Comparative Phytochemical Analysis and Characterization of Local Sugarcane Products

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***Dedicated to my beloved grandmother*(پیاری نانی جان)**

and my dearest parents

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Abstract

Sugarcane (*Saccharum officinarum*) is a widely cultivated crop known for its diverse applications in the food industry. Major products of sugarcane are table sugar, brown sugar, jaggery, and molasses. Sugarcane contains several significant nutrients which have medicinal properties. However, the current industrial process of producing table sugar from sugarcane juice involves the use of several chemicals that result in the loss of essential nutrients and medicinal properties of the juice. Additionally, this process is labor-intensive, expensive, and time-consuming, which makes it unsuitable for use by farmers and small-scale producers. The present study is aimed at the development of an innovative method of producing nutrient-rich sugar from sugarcane juice using low-temperature air drying. The process involves the extraction of sugarcane juice, pumping the juice into a drying chamber, air drying the juice into crystals or powder, collecting the sugar granules in a container, forming the sugar granules into tablets, and packaging the tablets in airtight plastic bags. The intention was to retain as many nutrients as possible in the final sugarcane juice powder. A comparative phytochemical analysis was carried out on dehydrated sugarcane powder which unveiled the presence of medicinally important compounds such as phenol, flavonoids, and alkaloids. Interestingly, these compounds were not identified in other sugarcane derivatives like table sugar, brown sugar, jaggery, and molasses. Advanced analytical techniques, including gas chromatography-mass spectrometry (GCMS), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD) were used in this study of sugarcane products. Through GC-MS analysis, compounds detected in dehydrated sugarcane juice powder such as ferulic acid, catechols, furanone, flavonoids, and Iso-benzo-furanone revealed that sugarcane juice powder contains maximum nutrients as fresh extracted sugarcane juice. These findings provided more detailed differentiation among local sugarcane products. Furthermore, the FTIR analysis exposed unique spectral patterns across these products, indicating the variability in their chemical composition. XRD analysis was conducted to evaluate the crystalline nature and crystal structure of the products. These techniques highlighted distinct variations in their chemical profiles and structural characteristics. The comparative analysis of sugarcane products revealed that these products contain lesser nutrient levels compared to fresh sugarcane juice. The development of innovative formulations and applications of the sugarcane juice powder and tablets as a natural sweetener alternative holds potential for expanding its market reach and promoting healthier sugar consumption habits among domestic consumers.

Keywords: Sugarcane, Table sugar, sugarcane juice powder, XRD, FTIR, GCMS, UV Spectrophotometer.

CHAPTER 1: INTRODUCTION

1.1 Sugarcane Crop

Sugarcane, a tall perennial grass from the genus Saccharum, is extensively cultivated for its high sugar content. This economically significant crop, which belongs to the Poaceae family, thrives in the warm temperate and tropical climates of India, Southeast Asia, and New Guinea (Martin *et al*., 2013). In 2020 alone, it accounted for 79% of the global sugar production, with about 70% of the sugar coming from Saccharum officinarum and its hybrids. This complexly genome plant is the world's leading crop by production volume, with Brazil accounting for 40% of the total yield. Once harvested, the sweet juice is extracted from sugarcane, concentrated, crystallized, and refined to produce sugar. This sugar is the primary raw material for the sugar industry and is predominantly consumed by the food and beverage industry, being a fundamental ingredient in chocolates, candies, desserts, soft drinks, juices, and many more products. Apart from providing sweetness, sugar also contributes to the texture and taste of these food items (Martin *et al*., 2013). In addition to sucrose, sugarcane is also a source of a variety of other sugars used around the world, such as table sugar, brown sugar, jaggery and molasses. Moreover, sugarcane and its products are rich in phytochemicals - secondary metabolites that exhibit a range of bioactivities.

Sugarcane is not just a valuable resource for the culinary and food industry, but it also has noteworthy applications in the industrial and biofuel sectors. With the increasing concern over non-renewable fossil fuels, sugarcane has emerged as a significant renewable source for producing biofuel, especially ethanol (Singh *et al*., 2022). Brazil, the largest sugarcane producer, uses sugarcane-derived ethanol as an alternative to gasoline, demonstrating a sustainable approach to energy production. Furthermore, bagasse, the fibrous matter that remains after sugarcane stalks are crushed to extract their juice, is utilized in the production of biodegradable plastics, paper, and building materials (Kumar *et al*., 2023). In addition to these uses, recent research has highlighted the potential health benefits of sugarcane and its derived products. Beyond its high sucrose content, sugarcane is rich in beneficial phytochemicals, including phenolic compounds, flavonoids, and antioxidants (Mohan *et al.,* 2013). These compounds have been found to possess anti-inflammatory, anti-cancer, and anti-diabetic properties, providing a potentially untapped source for natural therapeutic agents. However, more extensive research is needed to fully understand these health benefits and their application in medicine and nutrition.

Sugarcane stands as a key agricultural commodity on an industrial scale. The Food and Agriculture Organization of the United Nations (FAO) reveals that this crop leads in terms of global production, with an estimated 1.87 billion tons harvested in 2020. The sheer volume of this production underscores the significance of the sugarcane industry from both socio-economic and environmental viewpoints. Through the lens of a circular economy, questions have emerged surrounding the sustainability of sugar production, the creation of by-products and waste, and the overall sustainable evolution of the sugarcane industry. Notwithstanding, sugarcane is recognized as one of the most valuable and efficient sources of biomass for biofuel production.

The examination of various products derived from sugarcane, like sugarcane juice, sugar, molasses, and bagasse, often includes collecting samples for a detailed investigation of their phytochemical composition (Sivam *et al*., 2018). Using state-of-the art techniques like high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), and spectrophotometry, researchers can identify and measure the presence of bioactive compounds such as phenolic compounds, flavonoids, antioxidants, and other secondary metabolites (Sanchez *et al*., 2019). Comparative evaluations of these bioactive components are conducted across different sugarcane by products, considering the differences and similarities in their phytochemical profiles (Mandal *et al*., 2020). Additionally, the bioactive compounds identified are subjected to an in-depth characterization study, where their chemical properties, functional groups, and potential health benefits are investigated. These studies may include assessments of the antioxidant, antimicrobial, anti-inflammatory, and other bioactive properties of the compounds (Kumar & Pruthi, 2014). This understanding of the phytochemical composition and their potential health benefits can offer important knowledge about the nutritional value of these local sugarcane products. It also has the potential to find application in various industries such as food, pharmaceutical, and cosmetics (Kaur *et al*., 2020)

Pakistan's sugar production chiefly relies on the cultivation and processing of sugarcane, primarily grown in the fertile regions of Punjab and Sindh. Once matured, sugarcane is harvested and conveyed to sugar mills for processing. The processing involves crushing the cane to extract sugary juice, followed by filtration, heating, and chemical treatments to purify the juice from impurities. This juice is then concentrated through evaporation until sugar crystallizes. The crystals are spun in a centrifuge to separate them from the liquid, forming raw sugar. The raw sugar then undergoes refining to produce the fine, granulated white sugar commonly used (International Sugar Organization, 2020). Table sugar is a staple in Pakistani

diets and is extensively incorporated in various foods and beverages. Reports from the Pakistan Sugar Mills Association indicate that the per capita sugar consumption in the country is quite high, ranging between 25 to 30 kilograms annually (Pakistan Sugar Mills Association, 2022).

However, overconsumption of sugar can lead to several health issues. Weight gain and obesity are primary concerns, as excess sugar, particularly in sugary drinks and processed foods, leads to high calorie intake without substantial nutritional benefit, thereby increasing the risk of obesity (World Health Organization, 2019). High sugar diets also elevate the risk of type 2 diabetes by inducing insulin resistance, a condition where cells respond less to insulin, a hormone that controls blood sugar levels, resulting in heightened blood sugar levels and increased diabetes risk (American Diabetes Association, 2020). Additionally, sugar overconsumption can cause dental issues as oral bacteria metabolize sugar into acids that degrade tooth enamel and cause cavities and decay (American Dental Association, 2021). High sugar intake has also been associated with increased heart disease risk due to elevated triglyceride levels, LDL cholesterol ("bad" cholesterol), and inflammation, which can cause cardiovascular problems (American Heart Association, 2018). Lastly, excessive sugar consumption can lead to nutritional deficiencies as a diet rich in sugar often displaces nutrient-dense foods, leading to insufficient intake of vitamins, minerals, and fiber crucial for general health (US Department of Agriculture, 2020)

1.2 Importance of sugarcane Crop

Sugarcane is an important crop for many countries around the world, and its importance can be seen in several areas:

1.2.1 Economic Impact

In many nations, such as Brazil, India, China, Thailand, and Pakistan, sugarcane holds a crucial position as a commercial crop. It fuels local economies and promotes employment for a vast population (Lima *et al*., 2022).

1.2.2 Nutritional and Energy Source

Sugarcane serves as both a nutritional and energy resource. It contributes to the production of various sweeteners like table sugar, brown sugar, molasses, and jaggery, and biofuels like ethanol. While its sugar derivatives are indispensable in numerous food products, its biofuel output presents a sustainable alternative to traditional fossil fuels for powering vehicles (Martinez *et al*., 2020)

1.2.3. Environmental Benefits

The cultivation of sugarcane is also associated with significant environmental advantages. It acts as a carbon sink, absorbing CO_2 from the atmosphere, thereby aiding in mitigating the impact of greenhouse gases. Additionally, sugarcane cultivation can enhance soil fertility and prevent erosion (Wang *et al*., 2020)

1.2.4. Social Significance

The sociocultural influence of sugarcane is remarkable in several areas. It plays a role in folk medicine and forms a critical element of numerous celebrations and festivals. In summary, sugarcane's value is multi-dimensional, encompassing economic, nutritional, environmental, and sociocultural benefits that enrich communities worldwide (Castro *et al*., 2019)

1.3 Applications

Sugarcane products are used in a variety of different areas, including food and beverage, agriculture, and energy production. Here are some examples of how sugarcane products are applied in different areas:

1.3.1 Food and Beverage

Sugarcane serves as the primary source of sugar, a key sweetening ingredient in an array of food and beverage items, encompassing beverages, baked items, and sweets (Jackson *et al*., 2022). Sugarcane juice, renowned for its refreshing qualities, is a popular drink in many regions, notably in South Asia and Southeast Asia. Additionally, jaggery and molasses, by-products of sugarcane, are employed as sweetening agents in various traditional global cuisines.

1.3.2 Medical Applications

Historically, sugarcane has been utilized in folk medicine for managing diverse health conditions, and contemporary research affirms the potential health advantages of sugarcane extracts. Owing to their antioxidant and anti-inflammatory capacities, these extracts can neutralize free radicals in the body, thereby preventing them from interacting with proteins that may induce serious damage under certain circumstances (Sharma *et al*., 2014). Hence, the spectrum of applications of sugarcane products is vast, encompassing the realms of culinary arts, agriculture, energy generation, and healthcare. Sugarcane has also been utilized in traditional medicine, and recent research has revealed the potential health benefits of sugarcane extracts due to their antioxidant and anti-inflammatory properties. sugarcane offers

multidimensional benefits, making it an economically, environmentally, and sociocultural significant crop with diverse applications.

1.4 Processing of Table Sugar, Jaggery, Brown Sugar, Molasses

Various sweeteners such as table sugar, jaggery, brown sugar, and molasses are derived from sugarcane, each undergoing distinct processing procedures and featuring unique compositions, thereby leading to distinct flavors and applications in culinary practices (Smith *et al*., 2022) Table sugar, frequently referred to as granulated or white sugar, is a commonplace form of sugar. It is produced by extracting and purifying juice from sugarcane or sugar beets, followed by a process of evaporation and crystallization. The ensuing crystals are cleansed, dried, and prepared for packaging. This form of sugar is almost entirely composed of sucrose, with uniform dimensions and structure (Patel *et al*., 2021). Jaggery, also known as gur, is a customary sweetener predominantly utilized in South Asian cuisine. It's manufactured by boiling sugarcane juice or palm sap to a point where it solidifies. The resultant product is then molded into blocks or cakes. Unlike other sugars, jaggery comprises minute quantities of vitamins and minerals, giving it a distinctive flavor and texture (Kumar *et al*., 2017) Brown sugar, which is partially refined sugar, retains some molasses from the sugarcane juice. Its production involves the blending of granulated white sugar with molasses, followed by a drying process. The color and flavor intensity of the brown sugar are determined by the quantity of molasses added, with light brown sugar being milder in flavor than its dark brown counterpart (Gupta *et al*., 2014) Molasses, a byproduct of sugar refining, is a viscous, dark liquid left behind once the sugar crystals have been extracted from the sugarcane juice. Abundant in vitamins and minerals like iron, magnesium, and potassium, molasses is commonly used as a sweetening agent in cooking and baking, bringing a unique, deep flavor to dishes (Singh *et al*., 2016)

1.5 Dehydration of Sugarcane Juice

Drying sugarcane juice, whether by employing heat or not, eliminates its water content, yielding a concentrated product. However, these processes may lead to variations in nutrient content. If sugarcane juice is dried using heat, certain nutrients, such as vitamin C and some antioxidants, may degrade due to the high temperature (Sharma *et al*., 2013). Yet, this heat can simultaneously destroy harmful bacteria or contaminants, thereby enhancing the safety of the dried product. On the other hand, when drying sugarcane juice without heat, nutrients are likely better preserved as they aren't subjected to high temperatures that may degrade them (Singh *et al*., 2015). Nevertheless, ensuring hygienic drying conditions is vital to mitigate the risk of contamination.

