650 m^3/hr capacity was used to supply air to the furnace for better combustion (Figure 69). The blower was provided with two outlets: a primary air inlet (to burn fixed carbon) and a secondary air inlet (to burn volatiles). Ball valves were fitted at each outlet to regulate the air flow inside the furnace. To measure the air-flow rate, orifice meters were fabricated (Figure 69). Details of how these air inlets were calibrated are presented in Appendix S.

Figure 69: Left: blower for supplying air to the furnace; right: orifice meter.

5.3.6.3 Installation of bigger primary air inlet

Introduction

The old primary air inlet had a diameter of 60 cm. It covered approximately 20% of furnace cross-sectional area (diameter of furnace is about 130 cm). Because of its small size, the following issues were faced:

(a) A lot of bagasse accumulated outside the span of the primary air-inlet, which mandated manual stoking (this problem became more pronounced after removing the secondary air inlet ring),

(b) It was found through stoichiometric calculations that an air-inflow rate of 200 m^3/hr is required for proper combustion inside the furnace; but since the number of holes in the primary air inlet were less, the velocity of incoming air was high. This had two adverse effects: (a) high backpressure through the feeding port leading to shredder chute choking and inconvenient feeding, (b) high flue gas escape velocity through the chimney leading to lower furnace efficiency.

To solve these issues, a bigger primary air-inlet covering half of the furnace cross-sectional ai fabricated. A photograph of the new inlet is shown in Figure 70. The new inlet has 80 holes in comparison to 36 in the old one (with the hole-size being the same: 0.5 inches), which means that for a given air flow-rate, the air velocity is about half of that in the former.

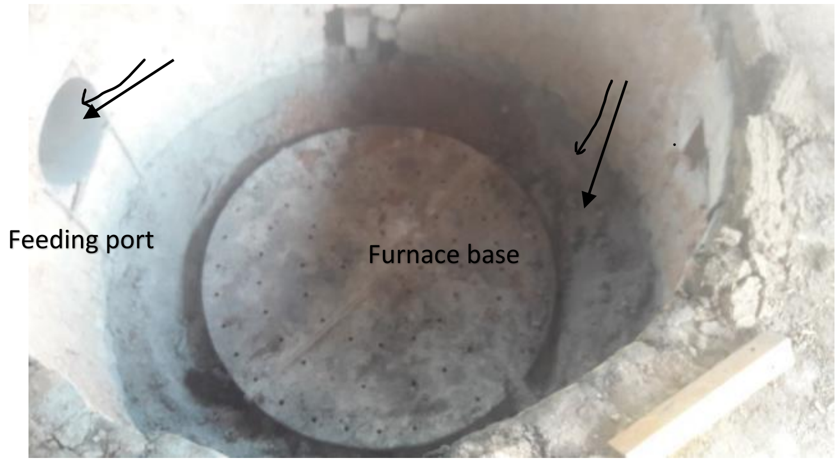
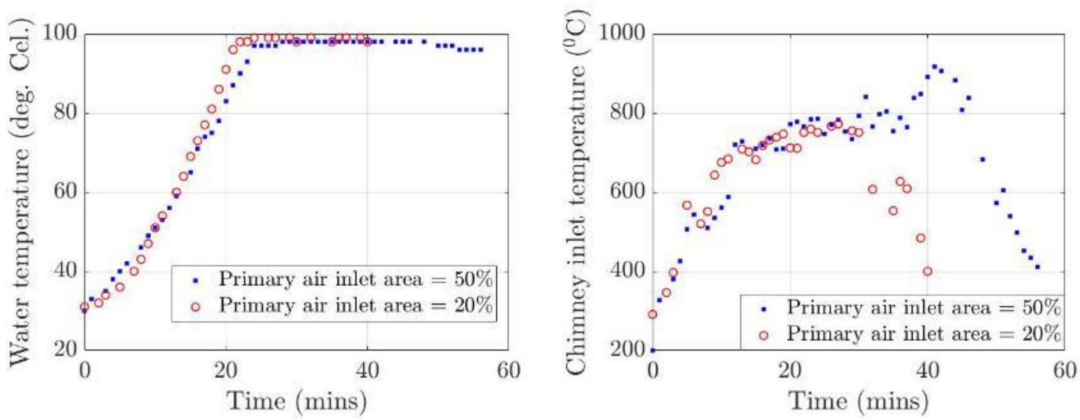


Figure 70: Photo (from top) of the bigger primary air inlet.

Observations from water-boiling tests

The performance of the two inlet manifolds is compared through results of water-boiling tests in which all other parameters were kept the same. Figure 71 shows (a) water temperature, (b) chimney inlet temperature (indicative of how hot the furnace is), (c) chimney outlet temperature, and (d) smoke ratings, obtained in these water-boiling tests.



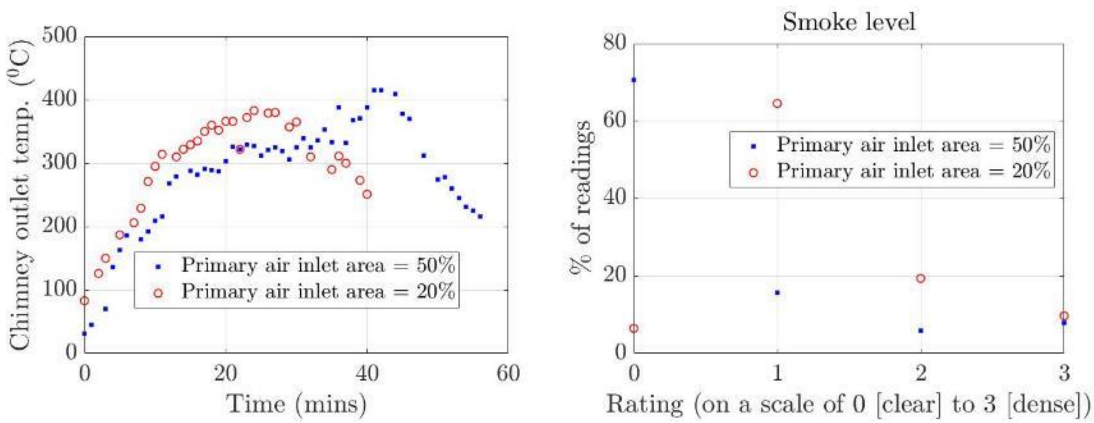


Figure 71: Comparison of the two primary air inlets. Top-left: water temperature versus time; it is seen that the heating rates are about the same, however, bigger inlet requires less fuel per unit time leading to longer experiment time. Top-right: chimney inlet temperature versus time; the fuel feeding rate was such that this temperature remains between 600 and 800 degrees-Celsius. Bottom-left: chimney outlet (CO) temperature versus time; lower CO temperatures were obtained with the bigger inlet, owing to the lower velocity of the air coming out through the inlet. Bottom-right: percentage of readings corresponding to smoke ratings on a scale of 0 (clear) to 3 (dense); it is seen that most of the readings (about 70%) with the bigger primary air inlet correspond to smokeless combustion.

Other observations from the water-boiling test with the bigger primary air inlet are listed below:

- The transient furnace efficiency was 16.87% (as compared to 13.93% with the smaller inlet).
- Backpressure through the feeding port was minimal.
- Shredder chute did not choke.
- No stoking was required. In comparison, with the smaller inlet, about five minutes of stoking was required to sustain fire in the end.

Conclusions

A bigger primary air-inlet which is about 2.5 times bigger in area than the old inlet and covers about half the furnace cross-sectional area has been installed. With the new inlet, (a) backpressure through the feeding port has reduced, (b) stoking is not required, (c) furnace efficiency has improved, and (d) smoke has reduced.

5.3.7 Furnace work: new furnace

5.3.7.1 Construction of new furnace

Since the old furnace was about 25 years old, several cracks had appeared in its walls. This led to both smoke and flue gases escaping through the furnace leading to low furnace efficiency and causing pollution. Moreover, the strength of the whole structure (furnace + chimney) had also reduced significantly after many repairs. It was thus decided to make a new furnace and chimney.

The new furnace incorporates all the modifications that were made in the old furnace in the course of this project: furnace volume, feeding port location, bigger chimney inlet with semi-circular obstacle and space for scum collector. In addition, the following features have been added:

(a) A raised platform alongside furnace for ease of scum removal. Earlier, the labourers used to sit atop a stool to remove scum. That arrangement (a) restricted their mobility, due to which two to three labourers were required, and (b) was inconvenient. The raised platform addresses both these issues: only one labourer is required since she/he can easily move around the periphery of the pan.

(b) The inner diameter of the furnace has been reduced by 10 cm (135 to 125 cm) to increase the resting area of the pan, whose base diameter is about 140 cm. This reduces the pressure on the furnace and also prevents the flue gases from escaping through gaps between pan-bottom and furnace-top surface.

A schematic of the new furnace and an actual photograph are given in Figure 72. A collage showing the construction work is shown in Appendix T.

Figure 72: Left: A schematic of the new furnace; right: actual photo.

5.3.7.2 More features added in the new furnace after construction

5.3.7.2.1 Ash screen

Sometimes, ash particles enter the juice while it is being heated, especially in the event of one or more of the following: (a) windy weather, (b) high backpressure through furnace feed-port, (c) usage of leaves as fuel (leaf-ash is very light); and the tiniest of the ash particles survive through to the final syrup escaping the intervening filtration. This problem was tackled with two simple design modifications: (a) blowing the ash particles away from the juice using a table fan and (b) fitting a flat metal sheet over the furnace-feed port to block the ash particles. The fan also serves additional purposes of (i) blowing the steam away when it is extremely dense for convenient scum removal and (ii) preventing the impending overflowing of syrup during heating by killing the foam. These two modifications are shown in Figure 73.

Figure 73: Fan for blowing away ash particles away from the juice and sheet to block them.

5.3.7.2.2 Plastering shed floor with cement

The area in front of the furnace feeding port was plastered with cement for the following reasons: (a) it makes the movement of the shredder and fuel-feeding easy, and (b) it prevents small stones from getting mixed with bagasse while feeding (which may damage the shredder blades) (Figure 74).

Figure 74: Area in front of the feeding port was plastered with cement.

5.3.7.2.3 Raised platform for pan tilting

Earlier, the valve extension pipe shown in Figure 75 used to get in the way of with the cooling pan upon tilting the heating pan by more than 15 degrees or so. To address that, a raised platform was constructed as shown in Figure 75 so that the heating pan could be tilted up to 45 degrees for effective syrup drainage.

Figure 75: A raised platform was constructed for convenient pan-tilting.

5.3.8 Summary of heating section

Table 31: Summary of work done in heating section. Number of experiments done (wherever applicable) are given in brackets.

Work	Key impact/result
Fabricated scum collector, improved its design; fabricated big scum removing ladles (3)	Reduction in juice loss and number of people required (from 3 to 1), convenient scum removal
Fabricated SS304 heating pan	Effective heating, easy handling, food-grade standard
Designed pan lifting and tilting mechanism (3)	Quick and safe operation, reduction in number of people required (from 4 to 1)
Designed a biomass shredder cum feeder cum air blower (6)	Convenient and uniform feeding of fuel
Correlated syrup end-point with its temperature (25)	Objective and easy determination of syrup end-point

Installed digital temperature recorders, explored many temperature sensors for determining syrup end-point (6)	Uniformity in syrup quality, prevention of burning/caramelization
Determined optimum furnace design parameters (65)	Enhancement in furnace efficiency
Determined optimum biomass-feeding strategy (continuous feeding rather than batchwise) (5)	Enhancement in furnace efficiency and heating rate, reduced smoke
Fabricated fuel-feeding cart	Convenient handling and feeding of loose biomass
Added obstruction at chimney inlet (13)	Enhancement in efficiency and heating rate, but increase in backpressure
Constructed new furnace	Reduced loss of flue gases, more convenient syrup-making
Made design modifications to prevent ash particles from going into the juice during heating (3)	Clear syrup
Designed an air-inlet manifold, made modifications in air blower, determined optimum air-flow rate (10)	Enhancement in combustion efficiency, reduced backpressure, safe working conditions

Table 32: Manpower consumption in heating section for 50 kg syrup production.

Activity	**Required number of labourers**	**Number of hours per labourer**	**Total labour-hours**
Collection of 200 kg bagasse in fuel carts	2	0.5	1
Feeding of fuel	1	3.5	3.5
Scum removal	1	3	3
Shifting and tilting of pan for syrup transfer	2	0.1	0.2

Table 33: Equipment used in heating section.

Equipment	Power consumption	What it does
Shredder	3 hp	Shreds and feeds bagasse and leaves mechanically to furnace, provides secondary air for combustion of volatiles
Air blower	1 hp	Provides air for combustion of fuel
Digital temperature scanner	10 W	Measures temperature of syrup, chimney inlet and chimney outlet

Table 34: Scope for future work in heating section

1. Survey market for a more robust and user-friendly temperature-recording device.
2. Design a simple and affordable pan-sealing mechanism to further enhance furnace efficiency.
3. Develop compact furnaces of heat output of about 70 kW which could be transported easily.

This concludes the work done in the ‘heating’ section.

5.4 Cooling and storage

As mentioned before, when the temperature of the syrup reaches 106 ^{0}C, the pan is promptly lifted, and the hot syrup is poured into a container by tilting the evaporation pan (using the block and tackle mechanism) (Figure 76 shows a schematic of the cooling process). The syrup is cooled rapidly to below 60^{0}C whereupon it is transferred to storage containers/bottles. These containers are then kept in an air-conditioned room.

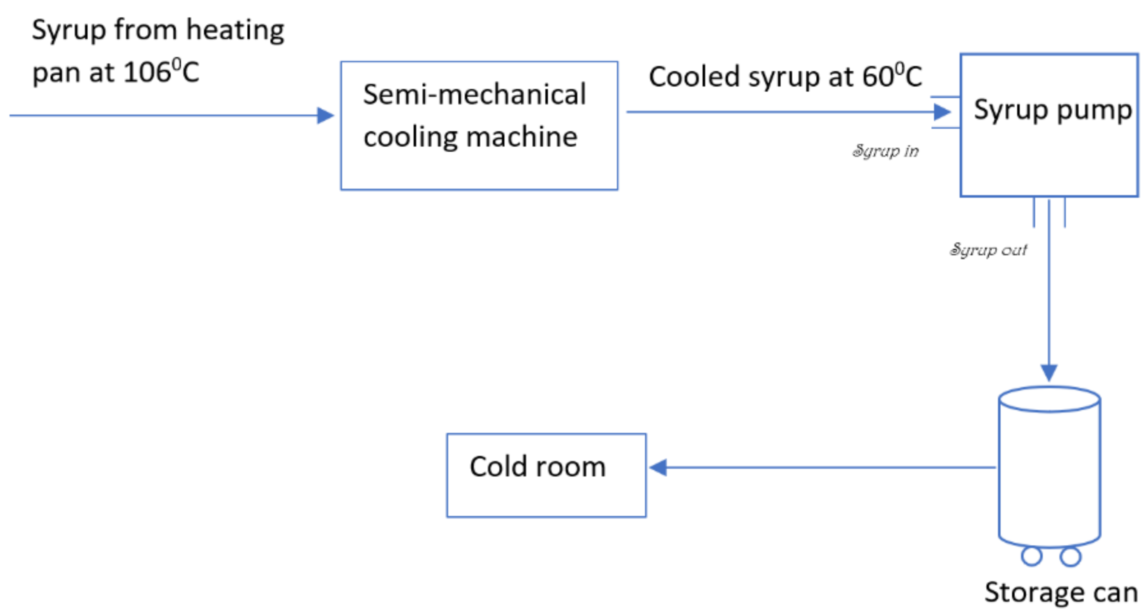


Figure 76: Schematic of the cooling process.

The following major activities were carried out in the cooling and storage section:

1. Determination of dominant mode of cooling.
2. Development of a semi-mechanical cooling device.
3. Determination of optimum conditions for storage.
4. Correlating syrup Brix with flowability.
5. Correlating syrup clarity with light transmissibility.
6. Installation of syrup pump, cleaning pump and cold-room.
7. Floor and shed work.

The details of each of these activities are now presented.

5.4.1 Determination of dominant mode of cooling

5.4.1.1 Introduction

Post heating, the temperature of the syrup needs to be brought down from 106^0C to below 60^0C rapidly, failing which the syrup becomes dark in colour. To prevent that, an effective cooling mechanism is required.

Previously at NARI, since the syrup was prepared on a small scale, the syrup from the pan was poured into stainless-steel buckets, which were then placed in a plastic tub filled with tap water for cooling. The syrup in the buckets was stirred thoroughly with the help of ladles to facilitate heat transfer. It took 15 to 20 minutes to reduce the temperature of the syrup from 106^0C to 60^0C.

For pilot scale, the same approach was followed: the cooling was done by pouring the 50 kg syrup into two identical aluminium pans submerged in water and stirred with two ladles to facilitate heat transfer between hot syrup and surrounding cool water. This process was both cumbersome and slow: it took about 15 minutes to cool the syrup. To address this, experiments were conducted to determine the most effective heat transfer mode while cooling.

5.4.1.2 Set-up

An initial syrup cooling design involved pumping syrup out of syrup container into a pipe fitted above the container. Four holes were drilled in the pipe through which the syrup would fall back into the container. This design is shown in Figure 77. It was envisaged that syrup will be cooled by natural convection through air.

Figure 77: Preliminary cooling device that used cooling by natural convection through air.

Three experiments were conducted. In the first, the set-up shown in Figure 77 that only involves pumping of syrup into the overhead pipe was used (denoted as 'only pump'). In the second, the syrup pan was also put in a water tank ('pump + water'). In the third, an air-cooler was also added ('pump + water + air-cooler'). In all the experiments, 25 kg syrup was heated to 80^{0}C and its temperature as it cooled was recorded every minute.

5.4.1.3 Results

The cooling rates for the three experiments are shown in Figure 78. It is seen that for Experiment 1, the average rate of cooling is about 0.25^{0}C per min. The fastest rate of cooling for Experiment 1 is about 0.5^{0}C per min. For Experiments 2 and 3, the average rates of cooling are about the same: 1^{0}C per min.

The results indicate that the dominant mechanism of cooling is conduction through the water in the tank, followed by the natural convective cooling while falling from the holes in the pipe, and lastly the forced convection by air-cooler.

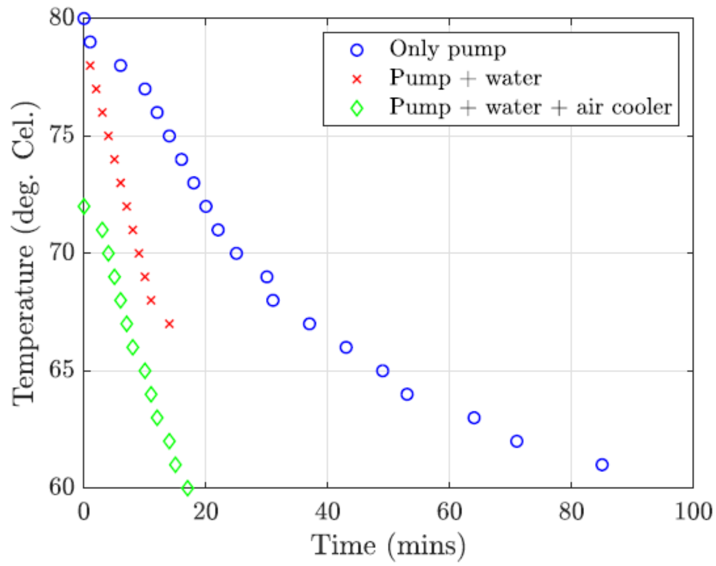


Figure 78: Cooling rates with the three modes of cooling. The dominant mechanism of cooling is conduction through water.

5.4.1.4 Conclusions

Although the overall cooling rates in all the three designs were dismal, an important lesson was learnt: the cooling device should be based on conductive cooling through water. The cooling device discussed next was made using this insight.

5.4.2 Development of a semi-mechanical cooling system

5.4.2.1 Introduction

As discussed in the introduction, manual stirring was both cumbersome and resulted in slow cooling. Accordingly, (a) a semi-mechanical cooling system was designed, and (b) it was decided to cool whole of 50 kg syrup in a single pan to reduce the overall effort.

The design consists of four stainless-steel flaps welded to a circular hub which is connected to a handle. The hub revolves when the handle is rotated manually. The flaps are submerged in the hot syrup and the handle is rotated; the spinning flaps cause vigorous stirring in the syrup. The pan containing the syrup is kept in a big tank filled with about 250 litres of water. Figure 79 and Figure 80 show the device.

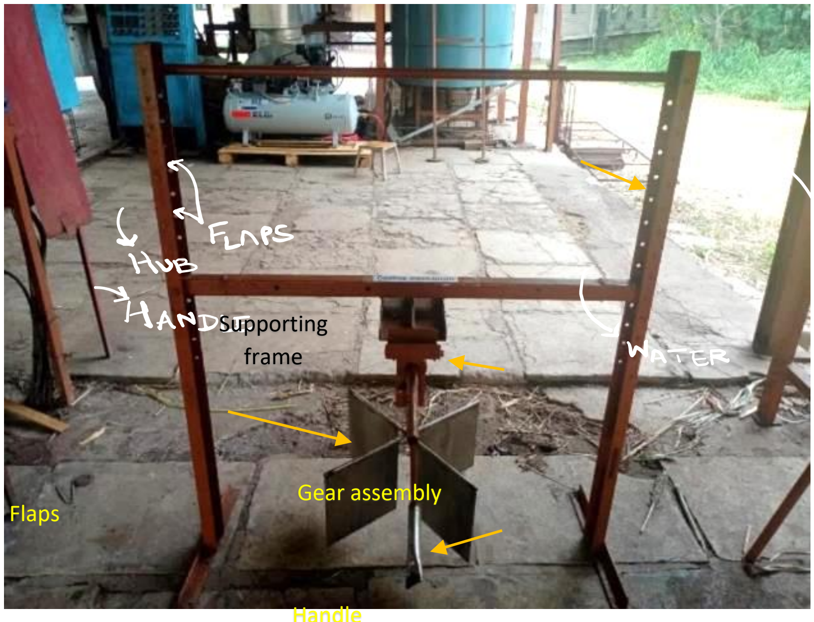


Figure 79: Cooling device (while not in operation).

Figure 80: Cooling device (while in operation).

5.4.2.2 Results

The average results obtained from three cooling experiments performed using the above device are tabulated below.

Table 35: Performance of the cooling device (average of three experiments).

Parameter	Value
Syrup weight	60 kg
Time to cool from 106 to 60^{0}C	About 7 minutes 30 seconds
Number of handle revolutions	317
Gear ratio (from handle to blades)	1.8
Blade rpm	67
Water level in tank	26 cm
Height of each blade	23 cm
Immersion level of blades in syrup	8 cm (on an average)

To estimate the effect of the cooling device, 60 kg syrup was cooled manually (with other settings being the same as in the above experiment). It was found that it takes 16 minutes 30 seconds. So, the cooling time is reduced to less than half with the cooling device.

The chief impacts of the cooling device are listed below:

(a) It has reduced the time to cool the syrup to less than half.

(b) Manual stirring is labour-intensive, and it was found that at least two persons have to stir in tandem to continue the operation for 15 minutes since SS syrup is viscous. On the other hand, one person can easily operate the cooling device to cool the syrup to 60^{0}C.

5.4.2.3 Conclusions

A semi-mechanical cooling device was fabricated. Moreover, it was decided to cool the syrup in one container (unlike earlier, where syrup was cooled in two containers). The syrup cooling time has reduced to more than half. The effort required has also reduced. Finally, at least two labourers were required, now only one labourer can do the job.

5.4.2.4 Future work

In future, options of transferring the syrup from heating pan to cold room directly could be explored. Major hurdles are: (a) cooling the syrup from 106 to 60^{0}C in about 10 minutes is not possible via natural convection, and setting up a device that uses forced convection in the cold-room is difficult, (b) the cold-room will have to be kept near the heating pan (lest the length of the connecting pipe becomes impractically long), which is difficult due to logistical reasons.

5.4.3 Determination of optimum conditions for syrup storage

5.4.3.1 Introduction

Previously, the prepared syrup was stored in a cold and dark room to prevent spoilage. However, fungus attack was observed in the syrup after a few months (Figure 81). The first task was to address this crucial issue.

Figure 81: Fungus attack on SS syrup.

5.4.3.2 New storage containers

It was noted that the fungus attack was because the storage containers were not airtight. Hence, airtight stainless-steel containers of 50-liters capacity were purchased (Figure 82).

Figure 82: Airtight stainless-steel containers (courtesy: Khambete Kothari Cans and Allied Products).

