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Original Paper

Development of an On-Site Protocol to Identify the Adulterations in Palmyrah Jaggery through Comparative Evaluation of Fresh Market Samples and Control Sample

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***Abstract*— Palmyrah jaggery, a traditional sweetener valued for its nutritional properties, is vulnerable to adulteration, compromising its authenticity and safety. This study aimed to develop a simple, cost-effective on-site protocol by examining the relationships between sensory attributes, physico-chemical properties, and adulterant test results in market samples compared to a control (QC) sample. Twenty freshly prepared jaggery samples from local producers and a laboratory-prepared QC sample were analyzed. Sensory evaluation assessed the attributes of jaggery, such as taste and aroma, by the Difference from Control (DFC) method. Simultaneously, physico-chemical parameters, including conductivity, total ash content, moisture content, Brix, pH, and color, were measured using standard methods. Adulterant-specific tests, such as sedimentation, iodine, and saccharin detection, were used to identify impurities like rice bran, starch, and $CaCO_3$. The sensory evaluation revealed significant differences ($p < 0.05$) in taste and aroma in 12 samples compared to QC, and 9 tested positive for adulterants like starch and $CaCO_3$. Conductivity and total ash content proved to be reliable indicators of adulteration, as adulterated samples displayed lower values, reflecting a reduction in mineral content compared to the QC. Moisture content, Brix, pH, and color parameters were less reliable indicators of adulteration due to variations in manufacturing practices, such as processing temperature and filtration methods. Additionally, all market samples exceeded the SLS 521:1981 limit for insoluble matter, indicating inadequate processing. This study demonstrates the effectiveness of a stepwise detection method combining sensory, physico-chemical, and adulterant-specific tests. The findings provide a foundation for ensuring the authenticity of palmyrah jaggery, promoting sustainable production, consumer safety, and market confidence.**

Keywords*— adulterant, jaggery, palmyrah, starch, white sugar

I. INTRODUCTION

The palmyrah palm (*Borassus flabellifer* .L) is widespread across the dry tropics of South America, East Africa, India, as well as Southeast Asia and South Asia, including India and Sri Lanka [1]. The economically valuable resources of the tree are used to produce baskets, fans, mats, hats, and fences using leaves and shoots [2]. Immature palmyrah fruits consist of an edible jelly-like kernel within the seeds. The germinated shoots also serve as food sources. The sugary sap extracted from young palmyrah inflorescences (male or female) is a clear, sweet liquid rich in sugars, vitamins, and minerals, particularly B-complex vitamins [3,4]. This sugar sap can be consumed in unprocessed forms or processed into various food products, namely jaggery, treacle, crude sugar, palm sugar, sugar candy, toddy, vinegar, arrack, and wine [5,6].

In Sri Lanka, jaggery is one of the major products derived from palmyrah sap. Palmyrah jaggery is more nutritious compared to cane sugar. Morton, (1988) reported the proximate composition of palmyrah jaggery as, 1.04% protein, 0.19% fat, 76.86% sucrose, 1.66% glucose, 3.15% total minerals, 0.86% calcium, 0.05% phosphorus, 11.01 mg/100 g iron, and 0.76 mg/100 g copper [7]. Palmyrah jaggery is popular among the public in the North of Sri Lanka and the South of India as a traditional sweetener and as a source of medicine for antitoxic and anti-carcinogenic effects [8].

Food adulteration refers to the intentional lowering of food quality by adding undeclared substitutes, replacing original ingredients, or removing essential components. This practice is commonly carried out to reduce production costs, increase the quantity of the product, or enhance its appearance, texture, or shelf life [9]. Adulteration may also include increasing the weight, primarily for economic gain. The substances used to diminish quality are known as adulterants. When a non-permitted material is added to enhance the quantity or quality of a product, it is also classified as adulteration [10].

Adulteration of palmyrah jaggery is often practiced due to consumer demand as a natural sweetener and medicinal properties. Cane or beet sugar, rice bran, wheat flour, corn flour, and minor impurities such as $CaCO_3$ are commonly added during jaggery production, either intentionally or unintentionally [11]. Calcium carbonate ($CaCO_3$) often originates from inefficient filtration and the use of low-grade lime during sap processing. The application of lime to the inner surface of the sap collecting pods reduces fermentation and prevents contamination from airborne microorganisms [12]. High-quality jaggery is distinguished by its golden yellow color, firm and crystalline texture, pleasant sweetness, and minimal levels of foreign materials and moisture [13].