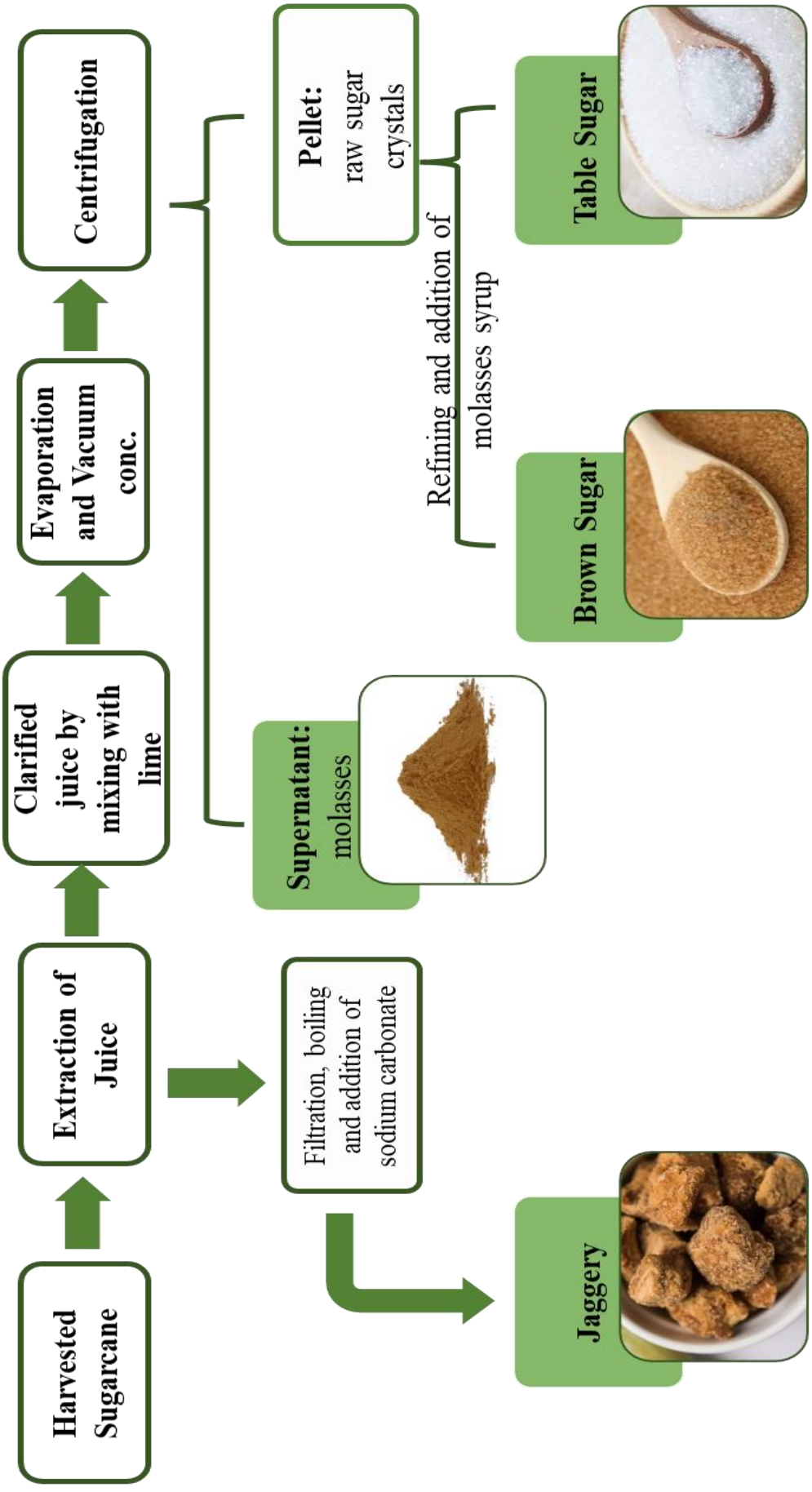

Figure 1.1: The schematic flowchart of formation of local sugarcane products

Numerous studies have delved into the phytochemical analysis and characterization of sugarcane products, including table sugar, jaggery, brown sugar, and molasses. These products encompass various phytochemicals that possess potential health benefits, embodying antioxidant, and anti-inflammatory properties (Prabakaran *et al*., 2016) Research has been executed on the phytochemical analysis of sugarcane juice using techniques like FTIR, GCMS, and XRD analysis, demonstrating the presence of a diverse range of phytochemicals such as polyphenols, flavonoids, and terpenoids (Li *et al*., 2017). Although these initial studies provide insights into the phytochemical composition of sugarcane juice and its potential health benefits, further research is required for a comprehensive understanding (Sagar *et al*., 2019)

1.6 Medicinal Properties of Sugarcane Juice

Sugarcane juice is relished as a refreshing drink as it is nutritious and rich in vitamins, carbohydrates, and amino acids. The chemical profile of the sugarcane juice indicates the presence of the several phytochemicals. It has been actively used in traditional Ayurvedic medicines. (Arif, Batool *et al*., 2019). Sugarcane contains various bioactivities like anti-inflammatory, analgesic, antihyperglycemic, diuretic, and hepatoprotective effects. (Takara *et al.*, 2002). It has been used to cure jaundice and liver-related disorders in Indian systems of medicine. Its possible mechanism of action was examined in terms of antioxidant availability. Sugarcane juice is also used as an aphrodisiac, laxative, demulcent, antiseptic, and tonic (Singh, A., *et al*., 2015).

The rich content of minerals and vitamins in sugarcane juice helps in supplying instant energy for the quick relief from heat stroke. The ability of sugarcane juice to scavenge free radicals, reduce iron complex and inhibit lipid peroxidation, may explain possible mechanisms by which sugarcane juice exhibits its beneficial effects in relation to its reported health benefits. (Nisha, *et al*., 2017). Natural sugarcane also contains substances called antioxidants. Antioxidants help combat free radicals (molecules that cause damage to cells) that can worsen several medical problems like diabetes, malaria, myocardial infarction, and skin cancer. Sugarcane juice serves as a potent preventive and curative agent for conditions like sore throats, colds, and flu due to its rich nutritional profile (Omar *et al*., 2019).

It boasts a low glycemic index, contributing to overall health and offering swift hydration, especially during prolonged heat exposure and physical exertion (Das *et al*., 2020). Not only does it provide immediate refreshment and energy, but it can also be a healthier alternative to carbonated beverages and cola (Kumar & Singh, 2021). Regular consumption of sugarcane juice

can also promote weight gain, rendering it a viable solution for individuals seeking weight gain (Patel *et al*., 2022).

1.7 Phytochemical Analysis of Local Sugarcane Products

Phytochemical analysis of table sugar, brown sugar, molasses, jaggery can provide valuable insights into their chemical composition and potential health benefits. It's important to note that the phytochemical composition of sugarcane products may vary depending on factors such as cultivar, processing methods, and storage conditions. Phytochemical analysis of different sugarcane products involves the identification and quantification of various bioactive compounds present in these products.

1.8 Characterization Techniques

In the broad field of research, various characterization techniques play a pivotal role in analyzing the properties and composition of different substances. These methods offer profound insights into the structural, physical, and chemical properties of the materials studied. These techniques include Ultraviolet-visible (UV-Vis) Spectrophotometry, Fourier Transform Infrared (FTIR) Spectroscopy, X-Ray Diffraction (XRD), Gas Chromatography-Mass Spectrometry (GC-MS), and various antioxidant activity assays.

1.8.1. UV Spectrophotometer

UV-Vis Spectrophotometry is a widely used analytical technique that allows the quantification of a substance by measuring its absorption of light at different wavelengths. It is used for determining the concentration of a compound in a solution and provides essential information regarding the electronic structure of molecules (Smith & Dent, 2005).

1.8.2. FTIR Spectroscopy

FTIR spectroscopy is another powerful analytical tool for identifying organic, polymeric, and, in some cases, inorganic materials. It can identify chemical compounds based on their characteristic absorption of infrared light, allowing researchers to identify functional groups and the chemical bonds within a sample (Stuart, 2004). FTIR spectroscopy is widely used in fields such as chemistry, biology, physics, and materials science. It is particularly useful in the analysis of polymers, organic compounds, and biomolecules such as proteins and nucleic acids. (Molina-Corte's *et al.,* 2023).

1.8.3. XRD

XRD is a non-destructive technique used primarily for phase identification of a crystalline material and can provide information on unit cell dimensions. It provides vital insights into the structural properties of materials, including atomic arrangement, crystallite size, and possible defects within the structure (Cullity & Stock, 2001). This technique is commonly used to identify and characterize the crystal structure of various materials. XRD analysis can provide valuable information about the structure of a material, which can be used to understand its properties and behavior.

1.8.4. GCMS

GC-MS is a hyphenated technique that combines the separating power of Gas Chromatography (GC) with the detection power of Mass Spectrometry (MS). GC separates the chemical mixture into individual components, while MS identifies and quantifies the compounds. This technique is extremely useful in analyzing complex mixtures, identifying unknown compounds, and tracing impurities (Snyder, Kirkland, & Glajch, 2011).

1.8.5. Antioxidant Activity

Finally, antioxidant activity assays are used to evaluate the ability of a substance to act against oxidation in a biological system. These assays, such as DPPH (1,1-diphenyl-2-picrylhydrazyl), ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), and FRAP (Ferric reducing ability of plasma), measure the ability of an antioxidant to neutralize free radicals or other reactive species. These are critical in evaluating the potential health benefits of various food substances, pharmaceuticals, and natural products (Prior, Wu, & Schaich, 2005). Antioxidant activity refers to the ability of a substance to prevent or reduce damage caused by reactive oxygen species (ROS) or free radicals. ROS are molecules that are produced naturally in the body during normal metabolic processes, but they can also be generated by exposure to external factors such as UV radiation, pollution, and cigarette smoke. Understanding these characterization techniques is crucial in any scientific research as they provide critical data that can be used to understand, interpret, and apply the results obtained in a meaningful way.

Objectives: Keeping in view the processing method of local sugarcane products and nutrient loss, the objectives of present study are designed as follows.

1. To conduct comparative phytochemical screening of local sugarcane products

2. Chemical characterization to determine structures and their functional groups.

3. Formulation of dehydrated sugarcane juice powder and conversion into tablet

CHAPTER 2: LITERATURE REVIEW

Sugarcane (Saccharum officinarum L.) is a key agricultural crop globally due to its pivotal role in the production of sugar and other by-products. Studies on its role in the world's sugar production reveal both its economic significance and the challenges that surround its cultivation and processing. In a global context, sugarcane is the world's largest crop by production quantity, contributing to over 80% of the sugar produced worldwide (Martinelli & Filho, 2016). As Martinelli & Filho (2016) argue, sugarcane's adaptability to various climates and soils and its high sucrose content makes it the most efficient plant for sugar production.

According to a study by (Silva *et al*.,2017) Brazil, India, China, Thailand, and Pakistan are the leading producers of sugarcane and its derived products, primarily sugar. These countries' economies benefit significantly from sugarcane cultivation and sugar production, providing employment opportunities and contributing substantially to their GDPs (Silva *et al*., 2017). However, the global sugar industry faces numerous challenges. Lobo & Leao (2018) note that the sugarcane production process involves intensive labor and land usage, leading to significant social and environmental issues. Such challenges include deforestation, soil degradation, and increased greenhouse gas emissions, which pose significant threats to the sustainability of sugarcane cultivation (Lobo & Leao, 2018).

The prevalence of phytochemicals - naturally occurring chemicals in plants - has become a topic of heightened interest due to their extensive medicinal uses. Such chemicals have proven instrumental in mitigating several diseases, such as asthma, arthritis, and cancer, without presenting side effects, earning them the nickname "human-friendly medicines" (Rajendran, Bharathidasan et al., 2017). One such plant that is rich in these beneficial phytochemicals is sugarcane (*Saccharum officinarum*). Sugarcane and its components, including the roots and stems, have demonstrated medicinal benefits supported by scientific evidence such as anti-cancer, anti-fibrotic, and anti-thrombotic activities (Ali, Yuan et al., 2021). The sugarcane plant's nutritional profile is quite impressive; one liter of sugarcane juice can provide 400 kcal of energy, 100 mg of iron, and sixty μg of carotene (Hithamani *et al*., 2018)

Sugarcane is primarily cultivated for its wide array of sugar products like table sugar, brown sugar, jaggery, molasses, and sugarcane juice (Eggleston, 2018). The phytochemical content in these products varies significantly depending on the degree of processing. For instance, table sugar, due to its extensive refining process, lacks significant phytochemical content. In contrast, jaggery and molasses retain a fair number of phytochemicals due to their minimal processing.

Out of all these products, sugarcane juice is the purest form, containing the highest number of phytochemicals since it is directly extracted from the sugarcane plant (Singh, 2022).

Medicinal plants have become a preferred treatment option in sub-Saharan Africa due to their abundance and cost-effectiveness (Agbor and Ngogang, 2005; Agbor et al., 2005). One such beneficial plant product is jaggery, a natural sweetener derived from sugarcane and/or palm trees. Jaggery is prized for its rich nutrient content, including protein, vitamins, and minerals like iron and copper. Not only is it used in culinary applications, but jaggery is also recognized as an energy food with therapeutic advantages, aiding in blood purification and liver function (Ahmed, 2021). Recent trends have seen the production of organic jaggery, which is free from certain chemicals and has been referred to as 'medicinal sugar' due to its use in pharmaceutical formulations (Hirpara, 2020).

Ahmed (2023) also suggested the importance of jaggery in various health benefits, such as improving digestion, relieving constipation, boosting energy, and purifying the blood. It is also known for its anti-toxic and anti-carcinogenic properties. Despite these benefits, the phytochemicals in jaggery might degrade or modify during the manufacturing process, which could affect its bioactive potential compared to raw sugarcane juice. Sugarcane (*Saccharum officinarum*) is a globally cultivated crop, and its derivatives have wide-ranging applications in the food industry, including table sugar, brown sugar, jaggery, and molasses (Bischoff, 2012). However, the nutritional content of these sugarcane products, particularly regarding their phytochemical profile, may vary significantly due to the processing methods employed.

Bischoff (2012) underlined that processed sugarcane products typically present lower nutrient levels compared to fresh sugarcane. This reduction is attributed to the processing mechanisms which often involve heat and chemical treatments, leading to the breakdown or loss of beneficial compounds. Several studies have shown a significant decrease in the concentration of essential nutrients and phytochemicals, such as phenolic compounds and flavonoids, in processed sugarcane products (Das, *et al.,* 2014). To counter these issues, efforts have been made to devise less invasive processing methods. An example is the use of a food dehydrator to create a direct sugarcane juice powder from freshly extracted juice, aiming to conserve as many nutrients as possible in the final product (Nandhakumar & Indumathi, 2015). Moreover, modern technologies such as vacuum and freeze-drying have been utilized to minimize nutrient loss during processing (Fang & Bhandari, 2016).