5.4.3.3 Experiments on storage conditions

The next task was to determine the storage conditions which would aid in enhancing the shelf-life of the syrup bottles. To that end, the following experiments were conducted. The syrup was filled in glass bottles under different conditions mentioned in Table 64 (Appendix U). The following parameters were varied: (a) air-tightness of the glass bottles (airtight or non-airtight), (b) temperature of the storage room (air-conditioned or non-air-conditioned), and (c) temperature of the syrup when filled (hot filling or normal filling). The bottles were monitored (visually) every day for fungus attack.

5.4.3.4 Conclusions

It was concluded from these experiments that the syrup needs to be filled in airtight containers and stored in an air-conditioned room. Hence, airtight stainless-steel containers of 50 litres capacity were purchased.

5.4.3.5 Future work

In future, more organic preservatives that increase the shelf-life of the syrup (without changing the syrup qualities, especially its taste) when kept at room-temperature and in non-airtight bottles must be explored.

5.4.4 Correlation of syrup Brix with flowability

5.4.4.1 Introduction

Syrup flow is one of the parameters participants are asked to rate during organoleptic tests. To remove the element of subjectivity individual preferences brings about, it was decided to correlate the Brix of the syrup with the time it takes a given volume of syrup to drain out of a pipette (characterizing its flowability).

5.4.4.2 Procedure

The procedure for generating the calibration curve is described below.

(a) While preparing syrup, samples corresponding to different viscosity (determined in an ad-hoc manner) were collected during the course of heating.
(b) These samples were kept for cooling overnight.
(c) Next day, the Brix of each sample was recorded using a refractometer.
(d) 10 ml of each sample was taken in a 10 ml pipette and time required to drain 9 ml syrup was recorded using a stop-watch.
(e) Three readings for each sample were taken and their average was computed.
(f) Graph between the drain time and the Brix was plotted.

5.4.4.3 Results

A one-to-one correlation curve, shown in Figure 83, with flowability varying almost exponentially with Brix, was obtained.

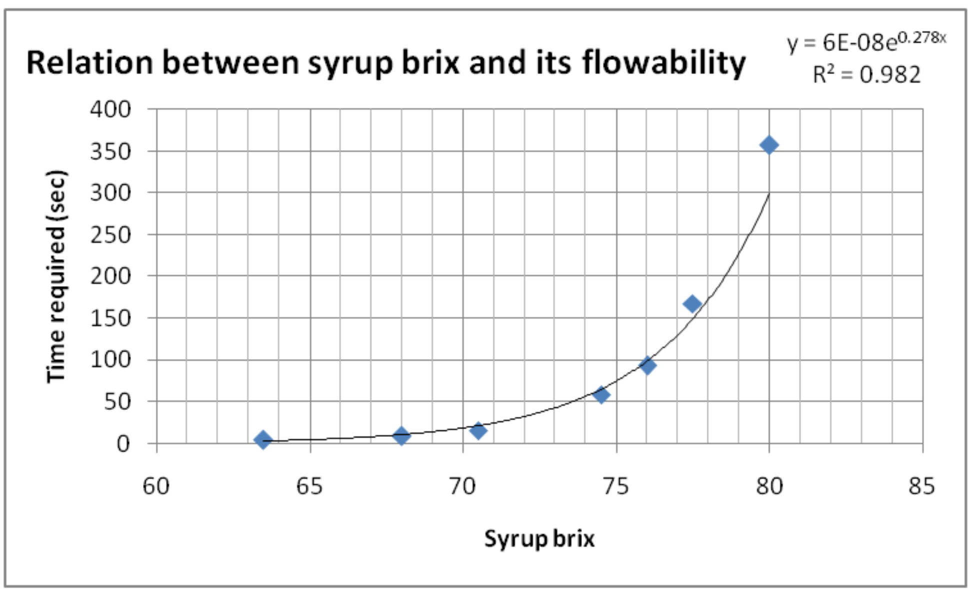


Figure 83: Correlation curve between time required to drain syrup out (characterizing flowability) and syrup Brix.

5.4.4.4 Future work

1. Quick syrup Brix determination at heating endpoint is difficult since the syrup must be cooled down to about 20^0C (for most measuring devices). The above correlation may be used to develop a criterion for quicker determination of the syrup end-point.
2. Variation in such correlation curves with SS variety and season must be studied.

5.4.5 Correlation of syrup clarity with light transmittance

5.4.5.1 Introduction

Like syrup flow, syrup clarity is another parameter participants are asked to rate during organoleptic tests. Again, to remove the subjectivity due to individual perception, it was decided to characterize clarity with its transmittance, i.e., the percent of incident light transmitted. The measuring instrument was calibrated to show 100% transmittance for clear water.

However, the transmittance of undiluted syrup is generally very low. Therefore, it was decided to dilute the syrup with fixed amount of distilled water and then measure the transmittance. To determine the proportion of water which must be added, the following experiment was conducted. Two syrup samples were considered: one rated low on clarity by the tasters ('poor sample'), and the other high ('good sample'). Different proportions of water (but same for both the samples) were added and the transmittance of each sample was measured.

5.4.5.2 Results

The following transmittance versus dilution-ratio curves were obtained for the two syrups. It was seen that one-to-six dilution ratio gave reasonable transmittance values and was finalised.

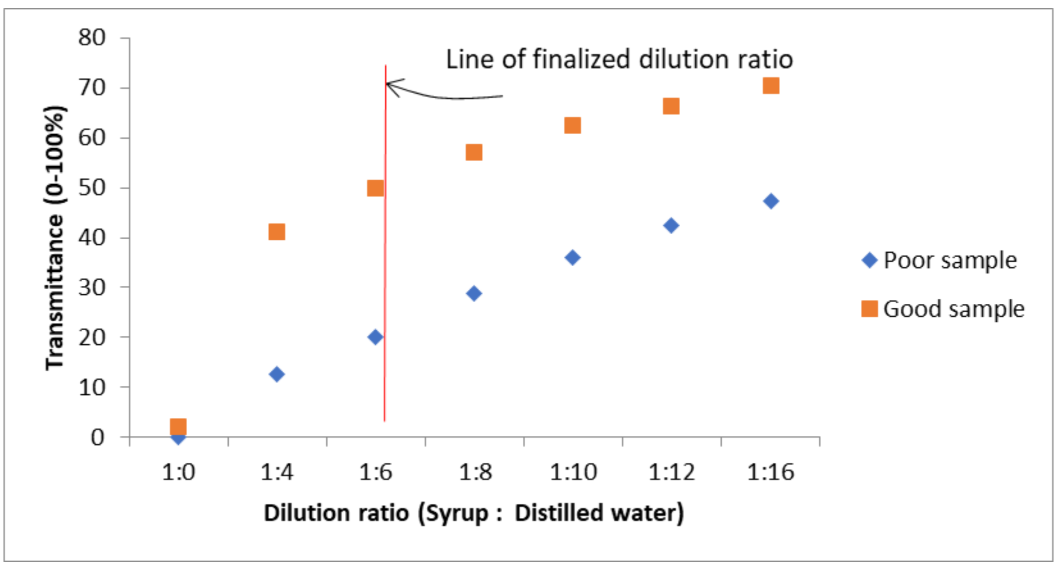


Figure 84: Transmittance versus dilution ratio (v/v). One is to six dilution ratio gives reasonable transmittance values and was finalised.

5.4.6 Installation of syrup pump, cleaning pump and cold-room

5.4.6.1 Syrup pump

Earlier, the syrup was transferred from the cooling pan to the storage can manually. This was both laborious and inconvenient, since the pan filled with syrup can weigh up to 80 kgs in some batches.

Therefore, a 3-phase lobe pump of 2-hp power was installed to transfer the syrup from the cooling pan to the storage can. The flow rate of syrup at 74^0 Brix and 60^0C was measured to be around 2 kg/sec. This means that on pilot scale, the syrup is transported from the cooling pan to the storage can in about 25 seconds. The pump does not need to be primed; however, it requires some syrup to be present at input end of the lobe-assembly for flow to begin. Also, food-grade PVC pipes that can withstand temperatures of up to 80^0C were also purchased. The cleaning of the pump is also quite easy: clean water is pumped through after use and dried by blowing air through a handheld blower. Figure 85 shows the syrup pumping operation.

Figure 85: Pumping of syrup from cooling pan to storage can.

5.4.6.2 Cleaning with the pump

About 250 litres water is filled in the cooling tank for cooling of syrup. This water is later used for cleaning of utensils, heating pan, floor etc. For more effective, quick and convenient cleaning, a single-phase 1-hp centrifugal pump was installed for pressure washing of utensils, heating pan, settling tank, meshes, floor, etc. This pressure washing takes about 15 minutes and is carried out by one person. Note that although further manual cleaning of some utensils and the heating pan is still required, the pre-cleaning with the pump greatly reduces this manual effort.

Figure 86: Pressure washing using the cleaning pump. Top-left: heating pan; top-right: cooling pan; bottom-left: semi-mechanical cooling machine; bottom-right: juice cum syrup filter.

5.4.6.3 Cold-room

A cold-room of capacity of half a ton and volume 6 ft x 6 ft x 7ft was installed to store syrup cans. The cold-room was installed near the plant so as to minimize the transit distance of syrup cans (Figure 87, left). Syrup-can-trolleys were fabricated for convenient transport of cans from the plant to the cold-room. A 10-m long concrete pathway connecting the plant to the cold room was built for easy passage of the trolleys (Figure 87, right).

Figure 87: Left: cold-room; right: transport of syrup can on trolley.

5.4.7 Floor and shed work

For hygienic work conditions, floor and shed work of the SS syrup pilot plant was carried out. A floor plan was prepared after considering the specifications and proposed location of each piece of equipment, and the floor was subsequently tiled (Figure 88). A roof was erected wherever necessary (Figure 89).

Figure 88: Floorwork of pilot plant.

Figure 89: Roofs for pilot plant.

5.4.8 Summary of cooling and storage section

Table 36: Summary of work done in cooling and storage section. Number of experiments done (wherever applicable) are given in brackets.

Work	Key impact/result
Developed a semi-mechanical cooling mechanism (10)	Better syrup appearance and flowability
Determined viable storage conditions (temperature, air-access, humidity) (7)	Longer syrup shelf-life
Developed correlation curves between various syrup parameters (14)	Objective evaluation of syrup quality
Installed syrup pump	Safe and convenient syrup transfer to storage can
Installed cleaning pump	Reduction in cleaning effort, saving of water
Installed cold room	Sanitary and controlled syrup storage conditions
Fabricated trolleys for syrup-can transport to cold room	Reduction in manpower (3 to 1 person), more convenient
Carried out floor and shed work of plant	Sanitary work conditions

Table 37: Manpower consumption in cooling and storage section for 50 kg syrup production.

Activity	Required number of labourers	Number of hours per labourer	Total labour-hours
Cooling of syrup	1	0.1	0.1
Syrup transfer to can	2	0.1	0.2
Can transfer to cold room	2	0.05	0.1
Pressure washing of utensils, equipment and plant	2	0.25	0.5

Table 38: Equipment used in cooling and storage section.

Equipment	Power consumption	What it does
Syrup pump	2 hp	Pumps syrup from cooling pan to storage container
Cold room	0.75 hp	Keeps syrup at 20^0C for long shelf-life
Cleaning pump	1 hp	Pressure washes utensils

Table 39: Scope for future work in cooling and storage section.

1. Explore options of transferring the syrup from heating pan to cold room directly.
2. Explore organic preservatives for increasing the shelf-life of SS syrup.
3. Use the correlation curve between syrup Brix and its flowability to develop a quicker method for heating endpoint determination.
4. Obtain correlation curves (discussed above) for other SS varieties and for different seasons.

This concludes the work done under the section ‘Cooling and storage of syrup’.

5.5 Popularization of sweet sorghum syrup-making technology

Before dissemination of the technology, it was imperative that a thorough economic analysis be carried out to adjudge whether growing SS can be a profitable venture, especially vis-à-vis sugarcane. It was also necessary to carry out a thorough energy consumption analysis of the syrup plant to gauge its suitability.

Once these analyses were performed, efforts were made to popularize the technology by inviting farmers over to our syrup-making sessions, and putting up banners and stalls.

The following major activities were carried out in this section:

1. Economic analysis of SS cultivation and syrup production.
2. Energy analysis of SS plant.
3. Popularization of SS syrup technology.

The details of each of these activities are presented below.

5.5.1 Economic analysis of sweet sorghum syrup production

Sugarcane is widely grown in the Phaltan region. Most of the sugarcane farmers sell their produce to the sugar mills. If it is envisaged that farmers grow SS, then their profits should at least be comparable with those obtained by growing sugarcane. In that light, it is imperative to perform a comparative analysis of sugarcane and SS production and determine the range of values for which SS syrup production becomes an attractive proposition for both farmers and syrup production units.

The total cost involved in syrup production can be broken down into the following four categories:

1. **Cultivation cost**: Cultivation incudes all activities from land preparation to readying the crop for harvesting, such as ploughing, sowing, fertilizer-application, weeding, etc. A complete list of items which have been included in the cultivation cost is given in Table 65.
2. **Harvesting cost**: Cost of harvesting of SS biomass. Note that it is assumed that the syrup production unit is situated nearby the fields, and thus the cost of transportation of biomass to the syrup unit will be negligible.
3. **Capital cost:** Cost of setting up a plant capable of producing 150 kg syrup per day for 300 days a year, plus its maintenance. It includes the cost of land, construction, equipment, measuring instruments, utensils etc. It also includes the equipment maintenance charges. A complete list of items which have been included in the capital cost is given in Table 68.
4. **Processing cost:** Cost incurred in processing of biomass to obtain SS syrup. It includes costs of stripping of stalks, human-resource (labourers, supervisor etc.), electricity and okra. For human-resource and electricity cost details, see Table 69 and Table 70, respectively.

The list of assumptions for the economic analysis is presented in Table 40.

Table 40: Assumptions for economic analysis.

1. Cultivation cost is Rs. 22,368/acre-season (average of last 10 syrup-making sessions at NARI, Table 65). 2. Harvesting cost is Rs. 449/tonne biomass (average of last 10 syrup-making sessions at NARI, Table 66). 3. Cost of setting up the plant is Rs. 17,50,000 (same as that of NARI plant). 4. Interest on capital cost is 15% (compounded annually) with a loan repayment period of 5 years. 5. From Assumptions 3 and 4, capital cost comes out to be Rs. 6,22,500 per year *during* payback period and Rs. 1,15,000 *after* payback period (Table 68). An **average** of these costs is considered as capital cost for analysis. 6. Stripping cost is Rs. 2000/ton biomass (at Rs. 4 per kg of stripped stalks). 7. Human-resource cost is Rs. 1,821 per 50-kg syrup production (estimated). 8. Electricity cost is Rs. 140 per 50-kg syrup production (estimated). 9. Okra fruit cost is Rs. 50/kg. About 4 kg okra is required per 50 kg syrup. 10. From Assumptions 6 through 9, processing cost comes out to be Rs. 4,611 per 50-kg syrup production. 11. Syrup production unit makes 50 kg syrup per day for 300 days a year. 12. 1.2 ton SS biomass gives 50 kg syrup. 13. 1.2 ton SS biomass gives 600 kg stripped stalk. 14. Furnace is fuel self-sufficient, i.e., no cost is incurred on the fuel. 15. Inflation is neglected for simplicity. 16. It takes 15 months to grow three cycles of SS crop on a piece of land (yearly profits on per-acre basis have been calculated using this assumption).

5.5.1.1 Scenario 1: Farmer grows sweet sorghum crop and gives harvested stalks to a syrup production unit

This scenario facilitates direct comparison with the existing practice of sugarcane farmers selling their produce to the sugar mills. In this case, farmers incur cultivation and harvesting costs, and the processing unit incurs capital and processing costs. Using the assumptions given in Table 40, the following graphs have been plotted:

(a) <u>Biomass selling price versus yearly profit to a farmer per acre</u> (Figure 90): From Table 71 it is seen that the SS biomass yield varies from about 10 to 30 tons per acre across the year. Therefore, three biomass yields have been considered in the figure. For comparison, yearly profit of a sugarcane farmer is shown with a dotted vertical line (details of calculation of profit for sugarcane farmers are presented in Table 72). It is seen that for biomass yield of about 16 tons per acre (which is the yearly average at NARI; Table 71), an SS farmer can earn more than a sugarcane farmer if the biomass price is Rs. 3,700 per ton or more. In seasons of high yield where the yield is about 30 tons per acre (Table 71), about 33% more profit can be earned if biomass price is assumed to be the same as that for sugarcane (Rs. 2,500/ton). For biomass price of Rs. 5,000/ton, up to three times the profit as that from sugarcane can be earned.

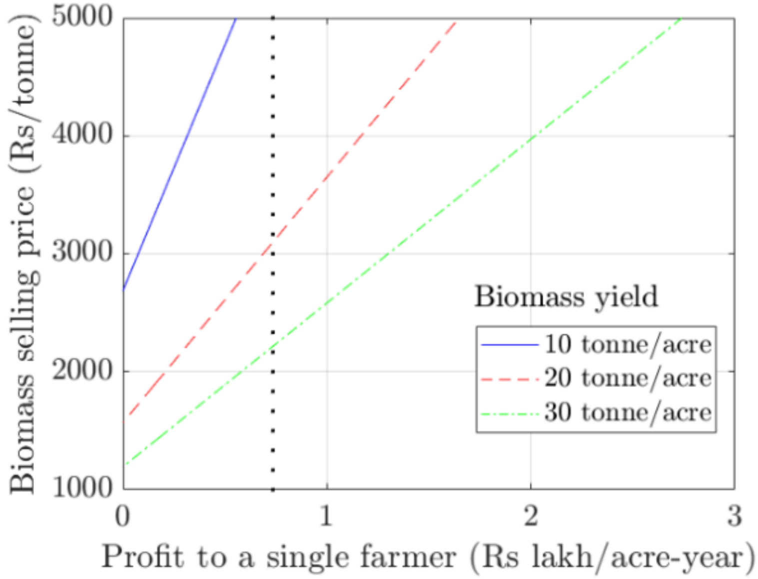


Figure 90: Biomass price versus profit of a farmer per acre for different biomass yields. The dotted vertical line represents profit of a sugarcane farmer per acre.

(b) Biomass cost versus selling price of syrup (Figure 91): It is seen from the figure that for a rate of return[1] of 50% and syrup selling price of Rs. 500/kg (current rate at NARI), a farmer can be paid about Rs. 10,000 per ton of biomass, earning up to about **six** times as compared to the earnings from sugarcane farming. With these rates, the syrup production unit can earn **Rs. 25 lakhs** per year**.**

[1] Selling price of syrup = Cost price of syrup * (1 + rate of return /100).

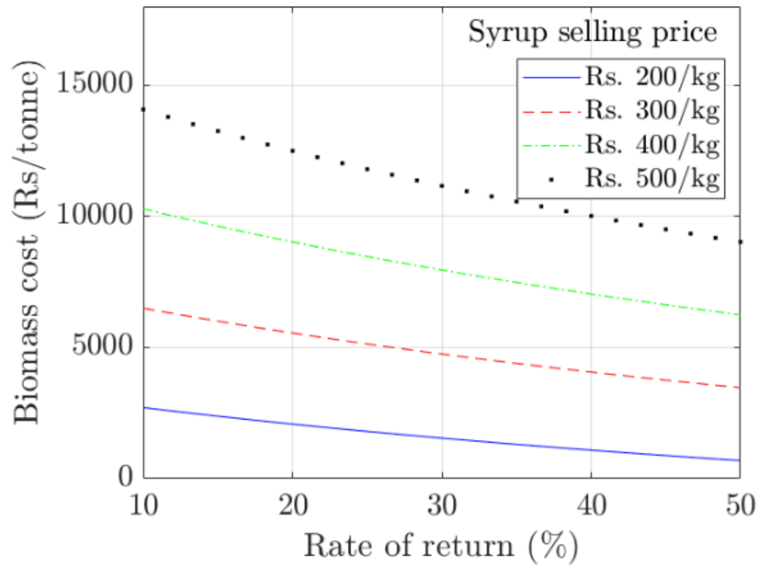


Figure 91: Biomass cost versus selling price of syrup for different rates of return.

(c) Biomass cost versus net profit to the syrup production company (Figure 92): It is seen that for syrup selling price of Rs. 500/kg (current rate at NARI) and biomass cost of Rs. 5,000/tonne (for which farmer can earn thrice the profit earned from sugarcane farming), the syrup production unit can earn about **Rs. 40 lakhs** yearly.

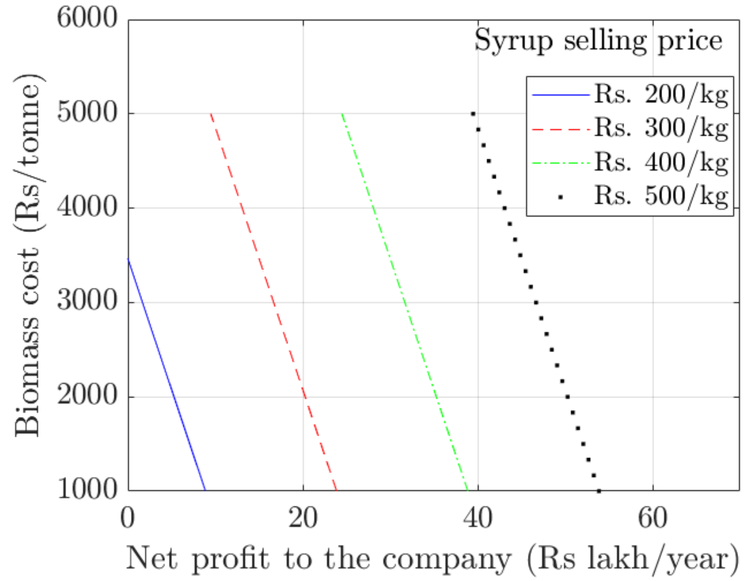


Figure 92: Biomass cost versus net profit to the syrup production company for different syrup selling prices.

Variation in profit throughout the year

Since the yield of SS varies across the year, so do the farmer profits. To ascertain the optimum sowing dates to maximize profits, month-wise yield data was analyzed. The graph obtained is presented in

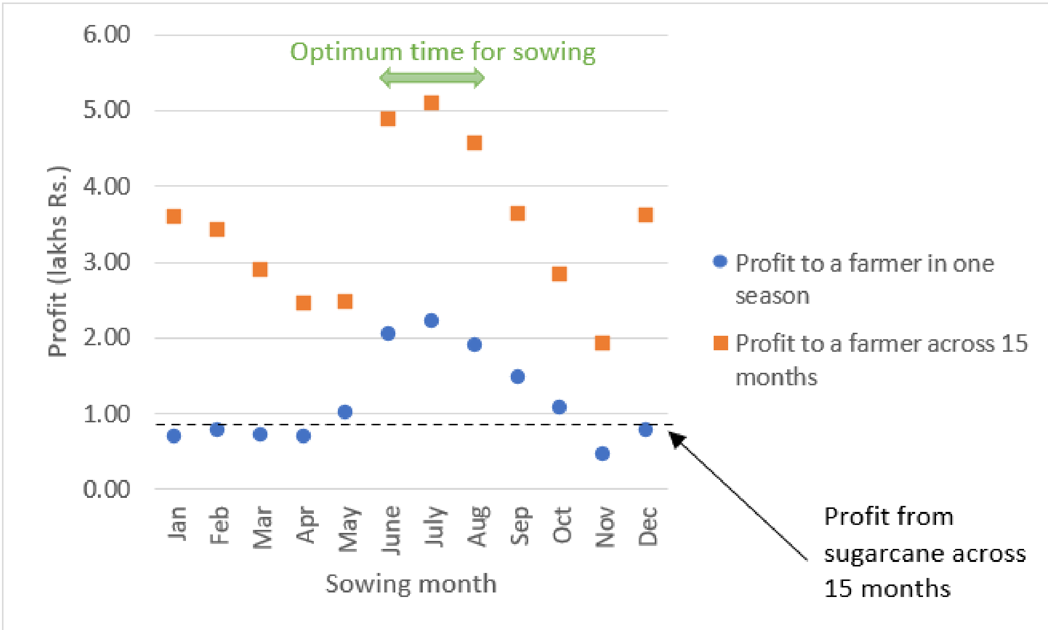


Figure 93. Note that the following assumptions (apart from those listed in Table 40) have been made to obtain this graph:

- Syrup selling price is Rs. 500/kg.
- Rate of return of syrup production unit is 50%.

Details on how this graph is obtained are presented on Page 235 in Appendix V.