Detecting adulterants in jaggery can be challenging because many adulterants share similar chemical compositions with authentic components [11]. Traditional analytical methods like gas chromatography-Mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), and DNA-based techniques are accurate but costly, time-intensive, and require specialized expertise, making them impractical for small-scale producers [14,15]. Studies like Velauthamurty et al. have demonstrated the feasibility of near-infrared for on-site applications, but the initial technical setup remains a barrier for small producers[11].

This study aimed to identify the relationships between sensory attributes, physico-chemical properties, and adulterant suspicion test results from fresh market samples and a control sample. Additionally, it sought to develop a simple and cost-effective solution for detecting adulteration in palmyrah jaggery, enabling an on-site testing protocol. By ensuring the authenticity of palmyrah jaggery, this approach aims to regulate production practices, educate producers, and enforce quality standards under existing government regulations. Strengthening monitoring efforts through Public Health Inspectors (PHI) and Food Inspectors (FI) can help minimize adulteration, ensuring compliance with food safety standards. Implementing awareness programs for producers will further promote adherence to best practices, preserving the traditional value of palmyrah jaggery while protecting public health and maintaining consumer trust in the market.

II. Materials and Methodology

A. Sample Collection

Twenty jaggery samples were collected from local production centers, which were made from different areas across different districts such as Mannar (Padappady), Mullaithivu (Mulliyavali), Jaffna (Pariththithurai, Udupitty, Oorkavatthurai, Pandatharippu, Karavedy, Achchuveli, Thinnaveli, Poonakari, Thellipalai), Kilinochchi, Vavuniya, and Batticaloa districts, Sri Lanka, which were labeled as JS 01- JS 20 following an unannounced visit. They were purchased within one week of the manufacturing date, 2024, and were stored in the refrigerator at -4 °C until they were used for further analysis. The palmyrah sap was collected from Kaithady, Jaffna, to prepare a control sample on a laboratory scale and labeled as QC. First, confirm that you have the correct template for your paper size.

B. Preparation of Control Jaggery Samples

The control palmyrah jaggery sample was prepared from fresh palmyrah sap without adding any adulterants or additives. First, about three litres of palmyrah sap were collected in cleaned clay pots, which were coated with high-purity hydrated lime inside to prevent the fermentation of sap by airborne microorganisms. The sap was filtered through muslin cloth to eliminate any particulate matter or impurities. Then, the deliming process was done for the filtered sap using phosphoric acid by adjusting the pH to 8.75. When phosphoric acid (H_3PO_4) reacts with calcium oxide (CaO), the reaction produces calcium phosphate ($Ca_3(PO_4)_2$), which is insoluble in water and forms a precipitate. The precipitate was filtered thoroughly through muslin cloth to obtain the sap mixture. Next, the mixture was heated until it reached 116°C–118°C. Finally, when the mixture thickened further, it was beaten forcefully until it began to solidify. At this stage, it was transferred into plastic molds and allowed to cool. About 70 g of QC jaggery sample was obtained and stored in the refrigerator at -4 °C until it was utilized for further analysis.

C. Adulterant Suspicion Tests for Jaggery Samples

1) Starch Test

The jaggery sample was dissolved in distilled water (10%) and filtered through filter paper. About 2 drops of iodine solution were added using a dropper. If the solution turns blue-black, it confirms the presence of starch (such as wheat or corn flour) in the jaggery [16], indicating it was added as an adulterant during the jaggery manufacturing process.

a) Sedimentation Test

Approximately 2 g of each jaggery sample was taken and dissolved in 5 mL of distilled water. If sedimentation occurs after 5 min, it indicates the presence of rice bran or unfiltered $CaCO_3$ in the jaggery, confirming that these substances were used as adulterants during the jaggery manufacturing process.