However, the evaluation of these new methods necessitates comprehensive analysis of the produced sugarcane products. Techniques such as Fourier-transform infrared spectroscopy (FTIR), gas chromatography-mass spectrometry (GCMS), and X-ray diffraction (XRD) have been employed to determine the chemical composition and structural characteristics of these products (Patel & Patel, 2018). For instance, the FTIR analysis offers spectral patterns that can indicate variations in chemical composition, while GC-MS can provide insights into the volatile components present in the samples (Zhang, *et al.,* 2019).

Sugarcane products, including table sugar (white sugar), brown sugar, jaggery, and molasses, have been integral to diets globally due to their unique tastes and nutritional profiles. These products, although derived from the same raw material, differ significantly in their phytochemical compositions and processing methods, as recent studies reveal. (Ali *et al*.,2018) The phytochemical composition of sugarcane and its byproducts, observing substantial variations in their concentrations of bioactive compounds. Notably, jaggery, an unrefined sugar product popular in South Asia, exhibited higher quantities of phenolics, flavonoids, and minerals, contributing to its distinctive color and taste compared to its refined counterparts (Singh & Solomon, 2016).

Brown sugar, retaining some of the sugarcane's natural molasses, was found to have more minerals such as calcium, potassium, and magnesium than white sugar (Costa et al., 2017). This higher mineral content can be attributed to the less-refined processing brown sugar undergoes, allowing it to retain more of the sugarcane's original phytochemicals (Costa et al., 2017). Molasses, a byproduct of the sugar production process, is a rich source of vitamins, minerals, and antioxidants (Ali, Chong, & Mah, 2018) reported that its composition can vary depending on the number of boiling-crystallization cycles the sugarcane juice undergoes.

Contrarily, table sugar (sucrose), being highly refined, lacks the diverse phytochemical composition found in the other sugarcane products (Jain & Sharma, 2020). The refining process eliminates most of the naturally occurring minerals and vitamins present in the original sugarcane juice, resulting in almost pure sucrose (Jain & Sharma, 2020). (Ahmad *et al*., 2018) used XRD to examine the crystalline structures of these sugarcane products, providing insight into their individual textures and qualities. It was observed that the crystallinity index of table sugar was significantly higher than that of jaggery and brown sugar, which have more amorphous structures due to the presence of impurities and molasses content (Ahmad *et al.*, 2018).

Subsequent studies have made use of FTIR spectroscopy to determine the functional groups present in different sugarcane products. (Rathod and Bhat 2019) identified the presence of hydroxyl, carbonyl, and carbon-oxygen functional groups, which are characteristic of carbohydrate substances in sugarcane derivatives. GC-MS is a powerful tool for the analysis and identification of volatile compounds in complex mixtures. GC-MS was used to detect a wide variety of volatile compounds, such as acetic acid, furfural, and phenols, in molasses, which contribute to its unique flavor and aroma. In contrast, these compounds were absent or found in much lower concentrations in table sugar due to their extensive refinement process (Choudhary *et al*., 2020).

Sugarcane is known to contain various phytochemicals including polyphenols, flavonoids, and triterpenoids, which exhibit antioxidant, anti-inflammatory, and anticancer activities (Severo *et al.*, 2019). Raw sugarcane juice has also been reported to contain significant amounts of minerals like potassium, calcium, magnesium, and iron, while processed sugarcane products such as sugar and jaggery hold residual phytochemicals (Dutta *et al*., 2018).

Sugarcane juice, derived from Saccharum officinarum L., is a popular beverage in tropical and subtropical regions, and has been traditionally used in Indian medicine for the treatment of liver disorders and jaundice. Research has explored its therapeutic effects in relation to its antioxidant capacity. Multiple antioxidant assays, including oxygen radical absorbance capacity (ORAC), 1,1-diphenyl-2-picryl hydrazyl (DPPH), 2,2′-azobis-3-ethyl benzthiazoline-6-sulfonic acid (ABTS), and ferric reducing antioxidant power (FRAP), have been used to determine its antioxidant potential. Furthermore, its ability to protect cellular structures was tested by investigating its influence on lipid peroxidation(Kadam *et al*., 2008) Additionally, quantification of phenolic compounds and total flavonoids present in sugarcane juice was conducted. The water-based extracts from three different sugarcane varieties were examined for their antioxidative properties (Mandal & Mitra 2014).

CHAPTER 3: MATERIALS & METHODS

3.1. Chemicals and Reagents

High-quality reagents of analytical grade, such as acetone, ethanol, hexane, and methanol, were acquired from a reputable chemical vendor associated with the ASAB to serve as solvents for the extraction process.

3.2. Samples

Table sugar, brown sugar, jaggery, molasses and sugarcane juice were obtained from the local market in Islamabad. The granules of different sugarcane products were converted into powder form. Fresh sugarcane juice was dehydrated in the food dehydrator to convert it in powder form.

3.3. Drying Sugarcane Juice without Heating

Drying sugarcane juice without heating can be challenging as it is the heat that helps to evaporate the water content and solidify the juice. However, there are a few methods you can try to dry sugarcane juice without heating. A food dehydrator was used to dry the sugarcane juice. Spread the juice out on a fruit leather tray or a mesh sheet and set the dehydrator to a low temperature. The dehydrator will slowly dry the juice without applying heat. This method is quicker than sun drying and can take a few hours to dry the juice completely.

3.4. Formation of Tablets from Dehydrated Sugarcane Juice Powder

The methodology for the formation of tablets without any binder from dehydrated sugarcane juice powder involves a manual tablet formation process known as dye pressing. This process is designed to produce solid, compact tablets from the powdered sugarcane juice without the need for any additional binding agents. Here's a detailed explanation of the methodology; **Powder Preparation:** The first step involves the preparation of dehydrated sugarcane juice powder. Sugarcane juice is dehydrated to remove moisture, resulting in a dry, fine powder. The powder is then carefully sieved to obtain a uniform particle size, ensuring consistency in tablet formation.

Selection of Dye: A dye is chosen based on the desired tablet size and shape. The dye used in this process will dictate the final appearance of the tablet. The dye is typically made of metal or other sturdy material, shaped as per the tablet design requirements. Powder Filling: A measured quantity of dehydrated sugarcane juice powder is placed into the dye cavity. The powder is evenly spread and lightly compacted to ensure uniform distribution within the dye.

Compression: Once the powder is evenly distributed, the upper punch is brought down onto the powder bed within the dye cavity. This compression process applies pressure to the powder, causing it to compact and adhere to itself. The absence of a binder is compensated for by the inherent stickiness of sugarcane juice powder, which allows the particles to bind together under pressure.

Ejection: After sufficient compression, the upper punch is lifted, and the tablet is ejected from the dye cavity. The ejection is facilitated by the release of pressure, allowing the solid tablet to retain its shape. By using the manual tablet formation process of dye pressing, tablets are successfully created from dehydrated sugarcane juice powder without the need for any additional binders. The method is simple, cost-effective, and results in tablets with potential health benefits attributed to the natural antioxidant properties of sugarcane juice.

Quality Control: The formed tablets are subjected to quality control checks, including weight, thickness, hardness, and friability tests, to ensure that they meet the required standards for storage and consumption.

3.5. Mechanical Strength of Tablet

The statement indicates the mechanical strength measurement of dehydrated sugarcane juice tablets. Three key parameters were determined: stress, strain percentage, and tensile strength, with the following values: Stress: Stress is a measure of the internal force experienced by a material per unit area. In this case, the stress of the dehydrated sugarcane juice tablet was found to be78.44%. It implies that the tablet can withstand an internal force equivalent to 78.44% of its cross-sectional area without breaking or undergoing significant deformation.

Strain Percentage: Strain percentage refers to the amount of deformation experienced by a material when subjected to stress. The value of 78.44% suggests that the dehydrated sugarcane juice tablet undergoes a significant 78.44% deformation or elongation when subjected to the applied stress. This indicates the tablet's ability to withstand a certain level of deformation before breaking. Tensile Strength: Tensile strength is a measure of a material's ability to resist breaking under tensile or pulling forces.

3.6. Dimensions of Tablet from Vernier Caliper

The diameter of the tablet was found to be 12.2 mm and height is 6.2 mm height.

Figure 3.1: Universal hardness testing machine

3.8. Phytochemical Analysis

3.8.1. Alkaloid's test

Alkaloids are a class of naturally occurring chemical compounds that are commonly found in various plant sources, including sugarcane and related products such as table sugar, jaggery, molasses, brown sugar, and sugarcane juice . Phytochemical analysis is a commonly employed method to detect and identify secondary metabolites in plant materials. Here is a brief description of the alkaloid detection process through phytochemical analysis:

Sample Preparation: The first step is to prepare the samples for analysis. Sugarcane products, such as jaggery, molasses, sugarcane juice, or brown sugar, are usually dried and powdered to facilitate extraction of alkaloids.

Extraction: The powdered samples are then subjected to extraction with a suitable solvent, such as methanol, ethanol, n-hexane, and acetone. This process helps to extract alkaloids from the plant matrix into the solvent.

Filtration and Concentration: After extraction, the solvent is separated from the solid residue using filtration. The resulting filtrate, which contains the extracted alkaloids, is then concentrated under reduced pressure to obtain a more concentrated extract.

Phytochemical Tests: The concentrated extract is subjected to a series of phytochemical tests to detect the presence of alkaloids. These tests are based on the characteristic reactions of

alkaloids with specific reagents and can help identify the presence of alkaloids in the extract. Commonly employed tests include Mayer's test, Wagner's test, and Hager's test.

3.8.2. Saponins Test (Froth test)

Saponin test was performed as follows.

a. Take a small volume of the filtered extract (e.g., 2 mL) in a test tube.

b. Add water to the test tube, leaving some headspace.

c. Shake the test tube vigorously for a few minutes.

d. Observe the formation of persistent froth or foam, which indicates the presence of saponins.

3.8.3. Phenols Test

Perform various phytochemical tests to detect the presence of phenols in the extracted solution. In Ferric Chloride Test few drops of a dilute solution of ferric chloride were added to the extracted sample.

3.8.4. Flavonoid

Flavonoids are a class of natural compounds found in plants that possess various health benefits and contribute to their color, taste, and antioxidant properties. Perform preliminary qualitative tests to confirm the presence of flavonoids. These tests may include color reactions, such as the formation of a yellow color with aluminum chloride or a green color with magnesium and hydrochloric acid. These tests provide a quick indication of flavonoid presence.

3.8.5. Reducing Sugar

Reducing sugars is a type of carbohydrate that can reduce certain chemicals, such as Fehling's solution or Benedict's solution. The qualitative tests confirm the presence of reducing sugars. The most common tests used are the Fehling's test and Benedict's test. These tests involve mixing the sample extract with the respective reagent and heating the mixture.

Table 3.1: A brief description of targeted metabolites, underlined principle, and anticipated results of each test performed in the study.

Sr No.	**Secondary Metabolites**	**Test Name**	**Procedures**	**Observations**
1	Alkaloids	Hager's Test	2ml extract + Few drops Hager's reagent	Yellow precipitate
2	Phenols	Phenol test	1ml extract + Few drops $FeCl_3$	Bluish Black color
3	Protein	Xanthoproteic Test	1ml extract + 1ml CH_2SO_4	White precipitate turned Yellow on boiling
4	Amino acids	Ninhydrin Test	1ml extract + Few drops Ninhydrine	Violet color
5	Reducing Sugars	Benedicts Test	1ml extract + Few drops Benedict's reagent + Δ (Water bath)	Reddish brown precipitate
6	Carbohydrates	Fehling's Test	2ml extract + 1 ml of Fehling's solution A and B + Heat	Red precipitate
7	Sterols	Salkowski's Test	1ml extract + Few drops of CH_2SO_4+ Shake	Red color appears at the lower layer
8	Saponins	Foam Test	5mlextract+ 5ml H_2O + Δ	Froth appearance

3.9. Qualitative Analysis Through Characterization Techniques

3.9.1. Fourier Transform Infrared Spectroscopy

FTIR is a powerful analytical technique used to identify and characterize chemical compounds based on their absorption of infrared radiation.

Sample Preparation for FTIR Analysis of Sugarcane Products

Obtain representative samples of the sugarcane products, such as table sugar, brown sugar, jaggery, molasses, and sugarcane juice. Grind the solid samples (table sugar, brown sugar, jaggery) into a fine powder using a mortar and pestle to ensure homogeneity. If necessary, dry

the samples in an oven to remove any moisture content. For sugarcane juice and molasses, filter the samples to remove any insoluble particles or impurities. If needed, centrifuge the samples to separate any suspended solids from the liquid portion. Place a small amount of the powdered samples or a drop of the filtered juice/molasses onto an infrared-transparent material, such as a potassium bromide (KBr) pellet. Spread the sample evenly to obtain a thin and uniform layer.

Instrument Setup for FTIR Analysis of Sugarcane Products

Ensure the Cary 630 FTIR is properly calibrated and functions according to the manufacturer's instructions. Select the appropriate measurement mode (transmission, attenuated total reflectance, or diffuse reflectance) based on the sample and the available accessories. Set the spectral range and resolution suitable for the analysis of organic compounds typically found in sugarcane products (e.g., 4000-400 cm-1 range with a resolution of 4 cm-1). Place the prepared sample on the sample stage and it gives the spectra of that product.

3.9.2. UV Spectrophotometer

Sample Preparation for UV-Vis Analysis of Sugarcane Products

Start by extracting the desired components from the sugarcane product. For example, if you are interested in analyzing the antioxidant activity, you may extract the antioxidants using a suitable solvent such as ethanol or water. The extraction method can vary depending on the specific compounds of interest. Once the extraction is complete, filter the sample to remove any solid particles or impurities that could interfere with the UV-Vis analysis. This step ensures a clear and homogeneous solution for measurement. Depending on the concentration of the extracted components, you may need to dilute the sample to bring it within the linear range of the UV-Vis spectrophotometer. This is important to obtain accurate and reliable absorbance readings.