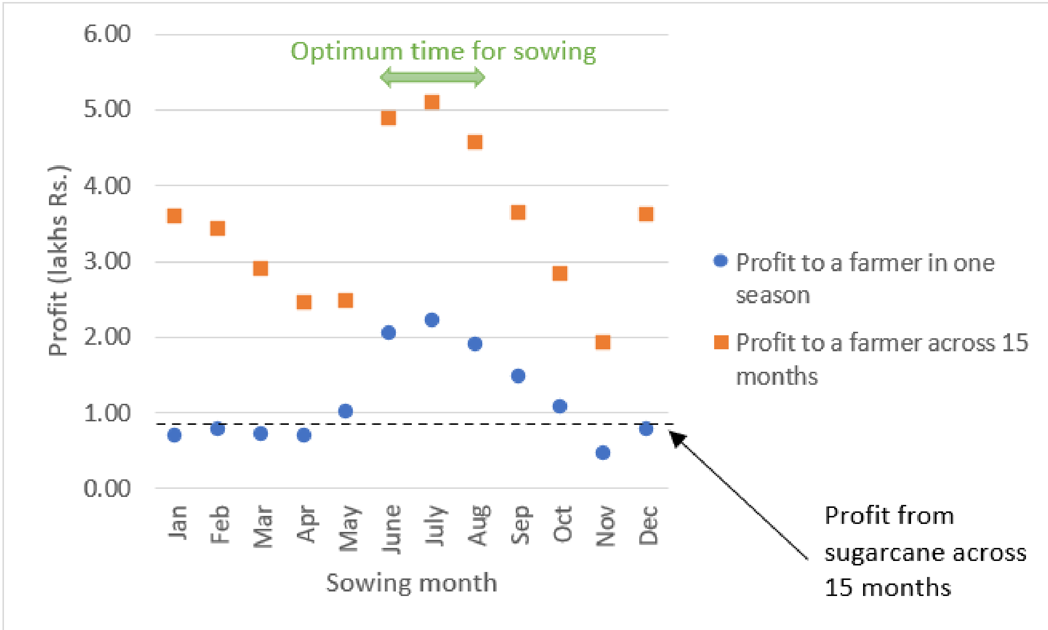


Figure 93: Profit for SS farmers across one and three crop cycles (i.e., across 15 months). The latter is presented to facilitate comparison with sugarcane, which takes 15 months from planting to harvest, and fetches a profit of Rs. 92,000/acre (shown with a black dashed line). Note that for the curve corresponding to three crop cycles, X-axis denotes the sowing month of the first crop. It is seen that June to August is the most optimum period of sowing. Even in the worst case (when the first crop is sown in November), the profit is about two times that from sugarcane.

5.5.1.2 Scenario 2: Farmer grows sweet sorghum crop and produces syrup in his own plant

In this scenario, a farmer can earn about Rs. 6 lakhs per acre-year for an average yield of 16 tons per acre (same as that at NARI in last 10 syrup batches) and syrup selling price of Rs. 500/kg (same as that at NARI) (Figure 94). This profit is much more than that earned in Scenario 1 (Figure 90), and thus, in line with our vision to enable small farmers (or a group of farmers) to produce their own syrup rather than simply selling their biomass to factories.

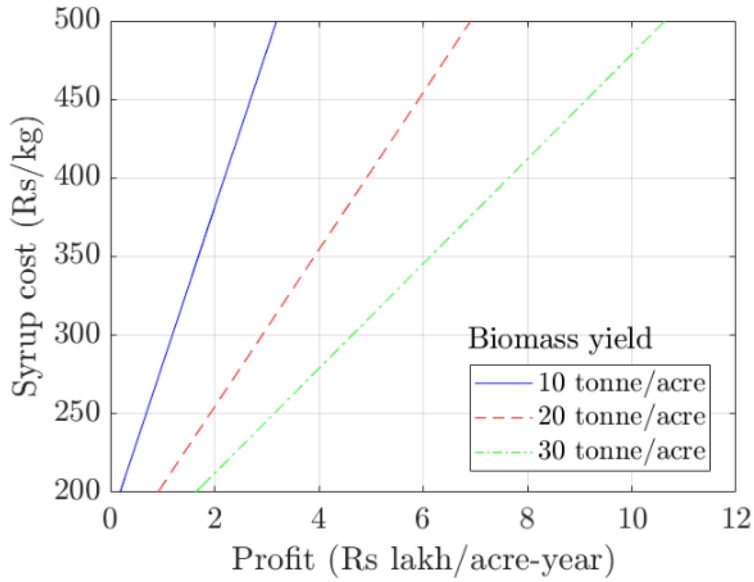


Figure 94: Syrup cost versus profit for different biomass yields for a farmer who produces syrup from his biomass.

5.5.1.3 Conclusions

It is seen that in most cases, irrespective of whether a farmer produces syrup at his own unit or gives his biomass to a dedicated production unit, he earns more on per acre basis by growing SS as compared to sugarcane. These results show that if market is present for syrup, SS farming is a profitable alternative to sugarcane. It was also seen that June to August is the most optimum period for sowing SS.

5.5.1.4 A note on production cost distribution

If SS syrup is to compete with other natural sweeteners like jaggery or honey, its cost must be lowered so that it is comparable to these sweeteners. It thus becomes important to determine which activities contribute the most to the production cost and focus on cutting their costs.

As mentioned at the beginning of Section 5.5.1, the total input-cost involved in syrup production can be broken down into the following four tabs: (a) cultivation cost, (b) harvesting cost, (c) capital cost and (d) processing cost. A breakdown of the input cost into these four tabs for the first five years of setting up the plant is shown in Figure 95. It is seen that the majority of the cost is incurred in cultivation and processing. A further breakdown of the processing cost into its constituent activities it shown in Figure 96. It is seen that most of the processing cost is incurred in stripping of stalks and human resource. This analysis reveals that in future work aiming to lower the SS syrup costs, focus should be on lowering the harvesting and the stripping costs. A *significant* reduction in these costs is only possible through their mechanization, and hence, in future, dedicated projects towards development of appropriate machines should be taken up.

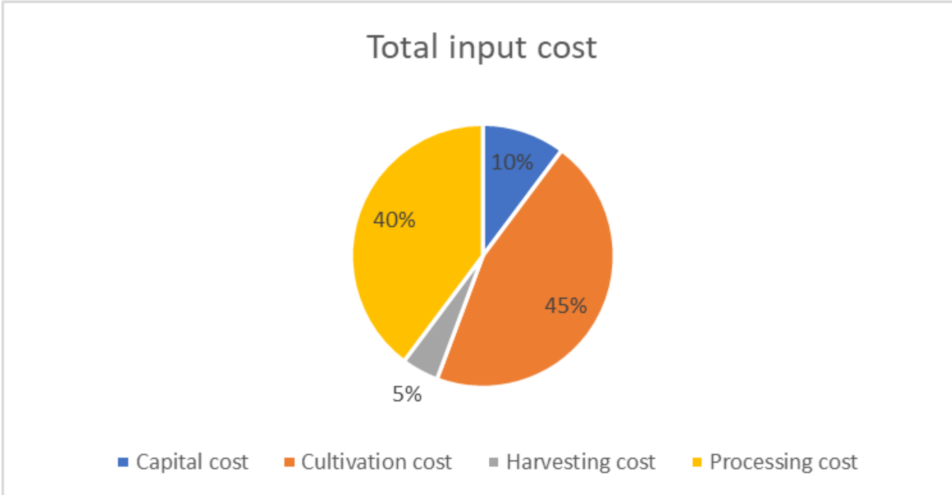


Figure 95: Breakdown of the total input cost over a five-year period.

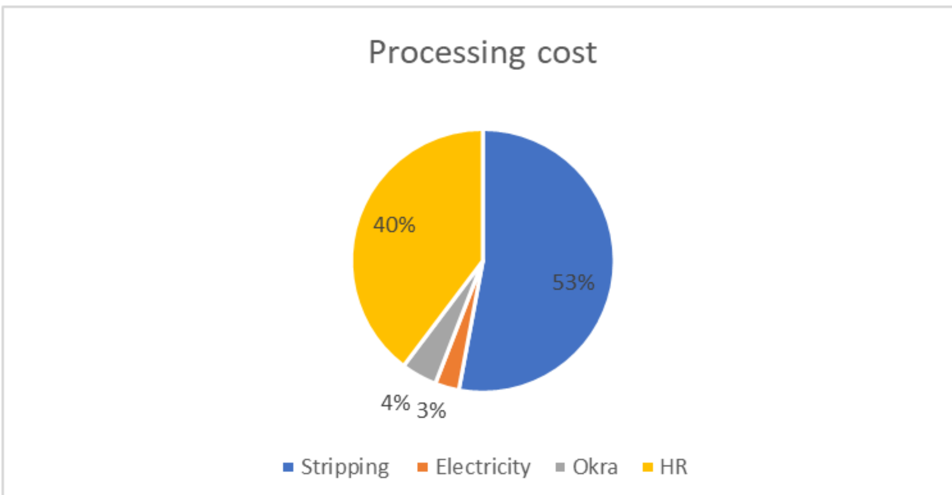


Figure 96: Breakdown of the processing cost.

5.5.1.5 Future work

- In future work, the variations in the following quantities across the year could be considered for a more comprehensive analysis: (a) juice Brix, (b) crushing efficiency (this varies since the average stalk diameter and the juiciness of stalk varies), (c) stem borer damage. This will result in varying syrup yield from a given amount of biomass, leading to variation in profits across the year.
- In this analysis, most of the data was taken from that generated at NARI during the past few seasons. More data should be incorporated in future work to estimate profits in different parts of the country.

5.5.2 Energy consumption analysis of the pilot plant

A detailed analysis of the energy requirements of the SS pilot plant (that produces 50 kg SS syrup in 8 hours) was carried out. The electrical power required by different equipment is provided in Table 41. The thermal energy consumption and energy expended in human resource are given in Table 42 and Table 43, respectively.

5.5.2.1 Electrical energy

Table 41: Electrical energy consumption of the pilot plant for producing 50 kg syrup.

Equipment	Power rating (kW)	Operating time (hours)	Energy (kWh)
Crusher	5.5	1	5.5
Juice pump	0.75	0.1	0.075
Air blower	0.75	4	3
Shredder	2.25	4	9
Syrup pump	1.5	0.007	0.01
Cleaning pump	0.75	0.16	0.12
Miscellaneous (fans, temp. scanner etc)	0.05	8	0.4
Total			18.1

5.5.2.2 Thermal energy

Table 42: Thermal energy consumption of the pilot plant for producing 50 kg syrup.

Fuel	Amount (kg)	Calorific value (MJ/kg)	Energy input (kWh)
SS bagasse and leaves	180 (dry basis)	18	900

5.5.2.3 Human resource

Table 43: Human resource requirement of the pilot plant for producing 50 kg syrup.

Operation	No. of people	Operating hours	Power rating (W)	Energy input (kWh)
Harvesting of SS biomass	12	2	50*	1.2
Stripping of SS biomass	12	6	50	3.6
Crushing of SS stalk	4	1	50	0.2
Heating of juice	4	5	50	1
Cooling, storage and transportation of syrup	2	1	50	0.1
Total				6.2

*Source: (Avallone, 2007).

5.5.2.4 Results and conclusions

Categorization of the total energy into the three major forms of energy (electrical, thermal and manpower) is presented in Table 44 and Figure 97. It is seen that most of the energy (about 97%) is expended in heating the juice. Therefore, it becomes imperative to increase the furnace efficiency, while keeping it affordable and accessible.

Table 44: Total energy consumption.

Form of energy	Amount (kWh)	Percentage of total energy
Electricity	24	2.58
Thermal	900	96.78
Manpower	6	0.64
Total	930	100

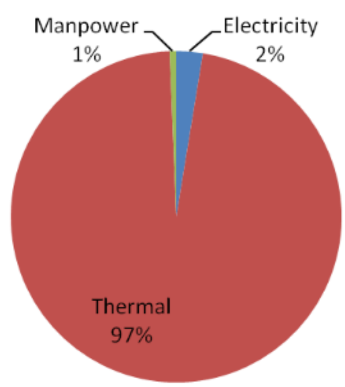


Figure 97: Energy consumption of the pilot plant.

5.5.3 Farmer visits

<u>Introduction</u>

Three farmers visited the syrup-making session on June 24, 2022. The working of the plant was demonstrated to them, laying special emphasis on procedures related to automation or standardization. The farmers were even encouraged to try their hands on activities like mucilage preparation and scum removal.

Farmers' details

1. Amarsingh Haridas Shendge, Village: Garpirwadi.
2. Ankush Shamrao Bhandwalkar, Village: Shindewadi.
3. Navnath Narayan Pawar, Village: Choudharwadi.

Questions they asked

- What is the yield of SS stalks per unit acre?
- Can ratoon crops be used for making syrup?
- What fertilizers are needed for SS crop?
- What is the typical height of stalks?
- What is the market for SS syrup like?
- Can jaggery be made from SS?
- Can extra bagasse and leaves be sold?

What they said about the plant

- 'Jaggery units they have visited are dirty. Our plant is very clean'.
- 'Automation is impressive and makes tasks convenient'.
- 'If there is a market for syrup, they will obviously grow SS, or even think about setting up a plant'.
- 'The taste of syrup is very good. It tastes very much like sugarcane jaggery'.
- 'Scum removing ladle is a bit heavy'.

Photographs

Figure 98: Demonstration of plant-working to local farmers.

5.5.4 Stalls put up by NARI for popularization of SS syrup

5.5.4.1 Stall at ‘Millet Jatra’ at Koregaon Park in Pune

NARI participated in the ‘Millet Jatra’, organized at the Monalisa Kalagram, Koregaon Park, Pune on August 21, 2022. The aim of the event was to build awareness about the millets, and bring about more interactions among all the stakeholders, i.e., NGOs, SHGs, KVKs, entrepreneurs, nutritionists and consumers. It was organized by three NGOs: Agro Rangers Trust, Indradhanusha Youth Social Foundation and Shekru Foundation.

A stall displaying the SS syrup *Madhura* produced at NARI, along with seeds of three SS varieties developed at NARI was put up. Banners displaying information about syrup production and its qualities were also put up. Finally, pamphlets, in both English and Marathi, with relevant information about SS varieties developed at NARI were given to interested persons.

About 50 people tasted the syrup. Most of them said that they really liked the syrup. Some found its taste to be very strong, but a few of them liked the aftertaste.

Many of the fellow participants who prepare sweetened food products from millets expressed interest in using the SS syrup in place of jaggery. Some entrepreneurs also showed interest in taking the syrup to customers through start-ups.

Figure 99: Stall put up by NARI at 'Millet Jatra'.

5.5.4.2 Stall in front of NARI main gate during annual pilgrimage to Pandharpur

About 3 lakh devotees travel for the annual pilgrimage to Pandharpur via the Lonand-Phaltan highway that passes in front of the institute main gate. A stall displaying SS syrup bottles and pamphlets was put up on July 2, 2022.

6 Conclusions and future plan of work

6.1 Conclusions

The work done in this project has resulted in a semi-mechanized SS syrup plant with continuous and well-integrated subprocesses. Many processes that were previously carried out manually have been mechanized. Moreover, many existing processes have been kept as is, but their parameters have been optimized for maximum efficiency. Finally, detailed economic analysis of the developed plant has been carried out and steps have been taken to disseminate this technology among rural populace.

This technology is now ready to be taken up for implementation, and future work should focus on its dissemination. It is believed that the newly emerging start-up ecosystem in the country could play a potentially huge role towards that. All the technical know-how of the SS syrup plant as developed in this project including detailed drawings, designs, etc will be provided to the start-ups interested in marketing this technology. Moreover, efforts towards reaching out to the start-ups interested in selling SS syrup or using it as a raw material for confectionaries will be continued. A couple of companies have purchased a total of **2060 kg** SS syrup from NARI since this project started (September 2020) which is a testament to the existence of a burgeoning market for natural sweeteners like SS syrup.

The major achievements of this project are listed below:

- **Reduction in labour and time:** Many of the processes that were tedious and labour-intensive have been made convenient. Maximum number of labourers required at a given time is **four** (during the crushing operation). The following table summarizes the items where labour has been reduced significantly.

Table 45: Reduction in labour requirement achieved due to the project. In the format A x B *presented in brackets,* A *denotes the number of labourers and* B *denotes the time in hours.*

Activity	**Labour-hours required earlier**	**Labour-hours required now**
Stripping of stalks	170 (10 x 17)	90 (10 x 9)
Feeding of stalks in crusher	10 (2 x 5)	4 (4 x 1)
Wet bagasse collection	10 (2 x 5)	1 (1 x 1)
Mucilage preparation	1 (2 x 0.5)	0.5 (2 x 0.25)
Heating of juice	30 (6 x 5)	12 (3 x 4)
Shifting and tilting of pan for syrup transfer	1 (5 x 0.2)	0.2 (2 x 0.1)
Cooling of syrup to 60^0C	0.5 (2 x 0.25)	0.1 (1 x 0.1)
Transferring syrup from cooling pan to storage room	2 (4 x 0.5)	0.2 (2 x 0.1)
Preliminary cleaning of utensils, equipment and plant	1 (2 x 0.5)	0.25 (1 x 0.25)

- **Standardization of processes:** A list of processes standardized during this project are listed in Table 46. It has been observed that the syrup quality obtained now is uniformly good across batches.

Table 46: Processes that have been standardized.

Juice filtration mechanism
Mucilage preparation
Mucilage addition strategy
Juice settling period
Furnace parameters
Scum removal devices
Heating endpoint determination
Syrup storage conditions

- **Improvement in hygiene:** At no stage in the process of syrup-making is there direct human contact with the juice or the syrup. Only during the second stage of mucilage preparation, the filter pouch containing okra fruit pulp is squished with hands. Overall hygiene of the plant has also substantially improved due to steps like bagasse collection through carts, juice and syrup transport via pumps and pipes, pressure washing etc.
- **Improvement in safety:** Earlier, processes like lifting of pan at heating endpoint, feeding of fuel in furnace, carrying of hot syrup can to cold -room etc were carried out manually, posing a danger to safety. All such processes have been made extremely safe and convenient through partial mechanization.
- **Reduction in losses:** For the same amount of biomass, about 8% more syrup is obtained now due to introduction of pumps, connecting pipes and scum collector.
- **Development of a clean multifuel-fired furnace:** A good outcome of this project has been the development of a multifuel-fired furnace which gives out clean smoke and provides good heating rate.

The specifications of the developed plant are tabulated below.

Table 47: Specifications of the developed plant.

Capital cost (not including land cost)	11.5 lakh rupees
Land required to set up plant	300 m^2 (3 ares)
Total energy required for production of 50 kg syrup	3,330 MJ
Time required for production of 50 kg syrup (from crushing of stalks to storing of syrup)	8 hours
Number of people required to run the plant	4
Furnace capacity	300 kW

6.2 Future work

Section: harvesting and stripping of stalks
• Improve designs of stripping machines developed during this project.
• Find out long term effects of incorporating leaf sheath and stem-borer-damaged stalks on syrup quality.
• Improve crushing efficiency of shorter stalk pieces so that the new method of damage detection can be used.
• Devise methods of damage detection so that leaf sheath removal is not required.
Section: crushing of cane and settling of juice
• Develop an objective but simple technique of uniform feeding of stalks at a rate which gives high crushing efficiency and smooth operation.
• Develop crushers more suitable for SS stalks; in particular, stalk feed-rate window for high crushing efficiency with smooth operation should be broad.
• Develop simple and affordable machines for bagasse transport. Conveyor belts and vacuum pumps are two possible avenues.
• Develop an objective criterion to recover as much clear juice from the settling tank as possible.
• Explore different shapes for settling tank to enhance settling rate.
Section: heating of juice
• Survey market for a more robust and user-friendly temperature-recording device.
• Design a simple and affordable pan-sealing mechanism to further enhance furnace efficiency.
• Develop compact furnaces of heat output of about 70 kW which could be transported easily.
Section: cooling and storage of syrup
• Explore options for transferring the syrup from heating pan to cold room directly.
• Explore natural preservatives suitable for SS syrup to increase its shelf-life.
• Use the correlation curve between syrup Brix and its flowability to develop a quicker method for heating endpoint determination.

• Obtain correlation curves (discussed above) for other SS varieties and different planting dates.
Section: popularization and dissemination of technology
• More variables should be included for a more comprehensive economic analysis.
• Data from different regions should be collected to calculate region-specific profits.
• Start-ups using jaggery in food products should be encouraged to try SS syrup as an alternative to jaggery.

7 Appendices

Appendix A

Procedure for Brix measurement

1. Note the date of sowing. Germination takes place in about one week, and the juice samples for the Brix analysis are generally taken about 80 days thereafter (i.e., around 90 days from sowing).
2. Measure the dimensions of the plot. Make a schematic of the plot as shown in Figure 100, indicating how the juice samples for Brix measurement are to be procured. Note that in the figure, Tenopol, Honey pot, Sugargraze, Madhura-1 (M1), Madhura-2 (M2) and Madhura-3 (M3) denote the different SS cultivars sown at NARI.

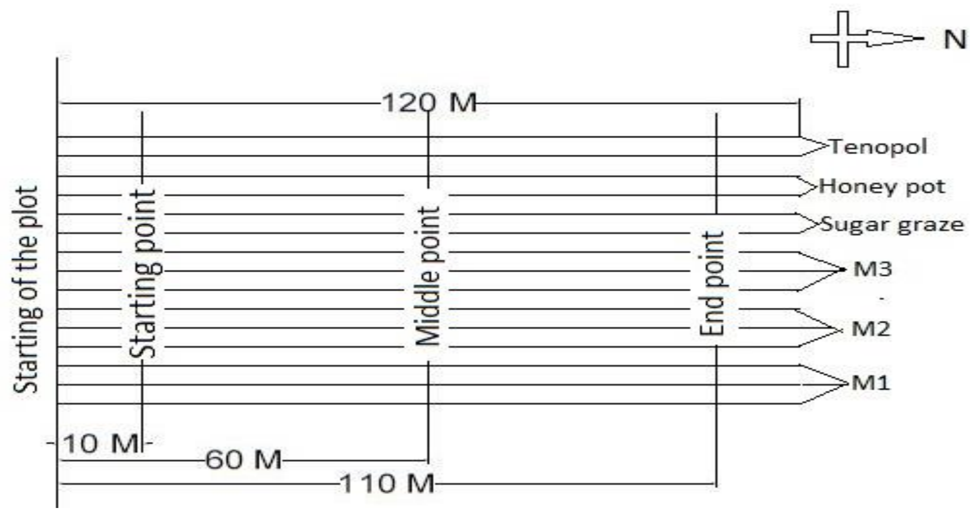


Figure 100: Schematic of a representative plot.

3. Measure the distance between the locations of the procured stalk samples.
4. Collect three samples from each location and label them according to their (a) cultivar, and (b) location name (tying all the three samples of a given location and giving a single label to the resulting bunch reduces the sample segregation effort).
5. For Brix measurement, the juice sample is collected from the 4th internode because of the following simple reason: it was observed in separate experiments that the mean of the Brix content of the juice from all the internodes in a given stalk matches most closely with that of the juice from the 4th internode of that stalk. In case the stalk at the 4th internode is borer-affected, select the adjacent internode for sampling.
6. Cut the stalk at the fourth and the third internode by a cutter. Note that the cut at the 4th node is slanted (at approximately 45-degree angle) for ease of juice collection. Now, squeeze the slanted edge using a plier, collect one drop of juice on a refractometer and measure its Brix.
7. Fetch samples from the plot every week and measure the corresponding Brix. Plot the variation of the Brix against crop duration (i.e., number of days from the date of sowing of the crop).
8. Harvest SS when the juice Brix reaches at least 15^{0}.

Appendix B

Experimental data of conventional stripping rate of SS

Table 48: Experimental data of conventional stripping rate of SS.

