Development and Process Optimization of Turmeric, Ginger and Black Pepper Infused Jaggery

by

Safrin K. K

(VM23FPT016)

A THESIS

Submitted in partial fulfillment of the requirements for the degree

MASTER OF VOCATION
IN
FOOD PROCESSING TECHNOLOGY

ST. TERESA'S COLLEGE (Autonomous), ERNAKULAM,
Mahatma Gandhi University, Kottayam, Kerala

Department of Plantation Products, Spices and Flavour Technology,

CSIR-Central Food Technological Research Institute (CFTRI),

Mysore-570020

April-2025

ST.TERESA'S COLLEGE, (AUTONOMOUS)
ERNAKULAM

Re- Accredited by NAAC in the 4th cycle with grade A++ and CGPA 3.57
Ranked 41st in National Institutional Ranking Framework (NIRF 2023)

ANNEXURE I

UNDERTAKING BY THE SELECTED STUDENT FOR PROJECT WORK AT CSIR-CFTRI

The project students and their college / staff members shall have no claim whatsoever on the results of the project work. CSIR-CFTRI retains all Intellectual Property Rights in patents, designs, software, copyright and publications, if any that may be generated during the course of project work. In the event of any dispute arising, the decision of Director, CSIR-CFTRI, is final and is binding on the student(s) and college. (Sl. No. 17 of Annexure I)

The college certificate in the project report prescribed by college / University shall categorically reflect that the place of project work is CSIR-CFTRI and acknowledge the name of the staff member who has guided. (Sl. No. 18 of Annexure I)

The successful execution of the project work by the students is solely under the guidance of scientific/technical guide of CFTRI. **No interference from the College/University is entertained.**

We have read the prescribed rules and regulations (Sl. Nos. 1 to 18 of Annexure I) and we agree to abide by them during our project work at CFTRI, Mysore and to the Conduct and Discipline mandate of the Institute.

26.9.2024
SAFRIN K K

ST. TERESA'S COLLEGE AUTONOMOUS * ERNAKULAM-682 011 *

Dr. ALPHONSA VIJAYA JOSEPH
PRINCIPAL
ST. TERESA'S COLLEGE
Autonomous
ERNAKULAM

Declaration

I hereby declare that the report on the project entitled **“Development and Process Optimization of Turmeric, Ginger and Black Pepper Infused Jaggery”** submitted by Ms. Safrin K. K to St. Teresa's College, Ernakulam, affiliated to Mahatma Gandhi University, Kottayam, Kerala, in partial fulfilment of the requirements for the award of the degree of Master of Vocational Studies in Food Processing Technology, is a record of the original work carried out by me under the guidance of Dr. Sachin R. Chaudhari, Senior Scientist, Department of Plantation Products, Spices and Flavour Technology (PPSFT), CSIR- CFTRI, Mysore, Karnataka. I further declare that the results of the present study have not formed the basis for the award of any other degree to any candidate of any university during the period of my study.

Place: Mysore **Safrin K. K**

Date:

Acknowledgement

I would like to thank God Almighty, my beloved parents, and my siblings for giving me the opportunity to pursue a career in the field of Food Technology. They are the most important people in my life, and I dedicate this work to them.

I am extremely grateful to Dr. Sachin R. Chaudhari, Senior Scientist, Department of Plantation Products, Spices and Flavour Technology, CSIR-CFTRI, Mysore, for his unwavering support and guidance. His in-depth knowledge and experience helped steer my project in the right direction at every stage. Sir, this project would not have been possible without your invaluable mentorship.

I sincerely express my heartfelt gratitude to Dr. Sridevi Annapurna Singh, Director, CSIR-CFTRI, Mysore, for granting me the opportunity to carry out my project at this prestigious institute. I also thank Dr. Revathy Baskaran, Head, HRD, CSIR-CFTRI, for providing the necessary facilities and support for the successful completion of my work.

I extend my sincere thanks to the Ph.D. scholars of the department, especially Anisha Biswas, Rajat Chandel, Surbhi Kapoor, and Yazhini Devi, for their invaluable guidance, technical support, and constant encouragement throughout the course of my project.

I am also grateful to Ms. Sonakshi A. N. and Mr. Krishna K. Reddy, Project Associates, for their timely assistance, thoughtful suggestions, and generous support during the practical phases of my research.

I would like to extend my deepest gratitude to St. Teresa's College (Autonomous), Ernakulam, for facilitating all the necessary resources to fulfil our project work. I also thank Ms. Sherin Mary Simon, Head, Department of Food Processing Technology, St. Teresa's College (Autonomous), Ernakulam, our class teacher Ms. Pinku Maria, and faculty members Ms. Anna Aleena Paul, Ms. Elizabeth Zarina, Ms. Sandra Santhosh, and all other faculty members and office staff for their constant support and encouragement. Last but not least, I sincerely thank my family for their unwavering support and motivation, which has been a tremendous source of strength throughout my academic journey.

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronym's

pH - Potential of Hydrogen

FFT - Free Flowing Triphala Powder

TFJ - Triphala Fortified Jaggery

RH - Relative Humidity

DPPH - 2, 2 Diphenyl -

1Picrylhydrazyl SS plate - Stainless

Steel Plate

MS plate - Mild Steel Plate

TSS - Total Soluble Solids

nm - Nanometer

aW- Water Activity

As - Absorbance of Test Solution

HDL - High Density Lipoprotein

TC and PC - Turmeric and Black Pepper Coated

UV Spectrophotometer - Ultraviolet - Visible Spectrophotometer

ETB - Encapsulated Turmeric and Black Pepper

EG - Encapsulated Ginger

GP - Ginger Powder

Abstract

Jaggery is an unrefined natural sweetener produced by concentrating sugarcane juice, commonly available in solid block or semi-liquid form. Valued for its natural sweetness and traditional appeal, jaggery provides sustained energy and is considered a healthier alternative to refined sugar. The sensory qualities and functional appeal of jaggery can be enhanced through the incorporation of spices. This study focuses on the development and optimization of turmeric, ginger, and black pepper-infused jaggery to enrich its flavour profile and overall consumer acceptability. The research involves optimizing ingredient ratios to achieve effective spice infusion while maintaining a balanced sensory and physicochemical profile. The production process includes preparing jaggery from high-quality sugarcane juice, precise blending of selected spices, controlled mixing, solidification, and the use of premium jaggery powder for enhanced product quality. Physicochemical parameters such as water activity, pH, °Brix, and reducing sugar content were analyzed to assess product stability. Sensory evaluation was conducted to determine consumer preferences based on taste, aroma, texture, colour, and overall acceptability. The results demonstrate that the optimized formulation offers a stable, flavour- rich jaggery product with enhanced sensory appeal. This study contributes to the development of innovative, spice-infused sweeteners that align with consumer interest in natural and flavourful food products.

Chapter - 1 Introduction

1.1 Background and Motivation

Gur, commonly known as jaggery, is a traditional unrefined sweetener widely consumed across South Asia and other parts of the world. It is typically produced in cottage and small-scale operations by concentrating sugarcane juice into a semi-solid or solid mass. India is the world's largest producer of sugar and sugarcane, where sugarcane is processed into three main products: sugar, gur (jaggery) and khandsari. Each of these products undergoes different manufacturing processes, resulting in significant weight reduction but considerable value addition. The production of gur not only supports traditional food practices but also provides employment to millions across the country.

Gur is made in nearly every part of India and is known by various regional names such as gul, gud, vellam, and bella (Ghosh et al., 2008). The most common method of preparing jaggery involves concentrating sugarcane juice through heating, resulting in either solid blocks or semi-liquid forms (Singh et al., 2013). In addition to sugarcane juice, sap collected from palm varieties such as palmyra palm, coconut palm, wild date palm, and sago palm is also used for jaggery production (Ghosh et al., 2008).

To improve ease of handling, packaging, and storage, jaggery is now also processed in granular form. However, the hygroscopic nature of granulated jaggery often leads to stickiness and caking, affecting its shelf stability (Deshmukh and Chavan, 2020).

Jaggery typically contains 65–85% sucrose (Solomon, 2006), and is available in three commercial forms: solid, liquid, and granulated. While the most common jaggery color ranges from light to dark brown, yellowish and reddish varieties also exist (Singh et al., 2013). Jaggery also contains essential minerals such as iron, calcium, and magnesium (Ghosh et al., 2008). The product's moisture content varies from 3% to 10%, depending on the preparation method, and its shelf life generally ranges from six months to a year (Deshmukh and Chavan, 2020). Notably, granulated jaggery with a lower moisture content of 1–2% has been reported to remain stable for up to two years (Solomon, 2006).

Jaggery plays a significant role in traditional Indian cuisine and is a key ingredient in various ethnic sweets such as naru (coconut balls), chikki (peanut brittle), and laadu (puffed rice sweet balls), where its binding property is particularly valued (Ghosh et al., 2008).

Beyond sugarcane, date palm and toddy palm sap are also used for making jaggery. Since palm sap ferments rapidly, it must be processed immediately after extraction. The partially concentrated sap is often molded into thick, rich liquid blocks and sold commercially (Singh et al., 2018). Although palm-based jaggery is more expensive and produced in smaller quantities, it is prized for its distinctive taste and aroma (Kumar and Prasad, 2017). A well-known variant is patali gur or khejurgur, molded into hemispherical or flat bar shapes with characteristic brown to golden yellow hues (Chattopadhyay et al., 2016).