Instrument Setup for UV-Vis Analysis of Sugarcane Products

Use a UV-Vis spectral-photometers-SPECORD Plus, which consists of a light source (typically a tungsten-halogen lamp or deuterium lamp), a monochromator to select specific wavelengths, a sample compartment, and a detector. The instrument should be properly calibrated and set to the desired measurement parameters. Choose the appropriate wavelength range for analysis based on the absorption characteristics of the compounds of interest. Sugarcane products typically exhibit absorption in the ultraviolet (UV) and visible (Vis) regions, so select the wavelength accordingly. Perform baseline correction using a suitable reference material or the solvent used for sample extraction. This step helps to compensate for any background

absorption or interference from the solvent. Fill the sample into a cuvette or a suitable transparent container. Place the cuvette in the sample compartment of the UV-Vis spectrophotometer, ensuring that the light beam passes through the sample uniformly. Measure the absorbance of the sample at the selected wavelength.

3.9.3. XRD

Sample Preparation for X-ray Diffraction (XRD) Analysis of Sugarcane Products

Start by grinding the sugarcane product sample to a fine powder. This step helps to ensure a homogeneous and uniform sample for analysis. If the sugarcane product contains a high moisture content, it may be necessary to dry the sample before the XRD analysis. This can be achieved by placing the sample in an oven at a low temperature or using a desiccator to remove moisture. In some cases, it may be beneficial to reduce the particle size of the sugarcane product sample further. This can be accomplished using techniques such as ball milling or mortar and pestle grinding to obtain a finer powder. The prepared sugarcane sample can be placed in a sample holder or mounted on a sample stage. The sample should be spread evenly and packed tightly to ensure a consistent XRD signal. After preparing the samples for XRD analysis, I submitted them to the SNS department for further analysis.

3.9.4. GCMS Analysis of Sugarcane Products

GC-MS analysis can be used to identify and quantify the various components of sugarcane products, such as juice, molasses, and ethanol. For example, in the analysis of sugarcane juice, the sample is first extracted and then derived to convert the various sugars and other components into volatile compounds that can be separated and identified by GC-MS. The resulting chromatogram will show peaks corresponding to the different sugars and other components, which can be identified by comparing their retention times and mass spectra to those of known standards or databases.

Instrument Setup

Gas Chromatograph (GC)

Shimadzu GCMS-QP-2020 was used for GCMS analysis. The GC portion of the system is where the separation of the compounds occurs. The sample is injected into the instrument, where it is volatilized and carried by an inert gas (usually helium) through a column. The choice of column will depend on the specific compounds you're analyzing.

Mass Spectrometer (MS)

After separation in the GC, the compounds enter the mass spectrometer, where they are ionized and fragmented. The fragments are then separated based on their mass-to-charge ratio (m/z). The type of ionization method used (commonly electron impact or chemical ionization) will depend on the compounds.

3.9.5. Antioxidant activity

The antioxidant activity of sugarcane juice can be determined by using the 1,1-diphenyl-2-picryl hydrazyl (DPPH) assay, which is a common method to evaluate the free radical scavenging potential of various substances (Brand-Williams, Cuvelier, & Berset, 1995).

Sample Preparation

The first step is to extract the antioxidants from the sugarcane products. This typically involves grinding the product to a fine powder, then extracting the bioactive compounds with a solvent such as ethanol or methanol. The sample is then filtered, and the solvent is removed through evaporation, leaving behind a concentrated extract of the antioxidant compounds. DPPH Solution Preparation: a. Prepare a 0.1 mM DPPH solution by dissolving the DPPH reagent in a suitable solvent, such as methanol or ethanol. The solution should be prepared fresh before each experiment.

Assay Procedure

1. Take 1 ml of the diluted sugarcane sample in a clean test tube.

2. Add 2 ml of the prepared DPPH solution to the test tube containing the sample. This will result in a final volume of 3 ml.

3. Mix the contents of the test tube thoroughly using a vortex mixer or by gently inverting the tube several times.

4. Incubate the test tube in a dark place at room temperature for 30 minutes. During this time, the DPPH radicals will react with the antioxidants present in the sugarcane sample, leading to a reduction in the purple color of the DPPH solution.

5. Prepare a control sample by replacing the sugarcane sample with the same volume of the solvent used for dilution (e.g., methanol or ethanol).

6. After 30 minutes, measure the absorbance of the sample and the control at the appropriate wavelength (usually around 517 nm) using a spectrophotometer. The decrease in absorbance of the sample compared to the control indicates the scavenging activity of the sugarcane sample against DPPH radicals.

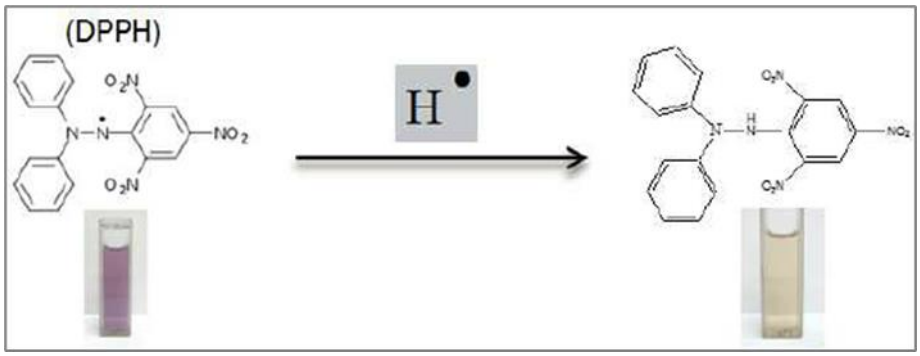

Figure 3.2: A solution of DPPH is mixed with the test substance. If the substance is an antioxidant, it will donate an electron to DPPH, which changes its color from purple to yellow. The change in absorbance measured by spectrophotometry is then used to calculate the antioxidant capacity of the test substance.

CHAPTER 4: RESULTS

4.1. Sample Collection

Figure 4.1: These are the local sugarcane products used in comparative phytochemical analysis and characterization (table sugar, jaggery, brown sugar and molasses)

4.2. Drying Sugarcane Juice without Heating

Drying sugarcane juice without heating can be challenging as it is the heat that helps to evaporate the water content and solidify the juice. However, there are a few methods you can try to dry sugarcane juice without heating. A food dehydrator was used to dry the sugarcane juice. Spread the juice out on a fruit leather tray or a mesh sheet and set the dehydrator to a low temperature. The dehydrator will slowly dry the juice without applying heat. This method is quicker than sun drying and can take a few hours to dry the juice completely.

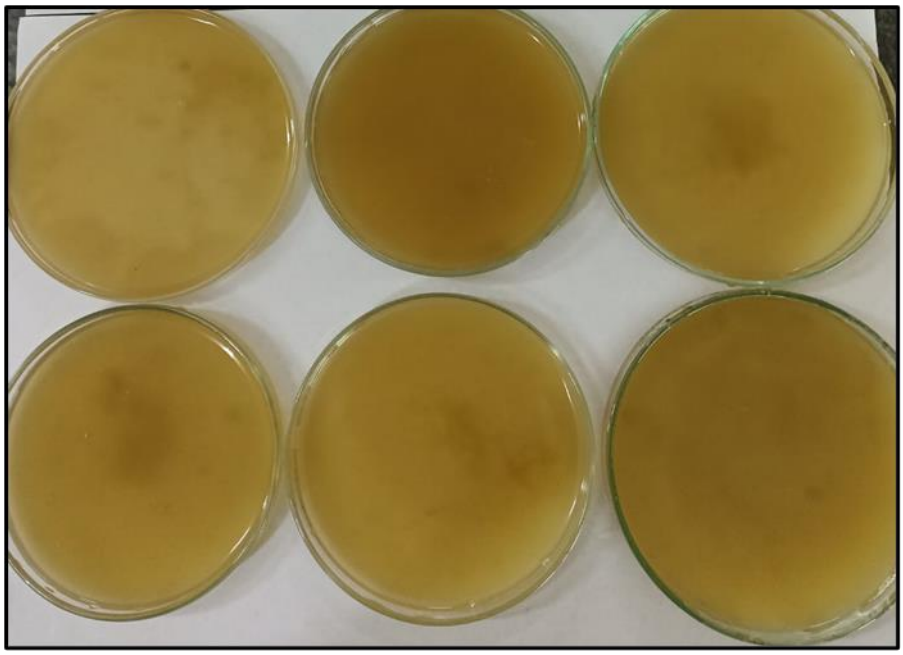

Figure 4.2: Petri plates in which freshly extracted sugarcane juice was poured for drying in food dehydrator.

Figure 4.3: The food dehydrator in which freshly extracted sugarcane juice is dried.

4.3. Conversion of Powder into Tablet Form

By using the manual tablet formation process of dye pressing, tablets are successfully created from dehydrated sugarcane juice powder without the need for any additional binders. The

method is simple, cost-effective, and results in tablets with potential health benefits attributed to the natural antioxidant properties of sugarcane juice.

Figure 4.4: Dehydrated sugarcane juice powder (i-sugar)

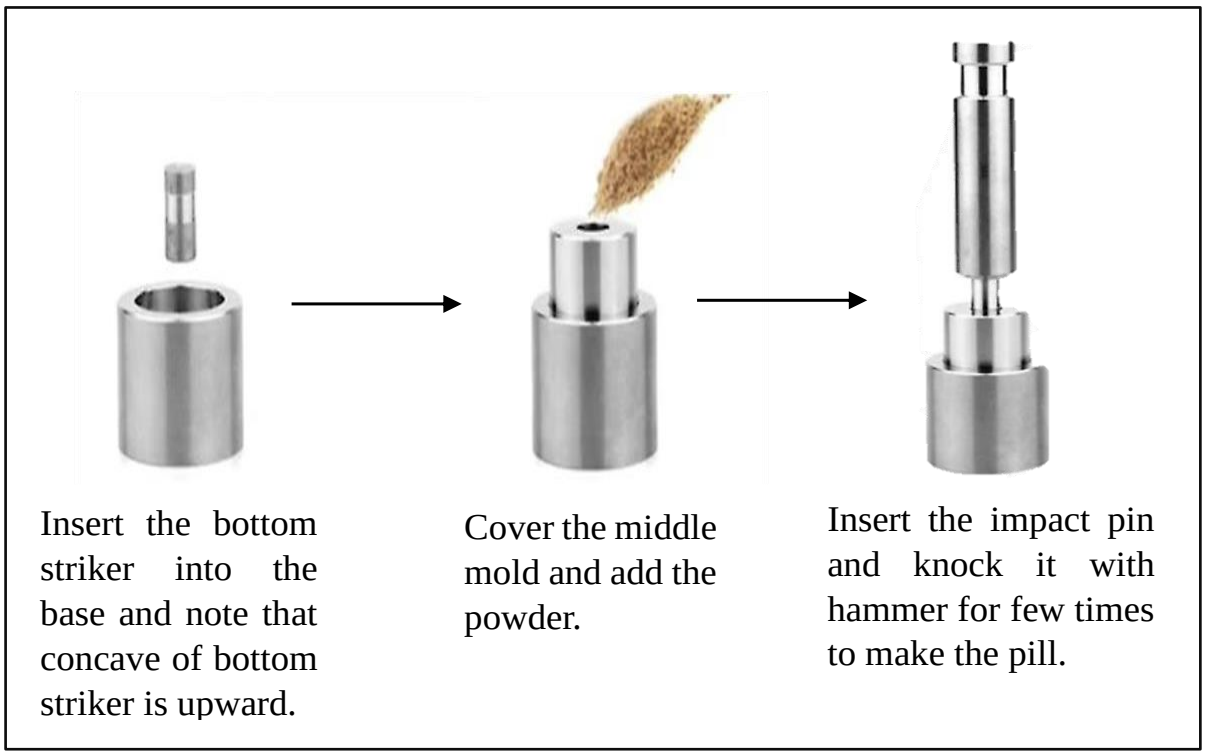

Figure 4.5: Schematic process of i-sugar formation

Figure 4.6: Dehydrated sugarcane juice tablets (i-sugar)

4.4. Mechanical Strength of i-sugar

The value of 78.44% might represent the tensile strength of the tablet, which means that the tablet can withstand a tensile force equivalent to 78.44% of its breaking strength before fracturing. Overall, these measurements provide valuable insights into the mechanical behavior and strength characteristics of the dehydrated sugarcane juice tablet. It suggests that the tablet has a significant capacity to withstand internal forces and deformation, which can be essential for its structural integrity during handling, storage, and consumption.

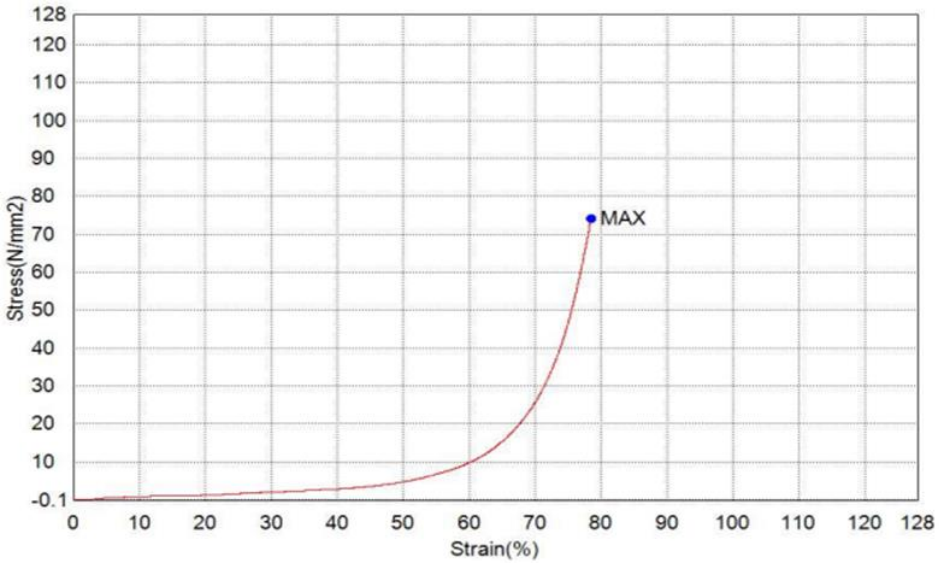

Figure 4.7: Mechanical stress/strain graph of i-sugar

4.5. Phytochemical Analysis of Local Sugarcane Products and i-Sugar

4.5.1. Alkaloid Test

Hager's reagent revealed the presence of alkaloids in table sugar, brown sugar, jaggery, molasses, and sugarcane juice. The presence of alkaloids provides valuable insights into the composition of these sugarcane-derived products and highlights the presence of alkaloids, which may have potential implications for their nutritional or medicinal property.