Variety	Date of harvesting	Biomass weight (kg)	Stripping efficiency (kg biomass/labour-hr)
Madhura-3	26-Sep-20	265	6.63
Madhura-3	28-Sep-20	255	7.97
Madhura-3	29-Sep-20	307	7.68
Madhura-3	09-Oct-20	397	6.20
M1+M2+M3	10-Dec-20	1316	6.09
Madhura-3	17-Feb-21	199	6.22
Madhura-3	18-Feb-21	193	6.89
Madhura-3	19-Feb-21	220	6.88
Madhura-3	22-Feb-21	150	4.69
Madhura-3	24-Feb-21	290	6.04
Madhura-3	25-Feb-21	298	6.21
Madhura-3	26-Feb-21	310	9.69
Madhura-3	02-Mar-21	294	7.35
Madhura-3	04-Mar-21	288	6.00
Madhura-3	05-Mar-21	278	6.95
Madhura-2	05-Mar-21	420	6.18
Madhura-2	09-Mar-21	338	6.04
Madhura-2	10-Mar-21	303	6.89

Madhura-2	11-Mar-21	315	7.16
Madhura-2	12-Mar-21	350	8.75
Madhura-2	16-Mar-21	350	7.95
Sugargraze	17-Mar-21	465	8.30
Madhura-3	23-Mar-21	1270	7.74
Madhura-3	25-Mar-21	330	8.25
Madhura-3	06-Apr-21	470	10.68
Madhura-2	07-Apr-21	325	10.16
Average			7.3 (Range: 4.69-10.68)

Appendix C

Details of stripping machines

Table-mounted stripping machine

Construction

This stripping machine consists of four blades. These blades are semi-circular in shape and are sharpened at one end. The blades are made of hardened stainless-steel. Two blades are mounted vertically, while the other two, horizontally. In each of these sets, one blade is fixed while the other is connected to a stainless-steel frame through a spring. Both the blade-spring arrangements are mounted on C shaped frames. A schematic of the stripping machine is shown in Figure 101.

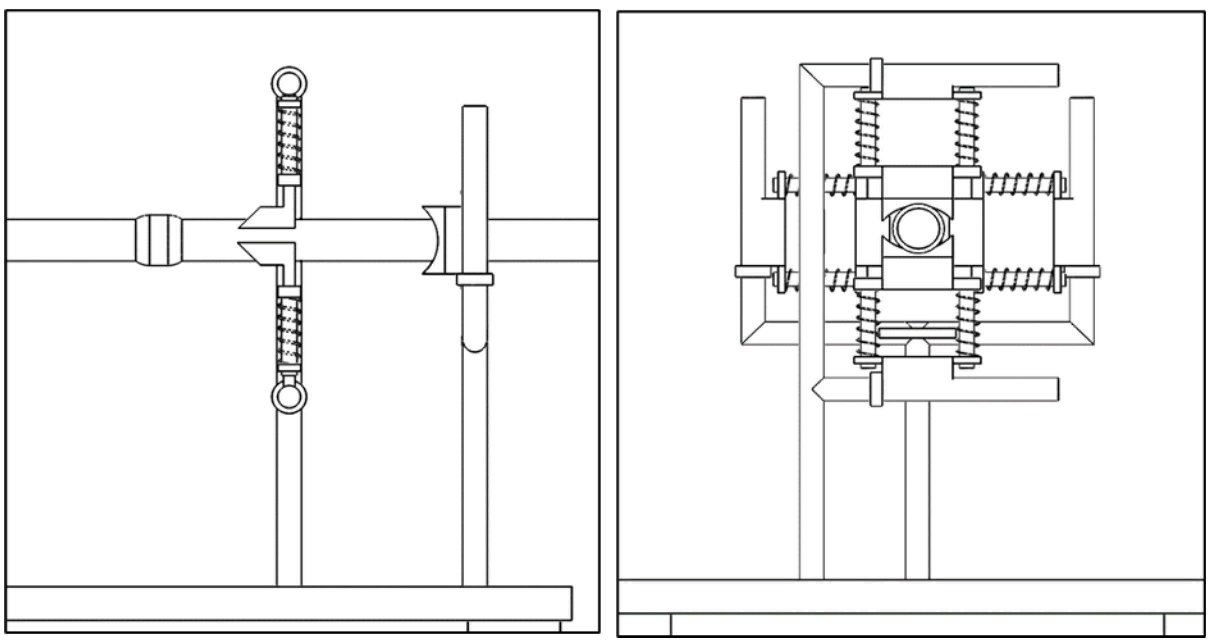


Figure 101: Schematic of stripping machine. Left: side view; right: front view.

Working

The SS stalk is fed horizontally into the stripping machine and pulled out at the other end. Currently, the feeding is done manually. First, the pair of vertical blades come in contact with the stalk followed by the horizontal pair. Springs allow for variation in the diameter of the stalks. A high stiffness of the springs ensures that sufficient friction is generated between the blades and the stalk to strip off the leaves and the sheath. To restrict the lateral movement of the stalk, two guideways are provided. A photograph of the machine while in operation is shown in Figure 23.

Handheld stripping machine experiment data

Table 49: Time taken with handheld stripping machine in comparison to manual stripping.

	Weight of biomass (kg)	**Time with handheld stripping machine (mins)**	**Time with manual stripping (mins)**
Experiment 1	10	25	30
Experiment 2	10	20	23
Experiment 3	10	17	21
Experiment 4	8	12	14

Appendix D

Details of experiments on effect of leaf sheath on syrup quality

New method of damage detection (without removing the sheath)

To detect stem borer damage without removing the sheath, it was decided to cut the stalks (after removing the leaf laminae and the panicles) near the nodes (since the stem borer is usually not able to penetrate the nodes) perpendicular to their long axis, without removing the leaf sheaths. Since a stalk after removing the panicle contains at least 6-7 nodes, many pieces were obtained from a stalk. A cut piece was inspected at both its cross-sections; if the cross-sections had a red coloration (Figure 102 shows how a damaged cross section with a red coloration looks like), indicating damage, the piece was put into the 'damage' bucket. If only one cross-section had a red coloration, the piece was further cut to salvage as much of the undamaged portion as possible. If both the cross-sections had no red coloration, the piece was put into the bucket meant for pieces to be crushed.

Figure 102: A cross-section of a pest-damaged stalk showing red coloration.

Experiment results

Some non-dimensional quantities of significance obtained from the experiments are plotted in Figure 103.

Damage removal: It is seen in the top-left figure that % damage by biomass, defined as

% damage by biomass = damaged biomass weight/total biomass weight x 100,

is more on an average (the dashed horizontal lines represent the mean values) for the 'with sheath' batch, indicating that the new method of damage detection is quite successful so far as damage removal is concerned.

Stripping efficiency: In the top-right figure, it is seen that % stripping, defined as

% stripping = stripped stalk weight/biomass weight x 100,

is more on an average for the 'with sheath' batch, despite a greater amount of mass being removed as damage. This is because the mass of leaf sheaths is included in it.

Juice extraction: The % juice extraction, defined as

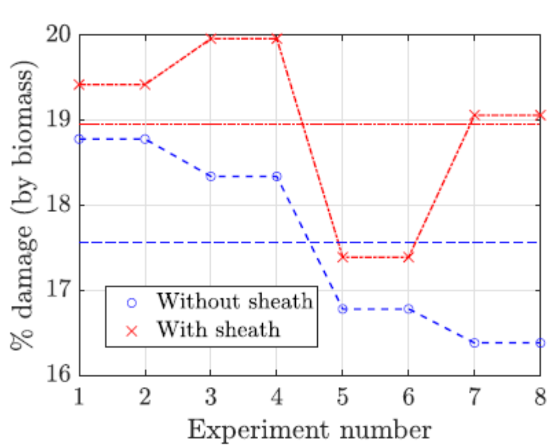
% juice extraction = extracted juice weight/stripped stalk weight x 100,

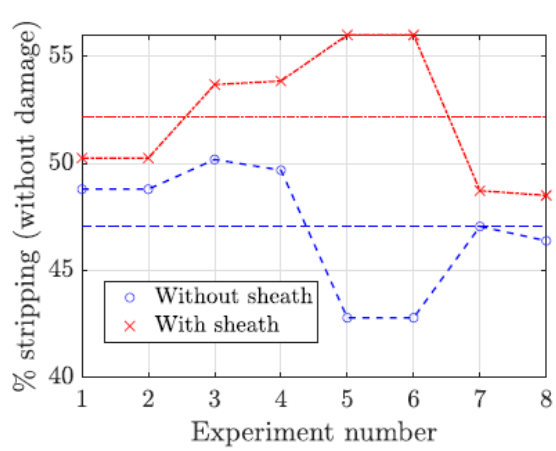
plotted in the bottom-left figure, is about 42% for the 'without sheath' batch and about 28% for the 'with sheath' batch. Separate experiments have indicated that this reduction in extraction for the `with sheath' batch is solely due to cutting of the stalk into pieces, and the sheath has no role to play in it (in these experiments, it has been observed that if the stalks are crushed with and without sheath, without cutting them into pieces, equal extraction of about 42% is obtained).

Syrup recovery: In the bottom-right figure, it is seen that % syrup recovery, defined as

% syrup recovery = syrup weight/biomass weight x 100,

is more on an average for the 'without sheath' batch, owing to its greater juice extraction.





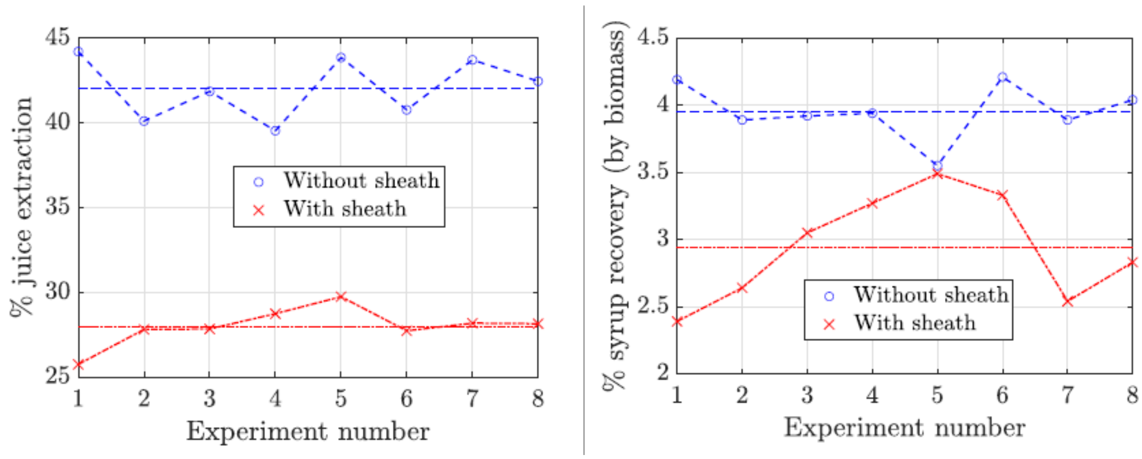


Figure 103: Some non-dimensional quantities in leaf sheath effect experiments. The dashed horizontal lines represent the mean values.

Organoleptic evaluation

Organoleptic testing of syrup was carried out for the eight experiments above. In the testing, 11 persons were asked to rate the syrups on five criteria: color, clarity, flow, smell and taste, on a scale of 1 (worst) to 3 (best). The average ratings are tabulated in Table 50. It is seen that on an average the 'with sheath' syrup was preferred on all criteria except color; the syrup from the 'with sheath' batch had a brownish hue to it. In particular, the 'with sheath' syrup obtained a rating of 2.25 on average as compared to 1.92 for the 'without sheath' batch in taste, perhaps the most important criterion of all.

Table 50: Average ratings of organoleptic evaluations.

Criterion	Without sheath	With sheath
Color	2.07	2.03
Clarity	1.69	1.76
Flow	2.11	2.44
Smell	2.24	2.40
Taste	1.92	2.25

Appendix E

Installation of crusher

Figure 104: Work from foundation construction to crusher installation.

Appendix F

Meshes in filtration unit

Figure 105: Four filters from coarsest (top-row) to finest (bottom-row). In the right column, close-ups with a scale alongside are presented.

Appendix G

Laboratory juice settling experiments

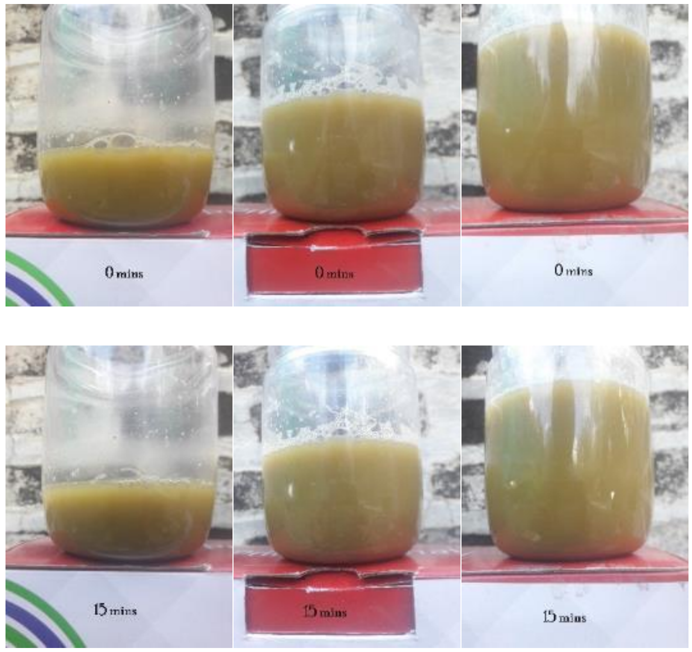
Three identical plastic containers were taken. 100, 200 and 300 ml juice was added in the containers, so that the L/D ratios of the juice were 0.4, 0.8 and 1.2; L denoting the juice height in the container and D its diameter. These details are provided in Table 1.

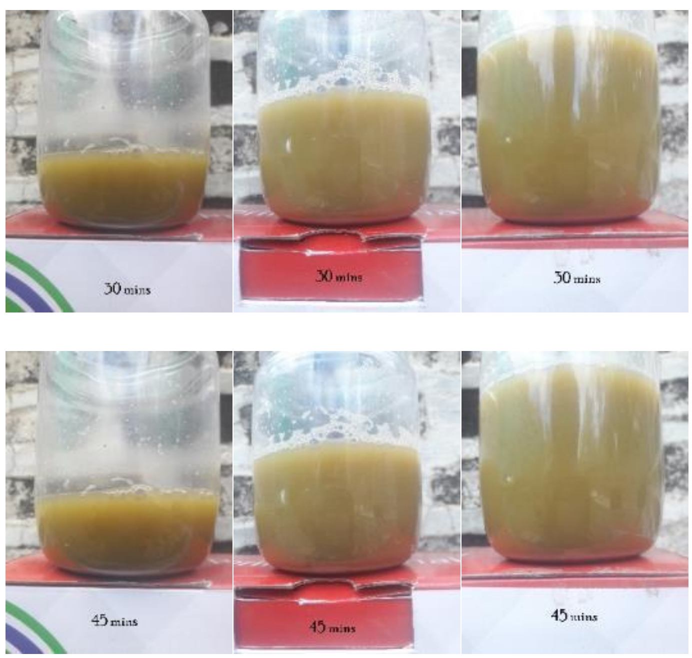
Table 51: Details of the experiment. Note that the settling time *is defined as the time after which no notable change in the settled mass was observed.*

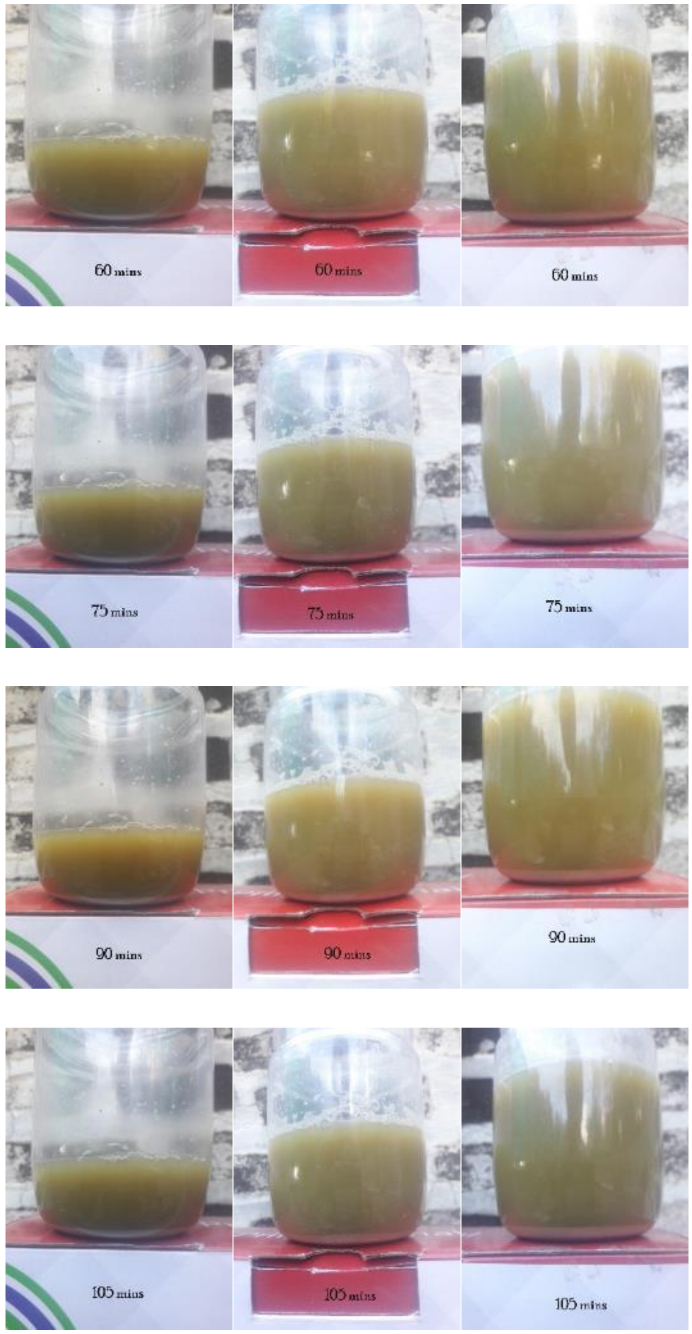
Container	Volume of juice (ml)	L/D	Settling time (mins)
1	100	0.4	90
2	200	0.8	90
3	300	1.2	90

Figure 106: Set up of the juice settling experiment.

Chronological progression of settling






60 mins
60 mins
60 mins
75 mins
75 mins
75 mins
90 mins
90 mins
90 mins
105 mins
105 mins
105 mins

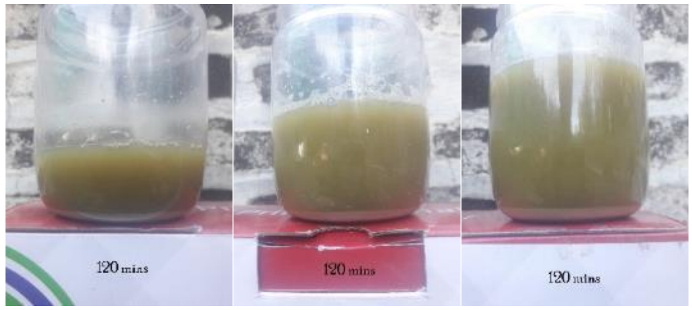


Figure 107: A collage of all photos. It is apparent that the increase in the settling mass between 90 and 120 minutes is much smaller than in the previous 30-minute periods. This becomes clearer in the next three photos.

Container-wise photos

Container 1

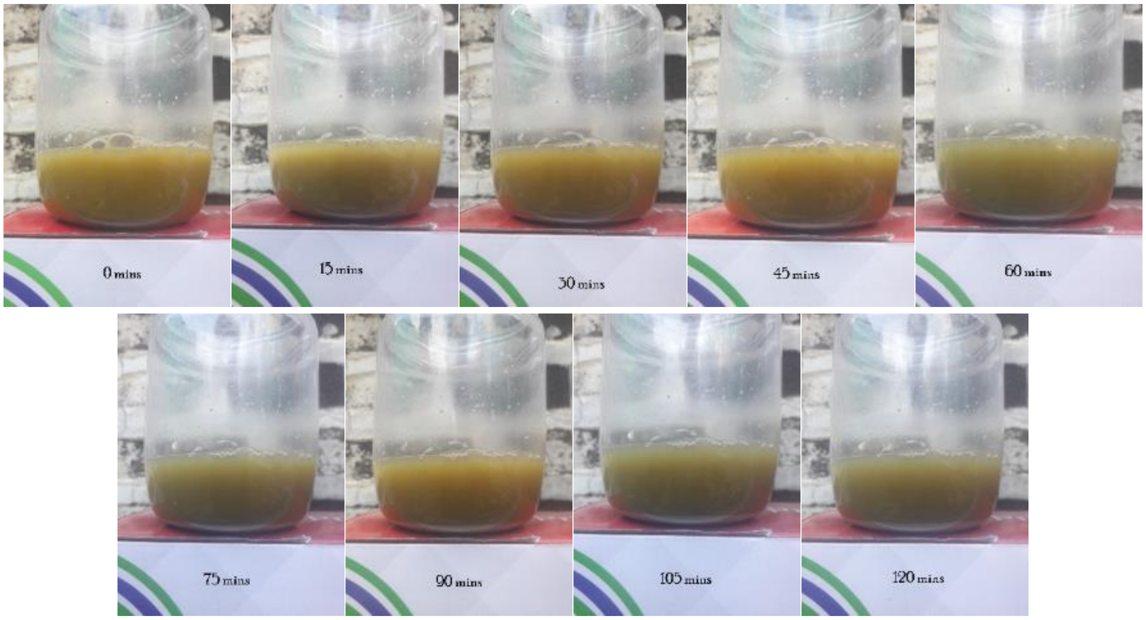


Figure 108: Photos of Container 1.

Container 2

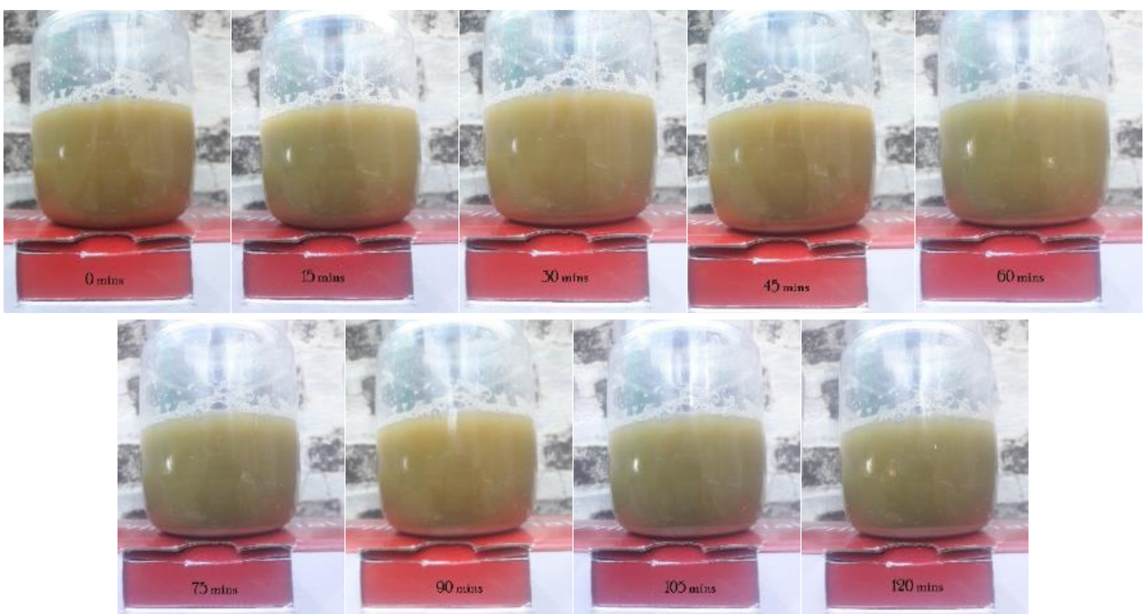


Figure 109: Photos of Container 2. It is apparent that the settling time is at least 90 minutes.