In addition to its culinary uses, jaggery serves diverse applications across various sectors. It is used as a feed ingredient in cattle farming, in traditional medicine formulations including Ayurvedic tonics and sura, and in the preparation of herbal health products (Sharma and Lal, 2019). Jaggery is also increasingly being used in the confectionery industry (Rao et al., 2020). Moreover, industries such as leather and tobacco, as well as cement factories and coal mines, supply jaggery to workers to help protect them from dust-related allergies. During natural calamities, district administrations often distribute jaggery to affected populations due to its perceived health benefits (Das, 2018).

Importance of Jaggery

Jaggery is far more complex than refined sugar, as it consists of longer chains of sucrose. Consequently, it is digested more slowly than sugar and releases energy gradually rather than all at once. This slow energy release provides sustained energy over a longer period and is considered less harmful to the body. However, this does not make it suitable for diabetic individuals, as jaggery is still essentially a form of sugar (Sharma and Rani, 2018). During its preparation in iron vessels, jaggery accumulates a significant amount of ferrous salts (iron), which can be beneficial for people suffering from anemia or iron deficiency (Ravi Kumar et al., 2017). Additionally, jaggery contains natural mineral salts absorbed from the sugarcane juice, which are beneficial fors the body and can impart a slightly salty taste (Kumar and Prasad, 2017)

Jaggery is also known for its cleansing properties. It acts as a natural detoxifying agent, helping to cleanse the lungs, stomach, intestines, esophagus, and respiratory tract. Regular consumption of jaggery is recommended for individuals frequently exposed to dust, as it may help prevent asthma, coughing, colds, and chest congestion (Verma et al., 2019). In India, jaggery is widely used in both sweet and savory recipes. It is also a key ingredient in various herbal and traditional medicines. In Ayurveda, jaggery is valued as a blood purifier and is commonly used as a base in medicinal syrups (Chattopadhyay et al., 2016).

Jaggery production represents a major agro-processing industry in India. Approximately 20–30% of the country's sugarcane output is used for jaggery production, which is regarded as a nutrient-rich sweetener. This sector provides employment to about 2.5 million people (Singh and Tiwari, 2020). Expanding the jaggery industry is vital for delivering high-quality jaggery at lower costs and for boosting the rural economy. It helps reduce raw material transportation costs and eliminates the need for complex machinery and highly skilled labor.

Jaggery continues to be a popular ingredient in traditional Indian confections such as reori, gazak, chikki, patti, and ramdana. Kakavi (liquid jaggery), commonly consumed in Maharashtra, is also gaining popularity across India. Notably, jaggery contains about 2.8 g of salt per 100 g, compared to just 300 mg per kilogram in refined sugar (Rao et al., 2020).

Different Forms of Jaggery

- **Solid Jaggery (Cube Shape)**

The filtered cane juice is cooked in open pans over a triple-pan furnace using bagasse as fuel. The juice is clarified using deola extract (45 g/100 kg juice) to lighten its color. High-quality jaggery is produced by removing suspended impurities, colloidal particles, and accumulated coloring substances. The juice is then boiled and condensed to achieve the desired consistency, shape, and size of jaggery cubes (Sharma et al., 2019).

• Liquid Jaggery

Liquid jaggery is a semi-liquid, syrup-like substance obtained by concentrating pure sugarcane juice during jaggery production. Its quality depends on the composition and quality of cane juice, the type of clarifying agents used, and the temperature at which it is collected (Singh and Rao, 2020).

To produce quality liquid jaggery, the juice concentrate should be removed from the boiling pan when the temperature reaches 103–106°C, depending on the sugarcane variety and agro-climatic zone. To prevent crystallization and enhance color, 0.04% (400 mg/kg) of citric acid is added. For extending shelf life without compromising quality, 0.1% (1 g/kg) of potassium metabisulfite or 0.5% (5 g/kg) of benzoic acid is recommended.After filtration, the liquid jaggery is packaged in sterile bottles. A typical composition of liquid jaggery includes water (30–36%), sucrose (40–60%), invert sugar (15–25%), calcium (0.30%), iron (8.5–10 mg/100 mg), phosphorus (0.05 mg/100 mg), protein (0.10/100 mg), and vitamin B (Kumar and Dhingra, 2018).

• Granular or Powdered Jaggery

Granular jaggery is produced through a process similar to that of solid jaggery up to the concentration stage. The concentrated slurry is rubbed with a wooden scraper to create granules, which are then cooled and sifted. For high-quality granular jaggery, crystals less than 3 mm in size are ideal. By raising the pH of cane juice to 6.0–6.2 using lime and heating it to a striking point temperature of 120°C, granular jaggery with desirable characteristics—such as 88.6% sucrose content, low moisture (1.65%), good color, friability, and crystallinity—can be obtained (Ravi Kumar et al., 2017).

The jaggery granules, sieved to around 3 mm and sun-dried to a moisture content below 2%, are typically packed in polyethylene-polyester bags or bottles. This allows them to be stored for over two years.

Jaggery powder may vary in color—golden yellow, golden brown, or dark brown—depending on the raw materials used. Its texture is softer than sugar and it is amorphous in nature. Unlike refined sugar, jaggery powder retains vitamins, proteins, and other components from the sugarcane. It mainly consists of sugar, mineral salts, and iron. Jaggery is especially recommended for individuals with iron-deficiency anemia. The longer sugar chains in jaggery slow down digestion and energy release, thereby providing sustained energy without being harmful to the body (Verma and Choudhary, 2021).

Spice-Infused Jaggery

Spiced jaggery is a variant of jaggery infused with herbs and spices, making it a nutritious, flavorful, and healthier alternative to refined sugar. Common spices used include cinnamon, cardamom, ginger, nutmeg, cloves, turmeric, and black pepper. Additionally, herbs such as tulsi (holy basil), hibiscus flower, and betel leaf may also be incorporated (Kumar et al., 2020).

Health benefits of spiced jaggery include its richness in iron, antioxidants, and essential minerals. It may help in maintaining weight and blood sugar levels, improving digestive health, and supporting liver detoxification. It also aids in preventing constipation, regulating liver function, and relieving flu-like symptoms (Verma et al., 2021).Spiced jaggery can be used in a wide range of culinary applications, including traditional sweets, beverages, curries, and baked goods. It is commonly used to make sweets such as chikki, laddu, and barfi. It can also be incorporated into beverages like herbal teas, shakes, and smoothies. Additionally, spiced jaggery is suitable for baking and can enhance the flavor of savory dishes such as curries (Joshi & Singh, 2020).

1.2. Problem Statement

Jaggery is a traditional unrefined sweetener widely used for its natural composition and cultural significance. However, conventional jaggery lacks added functional attributes beyond its basic composition. With growing consumer demand for healthier, functional, and convenient food products, there is a clear opportunity to enhance the value of jaggery through the integration of bioactive components.

Turmeric, ginger, and black pepper are well known for their anti-inflammatory, antioxidant, and digestive properties. Although these spices are commonly used in traditional medicinal and culinary applications, limited research has been conducted on their infusion into jaggery to create a convenient, ready-to-use product that offers both health-promoting and culinary benefits.

Key challenges in the development of spice-infused jaggery include:

- Ensuring uniform mixing and homogenization to achieve consistent flavor and functionality.
- Optimizing ingredient ratios to maintain a balance between taste, product stability, and consumer convenience.
- Evaluating physicochemical characteristics, storage stability, ease of use, and sensory acceptability to ensure consumer satisfaction.

This study aims to address these challenges by developing and optimizing a manufacturing process for jaggery infused with turmeric, ginger, and black pepper, while assessing its quality, convenience of use, and sensory appeal.

1.3 Objective of the Study

- Optimization of formulation parameters to enhance product quality, flavor.
- Characterization of the developed product, including physicochemical properties, sensory attributes.

By achieving these objectives, the research aims to contribute to the advancement of jaggery product technology and provide with valuable insights for developing consumer-friendly jaggery-based products.

1.4 Scope and Limitation

Scope of the Study

This study focuses on the formulation of turmeric, ginger, and black pepper- infused jaggery. The main topics include:

- **Ingredient Selection**: Encapsulated turmeric, ginger, black pepper, and regular ginger powder were used due to their known health benefits.
- **Jaggery Production**: The extent of spice infusion during mixing, homogenization, and solidification in the jaggery production process is examined.
- **Process Parameters**: Variables such as ingredient ratios, are evaluated to ensure a consistent and quality product.
- **Physicochemical and Sensory Analysis**: Assessment includes moisture content, ash content, curcumin content, water activity, texture, colour, antioxidant activity, and sensory attributes.
- **Comparative Analysis**: Infused jaggery is compared with standard jaggery in terms of quality, consumer acceptance, and physicochemical characteristics.

Limitations of the Study

When additional flavors are incorporated into jaggery, maintaining its original taste becomes challenging. To ensure uniform flavor distribution during production, precise mixing techniques are essential. The addition of heat-sensitive flavors during the boiling stage can lead to flavor degradation due to high temperatures, which may also affect chemical reactions and the consistency of the final product. Spoilage may occur with the inclusion of organic flavors such as spices and fruits, potentially reducing shelf life due to increased moisture content. To address this, appropriate packaging and preservation techniques are necessary. The manufacturing of flavored jaggery involves various processing steps, which may reduce the nutritional content and alter the health benefits of the final product.