b) Qualitative Surface Texture Analysis

To determine the surface texture of jaggery and investigate the hypothesis that soft jaggery may be adulterated with wheat flour and hard jaggery with cane sugar, a sharp knife was used to perform a scratching test on the jaggery's surface. The jaggery sample is placed on a flat, clean surface, and the knife is held at a 45° angle, applying gentle pressure to the surface. If the jaggery is soft, the knife will easily create a visible indentation or scratch, and the surface may crumble or break into small pieces, suggesting possible adulteration with wheat flour. In contrast, if the jaggery is hard, the knife will leave only a shallow scratch or no indentation at all, with the jaggery breaking off in larger, solid chunks, which may indicate adulteration with cane sugar. The depth of the scratch and the ease with which the surface is scratched help determine whether the jaggery is soft or hard, and these findings will be compared with the results of other chemical tests to confirm whether the hypothesis is accepted or not.

c) Detection of Saccharine

The rapid detection method for saccharin sodium involves using a mixture of chloroform and ethanol as the extracting agent, where ethanol comprises 1–2% of the total volume. For the acidified methylene blue solution, the concentration of methylene blue is between 4×10^{-3} mol/L and 0.16 mol/L, and the hydrogen ion concentration in the acidic medium was between 0.01 mol/L and 4 mol/L. In the detection procedure, 1–10 mL of the chloroform-ethanol mixture was added to the reaction bottle, followed by 1–10 mL of the sample. Then, 0.1–2 mL of the acidified methylene blue solution was added to initiate the reaction. After mixing and allowing the phases to separate, the intensity of the blue color in the lower organic phase was observed and compared against a standard color chart to assess saccharin sodium content [17].

D. *Sensory Evaluation*

To evaluate adulteration in market jaggery samples, the Difference-from-Control (DFC) sensory analysis method was employed [18]. Twenty market samples were grouped into five sets to minimize confusion during testing, and QC samples were coded as JS21–JS25 to be used as blind controls. Flavor and aroma were selected as key sensory attributes for detecting adulteration, as these characteristics exhibit significant changes when adulterants are present.

Fifteen trained panelists from the Palmyrah Research Institute, Jaffna, evaluated each test sample against the QC sample using a standardized DFC scale to rate the magnitude of differences. Texture and color were not included as primary evaluation parameters, as these attributes can vary due to differences in processing temperature during large-scale production. By focusing on flavor and aroma, this approach ensured a scientifically valid and targeted evaluation for identifying adulteration in jaggery.

E. Determination of physico-chemical characteristics of jaggery *samples*

1) *Total soluble solids (TSS)/ Brix°*

Approximately 10% (w/v) of jaggery solution was prepared in distilled water, and the TSS of each sample was determined directly by using an automatic refractometer (ATAGO SMART-1) at room temperature and expressed in terms of Brix value.

2) *pH*

The pH was measured by using a pH meter (PH8500) at room temperature. Buffers of pH 4.0 and 7.0 were used to calibrate the instrument. The 10 % (w/v) Jaggery solution was prepared in distilled water, and the pH was measured.

3) *Conductivity*

The conductivity was measured by using a conductivity meter (EC700) at room temperature. 10 % (w/v) of Jaggery solution was prepared in distilled water, and the conductivity was measured.

4) *Color transmittance*

The color transmittance percent of the jaggery was determined as per the method described by [19] with a UV-visible spectrophotometer Jasco V-730. The jaggery sample was dissolved in distilled water (10 % (w/v)) and filtered through Whatman No.2 filter paper. The filtrate was used for color measurement. The percentage transmittance of the jaggery sample was recorded at 540 nm. $A = 2 - \log(T\ \%)$, where: Absorbance = A and Transmittance = T

F. *Determination of quality characteristics of jaggery samples*

Quality characteristics such as moisture content, total ash, and matter insoluble in water of jaggery samples were analyzed by methods mentioned in the SLS 521:1981.

To determine moisture content, a known weight of the jaggery sample was dried in an oven at 105°C until a constant weight was achieved. The moisture content is then calculated based on the weight loss during the drying process. For total ash, a weighed sample of jaggery is heated in a muffle furnace at 550°C to burn up the organic material. After complete combustion, the remaining residue is weighed, and the ash content is determined from the weight of this residue. To assess the matter insoluble in water, a known quantity of jaggery is mixed with water, stirred, and filtered. The residue left on the filter paper is dried, and the amount of insoluble matter is calculated as a percentage of the original sample.