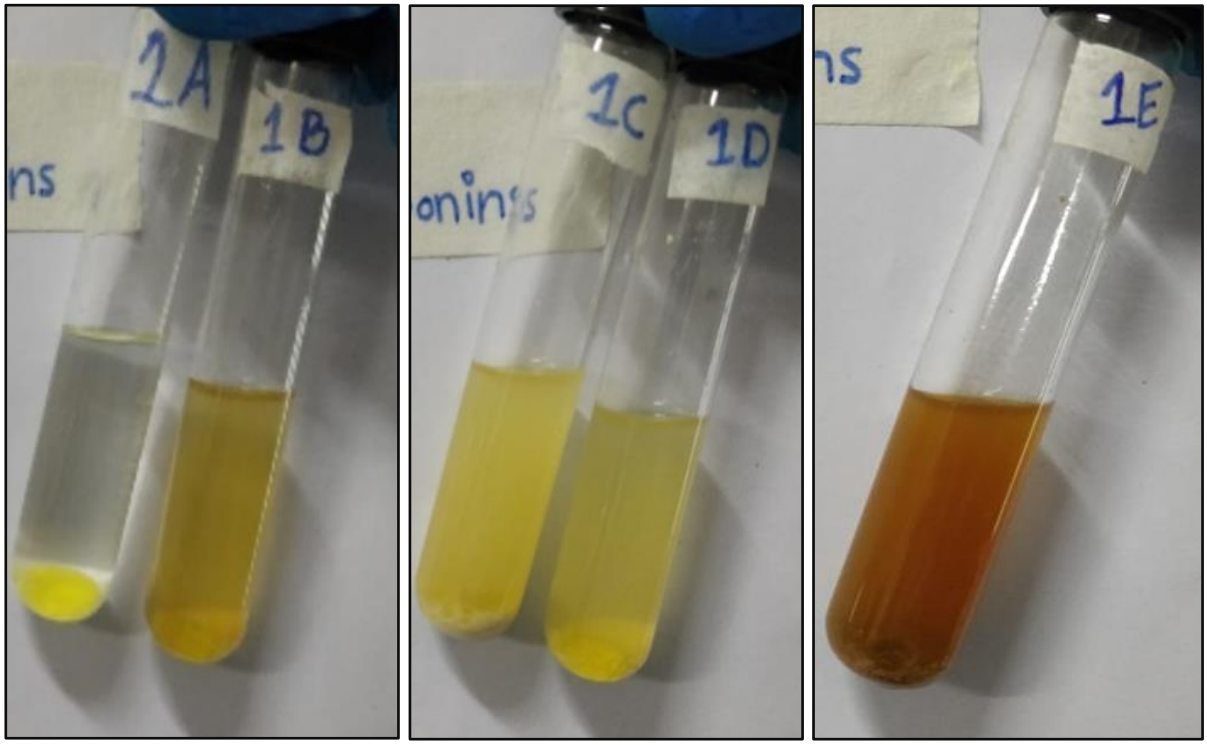

Figure 4.8: The presence of alkaloids in various sugarcane products. Including table sugar, brown sugar, jaggery, molasses, and dehydrated sugarcane juice powder, was investigated. Figure **1A** depicts the dissolution of table sugar in a solution of Hager's reagent and methanol, while **1B** shows a similar process for brown sugar. Figure **1C** represents the dissolution of jaggery in a mixture of Hager's reagent and methanol, **1D** demonstrates molasses and **1E** illustrates the same for dehydrated sugarcane juice powder. The varying degrees of color change in these solutions demonstrate the varying intensities of alkaloid presence in these sugarcane-based products.

4.5.2. Benedict's Test

The samples of table sugar, brown sugar, jaggery, molasses, and sugarcane juice were collected and subjected to rigorous testing. A comprehensive examination of the presence of reducing sugars was carried out using established analytical methods.

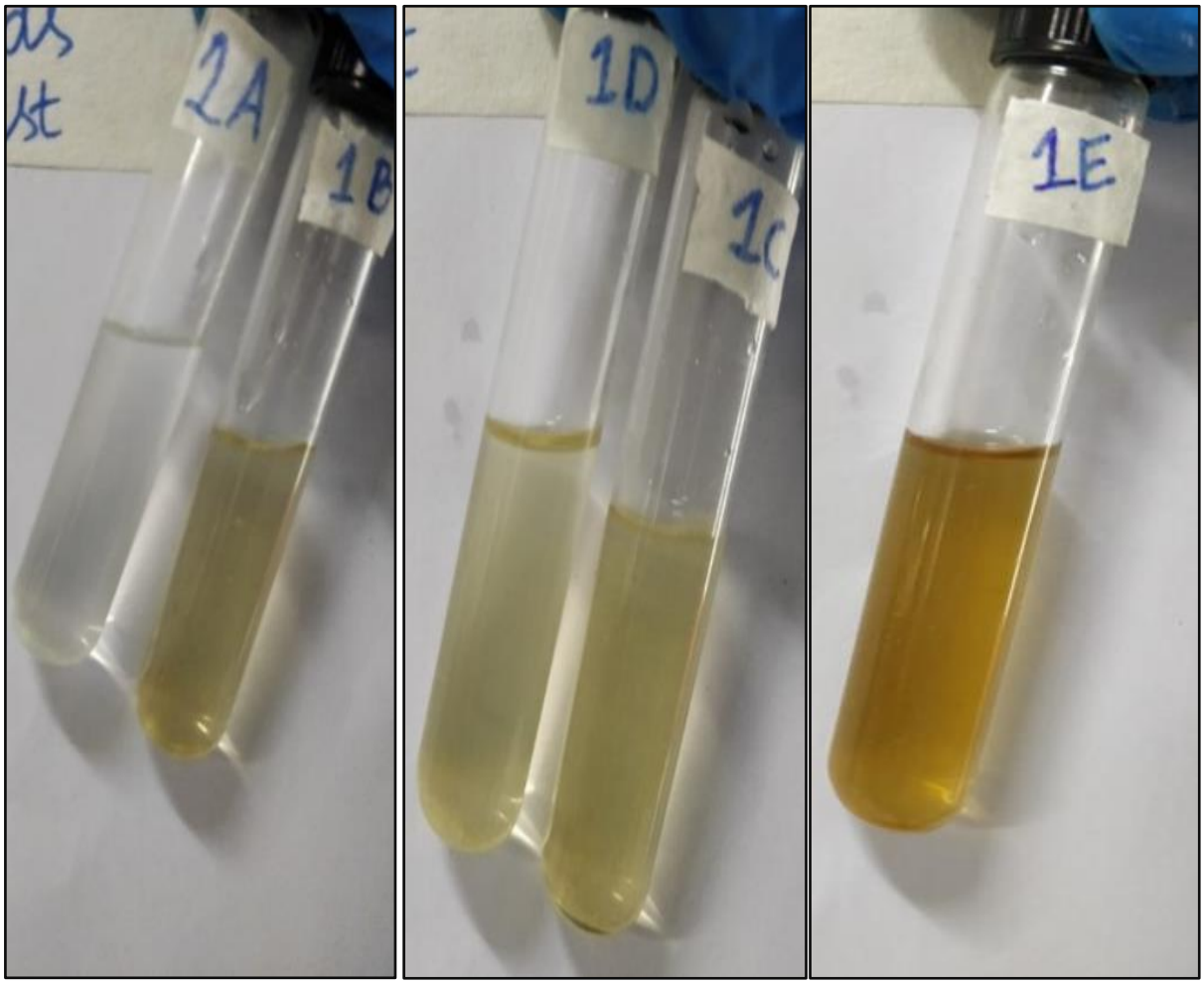

Figure 4.9: Detection of reducing sugars in sugarcane products. Benedict's test was conducted to determine the presence of reducing sugars in various samples. The test tubes were prepared by dissolving the samples in methanol and adding Benedict's reagent. Tube **1A** contained table sugar dissolved in methanol with Benedict's reagent. Tube **1B** contained brown sugar. Tube **1C** contained jaggery, tube **1D** contained molasses, and tube **1E** contained dehydrated sugarcane juice powder, all mixed with methanol and Benedict's reagent. The change in color shows the presence of reducing sugars in table sugar, brown sugar, jaggery, molasses and dehydrated sugarcane juice powder.

4.5.3. Detection of Flavonoids

The phytochemical analysis revealed variations in flavonoid content among different sugarcane products, with unrefined forms such as jaggery and sugarcane juice containing higher levels of these beneficial compounds. Sugarcane juice, obtained directly from the sugarcane plant, exhibited the highest concentration of flavonoids among the tested samples.

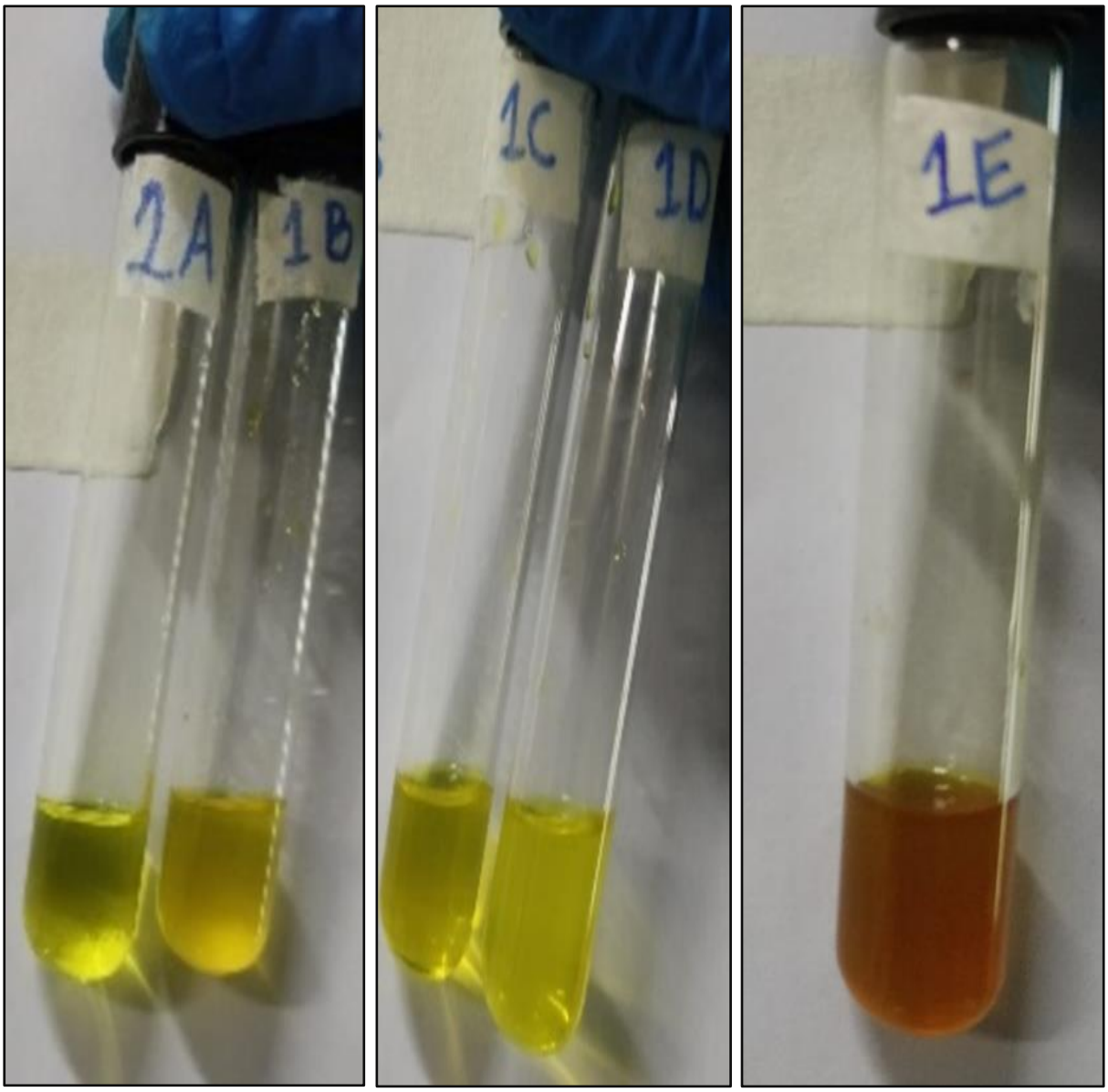

Figure 4.10: To detect flavonoids in sugarcane products, a method was employed using lead acetate in solutions containing methanol as a solvent and sugarcane products as solutes. Five different samples were analyzed: **1A** contained table sugar, **1B** contained brown sugar, **1C** contained jaggery, **1D** contained molasses, and **1E** contained dehydrated sugarcane juice powder. It is important to note that the concentration of flavonoids can vary in sugarcane products. The study aimed to determine the presence and number of flavonoids in each sample, providing insights into the flavonoid content of different sugarcane-based products.

4.5.4. Detection of Phenols

Phytochemical analysis is a valuable method for identifying and quantifying bioactive compounds present in plant-based materials. In this study, it was employed to investigate the presence and levels of phenolic compounds in different sugarcane products.