Chapter 2- Literature Review

2.1 Overview of Jaggery Production

2.1.1 Traditional Methods

The first step in jaggery preparation is the extraction of juice from sugarcane or palm. This is typically done using a traditional crusher powered either by bullocks or a diesel engine. The sugarcane or palm fronds are passed through two or three rollers to extract the juice (Kumae et al., 2018). The extracted juice is then filtered to remove impurities. Filtration is carried out using a cloth strainer or by adding a clarifying agent, such as lime (Rao and Reddy, 2020).

The clarified juice is transferred to a large iron pan and boiled. It is heated continuously until it thickens and begins to crystallize—a process that may take several hours (Sharma et al., 2019). Once the desired consistency is achieved, the thickened syrup is poured into molds to cool and solidify. These molds are traditionally made of clay or wood. After molding, the jaggery is sun-dried for several days, which helps to harden the product and extend its shelf life (Verma and Choudhary, 2021). Figure 1 presents the flowchart of traditional jaggery preparation.

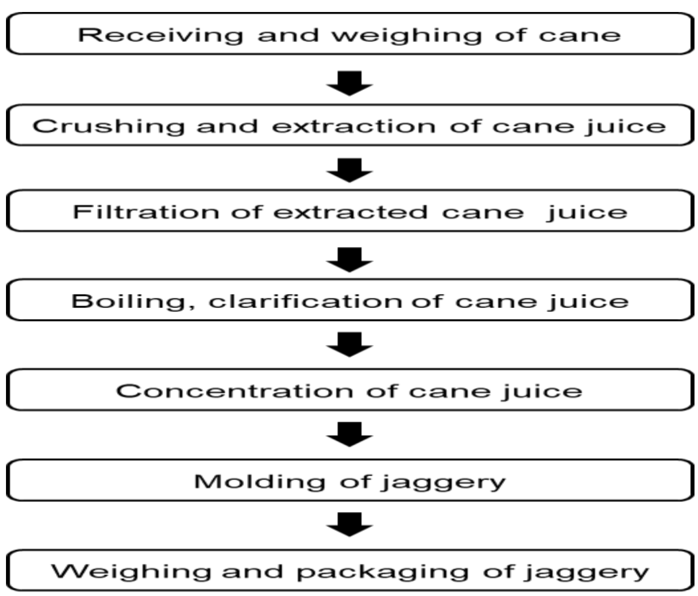

Figure 1 Flowchart of Traditional Jaggery Preparation

2.1.2 Industrial Method

Juice Extraction:

Juice extraction is typically carried out using a three-roller mill powered by either an electric motor or a diesel engine. The juice extraction efficiency generally ranges from 60% to 70% (Kumar et al., 2019). After extraction, the juice is filtered through a cotton cloth or fine mesh to remove suspended particles and impurities.

Juice Clarification:

a) Sugarcane juice contains various impurities such as colloidal particles, inorganic salts, fibers, nitrogenous compounds, lipids, gums, waxes, organic and inorganic acids, and pectin. These are partially or completely removed during the clarification process (Rao and Reddy).

b) Two types of clarifiers are commonly used: organic and inorganic. Organic clarifiers include okra, sulkali, and doela, while inorganic options include lime, hydrous powder, and superphosphate (Sharma et al., 2018).

c) The filtered juice is transferred to an open pan and slowly heated. This allows dissolved air to escape and facilitates the coagulation of gummy and colloidal substances. Clarifiers are added as needed, and the scum that forms on the surface is continuously removed. During this stage, the temperature is maintained between 70 °C and 80 °C.

d) Initially, juice is added to the pan, followed by a small amount of lime water to reduce acidity—without making the juice neutral. The pH is carefully maintained between 6.2 and 6.5. In certain cases, additives such as superphosphate (P_2O_5) and 0.25% concentrated hydrous powder are used to enhance the color of jaggery. As the temperature rises, perforated strainers are used to remove the scum (Verma et al., 2021).

Juice Concentration:

The clarified juice is rapidly boiled, and the boiling temperature is maintained between 110 °C and 115 °C. This boiling process takes approximately 2 to 3 hours. The resulting semi-fluid mass is then transferred to rectangular or bucket-shaped molds, depending on the desired shape and size. The mass is allowed to cool and solidify into jaggery

(Singh and Gupta, 2020).Figure 2 presents the flowchart of the industrial method of jaggery preparation.

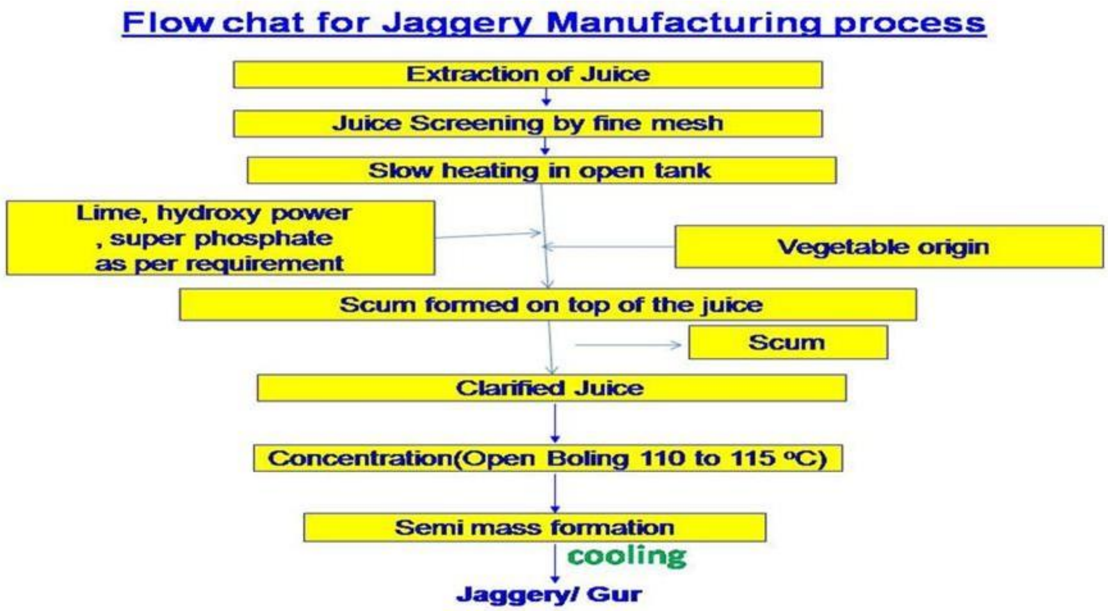

Figure 2 Flowchart of the Industrial Method for Jaggery Preparation

2.2 Nutritional and Functional Properties of Jaggery

Jaggery Nutritional Value

Jaggery is a powerhouse of essential nutrients. It contains approximately 98% carbohydrates and about 97% sugar content. A 10 g serving of jaggery provides around 38 calories. It can be considered a healthier alternative to industrial or chemically processed refined sugar. Unlike white refined sugar, jaggery retains certain minerals, making it a more nutritious option (Patel et al., 2018). Table 1 presents the nutritional components found in jaggery. Jaggery contains natural phytochemicals that aid digestion and help in alleviating digestive problems. Many people consume jaggery with black pepper to enhance appetite, a property not found in refined sugar (Sinha and Singh, 2017). Nutritional Composition of Jaggery; Values represent average concentrations of key nutrients found in jaggery, highlighting its calorific and mineral content(Pateletal.,2018).

Table 1: Nutritional Composition of Jaggery

Major Nutrient	Value per 10 g
Total Calories	38.3
Calories from Fat	0
Total Fat	0
Protein	0.01 g
Total Carbohydrate	9.8g
Water	0.40g
Dietary Fiber	Nil
Sugar	9.7 g
Starch	Nil
Calcium, Ca	8 mg
Iron, Fe	0.30 mg
Magnesium, Mg	16 mg
Phosphorus, P	4 mg
Potassium, K	13 mg
Sodium, Na	3 mg
Zinc, Zn	0
Copper	0
Manganese	0.01mg
Selenium	0.12mg

2.3 Health Benefits of Jaggery

1. Prevents Constipation: Jaggery activates digestive enzymes and works as a mild laxative, helping relieve constipation (Sharma & Chauhan, 2020).

2. Supports Liver Function: It helps flush out toxins, reducing liver load and aiding detoxification (Nath et al., 2019).

3. Relieves Flu Symptoms: Jaggery provides warmth to the body and helps relieve cold, cough, and flu symptoms. It can be added to tea or warm water (Mishra et al., 2021).

4. Purifies Blood: Regular intake helps cleanse the blood and improve overall health (Rao et al., 2017).

5. Boosts Immunity: Rich in zinc and selenium, jaggery helps protect cells from oxidative damage and strengthens immunity (Sahu & Paul, 2021).

6. Eases Menstrual Pain: Jaggery may reduce cramps and PMS symptoms by promoting endorphin release (Sharma & Chauhan, 2020).

7. Provides Sustained Energy: It offers complex carbs that release energy slowly, preventing fatigue (Nath et al., 2019).

8. Supports Urinary Health: As a natural diuretic, jaggery helps reduce inflammation and improves urine flow (Bal et al., 2019).