Container 3

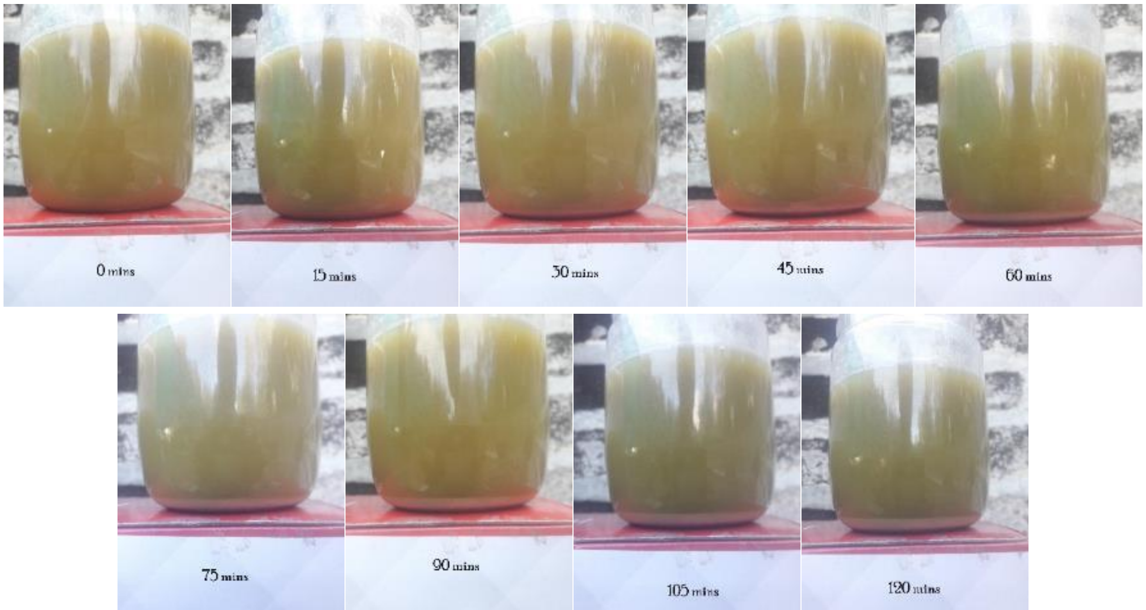


Figure 110: Photos of Container 3. It is apparent that the settling time is at least 90 minutes.

Conclusions

- In the three laboratory experiments on settling time, it was seen in the first experiment that the settled mass does not change much after 60 minutes in some containers, and 90 minutes in the others. The SS variety used for the first experiment was M3.
- In the second and the third experiments, in which M2 was used, it was seen that the settling time for all the three containers considered is at least 90 minutes, and definitely not 60 minutes. The difference in the settled mass at the 60-minute and the 90-minute marks is pronounced.

Appendix H

Effect of mucilage on syrup quality and new mucilage preparation strategy

Effect of mucilage

The percentage of scum obtained in these experiments (by the weight of the juice) is plotted in Figure 111. It is seen that mucilage addition marginally enhances the scum formation. Moreover, the clarity (as determined from organoleptic testing) of the syrups obtained with mucilage was superior (Figure 112).

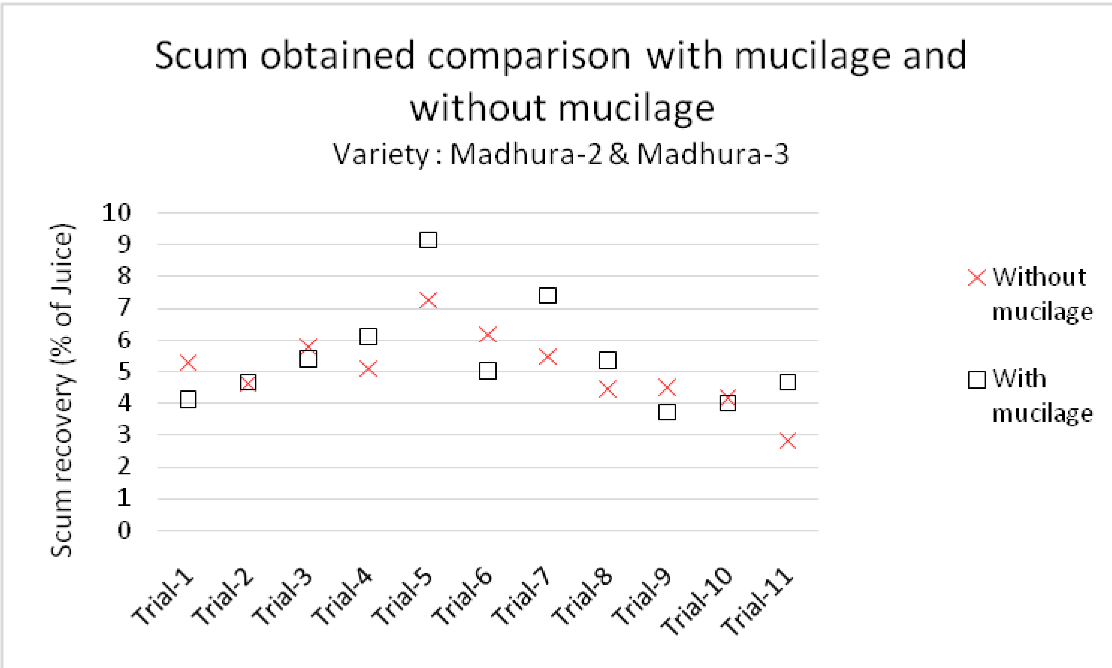


Figure 111: Scum obtained with and without mucilage addition.

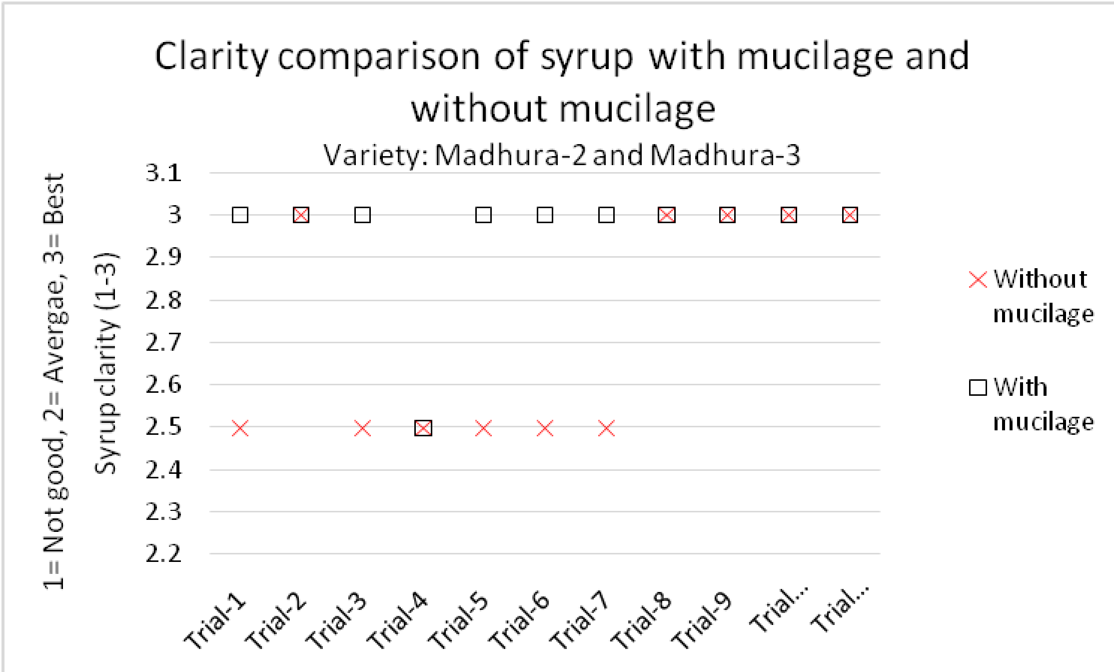


Figure 112: Clarity of syrups with and without mucilage addition (from organoleptic evaluations).

The effect of mucilage addition on the starch content of the juice, syrup and scum was also measured. The results of these measurements are plotted in Figure 113 to Figure 115 (for M3, M2 and Sugargraze cultivars, respectively). It is seen in the figures that mucilage addition reduces the starch content in the SS syrup in all the varieties. It is also seen that settling of the juice reduces the starch content in it.

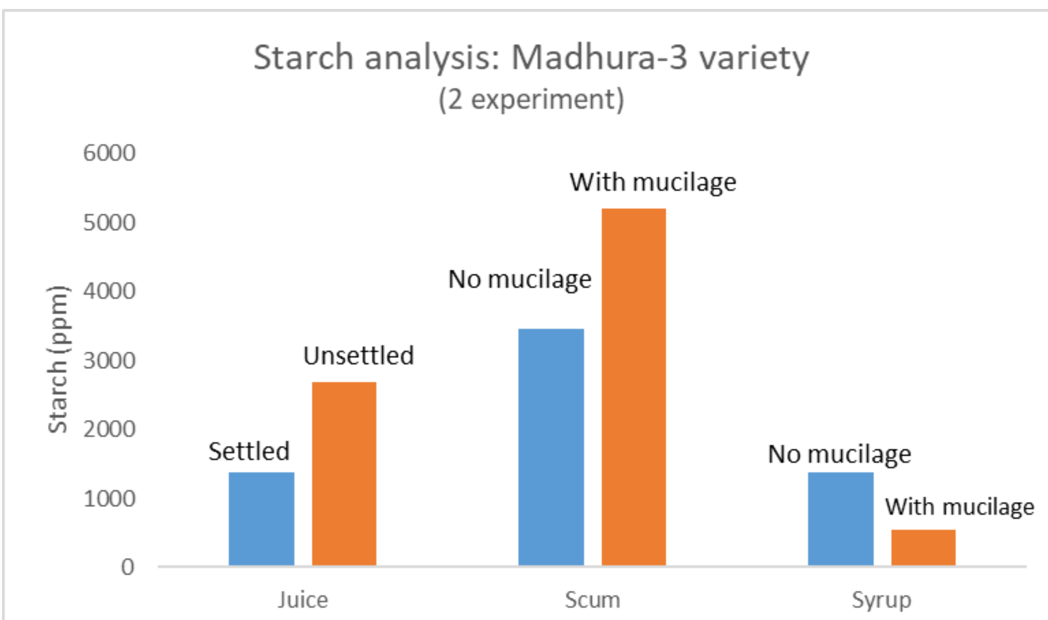


Figure 113: Starch content in juice, scum and syrup (Madhura-3).

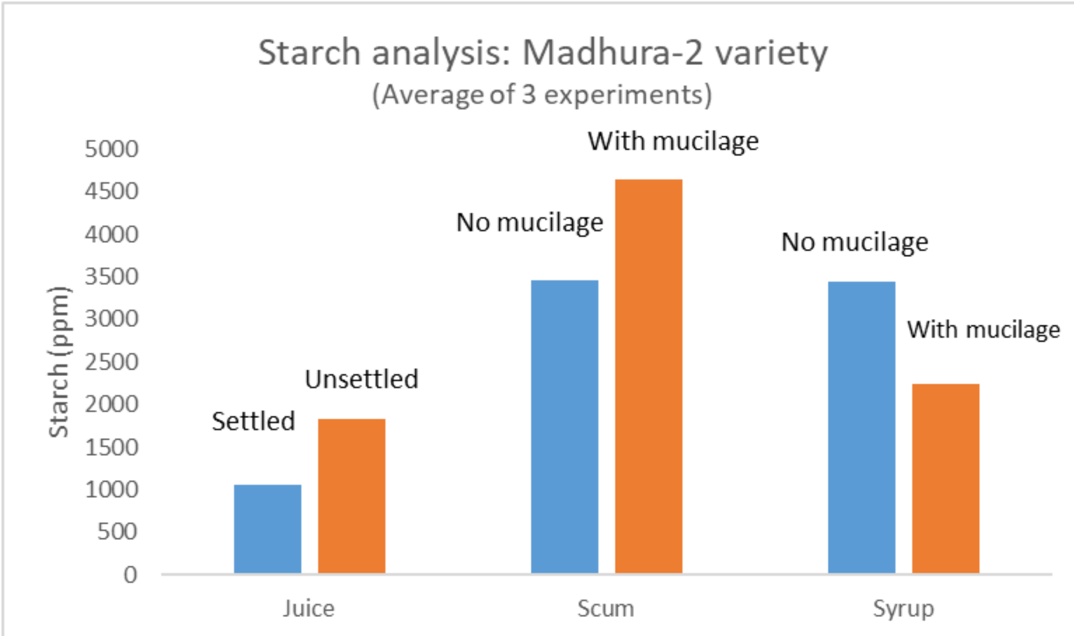


Figure 114: Starch content in juice, scum and syrup (Madhura-2).

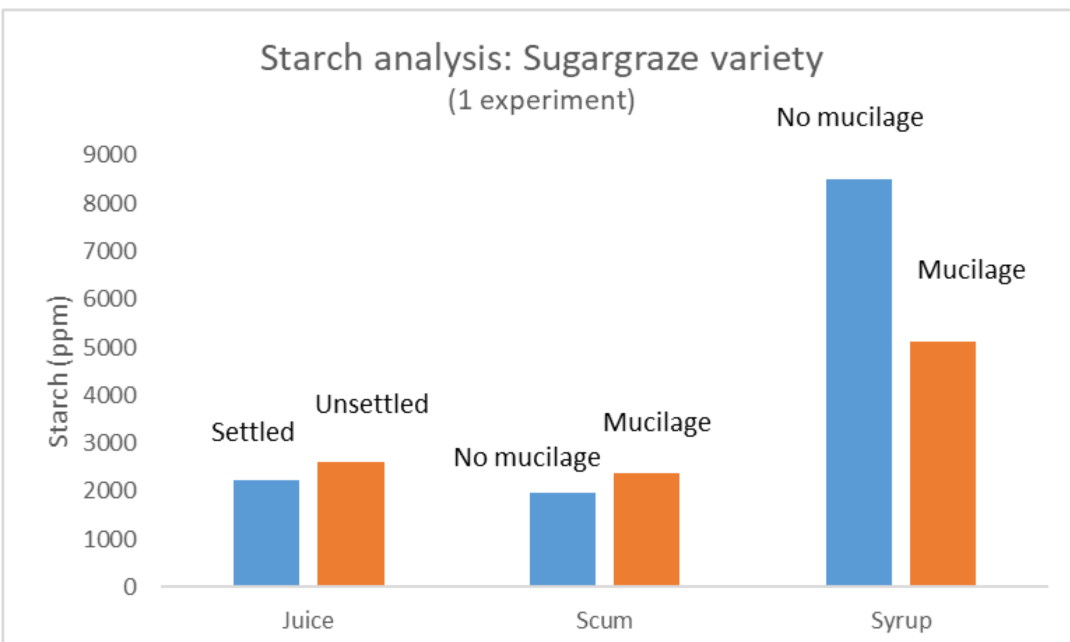


Figure 115: Starch content in juice, scum and syrup (Sugargraze).

New mucilage preparation strategy

1. Take 4 kg okra fruit (about 1.5% of clear juice).

2. Crush with 7.5 hp crusher; it takes about 12 minutes to crush (for comparison, it takes about thrice this time to cut okra fruit manually by a single labourer). As a result, 3.65 kg crushed okra fruit is obtained.
3. Soak the crushed okra fruit in 12 kg water for 1 hour 15 minutes.
4. About 6 kg clear mucilage is filtered out (no need for pressing) with 400-micron nylon filter.
5. In the remainder of the soaked crushed okra (which weighs about 9 kg), 4.5 kg water is added and mixed well.
6. This mixture is then fed slowly to the crusher. Both liquid mucilage (about 4.2 kg) at crusher drain outlet and solid okra pulp at crusher bagasse outlet are obtained. Solid okra pulp is fed again and more squished pulp (about 1.2 kg) is obtained through crusher drain outlet.
7. The squished pulp obtained at crusher drain outlet is filtered through 400-micron nylon cloth (this time by pressing with hands) and as a result, 4.3 kg mucilage is obtained. In this way, a total of 6+4.3=10.3 kg mucilage is obtained.
8. Total solid discard (okra pulp) obtained is about 7.5 kg.

The process is represented schematically through a mass-flow diagram in Figure 116.

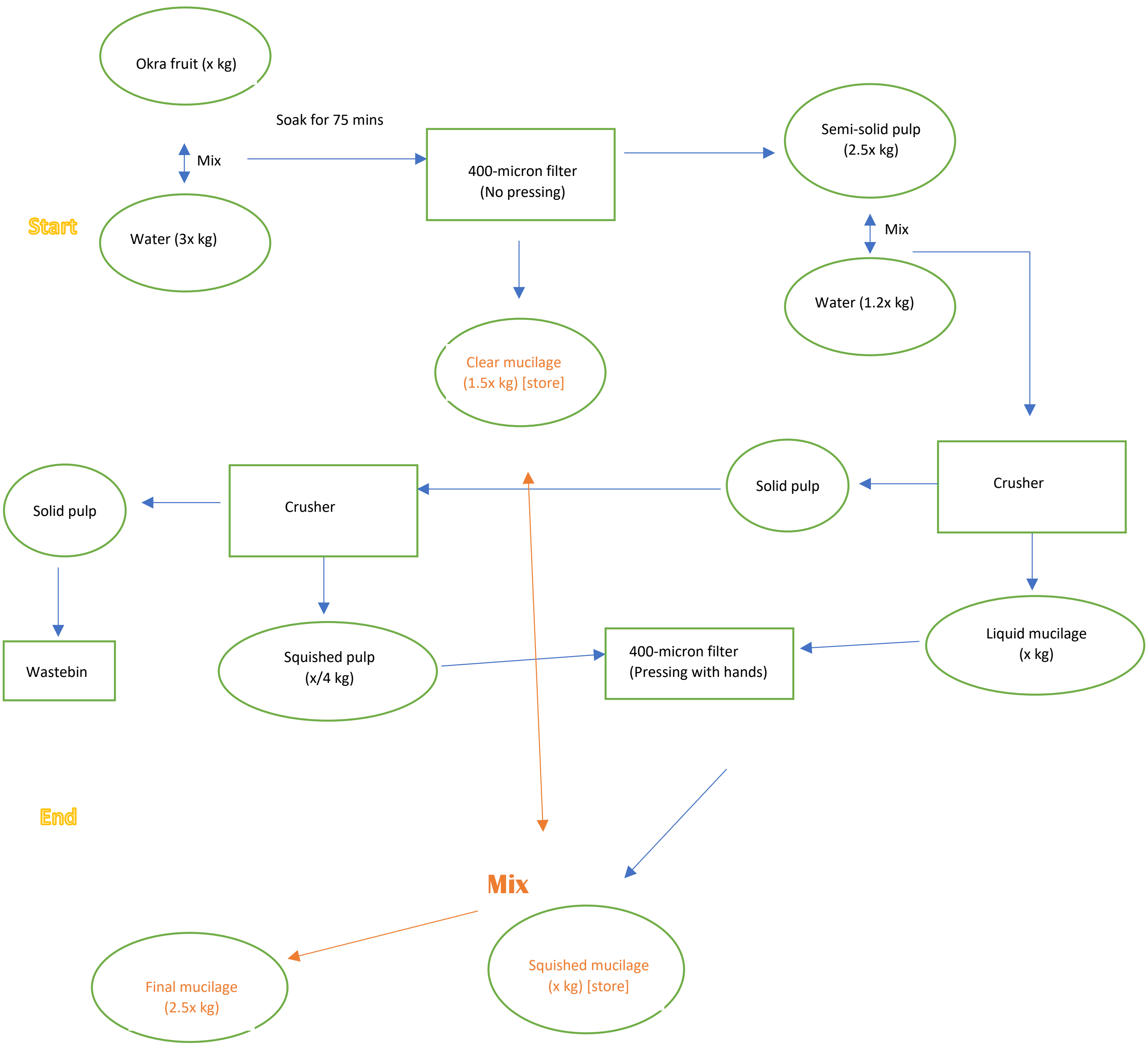


Figure 116: Mucilage preparation methodology.

Appendix I

Determination of optimum mesh size for scum collector

To determine the size of the mesh to be used in the scum collector, a small-scale syrup-making session was carried out. The following three meshes were tried: (a) mosquito net (about 13 holes per inch, mesh size: 1150 microns), (b) saree (about 60 holes per inch, mesh size: 250 microns) and (c) stainless steel mesh with 160 holes per inch (mesh size: 100 microns). Areas of these meshes were chosen so as to obtain the same amount of scum per unit area as in a typical large-scale syrup-making session. These three meshes are shown in Figure 117.

Figure 117: Meshes considered for scum collector. Left: saree; middle: stainless-steel mesh; right: mosquito net.

A photograph of the meshes immediately after removal of first scum layer is shown in Figure 118.

Figure 118: Immediately after the first scum layer removal. At this point, it is difficult to tell the three meshes apart. The difference in their performance becomes clear over a longer time period.

Finally, photographs of the three meshes after syrup preparation are shown in Figure 119.

Figure 119: After syrup preparation. It is seen that the mosquito net has let even the scum through (right). The scum amount is maximum with the stainless-steel mesh (middle).

Figure 120: Filtered juice from the three meshes. The juice obtained from the stainless-steel mesh (left) is clear and contains no foam. The juice becomes less clear and foamier as we move rightwards (middle: saree, right: mosquito net). Note that in the scum collector, this clear juice is drained back to the heating pan.

A comparison between the three meshes is presented in Table 52.

Table 52: Comparison between the three meshes.

	No. of holes/in	Juice weight	Scum weight
Stainless-steel sheet	160	105 g	125 g
Saree	60	220 g	15 g
Mosquito net	13	220 g	5 g

The above observations indicated that a mesh size of 160 holes/in is suitable.

Appendix J

Installation of pan lifting mechanism

Firstly, a structure to fix block and tackle was erected (Figure 121). After installation of the structure, a block and tackle of 2-ton capacity, which was available at the institute itself, was fixed (Figure 122).

Figure 121: Structure erected for installation of block and tackle.

Figure 122: Installation and trials on old chain block.

Some difficulties were faced in lifting of the pan as illustrated below in the order they occurred.

1. In the first trial, sagging of the pan upon lifting was observed (Figure 123).

Trial-1 on block and tackle:

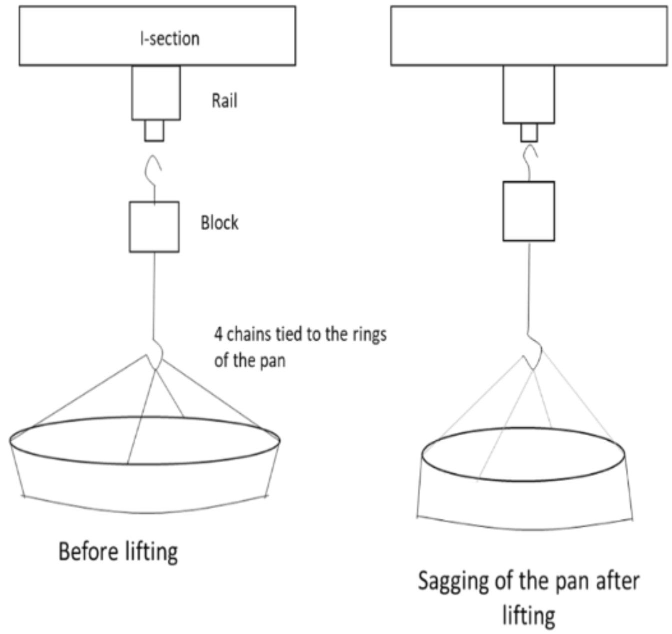


Figure 123: Sagging of the pan.

2. To address the issue of sagging, a mild steel frame was attached to the pan (as shown in Figure 124). The pan was then lifted with the help of four chains tied to the frame as shown in the figure. Upon lifting, it was observed that there was no sagging of the pan; however, the pan titled towards one side.

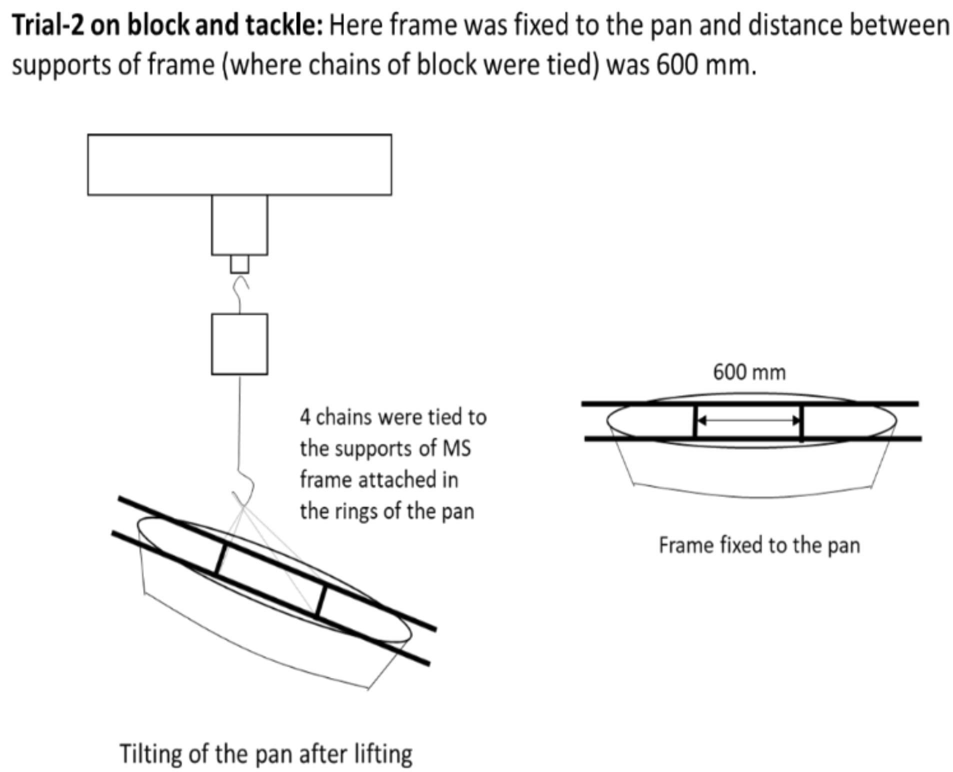


Figure 124: Tilting of the pan.