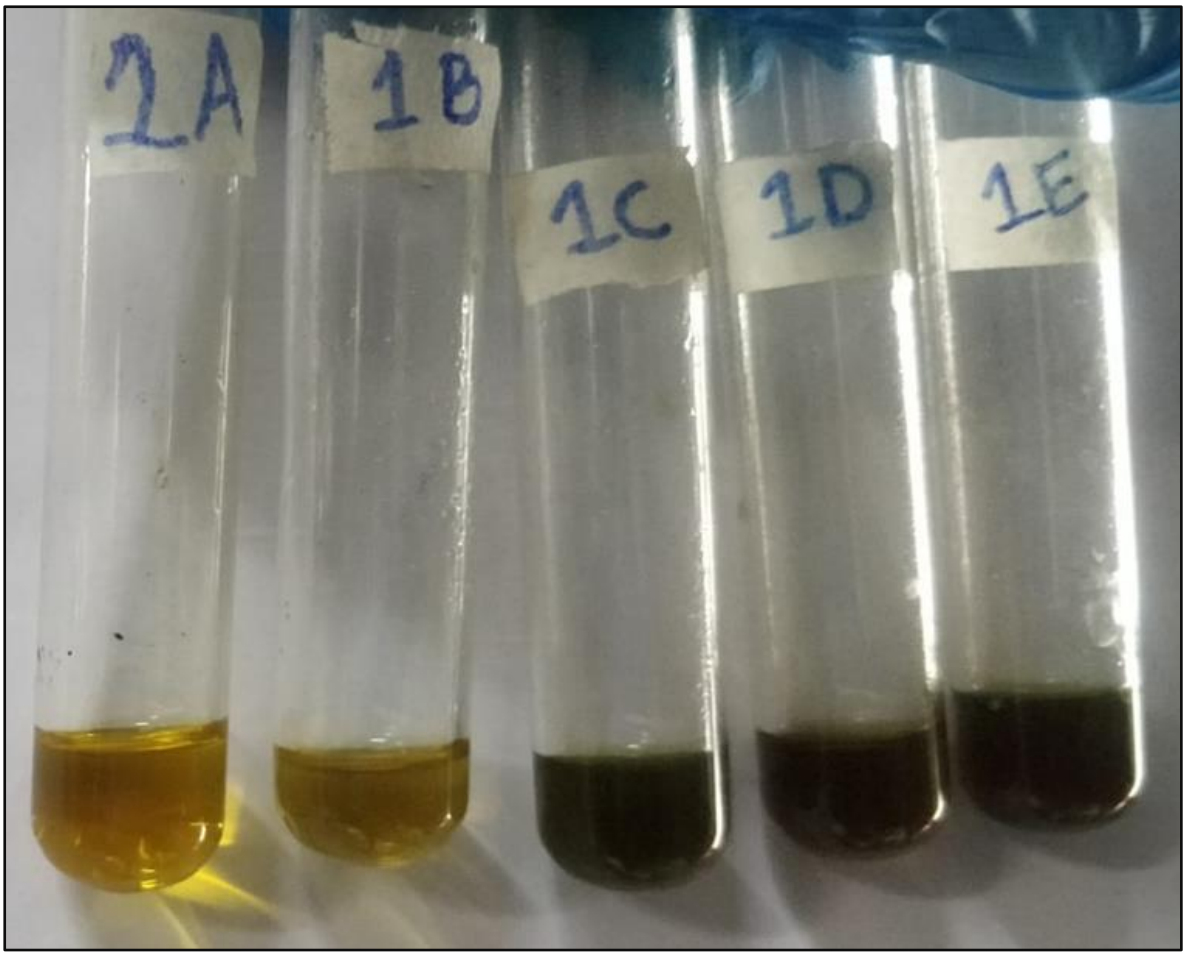

Figure 4.11: Phenols detection in sugarcane products. The test tubes in this experiment are labeled as follows: '1' denotes methanol, while **'A', 'B', 'C', 'D'**, and 'E' stand for table sugar, brown sugar, jaggery, molasses, and dehydrated sugarcane juice, respectively. A few drops of iron chloride were added to each tube to detect the presence of phenols. The variations in color changes clearly suggest that different sugarcane products contain differing concentrations of phenols.

4.6. Phytochemical Profile of each Sample

Results for phytochemical testing were not consistent in each sample. Each sample gave a variable phytochemical output, which is a clear indication of variable variation in the secondary metabolite profile of respective samples. Secondary metabolites are directly linked with the nutritional content of sample. Thus, these results clearly indicate the nutrient deficiency present in all available, and commonly consumed sugarcane products. On the other hand, i-sugar showed the presence of several beneficial phytochemicals, having a fundamental health benefit, and medicinal properties. Phytochemical profiles, based upon phytochemical testing, for each sample are tabulated in the later section.

Brown Sugar

Table 4.1: Conformation tests for secondary metabolites present in brown sugar by dissolving in water, ethanol, acetone, n-hexane, and methanol.

Sr No.	Phytochemical tests	Water	Ethanol	Acetone	n-hexane	Methanol
`1	Hager's test (A)	+	+	+	-	+
2	Wagner's test	+	+	+	-	+
3	Carbohydrate test	+	+	-	+	+
4	Test for phenol	-	-	-	-	-
5	Foam test(saponins)	+	+	-	-	-
6	Emulsion test(saponins)	+	+	-	-	+
7	Glycosides	+	+	+	-	+
8	Protein test	-	-	-	-	-
9	Benedict test (reducing sugar)	+	+	+	+	+
10	Ninhydrin	+	+	+	-	+

Table Sugar

Table 4.2: Conformation tests for secondary metabolites present in table sugar by dissolving in water, ethanol, acetone, n-hexane, and methanol.

Sr No.	Phytochemical tests	Water	Ethanol	Acetone	n-hexane	Methanol
1	Hager's test (A)	+	+	+	-	+
2	Wagner's test	+	+	+	-	+
3	Carbohydrate test	+	+	-	+	+
4	Test for phenol	-	-	-	-	-
5	Foam test(saponins)	+	+	-	-	+
6	Emulsion test(saponins)	+	+	-	+	+
7	Glycosides	+	+	+	-	+
8	Protein test	-	-	-	-	-
9	Benedict test (reducing sugar)	+	+	+	-	+
10	Ninhydrin	+	+	-	+	+

Molasses

Table 4.3: Conformation tests for secondary metabolites present in molasses by dissolving in water, ethanol, acetone, n-hexane, and methanol.

Sr No.	Phytochemical tests	Water	Ethanol	Acetone	n-hexane	Methanol
1	Hager's test (A)	+	+	+	-	+
2	Wagner's test	+	+	+	-	+
3	Carbohydrate test	+	+	-	+	+
4	Test for phenol	-	-	-	-	-
5	Foam test(saponins)	+	+	-	-	+
6	Emulsion test(saponins)	+	+	-	+	+
7	Glycosides	+	+	+	-	+
8	Protein test	-	-	-	-	-
9	Benedict test (reducing sugar)	+	+	+	+	+
10	Ninhydrin	+	+	-	-	+

Jaggery

Table 4.4: Conformation tests for secondary metabolites present in jaggery by dissolving in water, ethanol, acetone, n-hexane, and methanol.

Sr No.	Phytochemical tests	Water	Ethanol	Acetone	hexane	Methanol
1	Hager's test (A)	+	+	+	-	+
2	Wagner's test	+	+	+	-	+
3	Carbohydrate test	+	+	-	+	+
4	Test for phenol	-	-	-	-	-
5	Foam test(saponins)	+	+	-	-	+
6	Emulsion test(saponins)	+	+	-	-	+
7	Glycosides	+	+	+	-	+
8	Protein test	-	-	-	-	-
9	Benedict test (reducing sugar)	+	+	+	+	+
10	Ninhydrin	+	+	-	+	-

i-sugar

Table 4.5: Conformation tests for secondary metabolites present in sugarcane juice by dissolving in water, ethanol, acetone, and methanol.

Sr No.	Phytochemical tests	Water	Ethanol	Acetone	Methanol
1	Hager's test (A)	+	+	+	+
2	Wagner's test	+	+	-	+
3	Carbohydrate test	+	+	+	+
4	Test for phenol	-	+	-	+
5	Foam test(saponins)	+	-	-	+
6	Glycosides	+	+	+	+
7	Protein test	+	-	-	-
8	Benedict test	+	+	+	+
9	Ninhydrin	+	-	-	+

4.7. Antioxidant Activity of i-sugar

Antioxidants are substances that can prevent or slow damage to cells caused by free radicals, unstable molecules that the body produces as a reaction to environmental and other pressures. Free radicals are thought to play a role in various health conditions, including cancer, cardiovascular diseases, and age-related diseases. Thus, the antioxidant activity of various substances, like your sugarcane juice powder, is often assessed. The standard and the sample (sugarcane juice powder) are likely tested for their ability to inhibit a particular reaction (usually oxidation) that's initiated in a controlled way. The values for the sample and standard indicate their relative effectiveness in preventing this reaction compared to the control value. The control

value is presumably the level of this reaction that occurs without any antioxidant present (i.e., no inhibition). The % inhibition calculated is a measure of the antioxidant capacity of samples, the higher the percentage, the stronger the antioxidant activity, because a greater portion of the reaction is being prevented.

Calculated the percentage of DPPH inhibition activity using the following formula:

%inhibition=[(Absorbance_control-Absorbance_sample)/Absorbance_control] x 100

% inhibition values of Standard: 41.82%, 43.66%, 44.97%, 52.35%, 52.58% these are the % inhibition values ascorbic acid calculated from above formula with different concentrations.

% inhibition values of Sample (i-sugar): 7.68%, 14.94%, 20.48%, 28.49%, 31.16% these are the % inhibition values of sample calculated from above formula with different concentrations. These values suggest that the standard has a higher antioxidant activity compared to the sugarcane juice powder, as it inhibits a higher percentage of the reaction. For example, in the first instance, the standard inhibits 41.82% of the reaction, while the sugarcane juice powder inhibits 7.68%.

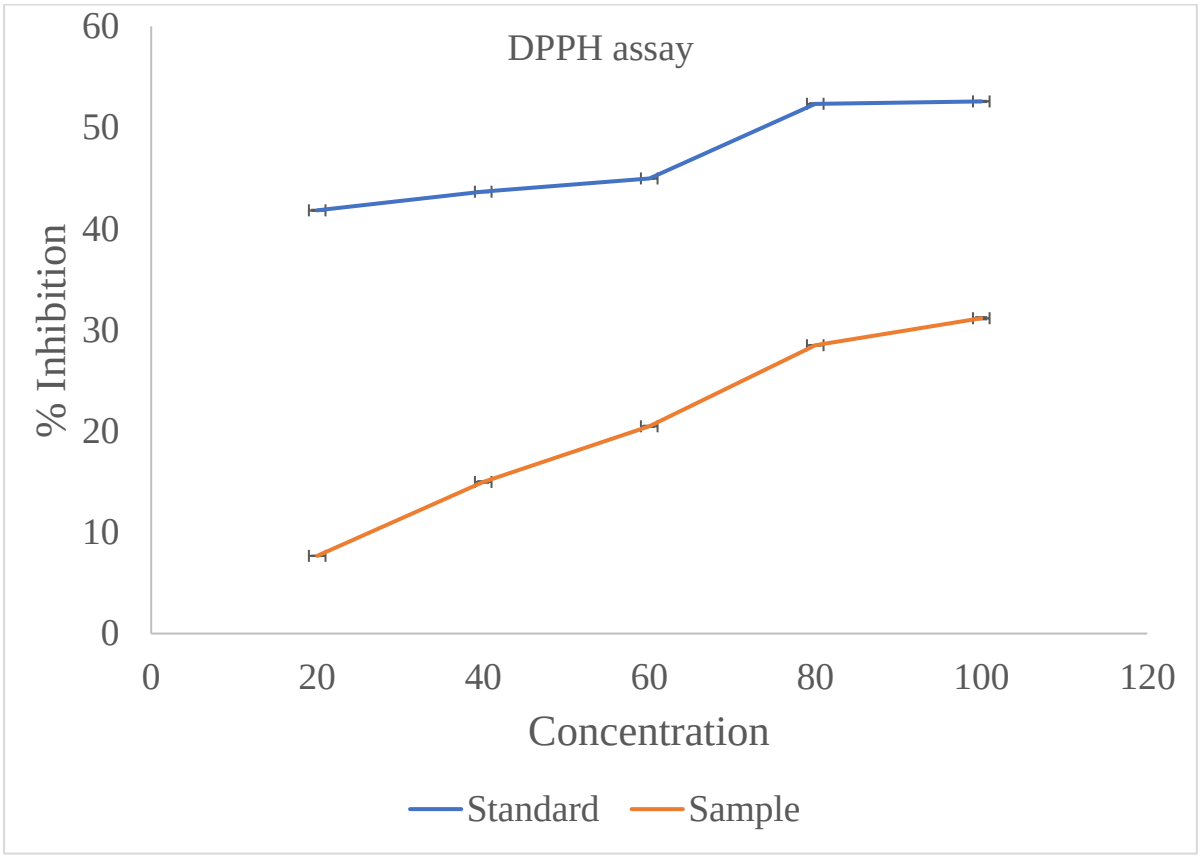

Figure 4.12: This graph is plot between Concentration and %inhibition value of standard that is ascorbic acid and sample is i-sugar. This graph shows the increasing antioxidant value of sample and standard.

4.7.1. Visual Representation of Antioxidant Activity of Table Sugar And i-sugar

On the other hand, the dehydrated sugarcane juice powder showing the disappearance of DPPH color signifies potent antioxidant activity. Sugarcane juice contains natural antioxidants, such as phenolic compounds, flavonoids, and vitamins, which contribute to its ability to neutralize free radicals and reduce the DPPH radical in the assay. The dehydration process may have concentrated these antioxidant compounds, further enhancing the powder's ability to scavenge DPPH radicals. These findings suggest that dehydrated sugarcane juice powder could be a promising natural source of antioxidants and may find potential applications in the food and nutraceutical industries.

Comparing the antioxidant activity of table sugar and dehydrated sugarcane juice powder using the DPPH assay is intriguing. The DPPH assay is a widely used method to assess the antioxidant capacity of various compounds and is based on the principle of color change due to the reduction of DPPH radicals by antioxidants. The absence of color change in the table sugar sample indicates that it possesses minimal or negligible antioxidant activity. Table sugar (sucrose) is a simple carbohydrate composed of glucose and fructose molecules and does not contain significant amounts of antioxidant compounds.