9. Promotes Gut Health: High in magnesium, it supports intestinal health and regular digestion (Mishra et al., 2021).

2.4 Health Benefits and Functional Properties of Selected Spices

2.4.1 Turmeric

- Turmeric is a natural antiseptic and antibacterial agent, commonly used for disinfecting cuts and burns (Prasad & Aggarwal, 2011).
- In combination with cauliflower, it may help prevent prostate cancer and inhibit breast cancer spread in animal studies (Anand et al., 2008).
- Acts as a liver protectant and natural detoxifier, useful in managing hepatitis, cirrhosis, and jaundice (Chainani-Wu, 2003).
- May help slow Alzheimer's progression by reducing amyloid plaque in the brain (Yang et al., 2005).
- Used both topically and internally in the treatment of skin cancer and precancerous conditions (Aggarwal & Harikumar, 2009).

- Eases menstrual cramps due to its antispasmodic properties; turmeric extract can be taken twice daily before menstruation (Daily et al., 2016).
- In traditional medicine, turmeric is used to manage depression, arthritis, and rheumatoid arthritis due to its anti-inflammatory effects (Ammon & Wahl, 1991).
- Enhances the efficacy of chemotherapy drugs like paclitaxel while reducing side effects.

Key Activities: Alterative, analgesic, anti-inflammatory, antioxidant, antiseptic, antispasmodic, digestive, diuretic, and vulnerary.

Therapeutic Uses: Supports treatment of anemia, cancer, diabetes, indigestion, IBS, infections, and wounds.

Ayurvedic Significance: Commonly used for purifying blood, treating skin disorders, and supporting liver, lungs, heart, and brain functions. It is also used for epilepsy, bleeding disorders, and overall detoxification (Jurenka, 2009).

2.4.2 Ginger

- **Cholesterol Management**: Ginger extract helps lower cholesterol by inhibiting its production, reducing thermogenesis, and increasing HDL levels (Sharma et al., 2014).
- **Digestive Health**: Ginger is effective in managing gastrointestinal issues like peptic and duodenal ulcers due to its anti-inflammatory and antioxidant properties, protecting the stomach lining (Mashhadi et al., 2013).
- **Antibacterial Action**: Ginger exhibits antimicrobial activity against both Gram-positive and Gram-negative bacteria, though this effect may reduce when heated. It also has antineoplastic potential (Sudershan et al., 2011).
- **Anti-Nausea in Chemotherapy**: Ginger effectively reduces nausea and vomiting associated with chemotherapy (Lete & Allué, 2016).
- **Blood Sugar and Lipid Regulation**: Dried ginger lowers blood glucose, cholesterol, and triglyceride levels, while increasing HDL cholesterol with regular use.

- **Preservative Use**: Due to its strong antimicrobial effects against bacteria, viruses, and fungi, ginger is also used as a natural food preservative in many countries (Ghosh et al., 2011).

2.4.3 Black Pepper

- **Cold and Cough Relief**: Adding black pepper to herbal tea or food helps clear phlegm and ease cold symptoms, especially in winter. Crushed pepper with honey or inhaled with eucalyptus steam can relieve chest congestion (Pruthi, 1992).
- **Aids Digestion**: Black pepper stimulates the release of hydrochloric acid, enhancing protein digestion and protecting against gastrointestinal issues (Srinivasan, 2007).
- **Cancer Prevention**: When combined with turmeric, black pepper may help prevent cancer due to its antioxidant properties and enhanced absorption of curcumin and beta-carotene (Gul et al., 2017; Shoba et al., 1998).
- **Antioxidant Activity**: It neutralizes free radicals, reducing cellular damage and the risk of chronic diseases.
- **Brain Health**: Piperine in black pepper may improve memory and reduce amyloid plaque formation linked to Alzheimer's and Parkinson’s disease (Wattanathorn et al., 2008).
- **Blood Sugar Regulation**: Some studies suggest piperine enhances insulin sensitivity and may support blood sugar control (Sunil and Kuttan, 2004).

2.5 Previous Studies on Jaggery and Infused Spice Products

Cardamom-Fortified Jaggery

Jaggery was prepared following the method by Jagannadha Rao et al. (2007) with minor modifications. Cardamom powder was added to sugarcane juice at concentrations of 0.05%, 0.1%, and 0.2% (w/v). The juice pH was adjusted to 6.6 using saturated calcium hydroxide, with no additional clarifiers. After initial heating for 10 minutes, the juice was filtered through muslin cloth, boiled until 118 °C, and the scum removed. The viscous syrup was air-cooled and molded into desired shapes.

Development of Herbal Jaggery Using Tulsi, Mint, and Ginger

Sugarcane variety VCF0517 was selected for herbal jaggery fortified with tulsi, mint, and ginger in both powdered and aqueous extract forms at concentrations of 1.0%, 1.5%, and 2.0%. Jaggery was prepared in powder, liquid, and cube forms, and incorporated into products such as flavored *chikki*, jaggery chocolates, and herbal tea. Sensory evaluations showed the best results at 2% concentration. On day one, there was no change in physical parameters like pH, moisture, or hardness. Over storage, pH dropped from 6.13 to 5.20. Compared to control and aqueous extracts, the herb powder-enriched jaggery had slightly lower total (81.23–82.30%), reducing (6.42– 6.59%), and sucrose sugars (72.62–74.10%), but significantly higher mineral content, polyphenols, flavonoids, and antioxidant activity (76.37–88.18 mg/mL) (Rao et al., 2011; Mishra et al., 2012; Ahmed et al., 2013).

Triphala-Fortified Jaggery (TFJ)

To assess consumer preference and bioactive potential, jaggery was fortified with *Triphala*—a blend of *amalaki*, *bhibhitaki*, and *haritaki*—known for its antioxidant and immunomodulatory properties (Kaur et al., 2017; Peterson et al., 2017). Fine Triphala powder (300 g) was extracted using 95% ethanol and vacuum-dried. The ethanolic extract (100 g) was adsorbed on Triphala powder (100 g) to create free-flowing Triphala powder (FFTP). FFTP was incorporated into hot jaggery syrup at 5%, 7.5%, and 10% (w/w). The mixture was spread and stirred repeatedly at 25–27 °C and 40–50% RH to produce semi-solid jaggery. This method improved the uniform dispersion of bioactives and contributed to the shelf stability of TFJ.

Zingiber officinale (Ginger)-Fortified Jaggery

Using the same base method (Jagannadha Rao et al., 2007), *Zingiber officinale* powder was added to sugarcane juice at 0.05%, 0.1%, and 0.2%. The juice pH was corrected to 6.6 with milk of lime. Post initial heating and scum removal, the juice was boiled to 118 °C, and the syrup was molded after cooling. Control samples lacked ginger. Ginger-fortified jaggery showed a slight (1%) increase in moisture at 0.05% and marginally lower a_W values, indicating potentially enhanced shelf life. Optimal a_W values (0.60– 0.65) were noted for controlling the growth of osmophilic/xerophilic microorganisms such as *Aspergillus euinulatus*.

Edible Coatings with Black Pepper and Turmeric

In a study by Ranna et al. (2022), edible coatings containing *Piper nigrum* (black pepper) and *Curcuma longa* (turmeric) were applied to jaggery to enhance its shelf life. These antimicrobial coatings acted as semi-permeable barriers to moisture and gases. Physicochemical properties (pH, moisture, phenolic content) showed no significant variation between coated and uncoated samples. However, coated jaggery exhibited significantly reduced microbial counts ($p \leq 0.01$), enhanced antioxidant activity (via DPPH assay), and retained more phenolics, flavonoids, and tannins. Antibacterial efficacy was confirmed against both Gram-positive and Gram-negative bacteria using the agar double diffusion method. The shelf life of coated jaggery extended up to six months without notable quality degradation.

Chapter - 3 Materials and Methods

3.1 Materials and Reagent

- **Sugarcane Juice:** Authenticated Sugarcane juice procured from cane cafe Mysore.
- **Jaggery Base:** Good quality of jaggery powder was purchased from local shop.
- **Spice powder:** Spice powder was purchased from super market.
- **Encapsulated flavour:** Variety of encapsulated spice flavors procured from Synthite Pvt Ltd.

3.2 Experimental Setup and Equipment

- **Strainer:** Strainer was used to filter out impurities, such as dirt, fibers, and other residues from the sugarcane juice.
- **Refractometer:** To take note of the initial brix of sugarcane juice.
- **Boiling pan:** stainless steel boiling pan was used for the preparation of jaggery.
- **Ladle:** During the boiling process, the sugarcane juice needs to be continuously stirred to prevent it from burning and to ensure it thickens uniformly. A ladle, made of metal was used to stir the juice in the pan.
- **Blender:** Blender used to mix flavors uniformly throught the jaggery.
- **Induction heater:** For concentrating sugarcane juice.

3.3 Methodology for Jaggery Production

Extraction and Filtration of Juice

After pre-cleaning, the sugarcane is crushed using crushers to extract the juice, then juice was filtered through a strainer to remove coarse impurities such as bagasse particles and dirt.

Clarification

Clarification is essential for producing light-coloured, crystalline, firm, less hygroscopic, and hygienic jaggery. Traditionally clarification was achieved through heating, the filtered juice was transferred to a boiling pan and subjected to clarification. Natural

clarifying agents, like bhindi (okra) extract or lime (CaO) were added to coagulate suspended particles. The juice was heated gradually to about 60–70 °C and the scum formed on the surface was removed regularly. Natural clarifying agents, such as mucilaginous extracts of okra, are advised for clarification.

Mixing and Concentration Process

After clarification, the juice was boiled continuously in a stainless steel pan till it reaches the striking point. Heating was done over direct fire with constant stirring to prevent charring. As the juice was boiled, impurities were removed by skimming the surface scum. The boiling continued until the juice reached the required concentration, typically around 87 °Brix and temperature of 100 - 110 °C.