3. To remedy the tilting, the distance between the two supports in the frame was increased from 600 mm to 1000 mm (Figure 125). This reduced the tilting significantly.

Trial-3 on block and tackle: Here frame was fixed to the block and distance between supports of frame (where chains of block were fixed) was 1000 mm.

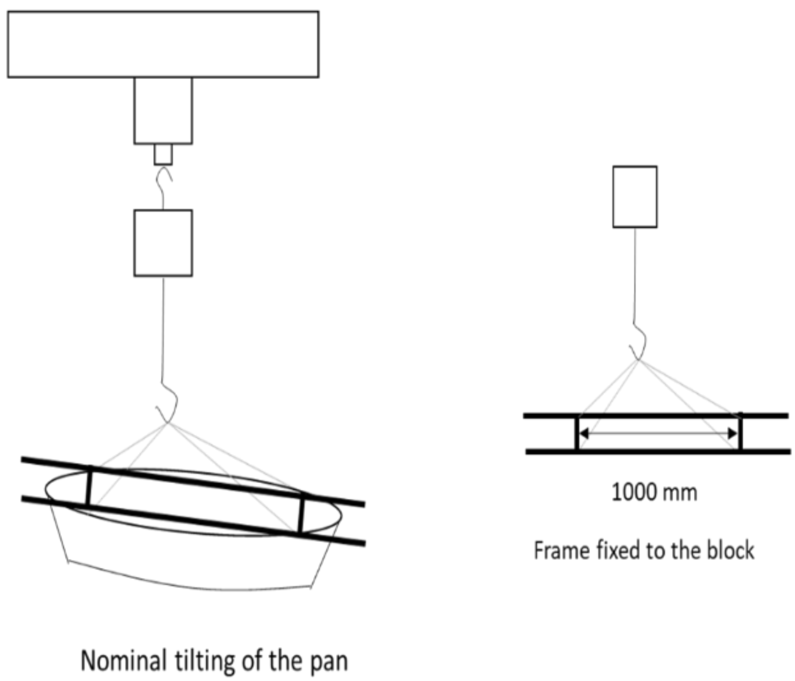


Figure 125: Reduction in tilting of the pan.

4. Finally, it was seen that the mechanism was not able to lift the pan to the desirable height. To address this issue, the support of the I-beam was lifted by 125 mm, whereupon it was seen that the pan was raised to the desired height (Figure 126).

Lifting of I beam: To make sure that bottom of the pan is above the furnace, I- beam was lifted by 125 mm. With this trial, we found that pan was getting lifted satisfactorily above the furnace.

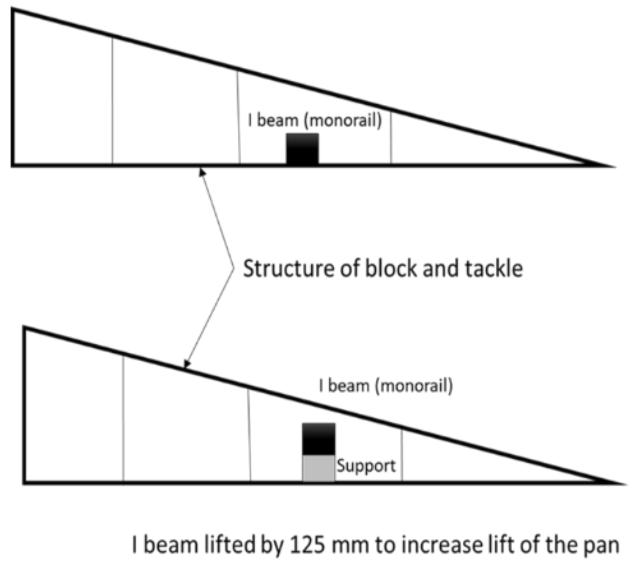


Figure 126: Lifting of the I-beam to increase the lift of the pan.

Once the issues mentioned above were resolved, some other minor modifications in the mechanism were made. Since existing block and tackle of 2-ton capacity was heavy (43 kg), a new chain block having 10 kg weight and lifting capacity of 1 ton was purchased (Figure 48).

Performance of the lifting mechanism

Multiple trials were taken on the new chain block by lifting the pan filled with 140 kg water (since this is well above the weight that actually needs to be lifted during syrup production; the weight of the pan is 60 kg, so the total weight lifted by the mechanism was 200 kg). It was found that, on an average, a single operator takes about 4 minutes from fitting the frame to the O-rings of the pan to finally tilting it for syrup drainage. The top right hand-side photograph in Figure 48 demonstrates the pan being lifted by the new chain block. It is clear from it that the pan is getting lifted to a sufficient height.

Appendix K

Fuel feeding strategies tried

Drum and guideway

Firstly, a plastic drum with a guideway was tried (Figure 127). The fuel was filled in the plastic drum and fed to the guideway with hands. It was then pushed into the furnace with the help of a push rod. The feeding was simple but time-consuming, because of which, this approach was abandoned.

Figure 127: Fuel-feeding using drum and guideway.

Blower and hopper

To semi-automate the fuel-feeding process, the fuel was fed into the furnace with the help of air pressure. The fuel (leaves and bagasse of SS) was filled in a hopper and pushed into the furnace by a blower (powered by a 3 hp motor) (Figure 128). Due to the nature of the bagasse and leaves, the hopper was getting clogged frequently, and hence this design was abandoned too.

Figure 128: Fuel-feeding using blower and hopper.

<u>Modified bagasse shredder (finalized)</u>

It was then decided to make modifications in the shredder itself so that it could also serve as a feeder. Since the shredder was designed for agricultural residues with thicker and longer pieces, following modifications were made to make it suitable for loose or dense agricultural residues with short or long pieces.

1. <u>Making new shute for the shredder</u>: The existing shredder machine was designed to shred stalk of sorghum, maize etc., for feeding them as fodder to animals. Its chute was angled to throw the chopped stalks 4-5 meters from the machine. To make the shredder suitable for feeding the furnace, its chute angle was changed so that the shredder biomass fell in a 1-1.5-meter range (Figure 129).

Figure 129: Left: shute of the old shredder machine; right: modified shute.

2. <u>Filling the gap beneath the rail with a wooden plank:</u> With the modified shredder, no difficulty was faced in feeding the leaves and stalks of the SS crop into the furnace. However, while feeding bagasse, it was observed that it fell through the gaps between the bars of the rails, and the rail-end and the rollers. This issue was resolved by adding a wooden plank below the rails, as shown in Figure 130. To reduce the gap between the rail-end and the rollers, a flat metal sheet was

welded in place. However, it was not possible to completely fill this gap, as the rail would have then engaged with the rollers.

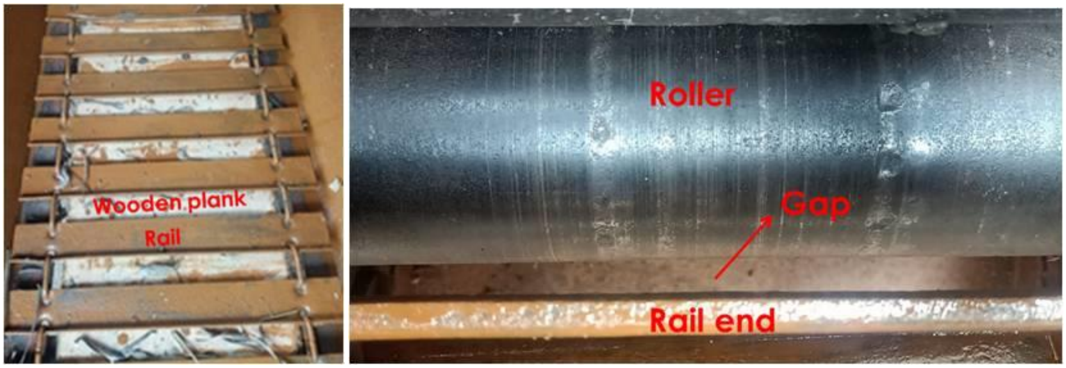


Figure 130: Filling up of gaps in the feeder of the shredding machine.

With this new arrangement, a few trials were taken by feeding SS bagasse (and threshed residue of sorghum, safflower and pearl millet). It was found that more than 10% of the bagasse was still falling through the gaps. In view of these difficulties, it was decided to make an altogether new arrangement for feeding loose agricultural waste.

3. <u>Designing of a separate feeding port for loose biomass</u>: A hopper was then used as an inlet port and installed on the shredder so that the loose biomass falls past the rollers (Figure 131).

Figure 131: Modification in the shredder machine to feed loose biomass.

Due to this arrangement, loose biomass fell directly onto the chopping blades, whereupon it was shoved into the furnace. Trials taken with different fuels were all successful.

4. <u>Covering the open spaces</u>: Later on, another minor issue was faced. If the loose biomass was very fine, it was falling out through the narrow open spaces in the machine. To address this, the area around the machine blades was covered with a mild steel sheet.

Appendix L

Renovation of the old furnace

Furnace details

The old furnace was made from regular construction bricks and mud. A schematic of the furnace and its specifications are given in Figure 132 and Table 53, respectively.

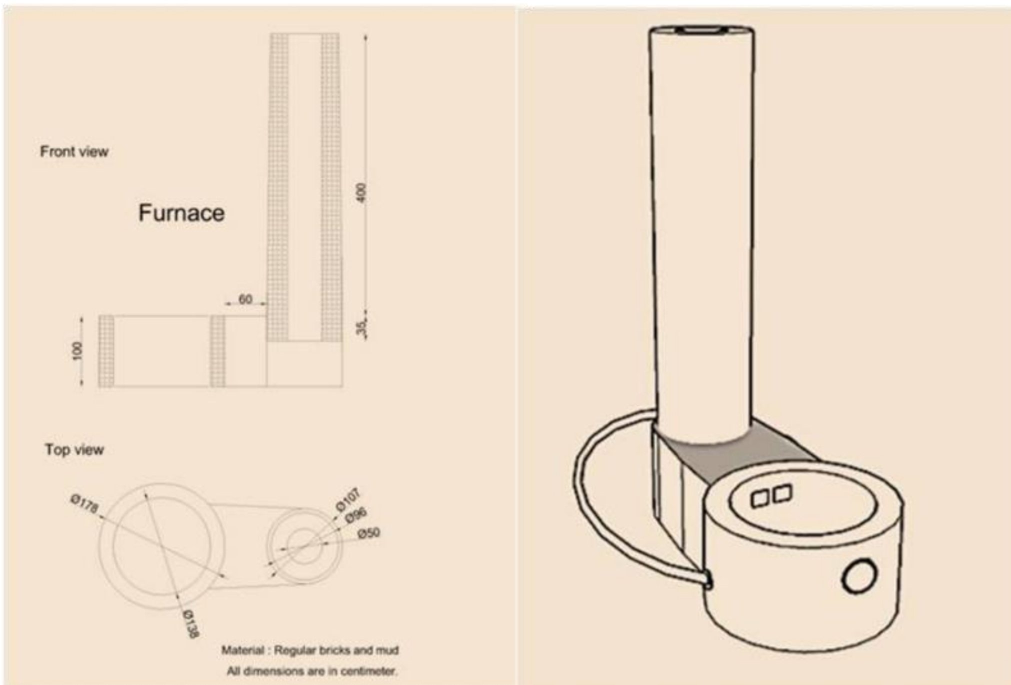


Figure 132: Schematic of the circular furnace developed by NARI.

Table 53: Specifications of the furnace.

Parameter	Value
Material	Construction bricks and mud
Inner diameter (mm)	1300
Thickness (mm)	230
Height (mm)	1000
Chimney height (mm)	4350
Chimney draft	1.6^0

Diameter of the fuel input door (mm)	250
No. of air openings	2 (one at the bottom and one at the furnace wall)

Renovation work

The furnace was reconstructed (Figure 133). Blower connections were provided to it. K-type thermocouples were placed at different locations in the furnace. Finally, it was plastered with a mud layer. Plastering helps in preventing the flue gases from escaping, thus enhancing the efficiency of the furnace.

Figure 133: Reconstruction of the furnace. Top-left: plastering of the furnace; top-right: plastering of the chimney; bottom-left: renovated furnace; bottom right: blower connection.

Based on the furnace dimensions, two stands of mild steel were fabricated at the institute for the operators to sit on while removing the scum (Figure 134).

Figure 134: Platforms for scum removal.

Appendix M

Determination of optimum supplementation to bagasse

Use of wood as supplement: Different amounts of wood and bagasse were used as fuel and the corresponding heating trends were plotted (Figure 135). Temperature control was found to be difficult when wood was added initially in excess quantity (more than 20 kg). Also, with only bagasse (and no wood), a low heating rate was obtained. A favourable heating trend was achieved with addition of 30 kg bagasse and 10 kg wood: the temperature of the water reached 80 ^{0}C rapidly, remaining steady thereafter for half an hour. As mentioned earlier, such a heating trend is desirable for optimum scum removal.

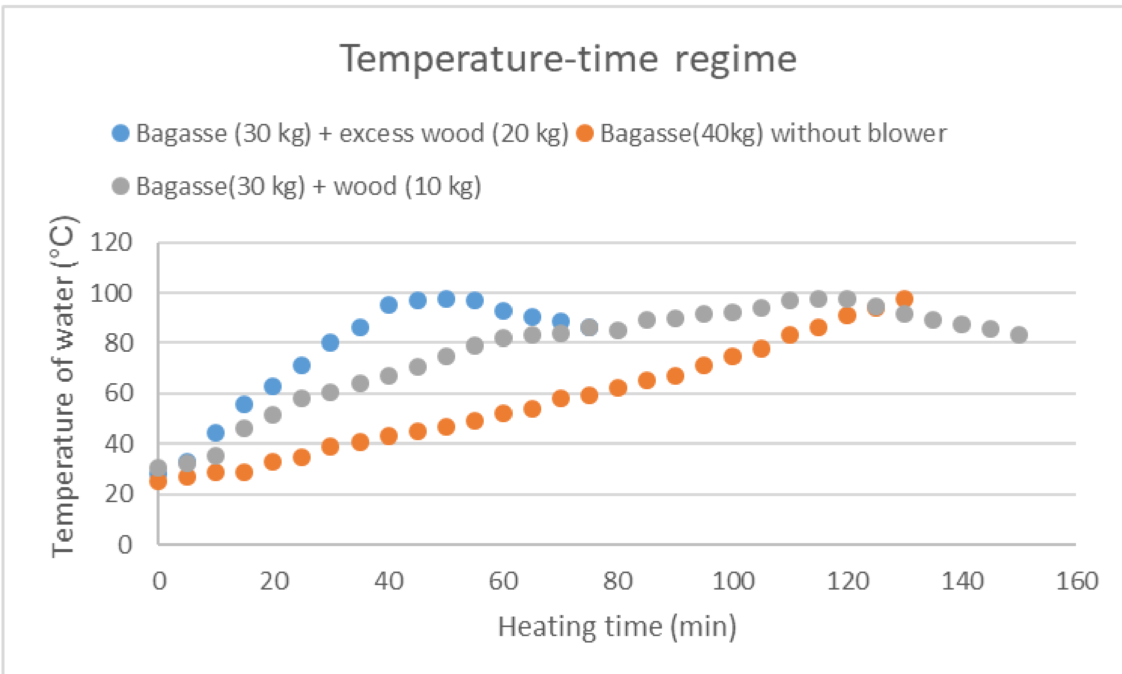


Figure 135: Heating rates for different proportions of wood and bagasse.

Use of diesel as supplement: Since wood is not available all the time, it was decided to use diesel instead of wood. The diesel was used after the juice attained a temperature of 80°C. To avoid uncontrolled heating, the diesel was sprayed over the bagasse which was then put into the furnace. No significant difference in heating was obtained, since diesel was used in a small quantity (about 0.5 kg). In actual syrup-making experiments, the heating process takes more than three hours, which will require a lot of diesel. Since diesel is expensive, this option is unviable.

A comparison of using wood and diesel as supplements to bagasse for producing 50 kg syrup is provided in Table 54.

Table 54: Comparison of wood and diesel as supplementary fuels for producing 50 kg syrup.

Fuel	Calorific value (MJ/kg)	Heating efficiency (%)	Amount needed (kg)	Price (Rs/kg)	Cost of required fuel (Rs)	Control on heating rate
Wood	15	30	50	5	250	Low
Diesel	46	45	10.9	100	1090	High

Use of SS leaves as supplement: In order to achieve fuel self-sufficiency, it was decided to test leaves of SS biomass as a supplement to the bagasse. Data of the SS crop was analysed, and it was found that, on an average, leaves make up 30% of the biomass (by weight). Hence a trial was conducted to first see whether the desired heating trend could be obtained with the bagasse-leaves combination. The result was promising, and a favourable heating trend was obtained (Figure 136).

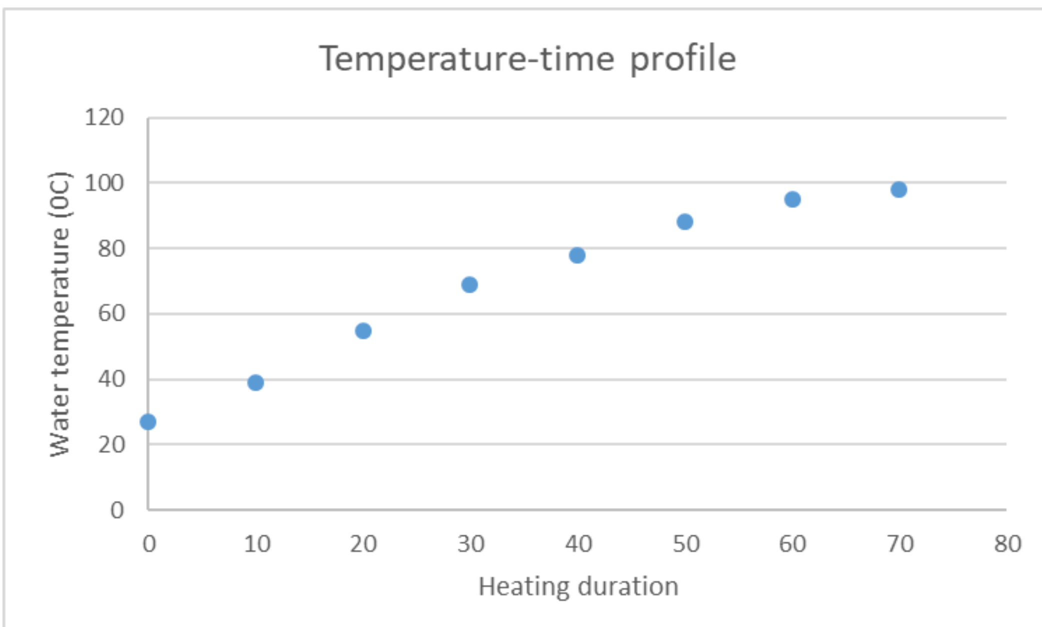


Figure 136: Heating trend with the bagasse-leaves combination.

The next step was to check whether fuel self-sufficiency can be achieved with the bagasse-leaves combination. Two experiments were conducted for this purpose, whose details are presented below.

<u>Experiment 1</u>

For the first experiment, sundried bagasse and leaves obtained from 1.2-ton biomass (used for making 50 kg syrup) were used as the fuel. A full-scale water-boiling test (equal in scale to producing 50 kg syrup;

300 kg water was boiled till only 50 kg remained) was carried out. The experimental data is given in Table 55. The corresponding temperature-time curve is shown in Figure 137.

Table 55: Experimental data of the first full scale water-boiling test.

Initial amount of water (kg)	297
Final amount of water (kg)	50
Bagasse used (kg)	150
Leaves used (kg)	100
Total fuel used	250
Moisture content of the fuel (%)	30
Fuel self-sufficiency achieved (Yes/No)	Yes
Efficiency of the furnace (%)	20.54

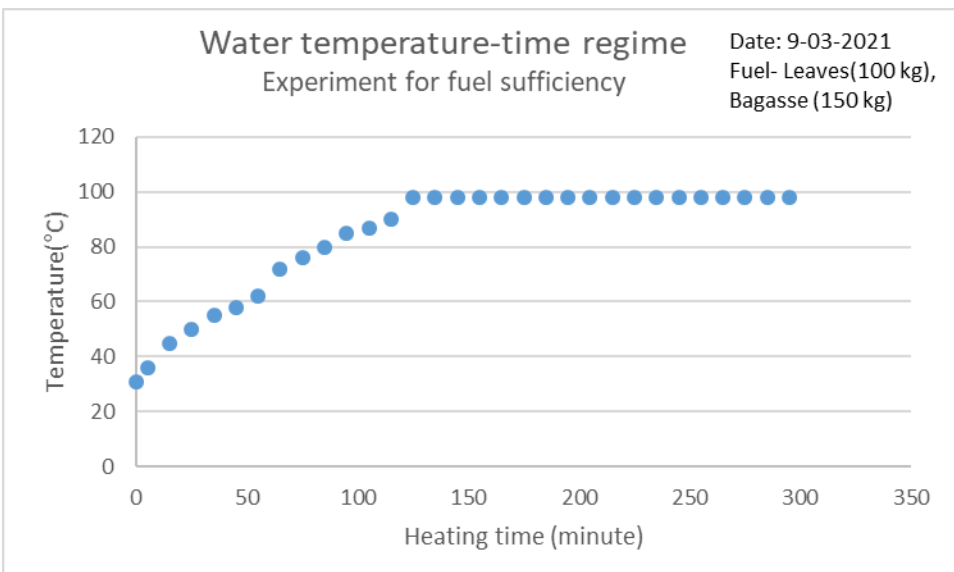


Figure 137: Temperature-time curve for the first full-scale WBT.

The following conclusions were drawn from this experiment:

- Fuel self-sufficiency was achieved. However, difficulty was faced in feeding the leaves to the furnace since they were long and loose. Hence it was decided to shred the leaves prior to feeding (done in Experiment 2).

- The leaf-bagasse combination provided a desirable temperature-time curve.

Experiment 2

In this experiment, the leaves were shredded (keeping everything else the same as Experiment 1) for ease of feeding (Figure 138 shows the difference between loose and shredded leaves). Upon shredding, the density of leaves increased from 33 to 76 kg/m^3 (density of the bagasse is about 60 kg/m^3).

Figure 138: SS leaves. Left: loose; right: shredded.

The details of this experiment are provided in Table 56. The temperature-time curve obtained is shown in Figure 139.

Table 56: Experimental data of the second full -scale WBT.