III. Results And Discussion

A. *Adulterant suspicion tests for jaggery samples*

Table I depicts the observations for the adulterant suspicion test. Nine jaggery samples (JS1, JS2, JS3, JS7, JS8, JS15, JS17, JS18, and JS20) tested positive for starch, which indicates that these were adulterated with any starch source, like wheat flour. The same 9 jaggery samples that tested positive for starch in the iodine test also gave positive results in the sedimentation test. It may be due to the presence of wheat flour, CaCO3 (from low-grade CaO used during sap collection), rice bran, or a less efficient filtration method during the deliming process. The hypothesis regarding surface texture suggested that soft jaggery might be adulterated with wheat flour, while hard jaggery might be adulterated with cane sugar. A sharp knife was used to perform a scratching test on the jaggery's surface. However, observations revealed that although the QC sample had a soft texture, adulterated samples exhibited both soft and hard textures. Therefore, the hypothesis was rejected, indicating that surface texture does not reliably depend on adulteration. The jaggery sample JS7 showed a positive result for the saccharine identification test, as well as the starch test, indicating that the jaggery sample JS7 is adulterated with both starch and saccharine.

B. *Sensory evaluation*

According to Table II, sensory evaluation revealed that 12 out of 20 jaggery samples showed significant differences ($p < 0.05$) in taste and aroma compared to the QC samples (Table II). Notably, 9 of these samples (JS1, JS2, JS3, JS7, JS8, JS15, JS17, JS18, and JS20), identified as adulterated through starch and sedimentation tests and were among those with significant sensory differences. This highlights sensory analysis as an effective tool for detecting adulteration in jaggery. The altered sensory properties of adulterated samples indicate that the addition of starch or other adulterants negatively impacts the product's taste and aroma. Interestingly, 3 additional samples (JS11, JS12, and JS19) also exhibited significant sensory differences despite not testing positive for adulteration, suggesting the presence of other unidentified adulterants.

TABLE I. OBSERVATIONS FOR ADULTERANT SUSPICION TESTS.

Sample Code	Starch test	Sedimentation	Surface texture	Presence of Saccharine
JS1	Present	May be	Soft	No
JS2	Present	May be	Hard	No
JS3	Present	May be	Hard	No
JS4	Absent	No	Soft	No
JS5	Absent	No	Soft	No
JS6	Absent	No	Soft	No
JS7	Present	May be	Hard	Yes
JS8	Present	May be	Hard	No
JS9	Absent	No	Soft	No
JS10	Absent	No	Hard	No
JS11	Absent	No	Hard	No
JS12	Absent	No	Hard	No
JS13	Absent	No	Soft	No
JS14	Absent	No	Soft	No
JS15	Present	May be	Soft	No
JS16	Absent	No	Soft	No
JS17	Present	May be	Hard	No
JS18	Present	May be	Hard	No
JS19	Absent	No	Hard	No
JS20	Present	May be	Soft	No
QC	Absent	No	Soft	No

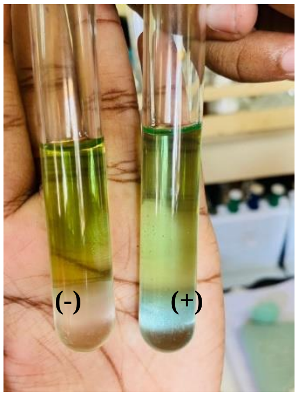

Fig. 1. Saccharine test observation for positive and negative samples

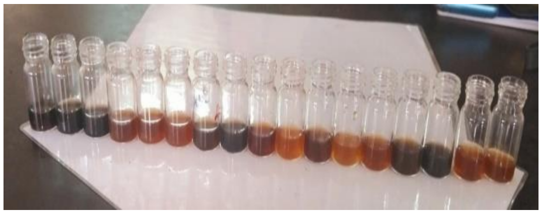

Fig. 2. Starch test observation for palmyrah jaggery market samples

TABLE II. MEAN PANEL DATA AND THE P-VALUE FOR THE JAGGERY DIFFERENCE FROM CONTROL (DFC) TEST.