Cooling and Solidification

Once the striking temperature is reached, the concentrated juice (slurry) is poured into molds. The slurry is allowed to cool undisturbed at room temperature. Once the shine of the slurry diminishes the jaggery is ready for demolding.

3.4 Production of Flavor-Infused Jaggery

Flavor infused jaggery has been prepared by following above method, mentioned in section 3.3 The encapsulated flavor was incorporated while concentrating the sugarcane juice, mixed thoroughly to get uniform flavor mixing equipment's like blender were used for efficient mixing.

3.5 Process Variables and Control Parameters

Process Variables in the Production of Flavor-Infused Jaggery

Several process variables must be carefully controlled to ensure the quality, flavor retention, and stability of flavor-infused jaggery.

a) Temperature

Excessively high temperatures can cause caramelization, leading to undesirable texture, flavor, color, and consistency. Moreover, adding flavors at high temperatures may result in flavor degradation. On the other hand, if the temperature is too low, the moisture content in the jaggery may remain high, negatively affecting its shelf life.

b) Mixing

Proper mixing speed and duration are crucial for maintaining the integrity of flavor compounds. Incorrect mixing can lead to poor flavor distribution or degradation of added flavors.

d) Solidification and Cooling

If the cooling rate is too rapid, it may result in improper structure development and uneven flavor distribution in the jaggery.

e) ^{0}Brix Level (Total Soluble Solids, TSS)

The ^{0}Brix level indicates the total soluble solids content. Maintaining appropriate Brix levels ensures proper consistency, enhances texture, and improves the shelf life of the final product.

3.6 Analytical Techniques

3.6.1 Physicochemical Analysis

3.6.1.1 Determination of Moisture in Jaggery

The sugar sample was heated under controlled conditions to remove moisture. The sample was weighed before and after drying, and the difference in weight was used to determine the moisture content.

Materials Required

- Petri dish with lid
- Weighing balance
- Oven
- Stop clock
- Desiccator

- Desiccants (for desiccator)

Sample Preparation

The sample was ground, if necessary, and mixed to obtain a uniform mass. Any lumps were broken using a glass plate or a mortar and pestle. The sample was then transferred to a dry, stoppered container.

Method of Analysis

Approximately 5 g of the prepared sample was transferred into a previously dried and tared Petri dish. The dish was covered with its lid and weighed accurately. The lid was then removed, and the sample was dried at 105 ± 1 °C for 3 hours. The sample was cooled in a desiccator and weighed. Redrying was carried out for 1 hour, and the process was repeated until the difference in weight between two successive dryings was less than 2 mg. The loss in weight was recorded as moisture content.

Calculation

Moisture (%) = $W_1 – W_2 / W_1 – W \times 100$

Where:

- W = Weight (g) of the empty Petri dish
- W_1 = Weight (g) of the Petri dish + sample before drying
- W_2 = Weight (g) of the Petri dish + sample after drying

3.5.1.2 Determination of Total Ash of Jaggery

Principle

Ash refers to the inorganic residue remaining after the complete combustion of organic matter at a temperature of 550 ± 25 °C. The total ash content was estimated by weighing the sample before and after heat treatment.

Materials required

- Silica dish

- Burner
- Muffle furnace
- Desiccator
- Analytical balance

Sample Preparation

The jaggery sample was ground and mixed uniformly to obtain a homogenous mass. Any lumps present were broken using a glass plate or mortar and pestle. The sample was then transferred to a dry, stoppered container for analysis.

Method of analysis

An accurately weighed 5–10 g portion of the sample was transferred into a pre-dried and weighed silica dish. The sample was charred on a burner and then placed in a muffle furnace maintained at 550 ± 25 °C. After ashing, the dish was cooled in a desiccator and weighed. The process was repeated until a constant weight was achieved. The percentage ash content was calculated accordingly.

Figures 3 and 4 show the images of the jaggery sample before and after ashing, respectively.

Calculation

Total Ash (% on dry weight basis) was calculated using the following formula:

Total ash (% on dry weight) = $(W_2 - W) \times 100 \times 100 / (W_1 - W) \times (100 - M)$

Where:

- W = Weight (g) of the empty silica dish
- W_1 = Weight (g) of the silica dish + sample before ashing
- W_2 = Weight (g) of the silica dish + ash after ashing
- M = Moisture content (%) of the sample

Figure 3 Snapshot of Sample before Charring

Figure 4 Snapshot of Sample after Charring

3.6.1.3 Determination of Total Solids

Principle

The °Brix scale measured the number of grams of sucrose present in 100 milliliters of solution. A refractometer utilized the refractive index of the solution to convert the reading into a weight percentage of sucrose content, expressed as % °Brix.

Materials Required

- Digital or handheld refractometer
- Pipette or dropper
- Beaker
- Stirrer
- Distilled water

Sample Preparation

A jaggery solution was prepared by dissolving 5-10 g of jaggery in 50 mL of distilled water, followed by thorough stirring to ensure complete dissolution.

Method of Analysis

The refractometer was calibrated using a few drops of distilled water, which was then wiped off and the prism surface dried. 2–4 drops of the prepared jaggery solution were placed on the prism surface of the refractometer. After waiting for a few seconds, the °Brix value of the sample was recorded. Upon completion, the refractometer was cleaned with distilled water and wiped dry using tissue paper.

3.6.1.4 pH

Principle

A pH meter measured the electric potential generated between two electrodes immersed in the liquid sample to form an electrical circuit. One of the electrodes, known as the reference electrode, contained a substance with a stable electric potential. The other, the sensor electrode, was immersed in the jaggery solution. The meter detected the electric potential difference between the reference and sensor electrodes, which corresponded to the pH of the solution.

Materials Required

- pH meter
- Beakers
- pH buffer solutions (pH 4.0, 7.0, and 9.2)
- Distilled water

Sample Preparation

A solution was prepared by dissolving 5–10 g of jaggery in 100 mL of distilled water. The mixture was stirred thoroughly to ensure complete dissolution, and then allowed to settle for 5 minutes**.**

Method of Analysis

The electrode of the pH meter was first rinsed with distilled water. The meter was then calibrated using standard buffer solutions (pH 4.0, 7.0, and 9.2) to ensure accuracy. After calibration, the electrode was immersed into the jaggery solution, which was gently stirred. The pH value was recorded once the reading stabilized. Figure 5 shows the prepared jaggery solution used for pH measurement.

Figure 5 Snapshot of Jaggery Samples for pH

3.6.1.5 Water Activity

Principle

Water activity (aw) was measured based on the principle of water adsorption and desorption equilibrium. The water activity meter determined the water activity of the jaggery sample by measuring the vapor pressure of water molecules or the relative humidity in a sealed chamber. At a constant temperature, the amount of water absorbed or released by the sample was directly proportional to its vapor pressure. Therefore, by measuring the vapor pressure or relative humidity at equilibrium, the water activity of the sample was accurately estimated.

Materials Required

- Water activity meter
- Petri dish
- Sample cup

Sample Preparation

The jaggery sample was finely powdered to eliminate any lumps and ensure uniform consistency before analysis.

Method of Analysis

A known quantity of the powdered jaggery sample was placed in a sample cup, which was then inserted into the sealed chamber of the water activity meter. The chamber was sealed properly to prevent external humidity interference. The instrument was allowed to reach equilibrium, after which the water activity value was recorded. This process was repeated multiple times to ensure the accuracy and reproducibility of the results. Figure 6 Illustrates the jaggery sample placed in the water activity meter for measurement.

Figure 6 Snapshot of Jaggery for Water Activity

3.6.1.6 Benedict's Test for Detecting Reducing Sugars

Principle: Benedict's test is a qualitative chemical test used to detect the presence of reducing sugars in a sample. When a reducing sugar is heated in the presence of an alkali, it is converted into an enediol, a strong reducing agent. These reducing sugars reduce the cupric ions (Cu^{2+}) present in Benedict's reagent to cuprous ions (Cu^{+}). The cuprous ions then react to form copper(I) oxide (Cu_2O), which precipitates out as a brick-red solid. A visible color change from blue to brick-red confirms the presence of reducing sugars in the sample.

Materials Required

- Test tubes
- Beaker
- Gun heater
- Volumetric flask (10 mL)
- Distilled water
- Benedict's reagent

Sample Preparation

A small amount of jaggery was dissolved in distilled water to prepare the test solution. From this, a 1 mL aliquot was taken and mixed with 2 mL of Benedict's reagent in a test tube. The mixture was heated for 3–5 minutes using a gun heater, and any color change was observed to determine the presence of reducing sugars.

Method of Analysis

Preparation of Benedict's reagent:

- 1 g of sodium carbonate, 1.73 g of sodium citrate, and 0.17 g of copper sulfate were weighed accurately.
- These were transferred into a 10 mL volumetric flask, and distilled water was added to bring the solution to volume.
- The mixture was sonicated in an ultrasonic bath to ensure complete dissolution.
- The purity of the prepared Benedict's reagent was confirmed by heating a small amount in a test tube. A lack of color change upon heating indicated that the reagent was pure.

Test Procedure:

- 1 mL of the prepared jaggery sample was mixed with 2 mL of Benedict's reagent in a test tube.
- The mixture was heated using a gun heater for 3 to 5 minutes.
- The appearance of a brick-red precipitate confirmed the presence of reducing sugars in the jaggery sample.
- A color change from blue to brick-red was used as a visual indicator of reducing sugars.