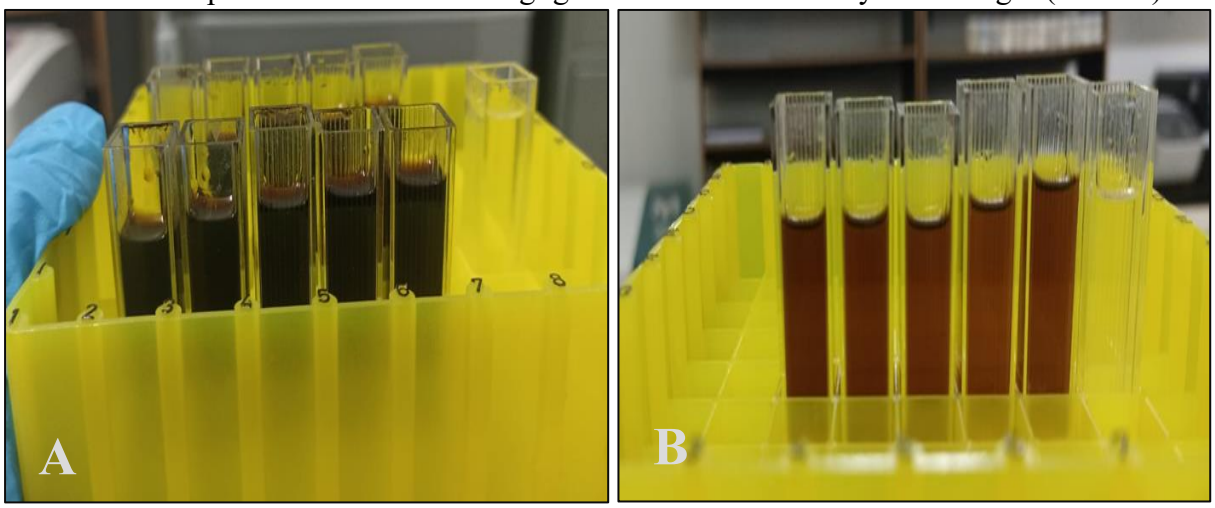

Figure 4.13: Antioxidant activity of **(A)** table sugar, **(B)** brown sugar using the DPPH assay. Five different concentrations of both samples were prepared and dissolved in the DPPH solution. However, upon visual inspection, it was observed that there was no noticeable color change in the solutions, indicating that table sugar did not exhibit significant antioxidant activity, but i-sugar shows significant color change indicating antioxidant activity of i-sugar.

4.8. UV Spectrophotometer of Sugarcane Solutes Dissolved in Water

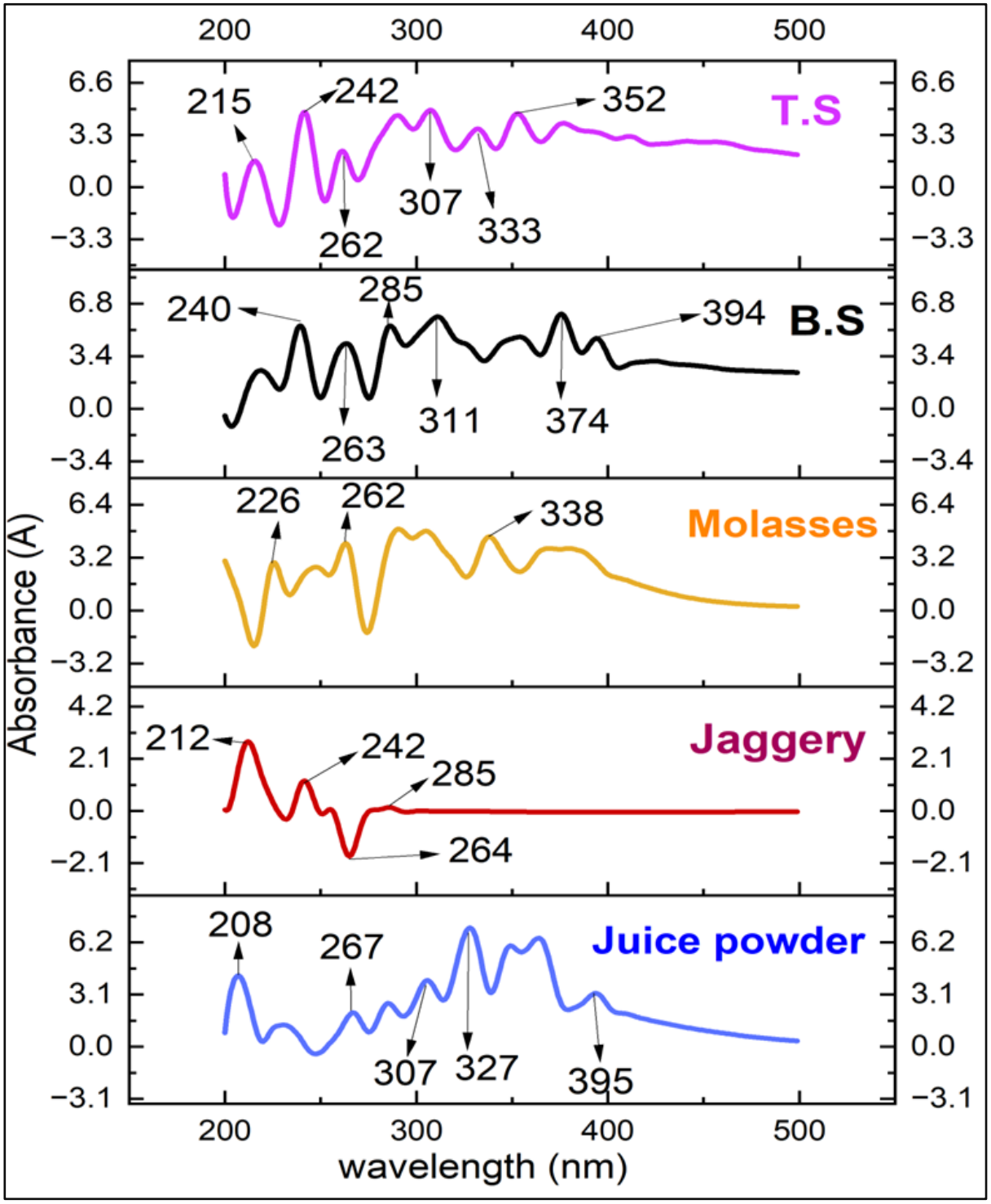

Figure 4.14: UV Spectrophotometer of sugarcane products dissolved in water. The UV spectra displayed in the graph consist of five different colored lines, each representing a specific sample. Starting from the bottom, the blue line represents the UV spectrum of dehydrated sugarcane juice powder(i-sugar). Above that, the red line corresponds to the spectrum of jaggery. The orange line represents the UV spectrum of molasses. Moving further up, the black line indicates the UV spectrum of brown sugar, and at the top, the purple line illustrates the UV spectrum of table sugar.

4.8.1. Absorption Peaks of Phytochemicals at Specific Wavelength

The specific absorption peaks and intensities can vary based on the composition of the samples, the extraction methods used, and the specific compounds present in each sugarcane product. The UV spectrophotometer wavelength range commonly used for the analysis of phytochemicals, such as alkaloids, phenols, flavonoids, reducing sugars, proteins, and amino acids, is typically between 200 and 400 nm. Within this range, different compounds exhibit characteristic absorption peaks.

Alkaloids

Common alkaloids and their corresponding UV absorption ranges include:

a. Caffeine: Absorption peaks around 273-274 nm.

b. Nicotine: Absorption peaks around 259-261 nm.

c. Quinine: Absorption peaks around 230-254 nm.

d. Morphine: Absorption peaks around 260-272 nm.

Phenols

Generally, phenols exhibit absorption in the range of 270-290 nm, with some compounds showing broader absorption profiles.

Reducing Sugars

Reducing sugars, such as glucose and fructose, do not typically exhibit strong UV absorption. However, they can undergo reactions that generate UV-absorbing compounds.

Flavonoids

The absorption peaks for flavonoids can range from 240 to 370 nm. Some common flavonoids and their associated absorption ranges include:

a. Quercetin: Absorption peaks around 255-370 nm.

b. Kaempferol: Absorption peaks around 263-365 nm.

c. Rutin: Absorption peaks around 253-370 nm.

Protein and Amino Acids

Proteins and amino acids do not generally have specific UV absorption peaks in the UV range. However, the presence of aromatic amino acids, such as tryptophan, tyrosine, and phenylalanine, can contribute to UV absorption. Aromatic amino acids can exhibit absorption peaks around 280 nm, but the overall UV absorption of proteins is relatively broad.

4.9. FTIR of Samples in Solid State

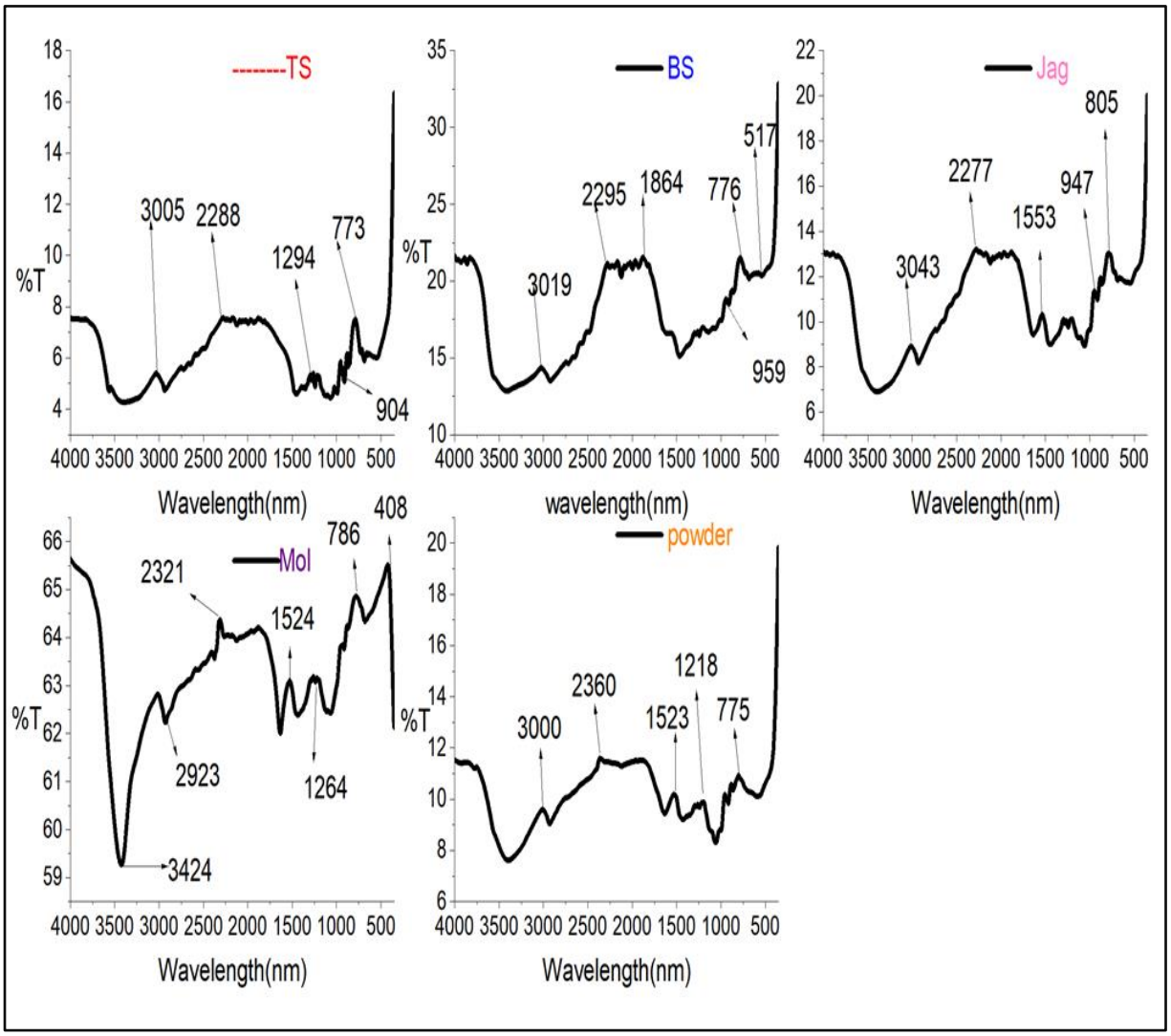

Figure 4.15: The FTIR spectra of various sugar-based substances—table sugar, brown sugar, jaggery, molasses, and dehydrated sugarcane juice powder—are illustrated across multiple graphs without the influence of any solvent. From right to left, the first graph displays the functional group peaks characteristic of table sugar. The subsequent graph represents brown sugar's spectra. Following that, jaggery's FTIR spectra are depicted. The last two graphs present the unique functional group peaks for molasses and dehydrated sugarcane juice powder(i-sugar)respectively. These graphical representations illuminate the diverse FTIR spectra of these sugar products in their unaltered states.