Sample Code	Taste			Aroma		
	Mean DFC	*Mean Test DFC-Blind control DFC*	*p-value*	*Mean DFC*	*Mean Test DFC- Blind control DFC*	*p-value*
JS1	2.95	1.70	0.000	2.95	1.70	0.000
JS21	1.25			1.25		
JS2	3.75	3.05	0.000	3.75	2.75	0.000
JS22	0.70			1.00		
JS3	3.60	2.50	0.000	3.85	3.05	0.000
JS23	1.10			0.8		
JS4	0.75	0.00	1.000	0.9	0	1.000
JS21	0.75			0.9		
JS5	1.00	0.00	1.000	1	0.25	0.545
JS25	1.00			0.75		
JS6	1.25	0.30	0.340	1.45	0.35	0.325
JS21	0.95			1.1		
JS7	3.90	3.25	0.000	3.95	3.00	0.000
JS21	0.65			0.95		
JS8	3.70	2.60	0.000	4	3.20	0.000
JS23	1.10			0.8		
JS9	1.15	0.30	0.657	0.95	0.35	0.203
JS24	0.85			0.6		
JS10	1.45	0.25	0.615	1.2	0.20	0.647
JS25	1.20			1		
JS11	3.00	1.7	0.000	3.3	1.95	0.000
JS22	1.30			1.35		
JS12	2.30	1.6	0.000	2.3	1.4	0.001
JS22	0.70			0.9		
JS13	1.50	0.4	0.331	1.5	0.7	0.033
JS23	1.10			0.8		
JS14	1.25	0.4	0.249	1.4	0.45	0.293
JS24	0.85			0.95		
JS15	4.50	3.3	0.000	4.15	3	0.000
JS25	1.20			1.15		
JS16	1.65	0.35	0.379	1.8	0.5	0.190
JS21	1.30			1.3		
JS17	3.65	2.95	0.000	3.7	2.8	0.000
JS22	0.70			0.9		
JS18	3.50	2.4	0.000	3.25	2.45	0.000
JS23	1.10			0.8		
JS19	3.60	2.75	0.000	3.5	2.55	0.000
JS24	0.85			0.95		
JS20	4.35	3.15	0.000	4.3	3.15	0.000
JS25	1.20			1.15		

C. Determination of physico-chemical characteristics of jaggery samples

1) Total soluble solids (TSS)/ Brix°

A standard palmyrah jaggery should contain a minimum of 70% sugar content according to the SLS 521:1981. According to the Brix values, jaggery samples adulterated with starch showed lower values (Fig. 3) compared to the QC sample (89.6°), although they still fell within the acceptable range for standard jaggery. This indicates that the addition of starch dilutes the sugar content by increasing the overall mass. However, manufacturers may use white sugar as an adulterant, which can contribute to a high Brix value. Therefore, the Brix value may not be a reliable indicator for detecting adulteration in jaggery.

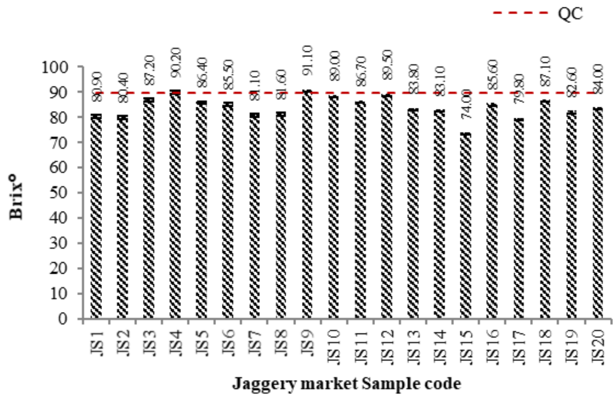

Fig. 3. Brix values of jaggery samples

2) pH value

The pH values of both adulterated and non-adulterated palmyrah jaggery samples fell within a similar range (Fig. 4). As with Brix, pH is not a reliable parameter for identifying adulteration in jaggery, as pure and adulterated samples show comparable values. The observed variation in pH may be attributed to the deliming process used during manufacturing.