Initial amount of water (kg)	300
Final amount of water (kg)	50
Bagasse used (kg)	120
Leaves + stems used (kg)	110
Total fuel used (kg)	230

Moisture content of the fuel (%)	30
Fuel self-sufficiency achieved (Yes/No)	Yes
Efficiency of the furnace (%)	22.56

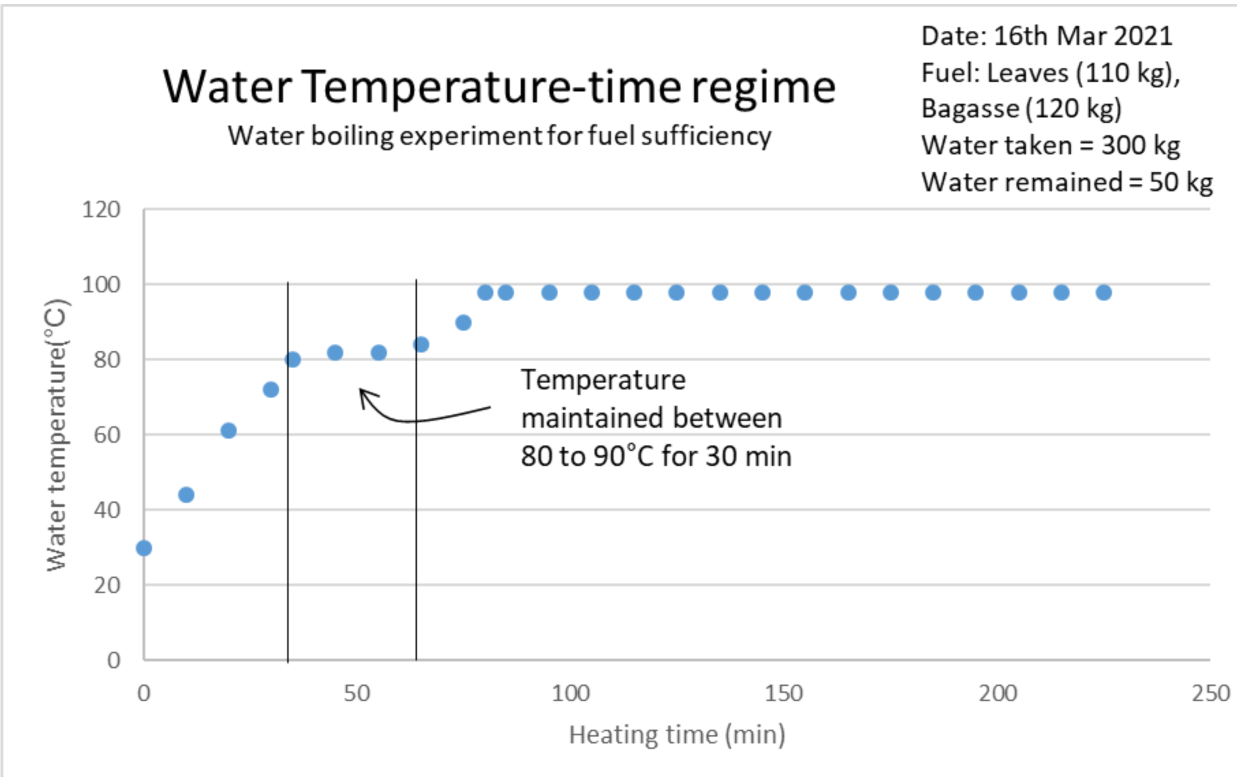


Figure 139: Temperature-time curve for the second full-scale WBT.

The following conclusions were drawn from this experiment:

- Due to shredding of the leaves, it was easy to feed them into the furnace.
- With bagasse-leaves combination, a desired temperature-time profile was being obtained.
- The bagasse-leaves combination gives fuel self-sufficiency.

Appendix N

Experiments to check fuel self-sufficiency

Four pilot-scale water-boiling tests were conducted (apart from those mentioned in Section Furnace work: old furnace) to make sure that fuel self-sufficiency was achieved. The results of these experiments are tabulated in Table 57. It is seen that fuel self-sufficiency was achieved in all the experiments since fuel (bagasse plus leaves) consumed in these experiments is less than 264 kg, which is the amount of bagasse plus leaves obtained as seen above.

Table 57: Data from fuel self-sufficiency experiments.

Date of experiment	09/03/21	16/03/21	15/04/21	16/04/21
Initial amount of water (kg)	297	300	290	290
Final amount of water (kg)	50	50	50	50
Bagasse used (kg)	150	120	90	96
Leaves used (kg)	100	110	92	90
Bagasse + leaves used (kg)	250	230	182	186
Fuel self-sufficiency achieved (Yes/No)	Yes	Yes	Yes	Yes

Appendix O

Determination of optimum chimney obstruction

In Figure 140 to Figure 143, the designs that were tried are shown. Then, a flowchart of proceedings is presented in Figure 144. The results of the water-boiling tests (with about 270 kg water) performed using these designs are shown in the next section.

Obstacle designs

Obstacle 1: rectangular sheet in front of the chimney inlet

A rectangular sheet was placed in front of the chimney inlet to resist the flow of the flue gases escaping through the chimney, as shown in Figure 140.

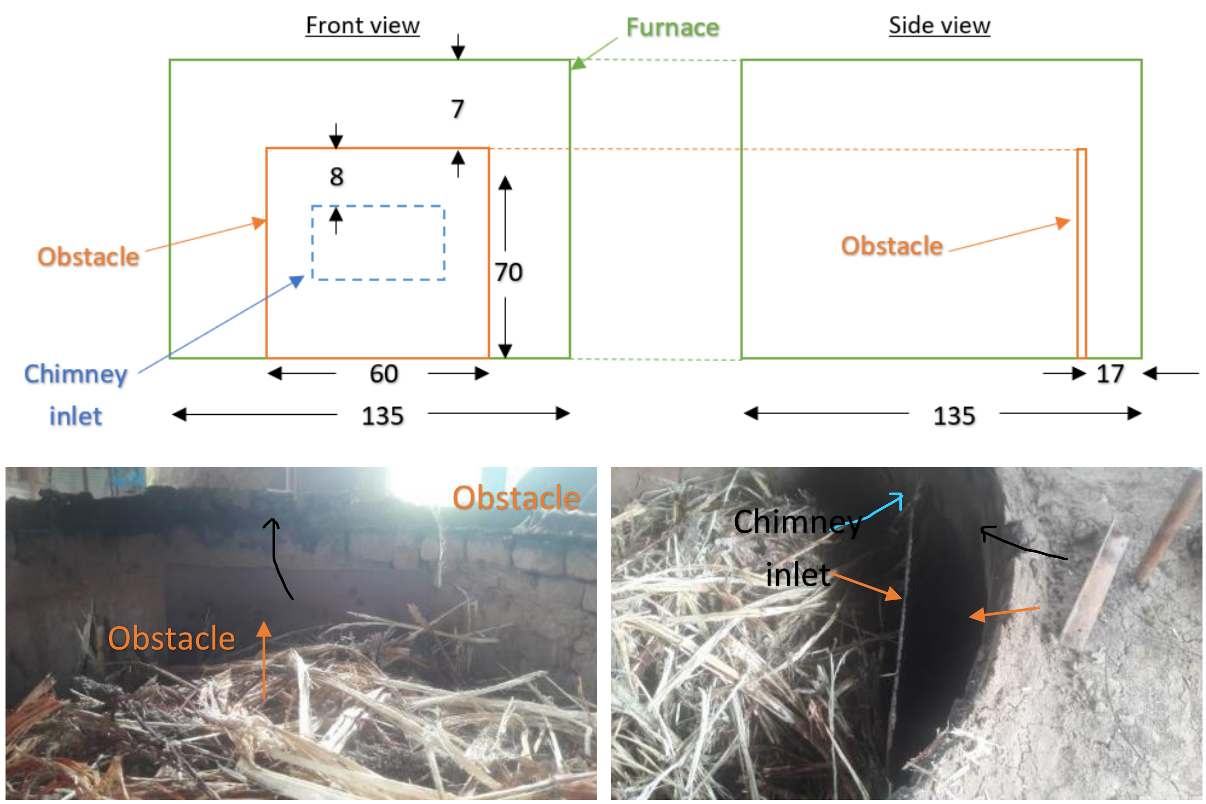


Figure 140: Rectangular sheet obstacle. Top: sketch depiction (all dimensions are in cm). Bottom-left: front-view photograph. Bottom-right: top-view photograph.

Obstacle 2: semi-circular sheet in front of the chimney inlet

A semi-circular sheet was placed in front of the chimney inlet, as shown in Figure 141.

Figure 141: Semi-circular obstacle. Top-left: front-view photograph. Top-right: top-view photograph. Bottom: oblique-view photograph.

<u>Obstacle 3: small square sheet in front of the chimney inlet</u>

A small square sheet was placed in front of the chimney inlet, as shown in Figure 142.

Figure 142: Small square obstacle. Left: front-view. Right: top-view.

<u>Obstacle 4: L-shaped chimney</u>

The obstruction in the chimney was increased by making it L-shaped, as shown in Figure 143. The chief differences in the old chimney and the new L-shaped chimney were: (a) the L-shaped chimney has both horizontal and vertical sections while the old chimney just had a horizontal section, (b) the L-shaped chimney has a circular cross-section while the old chimney had a rectangular cross-section of the same area.

Figure 143: L-shaped chimney. Left: before assembly. Right: during assembly.

<u>Flowchart of designs employed</u>

The flowchart shown in Figure 144 shows the rough progression of design. A rough description of how these designs came about is as follows: (a) a rectangular sheet was first placed in front of the chimney inlet and the furnace efficiency improved significantly indicating that the idea of increasing the resistance to the flue gas flow was correct, (b) since the rectangular sheet was reducing the combustion area of the furnace significantly, it was replaced by a semi-circular sheet, (c) encouraged by the results, it was decided to further increase the resistance by making the flue gases bend around through an L-shaped chimney; however, it was observed that this increased the resistance a bit too much, resulting in excessive back-pressure, (d) the resistance was decreased by removing the semi-circular sheet and instead putting a small square sheet in front of the chimney inlet; the backpressure was still more than desirable, (e) the chimney was restored to its original design of a simple horizontal section; moreover its cross-section area was increased slightly and the semi-circular sheet was put back. Finally, experiments were performed with varying heights of the semi-circular sheet and an optimum height was determined.

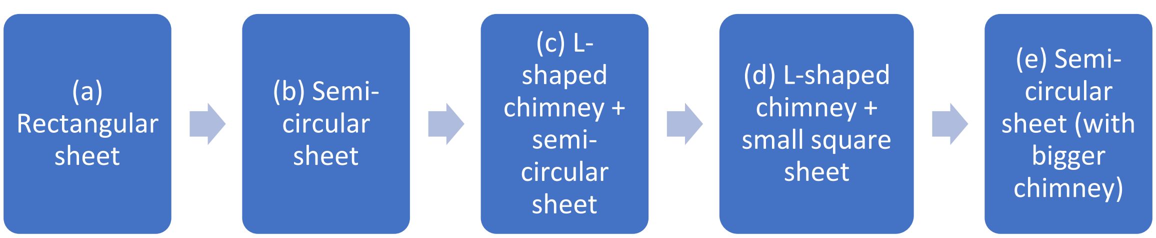


Figure 144: The designs progressed roughly in the manner shown above.

Observations from water-boiling tests

WBT 1: rectangular sheet in front of the chimney inlet

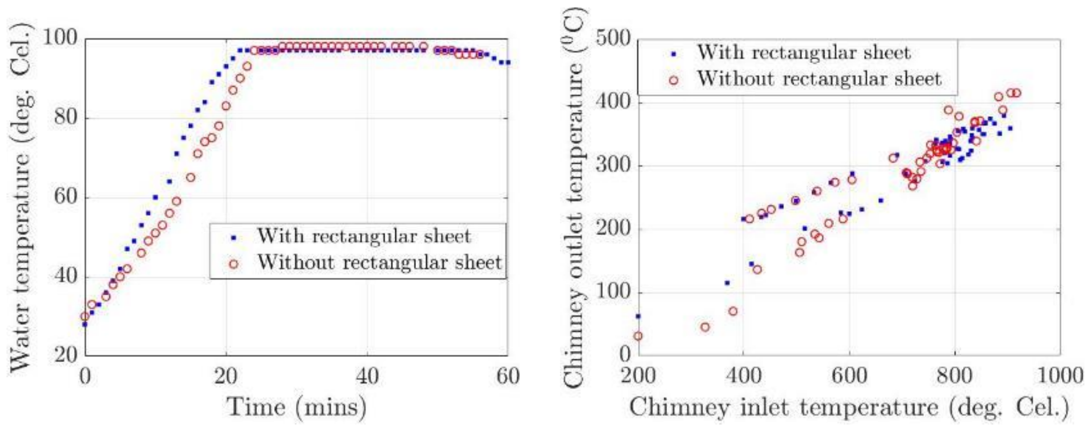


Figure 145: Effect of putting rectangular sheet in front of the chimney inlet. Left: the heating rate improved slightly. Right: For given chimney inlet temperatures, chimney outlet temperatures are higher on an average, indicating reduction in flue gas escape velocity. The air inflow rate through the air blower was 200 m^3/hr.

Table 58: Effect of putting rectangular sheet in front of the chimney inlet. Significant improvement in furnace efficiency was seen.

	Without rectangular sheet	**With rectangular sheet**
Time to reach boiling (mins)	24	22
Transient furnace efficiency (%)	16.87	19.42
Backpressure (scale of 0[none] to 3[excessive])	0	1
Moisture in bagasse (% w/w)	7	10
Smoke (scale of 0[clear] to 3[dense])	0.51	0.23

WBT 2: semi-circular sheet in front of the chimney inlet

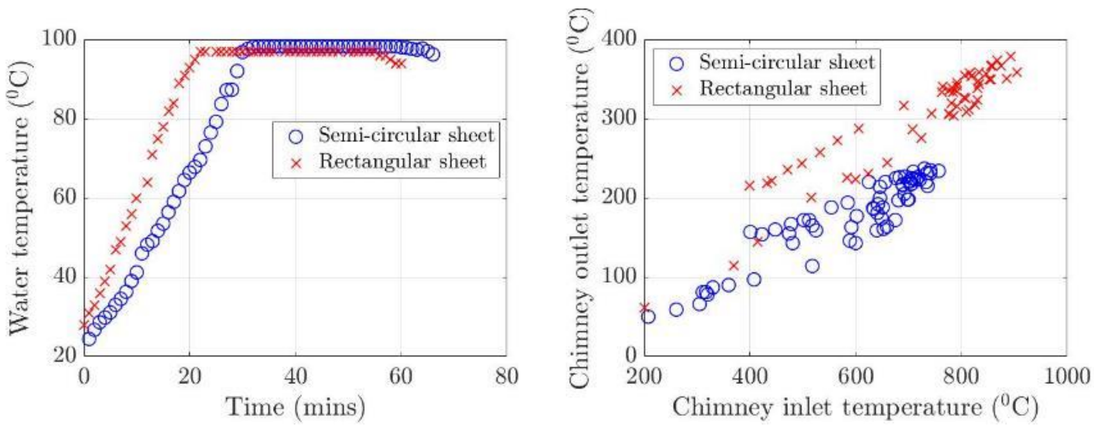


Figure 146: Comparison between semi-circular and rectangular sheets. Left: the heating rate deteriorated with the semi-circular sheet. Right: For given chimney inlet temperatures, chimney outlet temperatures are lower on an average for the semi-circular sheet, indicating reduction in flue gas escape velocity.

Table 59: Comparison between semi-circular and rectangular sheets. Significant improvement in furnace efficiency was seen with the semi-circular obstacle; however, the heating rate deteriorated and the backpressure was more.

	Semi-circular (s. c.) sheet	**Rectangular sheet**
Time to reach boiling (mins)	30	22
Transient furnace efficiency (%)	21.76	19.42
Backpressure (scale of 0[none] to 3[excessive])	2	1
Moisture in bagasse (% w/w)	19	10
Average smoke (scale of 0[clear] to 3[dense])	0.51	0.23

WBTs 3, 4 and 5: (a) L-shaped chimney plus semi-circular sheet in front of chimney inlet, (b) L-shaped chimney plus small square sheet in front of chimney inlet and (c) L-shaped chimney alone

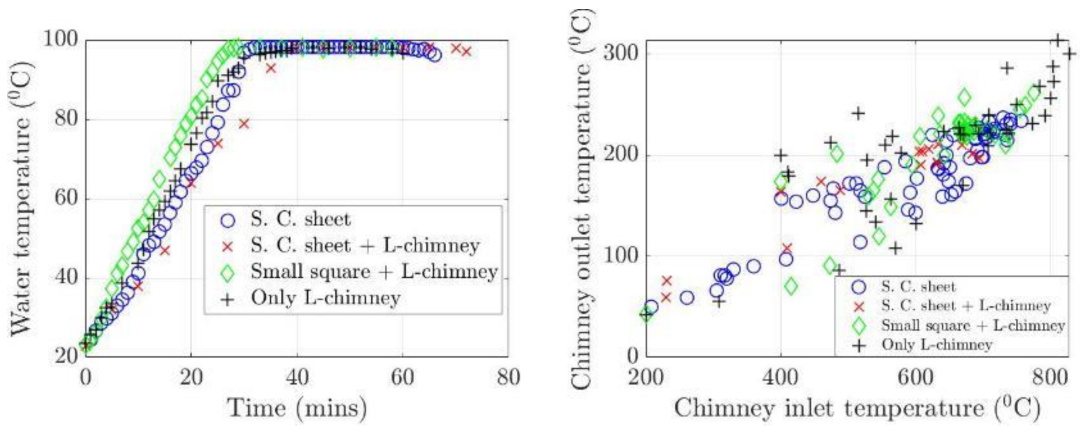


Figure 147: Performance of L-shaped chimney; for comparison, results with semi-circular sheet are also given. Left: In general, the heating rate deteriorates with increment in obstruction. Right: the chimney outlet temperature for a given chimney inlet temperature reduces on an average with increment in obstruction.

Table 60: Performance of L-shaped chimney; for comparison, results with semi-circular sheet are also given. It is seen that increment in obstruction has improved the furnace efficiency but reduced the heating rate and increased the backpressure.

	Semi-circular sheet	**Semi-circular sheet + L-shaped chimney**	**Small square sheet + L-shaped chimney**	**Only L-shaped chimney**
Time to reach boiling (mins)	30	40	27	33
Transient furnace efficiency (%)	21.76	22.21	21.26	21.43
Backpressure (scale of 0[none] to 3[excessive])	2	3	2	1
Moisture in bagasse (% w/w)	19	13	14	33
Average smoke (scale of 0[clear] to 3[dense])	0.51	0.75	1.19	0.27

It is seen above that increasing the obstruction has improved the furnace efficiency significantly but (a) reduced the heating rate and (b) increased the backpressure through the feeding port, thus resulting in inconvenient feeding. In view of these results, it was decided to (a) remove the L-shaped chimney and employ the old chimney design which consisted of a simple horizontal section, (b) increase the area of the chimney inlet to about 1.5 times (L-shaped chimney: 8-inch diameter, new bigger chimney: 10-inch diameter), and (c) put the semi-circular sheet back to create the required obstruction and vary its height to obtain an optimum obstruction.

WBT 6, 7, 8 and 9: Semi-circular sheet with bigger chimney

As mentioned above, a simple chimney with a single horizontal section and a bigger area was installed. The diameter of the new chimney was 10 inches (as opposed to 8 inches of the L-shaped chimney), implying an increment in area by 1.5 times.

Three heights of the semi-circular sheet were considered for WBTs, such that it was 2.5, 5 and 10 cm below the bottom surface of the pan, respectively. One WBT was done without the semi-circular sheet, for comparison. The results of these tests are presented in Figure 148 and Table 61.

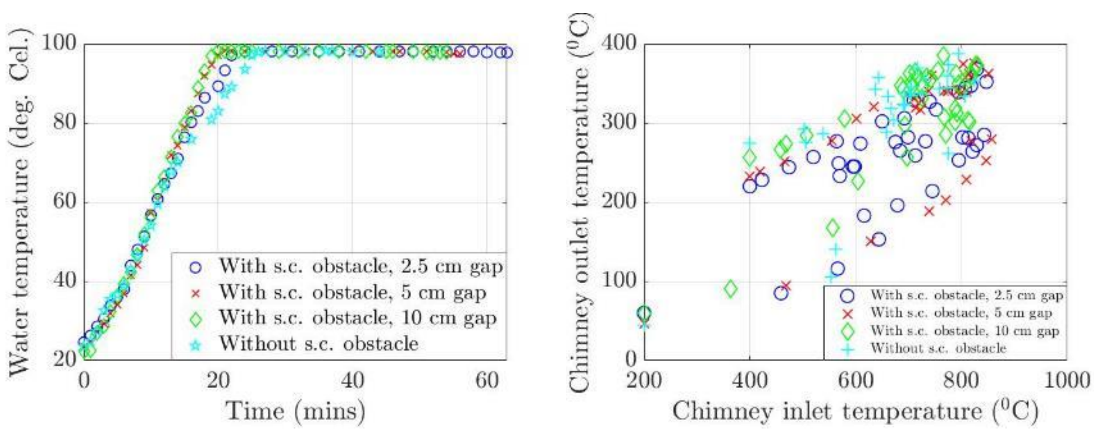


Figure 148: Performance with semi-circular sheet plus bigger chimney. Left: excellent heating rates were obtained, with boiling point reached in about 20 mins in all cases. Right: again, increment in obstruction (by decreasing the gap) leads to lower chimney outlet temperature for given chimney inlet temperature.

Table 61: Performance with semi-circular sheet plus bigger chimney. It is seen that with 5 and 10 cm gap, performance is excellent in all respects: heating rate is high, transient efficiency is excellent, smoke is minimal and backpressure is low.

	Without s. c. sheet	**With s. c. sheet, 10 cm gap**	**With s. c. sheet, 5 cm gap**	**With s. c. sheet, 2.5 cm gap**
Time to reach boiling (mins)	25	19	20	22
Transient furnace efficiency (%)	18.34	24.39	24.57	25.88
Backpressure (scale of 0[none] to 3[excessive])	0	1	1	2
Moisture in bagasse (% w/w)	22	14	11	11
Average smoke (scale of 0[clear] to 3[dense])	0.17	0.34	0.42	1.00

Improvement in furnace parameters with the water-boiling tests

The improvement in four critical furnace parameters with the water-boiling tests (arranged chronologically) can be seen in Figure 149. The four parameters that are plotted are: (a) average heating rate, (b) transient furnace efficiency, (c) backpressure on a scale of 0 (none) to 3 (maximum), and (d) average of all smoke ratings, rated on a scale of 0 (clear) to 3 (dense). Short descriptions of the 10 water-boiling tests discussed above are given in Table 62.

Table 62: Comparison of the 10 water-boiling tests.

Water boiling test number	Description	Date performed
WBT 0	Original design (no obstruction)	15 November, 2021
WBT 1	Rectangular sheet	16 November, 2021
WBT 2	Semi-circular (S.C.) sheet	6 December, 2021
WBT 3	S.C. sheet + L-shaped chimney	18 December, 2021
WBT 4	Small square sheet + L-shaped chimney	21 December, 2021
WBT 5	Only L-shaped chimney	27 December, 2021
WBT 6	Bigger chimney inlet, without S.C. sheet	29 December, 2021
WBT 7	Bigger chimney inlet, S.C. sheet with 10 cm gap	30 December, 2021
WBT 8	Bigger chimney inlet, S.C. sheet with 5 cm gap	31 December, 2021
WBT 9	Bigger chimney inlet, S.C. sheet with 2.5 cm gap	3 January, 2022

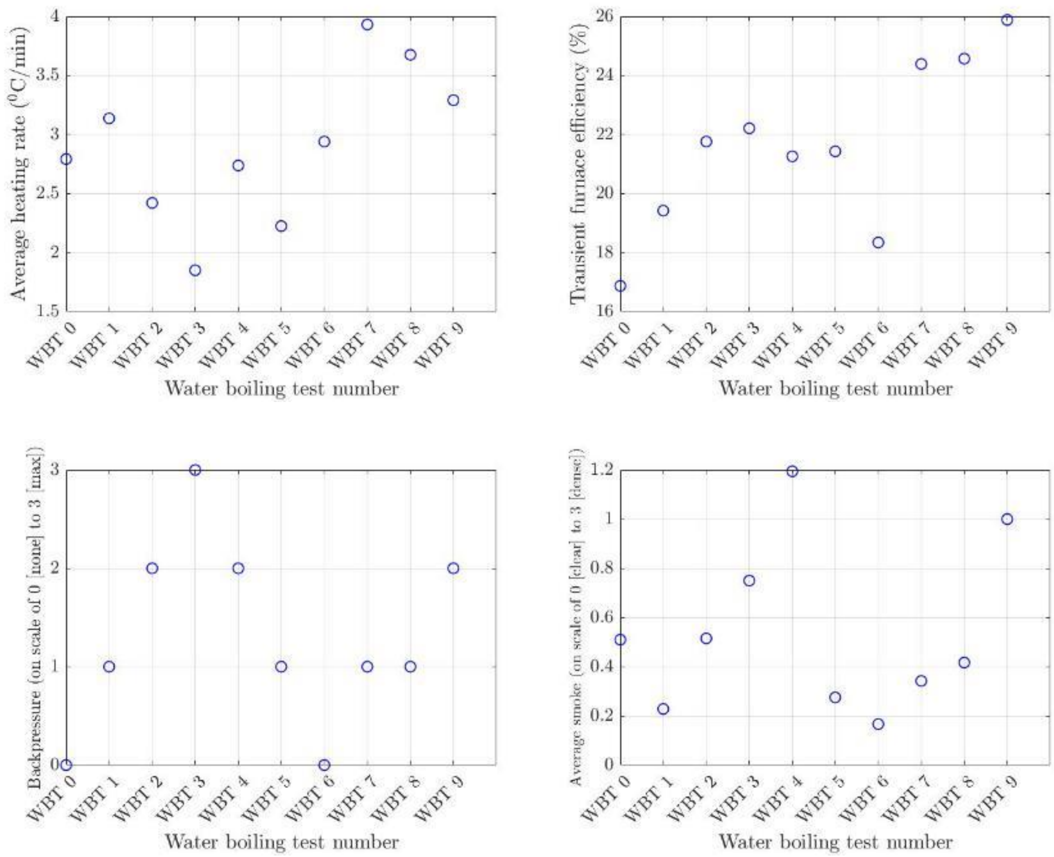


Figure 149: All the four parameters have desirable values for WBT 7 and WBT 8, corresponding to semi-circular sheet with 5 and 10 cm gap, plus bigger chimney.