Interpreting the Results of Benedict's Test:

The results were interpreted based on the intensity of the color change and the amount of precipitate formed. Table 2 represents the amount of reducing sugar present in the sample based on the intensity of the colour.

Table 2: Interpretation in Results of Benedict's test

Colour Change	**Interpretation**
Blue (no change)	No reducing sugars present
Green	Trace amounts of reducing sugars present
Yellow to orange	Moderate amount of reducing sugars present
Brick-red precipitate	High concentration of reducing sugars

3.6.1.7 Determination of Total Curcuminoid content of jaggery

Principle

Curcumin and its analogues—demethoxycurcumin and bisdemethoxycurcumin—are soluble in acetone and exhibit strong absorbance at 425 nm. The absorbance measured at this wavelength reflected the total curcuminoid content in the sample.

Materials Required

- UV-Visible Spectrophotometer

- Analytical Balance
- Silica Cuvettes
- 125 mL Erlenmeyer Flask / Round Bottom Flask
- West Condenser
- Volumetric Flasks (200 mL and 100 mL, glass stoppered)
- Pipettes
- Whatman No.1 Filter Paper (or equivalent)
- Funnel
- Anti-bumping Granules
- Sieve
- Acetone (analytical grade)

Sample Preparation

The curcumin-flavored jaggery sample was dried, sieved, and finely ground to ensure uniformity. An accurately weighed 1.000 g portion of the ground sample was transferred to a 125 mL Erlenmeyer flask, and 75 mL of acetone was added along with a few anti-bumping granules. The mixture was refluxed for 1 hour on a water bath using a West condenser. After refluxing, the extract was allowed to cool to 25 ± 2 °C and then filtered quantitatively into a 200 mL volumetric flask. The remaining solid residue was transferred onto the same filter, washed thoroughly with acetone, and the filtrate was diluted to volume with acetone.

From this solution, 1 mL was pipetted into a 100 mL volumetric flask, diluted to volume with acetone, and mixed thoroughly to obtain the final test solution.

Measurement

The absorbance of the test solution was measured at 425 nm using acetone as the blank. The measurement was carried out within 15 minutes of dilution to ensure stability of the curcuminoids.

Calculation

The curcumin content (%) was calculated using the following formula:

Curcumin content (%) = (As x V) / (Ws x1650 x 100) X 100

Where:

- As = Absorbance of the test solution
- V = Total dilution volume in mL
- Ws = Weight of the sample in grams
- 1650 = Specific absorptivity of curcumin in acetone at 425 nm ($L \cdot g^{-1} \cdot cm^{-1}$)

3.6.2 Sensory Evaluation

The sensory characteristics of the jaggery samples were evaluated by a panel of trained judges using a nine-point hedonic scale, following the standard procedure outlined by Larmond (1977). The evaluation parameters included freshness, colour, aroma, taste, mouthfeel, texture, and overall acceptability.

Each attribute was rated on a scale from 1 to 9, where:

- 9 – Like Extremely
- 8 – Like Very Much
- 7 – Like Moderately
- 6 – Like Slightly
- 5 – Neither Like nor Dislike
- 4 – Dislike Slightly

- 3 – Dislike Moderately
- 2 – Dislike Very Much
- 1 – Dislike Extremely

Panelists assessed the samples under controlled conditions to minimize bias and external influences. Each sample was coded with random three-digit numbers and presented in a randomized order. Water was provided to rinse the palate between samples.

The collected data were statistically analyzed to determine the overall acceptability and sensory performance of the jaggery samples, providing insights into consumer preferences and product quality.

Chapter 4 Results and Discussion

4.1 Development of Jaggery

4.1.1 Formulation Strategy

Filtration of Juice

Approximately 330mL of sugar cane juice has been taken and then filtered using strainer and transferred to boiling pan and kept for heating.

Clarification

Different clarifying agents such as lemon, milk, okra added to check the scum removing efficiency. During this stage impurities rise to the surface and are removed by straining.

Lemon: 2mL of lemon juice was used to clarify the juice. But there was a development of tangy flavor in the prepared jaggery.

Milk: 2 table spoon of milk was used as a clarifying agent, it was observed that the developed jiggery colour was too light.

Okra: 2mL okra was used as clarifying agent it was found the best among all clarifying agent.

Mixing and Concentration Process

After clarification the temperature has been increased to 110°C. As boiling continues, the juice concentrates and forms a thick, crystalline yellow substance called slurry. The juice is boiled until it reaches the striking point typically between 100°C and 110°C at which point it achieves the desired consistency for solid jaggery.

Cooling and Solidification

Once the striking temperature is reached, the concentrated juice (slurry) is poured into, silicon molds. The slurry is allowed to cool undisturbed for 4–6 hours at room temperature. Once the shine of the slurry diminishes, the jaggery is ready for demolding. Approximately 62g of jaggery has been obtained.

4.2 Development of Turmeric, Ginger, and Black Pepper Infused Jaggery

Flavor infused jaggery has been prepared by following above method, mentioned in section 4.1. The encapsulated flavor was incorporated while concentrating the sugarcane juice, at 86 ^{0}brix and mixed thoroughly to get uniform flavor. Further concentrated juice (slurry) is poured into cooling pans, molds, or trays. The slurry is allowed to cool undisturbed for 4–6 hours at room temperature. Once the shine of the slurry diminishes, the jaggery is ready for demolding.

The formulation of flavored jaggery was designed using preliminary data and literature references. The formulation strategy for flavor-infused jaggery was based on optimizing the ratios of the ingredients.

- The formulation strategy considered various criteria, including sensory evaluation.
- One of the important objectives during formulation was to achieve a balanced final product without allowing the sweetness of jaggery or the pungency of spices to overpower the overall flavor.
- Three variants of spice-infused jaggery were developed, and optimization with jaggery powder was also carried out, as shown in Table 3.
  1. Encapsulated ginger-infused jaggery
  2. Encapsulated turmeric and black pepper-infused jaggery
  3. Ginger powder-infused jaggery

Table 3: Optimization of Flavors with Minimum and Maximum Quantity

Ingredient	Minimum amount	Maximum amount
Encapsulated turmeric	3.8%	11.2%
Encapsulated ginger	0.64%	5.6%
Encapsulated Black pepper	0.38%	4.3%
Ginger powder	3.2%	9.6%

4.3 Process Trials and Preliminary Results

After a few trials with regular jaggery preparation, turmeric, ginger, and black pepper were gradually incorporated. These spices were added at various stages of the jaggery- making process, including before boiling, after boiling, and during the cooling stage. Turmeric and black pepper were also tested in combination.

- During the initial trials, manual stirring was performed; later, hand blenders were employed. Various spice concentrations were tested to evaluate their impact on color, flavor, texture, and consistency.
- In the first trial, the consistency of the jaggery turned out too hard and chewy due to excessive heating. Figure 9 shows the first trial of ginger-flavored jaggery, where the ginger flavor was not prominent. In the second trial, the consistency of the flavored jaggery was too loose, and the spice pungency was excessive. Figure 10 shows the trial of encapsulated turmeric and pepper jaggery.
- The spice-infused jaggery samples showed a variety of flavor profiles. The addition of turmeric imparted a new color to the sample, ginger enhanced the aroma, and black pepper contributed pungency. Figure 11 shows the trial of encapsulated ginger-infused jaggery.

- When jaggery is cooled using mechanical methods, it may lead to surface crystallization due to rapid cooling. Hence, cooling at ambient temperature is preferred. The °Brix level of jaggery after processing is higher than that of raw sugarcane juice. Likewise, physicochemical properties of jaggery change following preparation.

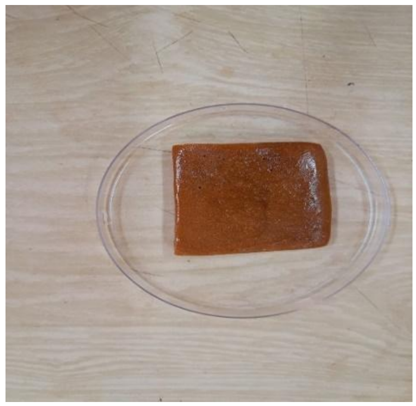

Figure 7Snapshot of Ginger Flavored Jaggery Trail

Figure 8Snapshot of Encapsulated Turmeric and Pepper Jaggery Trial

Figure 9Snapshot of Encapsulated Ginger Jaggery Trial

4.4 Optimization of Ingredient Ratios

This section is about providing ideal proportion of turmeric, ginger and black pepper flavored jaggery. Table 4 and 5 shows optimization of spice in solid and powdered jaggery.

4.4.1 Optimization of Spices while Preparing Flavored Jaggery

Table 4 Optimization of Spices in Jaggery

Flavors	Optimum value
Encapsulated black pepper and turmeric	1.6% and 8%
Encapsulated ginger	1.6%
Ginger powder	9.2%

4.4.2 Optimization of Spices with Jaggery Powder

Table 5 Optimization of Flavor in Jaggery Powder

Flavors	Optimum value
Encapsulated black pepper and turmeric	0.6% and 4%
Encapsulated ginger	2.5%

Ginger powder	17.1%

Ingredient ratio is based on the flavor balance and sensory acceptability. After preparing different combination it is subjected to sensory and physicochemical analysis. A proper standardized recipe will give a good consistency, taste, texture and bioactive content. Figure 12 and 13 shows encapsulated and normal ginger infused jaggery, Figure 14 shows the image of encapsulated turmeric and black pepper infused jaggery.