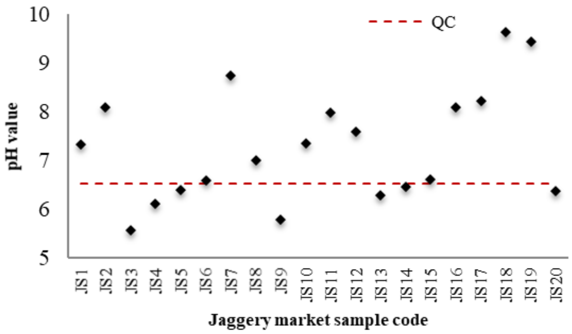

Fig. 4. pH values of jaggery samples

3) Conductivity

The jaggery samples adulterated with starch and saccharine (JS1, JS2, JS3, JS7, JS8, JS15, JS17, JS18, and JS20) showed lower conductivity compared to the QC sample (2420 µS/cm) (Fig. 5). In contrast, samples such as JS11, JS12, and JS19, which were identified as potentially adulterated based on sensory evaluation, exhibited conductivity values lower than the QC sample but higher than the samples adulterated with starch and saccharine. This variation in conductivity indicates that the addition of starch dilutes the ion content by increasing the overall mass, resulting in lower conductivity. The ion content in jaggery originates from the natural minerals in palmyrah sap, such as potassium, calcium, magnesium, and sodium [7], which contribute to its conductivity. The conductivity range of 400–800 µS/cm [20], typical for white sugar, explains why jaggery samples adulterated with white sugar (JS11, JS12, and JS19) showed conductivity lower than the QC sample but higher than starch-adulterated jaggery. Thus, conductivity is a reliable parameter for identifying adulteration, as it reflects the ion content characteristic of pure jaggery derived from palmyrah sap. To effectively use this parameter as a detection tool, standards should establish a minimum conductivity value for authentic palmyrah jaggery, ensuring the reliable identification of adulterated samples.

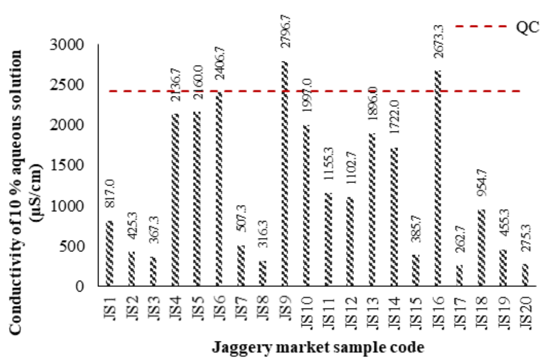

Fig. 5. Conductivity of 10% jaggery aqueous solution samples

4) Color (% transmittance)

The standard jaggery color is golden yellow, with 61.10% transmittance at 540 nm [2]. According to Fig. 6, jaggery samples adulterated with starch and saccharine (JS1, JS2, JS3, JS7, JS8, JS15, JS17, JS18, and JS20), white sugar (JS11, JS12, and JS19), and non-adulterated samples showed variations in color transmittance compared to the QC sample.

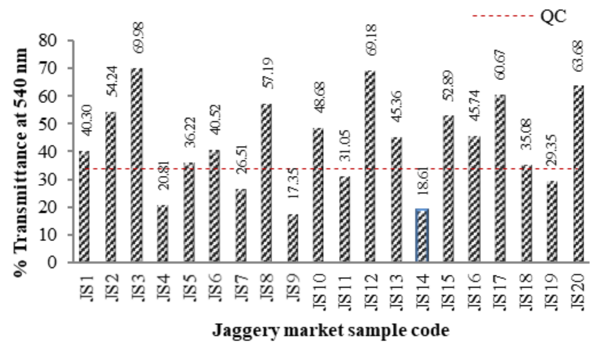

Fig. 6. Color (% transmittance) of 10% jaggery aqueous solution

These variations are primarily influenced by the processing temperature during manufacturing, rather than the presence of adulterants like starch, white sugar, or saccharine. Temperature plays a crucial role in the Maillard reaction and caramelization, the key processes that define the color and appearance of jaggery. Elevated temperatures accelerate the Maillard reaction, resulting in quicker color development and enhanced flavor formation in the final product [21]. Additionally, some manufacturers may add yellow coloring to achieve a golden appearance, which can be detected using specific tests. Therefore, color alone is not a reliable indicator of adulteration.