Appendix P

Overall furnace performance parameter

The four furnace parameters: heating rate, furnace efficiency, backpressure and smoke level are combined into one single non-dimensional parameter to depict overall furnace performance. To develop this combined parameter, the above four parameters are first non-dimensionalised so that they go from 0 to 1 as the furnace performance improves. This is explained below.

Non-dimensional parameter corresponding to heating rate, p_{hr}: First, notionally maximum and minimum heating rates are determined. Based on experience, it is reasonable to suppose that water can be heated from 22 to 97.5 ^{0}C in 15 minutes at best and 60 minutes at worst. This implies that the maximum and minimum heating rates are 5 and 1.25 ^{0}C/min. Based on these, a non-dimensional parameter p_{hr} can be defined as follows:

p_{hr} = (heating rate – minimum heating rate)/(maximum heating rate - minimum heating rate)

= (heating rate – 5)/(5 - 1.25).

p_{hr} is plotted in Figure 150.

Non-dimensional parameter corresponding to furnace efficiency, p_{fe}: Similar to above, p_{fe} is defined as

p_{fe} = (transient furnace efficiency – minimum transient furnace efficiency)/(maximum transient furnace efficiency - minimum transient furnace efficiency).

Based on observations, maximum and minimum transient furnace efficiencies are chosen to be 30% and 5%, respectively. So,

p_{fe} = (transient furnace efficiency – 5)/(30 - 5).

p_{fe} is plotted in Figure 150.

Non-dimensional parameter corresponding to backpressure, p_{bp}: Since backpressure is undesirable, and increase in backpressure directly corresponds to decreasing convenience, a new quantity is defined as follows:

convenience = 3 – backpressure,

since 3 is the maximum backpressure on the scale chosen.

Accordingly, the non-dimensional parameter corresponding to backpressure is defined to be

p_{bp} = (convenience – minimum convenience)/ (maximum convenience – minimum convenience)

= (convenience – 0)/ (3 – 0).

p_{bp} is plotted in Figure 150.

<u>Non-dimensional parameter corresponding to smoke level, p_{sl}:</u> Similar to above, a new quantity is first defined as follows:

smoke clarity = 3 – smoke level,

since 3 is the maximum smoke level on the scale chosen.

Accordingly, the non-dimensional parameter corresponding to smoke level is defined to be

p_{sl} = (smoke clarity – minimum smoke clarity)/ (maximum smoke clarity – minimum smoke clarity)

= (smoke clarity – 0)/ (3 – 0).

p_{sl} is plotted in Figure 20.

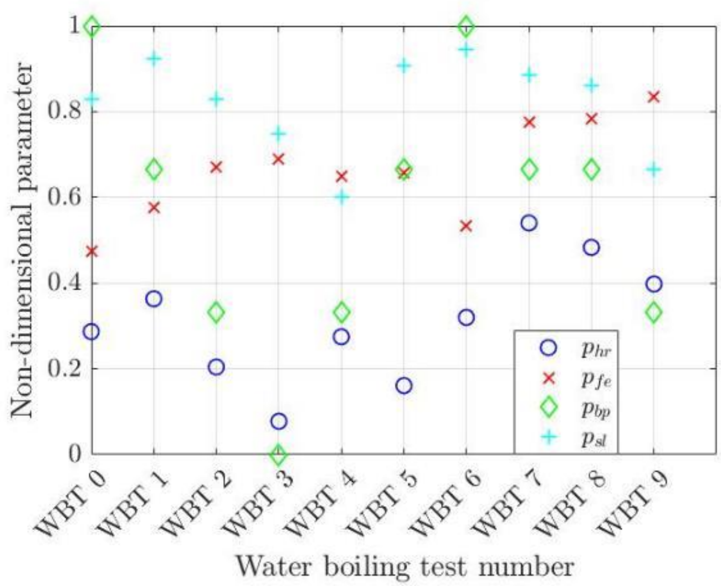


Figure 150: Variation of the four non-dimensional parameters.

Finally, a combined non-dimensional parameter, denoted as 'furnace performance parameter', p is defined as follows:

$p = 2/6*p_{hr} + 2/6*p_{fe} + 1/6*p_{bp} + 1/6*p_{sl}$,

where p_{hr} and p_{fe} are given double the weight of the latter two since (a) they are more important, and (b) they are measured more robustly (p_{bp} and p_{sl} are somewhat subjective).

The furnace performance parameter p is plotted in Figure 68.

Appendix Q

Determination of optimum feeding port location

Two WBTs were performed: with feeding ports at 180 and 90^0 (with respect to chimney), respectively. The results of the corresponding water boiling tests are presented below in Figure 151 and Table 63.

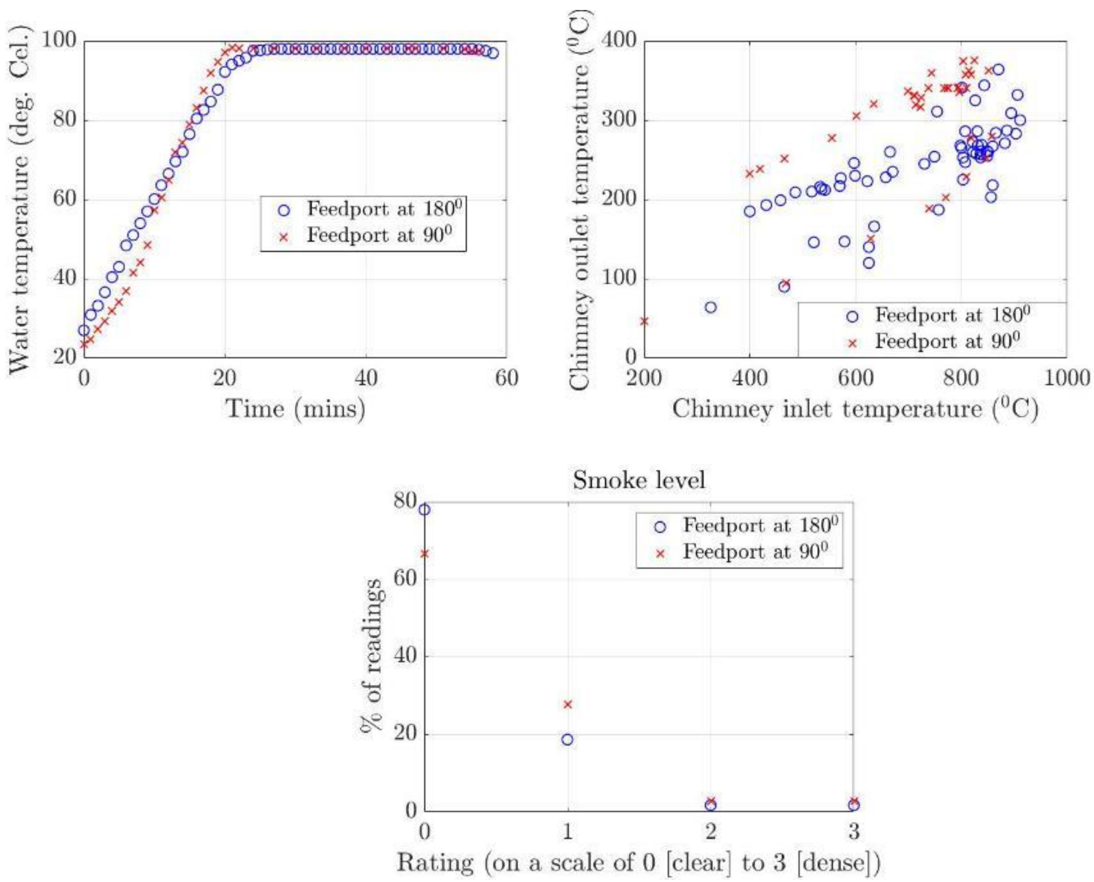


Figure 151: Comparison of feeding ports at 180 and 90 degrees with respect to chimney. Note that the air inflow rate through the blower was 200 m^3/hr, a semi-circular sheet was put in front of the chimney inlet with 5 cm gap between the sheet and the pan bottom, and the bagasse moisture contents were 21 and 11%, respectively. Top-left: the heating rates are similar with the two ports. Top-right: For given chimney inlet temperatures, chimney outlet temperatures were lower on an average with the 180-degree feed port; this is because in that case the bagasse was hitting the semi-circular obstacle and dropping right beneath it, as a result the flue gases had to sharply turn over and around the obstacle while exiting via the chimney inlet. Bottom: there was little to differentiate between the two feeding ports as far as the smoke levels are concerned.

Table 63: Comparison of feeding ports at 180 and 90^0 with respect to the chimney. It is seen that better heating rate and furnace efficiency were obtained with the 90^0 feeding port, although the bagasse was significantly more moist in the 180^0 experiment.

	180^0	90^0
Time to reach boiling (mins)	24	20
Transient furnace efficiency (%)	20.61	24.57
Backpressure (scale of 0[none] to 3[excessive])	1	1
Moisture in bagasse (% w/w)	21	11
Average smoke (scale of 0[clear] to 3[dense])	0.27	0.42

Overall, as was borne out by other experiments too, there was little to choose between the two locations of feed port, and instead of doing more experiments, it was decided to keep the feeding port at 90^0.

Appendix R

Preliminary pan-sealing designs

Introduction

To minimize the loss of flue gases through gaps between the pan and the top surface of the furnace, two simple actions were carried out to seal these gaps. The first action was to put loose soil on furnace top layer over which the pan sits; soil being spongy will take the shape of the pan bottom under the pressure of its weight, plugging the gaps. The second action was to additionally have a gasket along furnace walls that would trap the flue gases. These two designs are shown in Figure 152 and Figure 153, respectively. To save on resources and time, it was decided to test these ideas on a small-scale furnace. Care was taken to scale down all the parameters from the actual syrup-making set-up (such as dimensions of pan and furnace, weight of pan filled with water etc) to the extent possible.

Figure 152: Design 1 for pan sealing using loose soil.

Loose soil

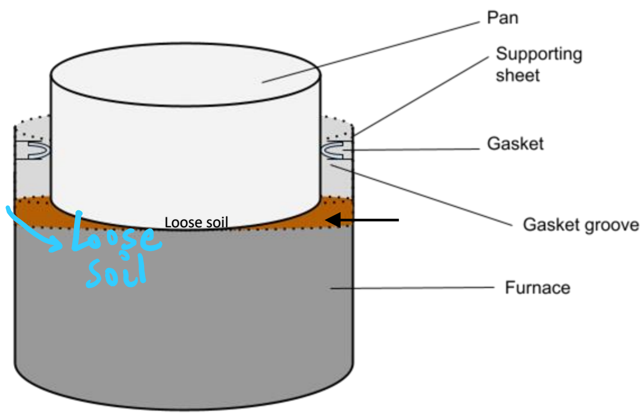


Figure 153: Design 2 for pan sealing with loose soil and gasket lining.

<u>Results</u>

It was seen that with Design 1, only a small amount of smoke was escaping through the gaps beneath the pan bottom (a qualitative estimate would be 10%). With Design 2, almost no smoke escaped through these gaps.

Although these designs have not been incorporated in the actual furnace, the above experiments demonstrate the feasibility of these ideas.

Appendix S

Calibration of air-inlets

The primary and the secondary air inlets were calibrated using a plastic air bag as follows: the bag was filled with air from the blower outlets. The volume of the filled air bag and the time required to fill it was recorded (Figure 154). Based on this, calibration curves were drawn (Figure 155 and Figure 156).

Figure 154: Filled plastic bag used for blower calibration.

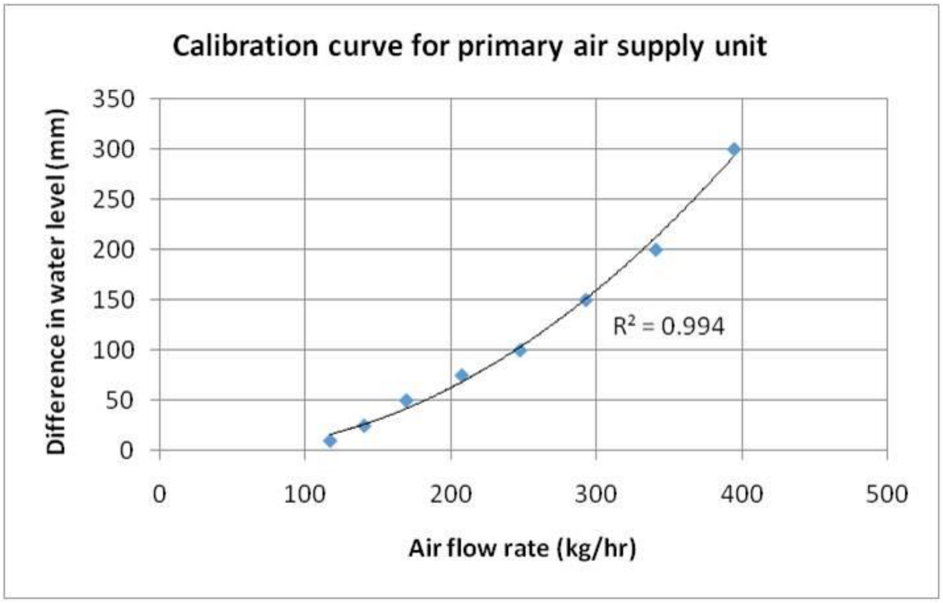


Figure 155: Calibration curve for primary air-inlet.

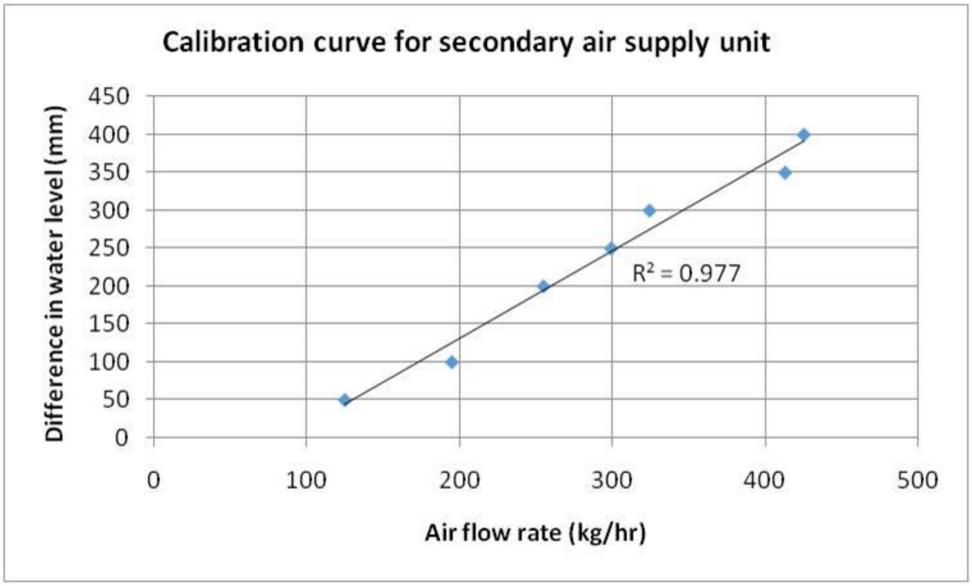


Figure 156: Calibration curve for secondary air-inlet.

Appendix T

<u>Construction of new furnace</u>

Figure 157: New furnace construction. Top-left and bottom-right photographs are the first and the last in chronological order.

Appendix U

Determination of correct syrup storage conditions

Table 64: Determination of optimum syrup storage conditions. For each storage condition, three sample bottles were taken.

Storage condition of SS syrup	Fungus attack (Yes/No)	No. of days for which syrup was monitored
Non-airtight glass bottle kept in a non-air-conditioned room	Yes	7
Non-airtight glass bottle kept in an air-conditioned room	Yes	60
Airtight glass bottle kept in a non-air-conditioned room	Yes	17
Airtight glass bottle kept in non-air-conditioned room (hot-filling)	Yes	24
Airtight glass bottle kept in an air-conditioned room	No	193
Airtight glass bottle kept in an air-conditioned room (with 0.25 and 0.5 cm layer of safflower oil over the syrup)	No	193
Airtight glass bottle kept in air-conditioned room (hot-filling)	No	31

Note-1: Air-conditioned room is maintained at 18^0C.

Note 2: Hot-filling means that hot syrup at 70^0C is filled in the glass bottle.

Appendix V

Details of economic analysis

Tables

Table 65: Average cultivation cost for last 10 syrup-making sessions at NARI.

Operation	**Rs/ha**	**Rs/1.2 tons SS biomass**
Ploughing	6,000	250
Cultivation	3,250	135
Furrow opening	3,000	125
Mending of furrows	2,500	104
Sowing	7,000	291
Weeding	15,000	623
Irrigations	4,500	187
Pesticide spraying	3,500	146
Fertilizer application	7,500	312
Seed cost	1,000	42
Water and electricity charges	2,000	84
Total	55,250	2,295

Table 66: Harvesting and stripping costs for last 10 syrup-making sessions at NARI.

Batch. No	Area of the plot (m^2)	Biomass (kg/plot)	Cost of harvesting and stripping/plot (Rs)
1	340.2	1240	3100
2	256.5	1192	3400
3	356.4	1420	3300
4	500	1660	4100
5	550.8	1320	3500
6	477	1515	3600
7	561.6	1215	2800
8	653	1520	3464
9	615	1530	3884
10	615.6	1620	3710
Average	492.61	1423.2	3485.8

Table 67: Capital cost.

Item	Price (Rs.)
Crusher	2,28,114
Collection tank	1,500
Settling tank	2,500
Juice filtration unit	10,000

Pump	15,680
Juice transport pipe	6,200
MS stands	15,000
Evaporation pan	30,000
Blower	39,164
Shredder	1,58,000
Refractometer	1,800
Syrup-cooling tank (MS)	10,000
Syrup-cooling utensils (SS)	6,000
Storage containers	30,000
Cold room	2,28,428
Furnace	48,107
Electric work	10,000
Flooring - Kota stone work and roofing	2,50,000
Land (2 ares @ Rs. 3 lakh /are*)	6,00,000
Temperature scanner + chimney inlet probe + PT-100 sensor	5,353

Ladles	2,250
Scum collector stand	4,200
Travelling trolley + block-and-tackle	13,500
Cooling device	6,000
Miscellaneous	25,000
Total	17,50,000 (approx.)

*1 are *(guntha)* is 100 m^2.

Table 68: Calculation of fixed charges for syrup production unit per 50 kg syrup.

Year	**1**	**2**	**3**	**4**	**5**
Fixed charges (Rs. lakh)	17.5	14	10.5	7	3.5
Capital amount to be paid yearly (Rs. lakh/year)	3.5	3.5	3.5	3.5	3.5
Interest amount to be paid yearly (15% rate) (Rs. lakh/year)	2.625	2.1	1.575	1.05	0.525
Overhead cost (10% of equip) (Rs. lakh/year)	1.15	1.15	1.15	1.15	1.15
Total fixed charges in a year (Rs. lakh/year)	7.275	6.75	6.225	5.7	5.175
No. of days the syrup will be produced in a year	100	100	100	100	100
Fixed charges (per day, i.e., per 50 kg syrup)	7275.00	6750.00	6225.00	5700.00	5175.00

Average fixed charge per day	Rs. 6,225

Table 69: Manpower cost for production of 50 kg syrup.

Activity	**Labourers required**	**Time (hours)**	**Labour-hours**	**Rate (Rs/hr)**	**Total (Rs)**
Crushing	4	1	4	40	160
Heating	4	3	12	40	480
Cooling and storage	1	0.2	0.2	40	8
Cleaning	1	0.17	0.17	40	7
Transport vehicle diesel and driver	1	4	4	40	166
Supervision cost					1,000
Total manpower cost for 50 kg syrup production	Rs. 1,821				

Table 70: Electricity cost for production of 50 kg syrup.

Equipment	Power (kW)	Usage time (hour)	Consumption (kWh)
Crusher	5.58	1	5.58
Pumps	2.235	0.25	0.56
Blower	0.745	3	2.23
Shredder	3.725	3	11.18
Fan	0.13	2	0.26
		Total units	19.81
		Total money	Rs. 140 (@ Rs. 7 per kWh)

Table 71: Month-wise biomass yield data for NARI (average of data from 2019-22).

Month	Biomass yield in T / acre
Jan	10.6
Feb	11.4
Mar	10.8
Apr	10.5
May	14.2
June	26.3
July	28.0

Aug	24.6
Sep	19.5
Oct	15.0
Nov	7.8
Dec	11.6
Average	15.8

Table 72: Average profit earned by a sugarcane farmer in Phaltan region.

Cost of cultivation per acre	Rs. 34,752 (average of last 4 years' NARI data)
Biomass yield per acre	50.6 tonnes (average of last 4 years' NARI data)
Selling price of 1 ton biomass	Rs. 2,500 (standard sugar mills' rates in Phaltan region)
Profit per acre in 15-month period	(Rs. 2,500*50.6) – Rs. 34,752 = Rs. 91,748
Profit per acre in 12-month period	Rs. 73,400

Variation in profit across year

Assumptions

- Syrup production unit sells syrup at Rs. 500 per kg at a fixed profit margin of 50%, i.e., cost price of syrup to the production unit is Rs. 333 per kg.
- It takes 15 months for one complete cycle of sugarcane production.
- In 15 months, three cycles of SS crop can be grown.

Note: all calculations, unless stated, are on per acre basis.

Profit from growing SS across a 15-month period if first harvest is in January

As an example, let us say that the farmer harvests the first cycle in January, leaves the land fallow in February and March; sows the second cycle in April, harvests it in July, leaves the land fallow in August and September; sows the third cycle in October, harvests it in following January, leaves the land fallow in February and March. This completes a 15-month cycle in which three SS crops were obtained.

Cost of cultivation per acre = Rs. 22,368 (average of last 4-year NARI data).

Biomass yield in January (average of last 4-year NARI data): 10.5 tons/acre.

Money spent by farmer per acre for January harvest: cultivation cost per acre + harvesting cost per acre = Rs. 22,368 + Rs. 539*10.5/1.2 = Rs. 27,106.

Syrup produced from 1 acre land (or 10.5 tons biomass) for January harvest: 440 kg.

Money spent by production unit in stripping + processing of one acre syrup produce + equipment overhead cost: Rs. 5,761*440/50 = Rs. 50,696 (since for 50 kg syrup, it is Rs. 2,400 + Rs. 2,211 + Rs. 1,150 = Rs. 5,761; see Scenario 1 in the previous section).

Money given to the farmer by the production-unit per acre for January harvest: Rs. 333*440 – Rs. 50,696 = Rs. 95,969.

Profit earned by farmer per acre for January harvest: Rs. 95,969 – Rs. 27,106 = Rs. 68,863.

Similarly, it can be calculated (using data given in Table 71) that profit earned by farmer per acre for July harvest: Rs. 2,19,903.

So, total profit for farmer for 15-month cycle: January profit + July profit + (following year's) January profit = Rs. 68,863+ Rs. 2,19,903 + Rs. 68,863 = Rs. 3,57,629.

Variation through the year of profit from growing SS across a 15-month period

In the above analysis, first harvest in the 15-month period was in January. By performing the same analysis for other months, the following table is obtained.

Table 73: Profit for SS farmers across one and three crop cycles. The latter is presented to facilitate comparison with sugarcane, which takes 15 months to grow, and fetches a profit of rupees 92,000/acre.

Harvesting month	**Profit to farmer/acre in one crop cycle (Rs. in lakhs)**	**Profit to farmer/acre in three crop cycles (across 15 months) (Rs.)**
Jan	0.69	3.57
Feb	0.76	3.42
Mar	0.71	2.88
Apr	0.68	2.43
May	1.00	2.45
June	2.05	4.87
July	2.20	5.09
Aug	1.90	4.56
Sep	1.46	3.63
Oct	1.07	2.83
Nov	0.45	1.91
Dec	0.77	3.60
Average	1.15	3.44