Figure 10 Snapshot of Encapsulated Ginger Jaggery

Figure 11 Snapshot of Ginger Powder Jaggery

Figure 12 Snapshot of Encapsulated Pepper and Turmeric Jaggery

4.5 Process Parameter Adjustment

a) Temperature

The boiling temperature of jaggery should not be too high or too low, it has a major impact on the bioactive chemicals of jaggery. If the temperature is low the formation may be hampered, and the resulting product will be high in moisture. The boiling temperature of jaggery can be adjusted between 90-110 °C to regulate caramelization and maintain bioactive components.

b) Mixing

Increased mixing rate and time may lead to destruction of flavor compounds. Lower mixing rate results in irregular distribution of flavors. To ensure consistent ingredient distribution, the mixing rate and time should be tuned.

c) Solidification and cooling

Slow cooling under room temperature is performed in order to prevent the product from deformation and it also helps in the regular distribution of flavors throughout the product. Rapid cooling with mechanical coolers can leads to crystallization issues so that cooling rate should be adjusted to get proper texture of jaggery.

d) ^{0}Brix Level (Total Soluble Solids, TSS)

The ^{0}Brix level indicates the total soluble solids content:

Before boiling: 20-22 ^{0}Brix

After concentration: 60-70 ^{0}Brix

Final stage of jaggery: 85-90 ^{0}Brix

Maintaining appropriate Brix levels ensures proper consistency, enhances texture, and improves the shelf life of the final product.

e) Stage of ingredient addition

There are different stages for spice addition before boiling can leads to irregular distribution of flavor, during boiling may have the risk of flavor degradation, and after boiling it may impact on its texture. Adjustment can be done by finalizing best stage for flavor addition.

4.6 Evaluation of Process Efficiency and Product Quality

Process efficiency of jaggery making can be evaluated through various characters including yield %, processing time, energy consumption.

Product yield can be calculated by measuring the final weight of jaggery obtained from sugarcane juice.

Yield % = (weight of jaggery) / (weight of sugarcane juice) x100

Energy consumption can be measured by calculating amount of power required for the jaggery preparation and processing time is the time taken for boiling, mixing and cooling of the jaggery. Evaluation of product quality involves physicochemical analyze like °brix, water activity, pH, ash, moisture content, reducing sugar, colour value etc. are done across multiple batches of jaggery and trained panelists conduct sensory evaluation. Shelf life study and microbial analyses can be done to evaluate the quality and shelf life of jaggery

4.7 Physicochemical Properties of Infused Jaggery

4.7.1Moisture Content

The developed flavored infused jaggery contains a moisture content of 11.3%.

4.7.2 Ash Content

Ash content in developed infused jaggery is 1.55%.

4.7.3 pH Content

pH of flavored jaggery developed is 6.67. pH measures how acidic or basic a substance is, with lower number being more acidic and higher number being more basic. Here the developed jaggery is neutral.

4.7.4 TSS

The TSS of flavored infused jaggery sample was 84.3 °brix.

4.7.5 Water Activity

Water activity of flavor infused jaggery is 0.519.

4.7.6 Reducing Sugar

As per benedict test sample shows an orange colour which means that 1.5 % of reducing sugar present in the developed jaggery

4.7.7Curcumin Content

Curcumin content present in jaggery is 0.03%

4.8 Sensory Evaluation

4.8.1Sensory Evaluation of Prepared Flavored Jaggery

Table 6 Sensory Evaluation of Prepared Flavored Jaggery

Sample code	Appearance	Aroma	Flavor	Colour	Mouthfeel	Aftertaste	Overall acceptability
ETB	9	8	8	8	9	9	9
EG	7	8	7	6	8	8	7
GP	8	7	7	7	8	8	8

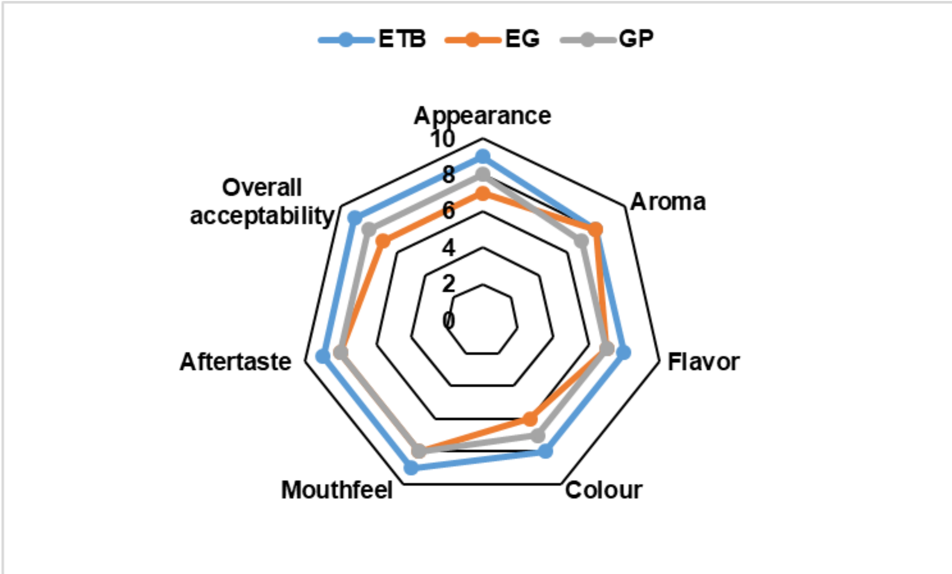

Figure 13 Sensory Evaluation of Prepared Flavored Jaggery

4.8.2 Sensory Evaluation of Flavor Optimized Jaggery Powder

Table 7 Shows the Sensory Evaluation of Optimized Jaggery Powder

Sample code	Appearance	Aroma	Flavor	Colour	Mouthfeel	Aftertaste	Overall acceptability
ETB	6	6	7	6	7	7	6
EG	7	8	7	6	7	7	7
GP	8	7	7	6	6	7	7

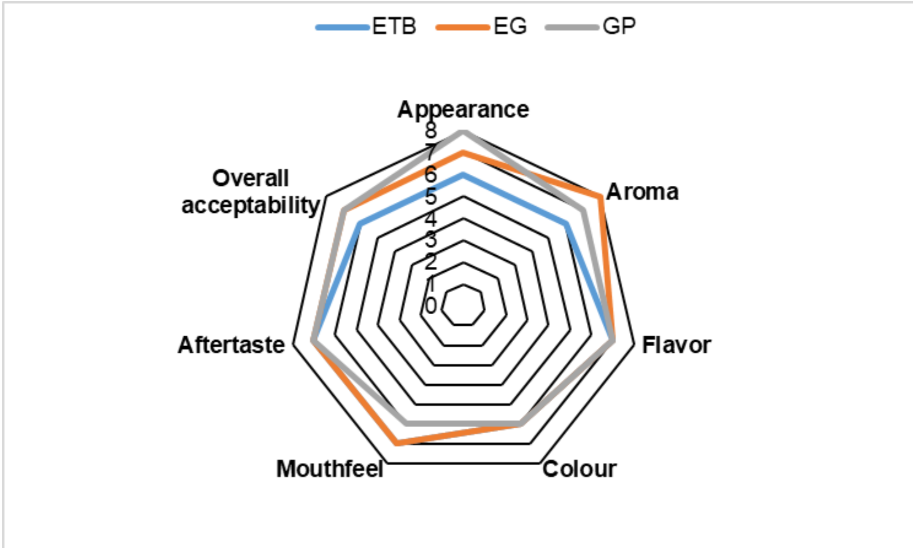

Figure 16 Sensory Evaluation of Flavor Jaggery Powder

Sensory evaluation of flavor infused jaggery was conducted by mixing it with milk, sample ETB was the highly accepted jaggery, its flavor and appearance was excellent. Encapsulated ginger sample gives a little pungency flavor to the milk and aroma was better than jaggery with normal ginger powder. Then the jaggery prepared from normal ginger powder required a large quantity of ginger powder as compared to encapsulated ginger. When optimized jaggery powder is mixed with milk it gives a powdery appearance to the drink unlike prepared jaggery. Appearance of ETB sample in flavor optimized jaggery powder is not that appealing like prepared jaggery and spice of pepper is not prominent. Overall acceptability of optimized jaggery powder was lower compared to prepared jaggery. Table 6 and 7 shows sensory evaluation of flavor infused jaggery solid and favor optimized jaggery powder. Sensory evaluation Figure 15 and 16 shows the radar chart of sensory evaluation of both the set of samples in 9 point hedonic scale, with attributes such as appearance, aroma, mouthfeel, overall acceptance, coloure, aftertaste, and flavoure. ETB - Encapsulated Turmeric and Black Pepper, EG- Encapsulated Ginger, GP- Ginger Powder.

4.9 Comparative Analysis with Standard Jaggery

Comparative analysis deals with the differences between the infused jaggery and standard jaggery based on physicochemical and sensory properties. Table 8 shows comparison of spice infused jaggery with standard jaggery.