D. Determination of quality characteristics of jaggery samples

1) Moisture content

According to SLS 521:1981, palmyrah jaggery should have a maximum moisture content of 10%. Jaggery samples adulterated with starch and saccharine (JS1, JS2, JS3, JS7, JS8, JS15, JS17, JS18, and JS20), white sugar (JS11, JS12, and JS19), as *well* as non-adulterated samples, showed varying moisture content compared to the QC sample (Fig. 7). However, all were within the acceptable range except for sample JS8. While moisture content can be a useful parameter for determining shelf life [22], it is not a reliable indicator for identifying adulteration.

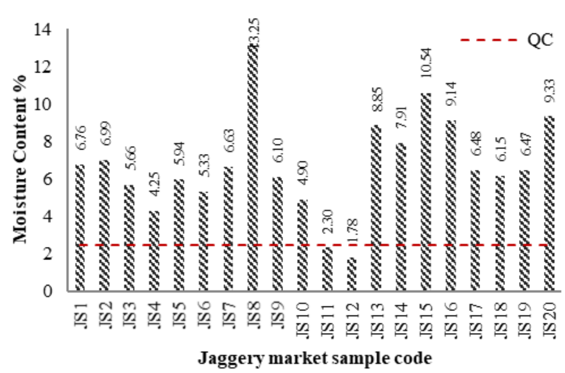

Fig. 7. Moisture content of jaggery samples

2) Matter insoluble in water

According to SLS 521:1981, jaggery should contain no more than 2% matter insoluble in water. However, all the tested samples exceeded this limit (Fig. 8).

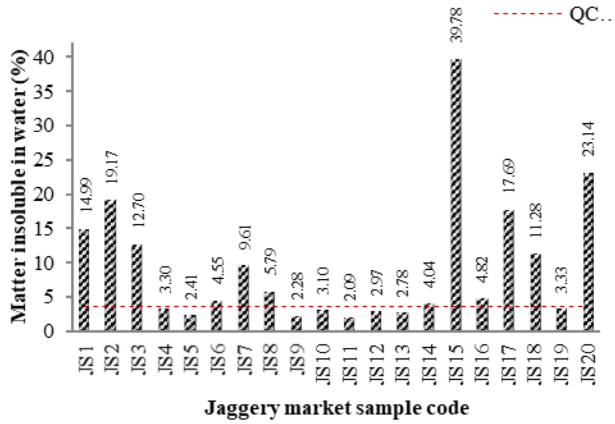

Fig. 8. Matter insoluble in water of jaggery samples.

The high insoluble content could be attributed to improper filtration, contamination during processing, or the use of inferior raw materials. Variations in manufacturing practices across different suppliers may also have contributed to this inconsistency. Further studies are needed to assess whether the SLS limit is realistic or if stricter adherence to processing methods is required.

3) Total ash content

According to SLS 521:1981, jaggery should have a maximum total ash content of 3.5%. All jaggery samples, whether adulterated or not, fell within this acceptable range as shown in Fig. 9. However, samples adulterated with starch and saccharine (JS1, JS2, JS3, JS7, JS8, JS15, JS17, JS18, and JS20) and white sugar (JS11, JS12, and JS19) showed lower total ash content compared to the QC sample (2.31%) and non-adulterated samples. This reduction occurs because the addition of starch or white sugar dilutes the mineral content, resulting in lower ash values, as these adulterants contain fewer minerals, which is consistent with previous studies. In contrast, if rice bran is used as an adulterant, the total ash content would increase due to its higher mineral content [8]. However, such adulteration can be identified through a sedimentation test. While total ash content is a reliable indicator for detecting adulteration with starch, white sugar, or saccharine, it is not as effective for identifying rice bran adulteration. To effectively use total ash content as a parameter for identifying specific adulterants, it is necessary to establish both minimum and maximum acceptable ranges in the standards through further research and studies. This would enhance its reliability as an adulteration detection tool.

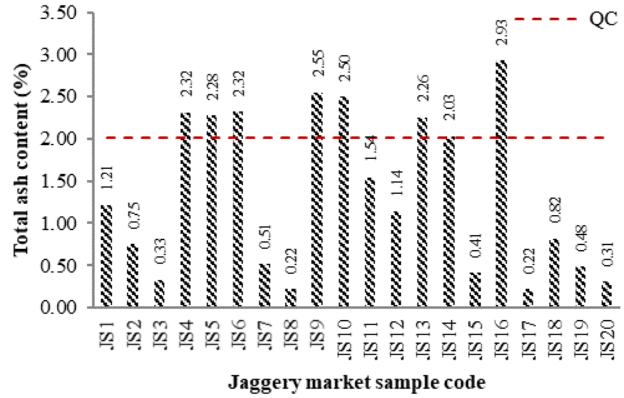

Fig. 9. Total ash content of jaggery samples

IV. Conclusion

This study demonstrated that adulteration in palmyrah jaggery, particularly with starch, saccharine, and white sugar, can be effectively detected using a combination of conductivity, total ash content, sedimentation, and sensory analysis. However, parameters such as Brix, pH, color, and moisture content were less reliable due to variability in processing methods and the masking effects of adulterants. Adulterated samples exhibited lower conductivity (< 954.7 µS/cm) and total ash content (< 1.21%), indicating reduced mineral levels, with white sugar-adulterated samples showing intermediate conductivity values. Sedimentation tests successfully identified adulteration sources like wheat flour and low-grade lime, while sensory evaluation highlighted significant differences in taste and aroma between adulterated and control samples. A simple, on-site detection method was developed (Fig. 10); however, further testing methods are required to reliably detect adulterants when their composition varies. Additionally, all market samples exceeded the SLS standards for insoluble matter, suggesting inadequate filtration or contamination during processing and underscoring the need for stricter manufacturing practices. These findings emphasize the necessity of robust and adaptable detection methods alongside stringent quality standards to ensure the authenticity and safety of palmyrah jaggery.

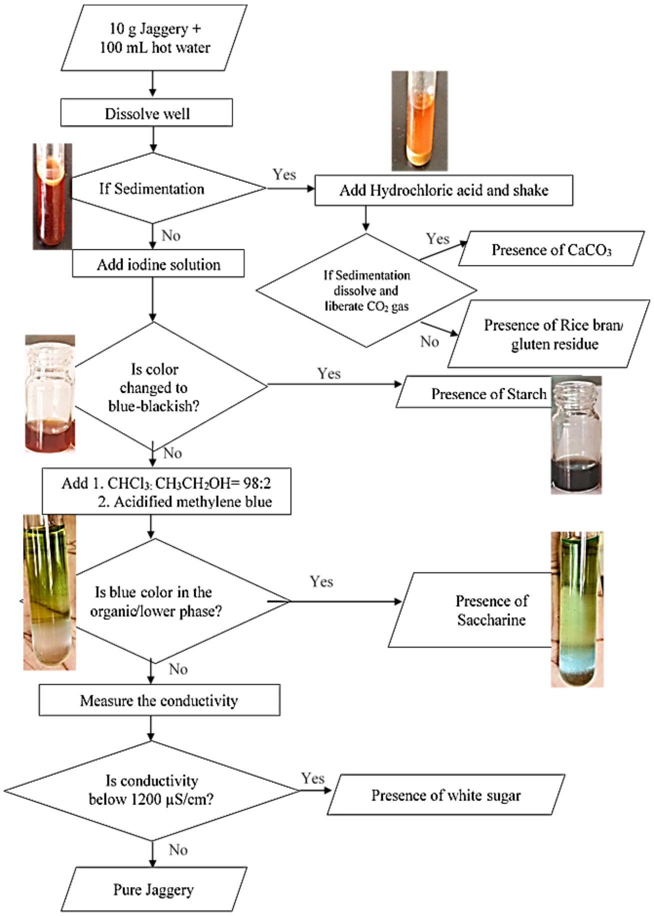

Fig. 10. On-site protocol to identify the possible adulterants in Jaggery

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