Table 8: Comparison with Standard Jaggery

Parameter	Flavored jaggery	Standard jaggery
Moisture content	11.3%	5.22%
Ash content	1.55%	1.06%
°brix	84.3%	89.6%
Water activity	0.48%	0.52%
pH	6.67%	6.2%

- pH of infused jaggery can be alkaline or acidic based on its spice composition, water activity of the jaggery may have great impact on its microbial stability.
- Moisture content of infused jaggery as per the preparation is higher than that of standard jaggery and the °brix percent of infused jaggery is similar to that of standard jaggery.
- Ash content of infused jaggery is higher than that of normal jaggery due to the presence of spices so that the mineral content will be higher in flavored jaggery.
- Infused jaggery will have darker colour due to the presence of turmeric and ginger. Infused jaggery will also contribute to a distinctive aroma. Compared to normal jaggery.
- Infused jaggery adds a nuanced flavor with spice and pungency, unlike the caramel like flavor of regular jaggery.

4.10 Discussion of Process Optimization Findings

A proper standardized recipe will give a good consistency, taste, texture and bioactive content. Encapsulated black pepper and turmeric infused jaggery (prepared jaggery) was the highly accepted jaggery, its flavor and appearance was excellent. Encapsulated ginger sample gives a little pungency flavor to the milk and aroma was better than jaggery with normal ginger powder. Then the jaggery prepared from normal ginger powder required a large quantity of ginger powder as compared to encapsulated ginger.

When optimized jaggery powder is mixed with milk it gives a powdery appearance to the drink unlike prepared jaggery. Appearance of encapsulated turmeric and black pepper infused jaggery sample in flavor optimized jaggery powder is not appealing and spice of pepper is not prominent. Overall acceptability of optimized jaggery powder was lower compared to prepared jaggery. Final standardized recipe is selected based on the consumer acceptability. Spice infused jaggery ensures increased mineral content in the product so that optimized mixing helps to achieve uniform mineral distribution throughout the product.

Chapter 5 Conclusions and Recommendations

5.1 Summery of Key Findings

This study successfully developed and optimized jaggery infused with turmeric, black pepper, and ginger by improving its physicochemical and sensory qualities. The process focused on balancing key parameters to achieve consistent and high-quality results. The infused jaggery showed good physicochemical values, with water activity of 0.48%, ash content of 1.55%, moisture content of 11.3%, °Brix of 84.3, and pH of 6.67.

The addition of spices enhanced the overall flavor and aroma, resulting in better taste and texture compared to regular jaggery. Properly optimized spice-infused jaggery also showed improved shelf life and strong potential for commercial use.

5.2 Conclusions

This study successfully made and improved jaggery infused with turmeric, black pepper, and ginger. The process of heating, mixing, and cooling was carefully adjusted to make the jaggery more flavorful, with better texture and longer shelf life. The infused jaggery showed good results in moisture content, ash value, pH, water activity, and °Brix. It also had added health benefits like anti-inflammatory and antioxidant properties. People liked the taste, and it has good potential in the market. This study shows that spice-infused jaggery can be a better option than regular jaggery.

5.3 Recommendations for Future Research

Future research on infused jaggery can explore the use of other medicinal herbs and probiotics to enhance its nutritional value, flavor, and therapeutic properties. Ingredients such as cinnamon, cardamom, fenugreek, moringa, and ashwagandha can be used to improve functional characteristics. These components may also be tested for their effect on shelf-life enhancement.

5.4 Potential Industrial Applications

In the food industry, jaggery is used as a natural sweetener and serves as a good substitute for refined sugar, which is a major ingredient in many confectionery products. Infused jaggery can be incorporated into health drinks, herbal teas, and Ayurvedic formulations. It is also commonly used in dietary supplements, energy bars, and herbal tonics. Additionally, it finds applications in flavored jaggery-based syrups, chocolates, and spreads.

Beyond human consumption, jaggery is mixed with fodder to improve the palatability and acceptability of livestock feed. It also enhances the nutritional value of cattle feed. In poultry diets, it is used as an energy supplement to support egg production and growth rates. Jaggery is even used as a natural fertilizer due to its organic content and soil-enriching properties.

Chapter- 6 References

- Al-Amin, Z. M., Thomson, M., Al-Qattan, K. K., Peltonen-Shalaby, R., & Ali, M. (2006). Anti-diabetic and hypolipidemic properties of ginger in streptozotocin-induced diabetic rats. Br J Nutr, 96(4), 660–666. https://doi.org/10.1079/BJN20061849
- composition and health benefits—a review. Int J Chem Stud, 8(5), 2932–2936.
- Chattopadhyay, P., Ghosh, M., & Roy, A. (2016). Traditional sweeteners of India: Potential for value addition and product diversification. J Food Sci Technol, 53(3), 1250–1258. https://doi.org/10.1007/s13197-015-2083-4
- Das, R. (2018). Role of traditional foods in disaster relief: Case study of jaggery distribution in rural India. J Soc Dev, 12(1), 43–51.
- Deshmukh, S. R., & Chavan, U. D. (2020). Development of jaggery-based functional products: A review. J Pharmacogn Phytochem, 9(2), 1119–1125..
- Ghosh, S., Maiti, C. K., & Banerjee, S. (2008). Jaggery – A traditional Indian sweetener. Indian Journal of Traditional Knowledge, 7(1), 95–100.
- Gupta, R. K., Patel, A. K., Shah, D., & Jha, A. (2021). Evaluation of physicochemical and nutritional properties of jaggery fortified with turmeric and ginger powder. International Journal of Agriculture Sciences, 13(2), 10261–10264.
- Gupta, R., & Sinha, A. (2015). Health implications of jaggery use in industrial and occupational sectors. Ind Health Rev, 21(4), 214–220.

- Kumar, A., & Prasad, R. (2017). Processing and value addition of palm-based jaggery in Eastern India. Int J Agric Sci, 9(2), 487–492.
- Kumar, A., Nanda, V., & Sharma, A. (2022). Nutritional, phytochemical, and antioxidant evaluation of sugarcane juice and its products: A comparative study. Sugar Tech, 24, 1035–1045. https://doi.org/10.1007/s12355-021-01037-6
- Kumar, V., Yadav, P. K., Mishra, M. M., Singh, N. P., & Gautam, S. (2022). Effect of turmeric and black pepper on storage stability of jaggery. The Pharma Innovation Journal, 11(6), 1948–1952.
- Liu, X., Wang, F., & Chen, Y. (2017). Laboratory best practices: Use of desiccators in sample handling. Journal of Lab Science, 10(1), 12–17.
- Meghwal, M., & Goswami, T. K. (2012). Piper nigrum and piperine: An update. Phytother Res, 27(8), 1121–1130. https://doi.org/10.1002/ptr.4972
- Mishra, A., Bharti, S., & Saxena, A. (2022). Development of value added herbal jaggery using black pepper and ginger. Journal of Pharmacognosy and Phytochemistry, 11(3), 1770–1772.
- Nath, A., Dutta, D., Kumar, P., & Singh, J. P. (2015). Review on recent advances in value addition of jaggery based products. *J Food Process Techno*, *6*(4), 1000440.
- Rana, H., Garg, A. P., & Jain, S. (2022). Evaluation of edible coatings containing black pepper and turmeric for enhancement of shelf life of jaggery. J Food Process Preserv, 46(9), e16890. https://doi.org/10.1111/jfpp.16890
- Rao, K. P., Sharma, V., & Kaur, M. (2020). Recent trends in the use of traditional sweeteners in functional confectionery products. J Food Process Preserv, 44(6), e14430. https://doi.org/10.1111/jfpp.14430
- Rathore, A. K., & Batra, A. (2020). Quality evaluation of ginger based herbal jaggery. International Journal of Chemical Studies, 8(2), 2381–2384.

- Sahu, S. C., Patel, Y. R., & Patel, B. B. (2020). Preparation and quality evaluation of herbal jaggery. The Pharma Innovation Journal, 9(11), 261–263
- Sahu, V., Sharma, H. K., & Kumar, N. (2015). Production, consumption and potential expansion of jaggery industry in India—Can it be a prospective business opportunity. Indian Journal of Traditional Knowledge, 14(4), 752–760.
- Sasidharan, S., Chen, Y., Saravanan, D., Sundram, K. M., & Yoga Latha, L. (2011). Extraction, isolation and characterization of bioactive compounds from plants' extracts. Afr J Tradit Complement Altern Med, 8(1), 1–10.
- Sharma, A., & Lal, R. (2019). Traditional medicinal uses of jaggery and its role in Ayurvedic formulations. Ayurveda Res J, 10(2), 109–115.
- Shrivastava, S., Shrivastava, A. K., & Dangi, A. (2022). Development and quality evaluation of turmeric incorporated herbal jaggery. International Journal of Chemical Studies, 10(1), 330–334.
- Singh, J., Singh, P., Verma, A., & Singh, R. K. (2020). Studies on preparation and quality evaluation of spiced jaggery. The Pharma Innovation Journal, 9(6), 396–398.
- Singh, J., Solomon, S., & Kumar, D. (2013). Manufacturing jaggery, a product of sugarcane, as health food. Agrotechnology, 2(2), 1000120.
- Singh, M., Yadav, R. K., & Thomas, L. (2018). Fermentation characteristics of palm sap and its preservation techniques. Food Beverage Process, 8(3), 175– 180.
- Verma, N., & Choudhary, R. (2021). Traditional jaggery in modern diets: A nutraceutical perspective. Journal of Ethnic Foods, 8(1), 15–22. https://doi.org/10.1186/s42779-021-00089-z