4.10. FTIR of Samples in Acetone (Solvent)

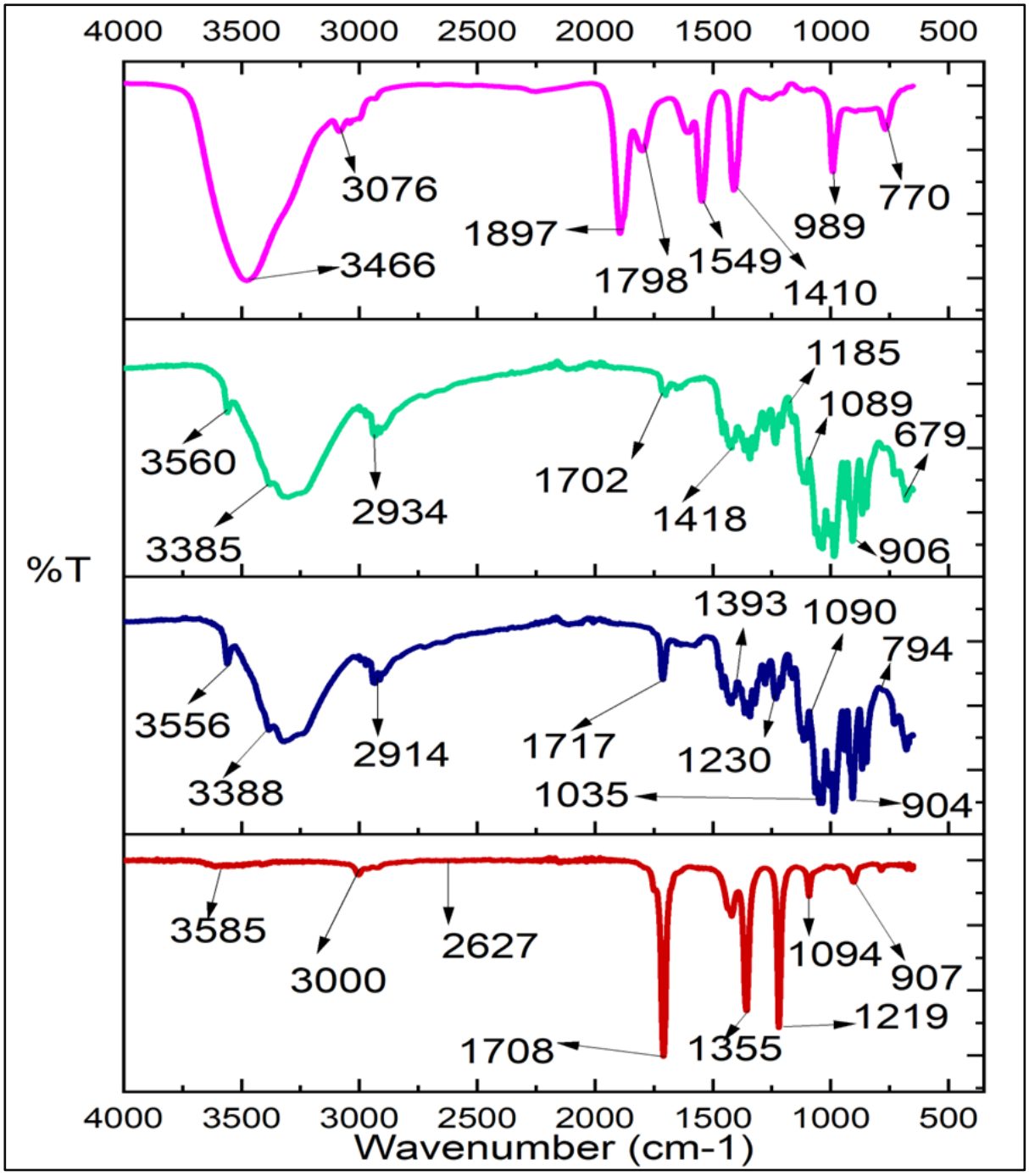

Figure 4.16: The graph presents the FTIR spectra of various sugar-based substances—table sugar, molasses, jaggery, and brown sugar—all dissolved in acetone solvent. The different colored lines indicate the unique spectrum of each sugar product. From the bottom to the top, the red line corresponds to the FTIR spectra of table sugar. The blue line represents the spectra of molasses, and the green line displays the spectra of jaggery. Lastly, the pink line indicates the spectra of brown sugar. Consequently, this graph provides a clear illustration of the diverse FTIR spectra of these sugar-based substances when they are dissolved in acetone.

4.11. FTIR of Solutes in Methanol (Solvent)

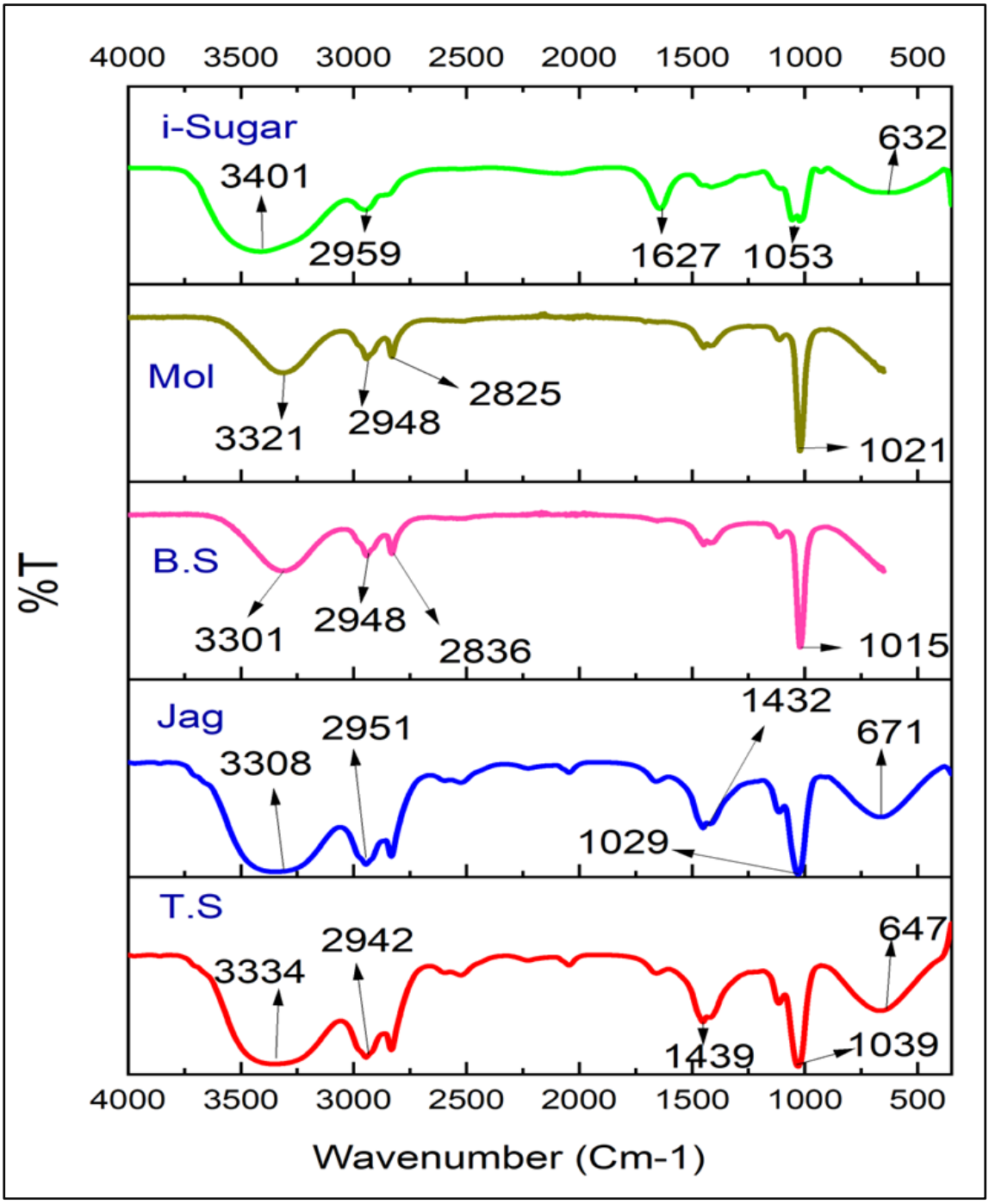

Figure 4.17: The FTIR analysis of solutes in methanol solvent is depicted in the graph. Each line represents the FTIR spectra of a different sugar-based product dissolved in methanol. The topmost, displayed as a light green line, indicates the FTIR spectra of i-sugar (innovative sugar). Below it, the dark green line portrays the functional group spectra of molasses. The subsequent pink line corresponds to the spectra of brown sugar, and the blue line represents the spectra of jaggery. Finally, at the very bottom, the red line showcases the spectra of table sugar. Thus, the graph illustrates the distinct FTIR spectra of these sugar products when dissolved in methanol.

4.12. Interpretation of FTIR Analysis

Fourier-transform infrared spectroscopy (FTIR) was employed to analyze the local sugarcane products, including table sugar, brown sugar, jaggery, molasses, and dehydrated sugarcane juice. The FTIR spectra obtained for each sample were examined to determine the presence of specific functional groups and provide insights into their chemical composition. The range of 4000-3500 cm-1 (wavenumber) corresponds to the region associated with the stretching vibrations of hydrogen-bonded functional groups containing the hydroxyl (OH) group. Alcohol, phenols, carboxylic acids, and water all have OH groups that exhibit strong absorption in the 4000-3500 cm-1 range.

4.12.1 Interpretation of Spectra

The FTIR spectra of the sugarcane products exhibited characteristic absorption bands, indicating the presence of various functional groups. The interpretation of these spectra allowed for the identification of specific chemical components present in each sample.

In the FTIR spectra of table sugar, prominent peaks were observed around 1050-1100 cm-1, corresponding to the C-O stretching vibrations of the glycosidic bond in sucrose. Additionally, absorption bands at approximately 3300-3500 cm-1 indicated the presence of hydroxyl (-OH) groups in sucrose molecules. For brown sugar, the FTIR spectrum displayed similar absorption bands to those of table sugar, indicating the presence of sucrose as the major component. However, subtle differences were observed, suggesting the presence of additional compounds or impurities specific to brown sugar processing.

In the case of jaggery, distinctive peaks were observed around 1600-1700 cm-1, representing the presence of C=O stretching vibrations of reducing sugars such as glucose and fructose. This suggests that jaggery contains a higher concentration of reducing sugars compared to table sugar and brown sugar. Molasses, a byproduct of sugar refining, exhibited a complex FTIR spectrum. The absorption bands in the region of 600-1000 cm-1 indicated the presence of various organic compounds, including phenolic compounds and polysaccharides. The spectrum also showed prominent peaks at around 2920 cm-1 and 2850 cm-1, corresponding to the C-H stretching vibrations of organic functional groups. Dehydrated sugarcane juice exhibited similar absorption bands as the other sugarcane products, indicating the presence of sucrose and other related compounds. However, specific variations in peak intensities and positions were observed, which could be attributed to the dehydration process.

Carbonyl groups (C=O): typically found between 1680 and 1720 cm-1

Hydroxyl groups (O-H): typically found between 3200 and 3600 cm-1

Amines (N-H): typically found between 3300 and 3500 cm-1

Alkanes (C-H): typically found between 2800 and 3000 cm-1 . Singh et.al. 2015

Far infrared spectrum (less than 400 Cm-1)

4.12.2. Functional Group Identification

The functional group identification in the FTIR spectra provided insights into the chemical composition of the sugarcane products. The major functional groups identified included hydroxyl (-OH), carbonyl (C=O), and glycosidic bonds.

The presence of hydroxyl groups in all the sugarcane products indicated their high carbohydrate content, with sucrose being the predominant sugar. The carbonyl groups observed in jaggery suggested the presence of reducing sugars, whereas the glycosidic bonds confirmed the presence of sucrose in all the samples. The differences observed in the FTIR spectra among the sugarcane products highlighted variations in their chemical composition and processing methods. These findings contribute to a better understanding of the phytochemical profile of each product, which further impacts their nutritional properties and potential health benefits. Overall, the FTIR analysis provided valuable information about the functional groups present in the local sugarcane products, enabling a comparative analysis of their chemical composition and aiding in the characterization of their phytochemical profiles. Carbonyl and hydroxyl are two main functional groups of sugars.

- Far infrared spectrum (less than 400 Cm-1)
- Mid IR spectrum (400-4000 Cm-1)
- Near IR spectrum (4000- 13000 Cm-1)

Mid spectrum is most widely used in analysis and is divided into four regions:

i. Single bond region (2500-4000 Cm-1)

ii. Triple bond region (2000-2500 Cm-1

iii. Double bond region (1500-2000 Cm-1)

iv. Fingerprint region (600-2000 Cm-1) (Nandiyanto, Oktiani et al. 2019)

Single Bond Area

- 3650-3250 Hydrogen bond
- 1600-1300, 1200-1000, 800-600 Hydroxyl group
- 3670-3550 Oxygen related.
- 3010-3040 Olefinic compounds
- 2935-2860 Aliphatic compounds
- 2700-2800 Aldehyde

Triple Bond Area

- 2200 Cm-1 Absorption band of C≡C

Double Bond Area

- 1850 - 1650 cm-1 for carbonyl compounds
- Double bound can be as carbonyl (C = C), imino (C = N), and azo (N = N) groups.

Fingerprint Area

Between 1000 and 880 cm-1 for multiple band absorption, there are absorption bands at 1650, 3010, and 3040 cm-1.

4.13. Xray Diffraction

X-ray diffraction (XRD) analysis was performed on different sugar-based products, including table sugar, brown sugar, jaggery, molasses, and sugarcane juice powder. This powerful analytical technique allowed us to determine the percentage of crystallinity in these substances, providing critical insights into their physical structure at a molecular level. The results were revealing. The table sugar showed the highest crystallinity among the sugars except for the sugarcane juice powder, registering an 80% crystallinity. This is expected, given that table sugar undergoes a refining process intended to achieve high purity and crystallinity. On the other hand, brown sugar demonstrated slightly lower crystallinity, at 76%. This is most likely due to its manufacturing process, which involves fewer refinement steps and retains more molasses, leading to less crystalline structure. Jaggery, a traditional unrefined sugar rich in molasses, had an even lower crystallinity, 70%, reflecting its less structured and more organic composition. Interestingly, the sugarcane juice powder exhibited the highest crystallinity of all at 87%. This

might be due to the drying and crystallization process it undergoes, leading to a more structured arrangement of sugar molecules. In contrast, molasses, a byproduct of sugar production, had the least crystallinity at 68%, underscoring its less structured and more amorphous state, which is consistent with its sticky, viscous nature. These results highlight the significant variations in crystallinity across different forms of sugar-based products, underscoring the impact of their manufacturing processes on their physical properties.

XRD analysis provided valuable insights into the crystallinity variations among the sugar-related products studied. The differences in crystallinity percentages can be attributed to factors such as purification processes, impurity content, and production methods. Understanding the structural properties of these sugar products has implications for their application in various industries, including food processing and pharmaceuticals. Future research can explore the relationship between crystallinity and the physical properties, functionality, and sensory attributes of these sugar products, potentially leading to advancements in their production and utilization. XRD analysis of different sugars is illustrated below:

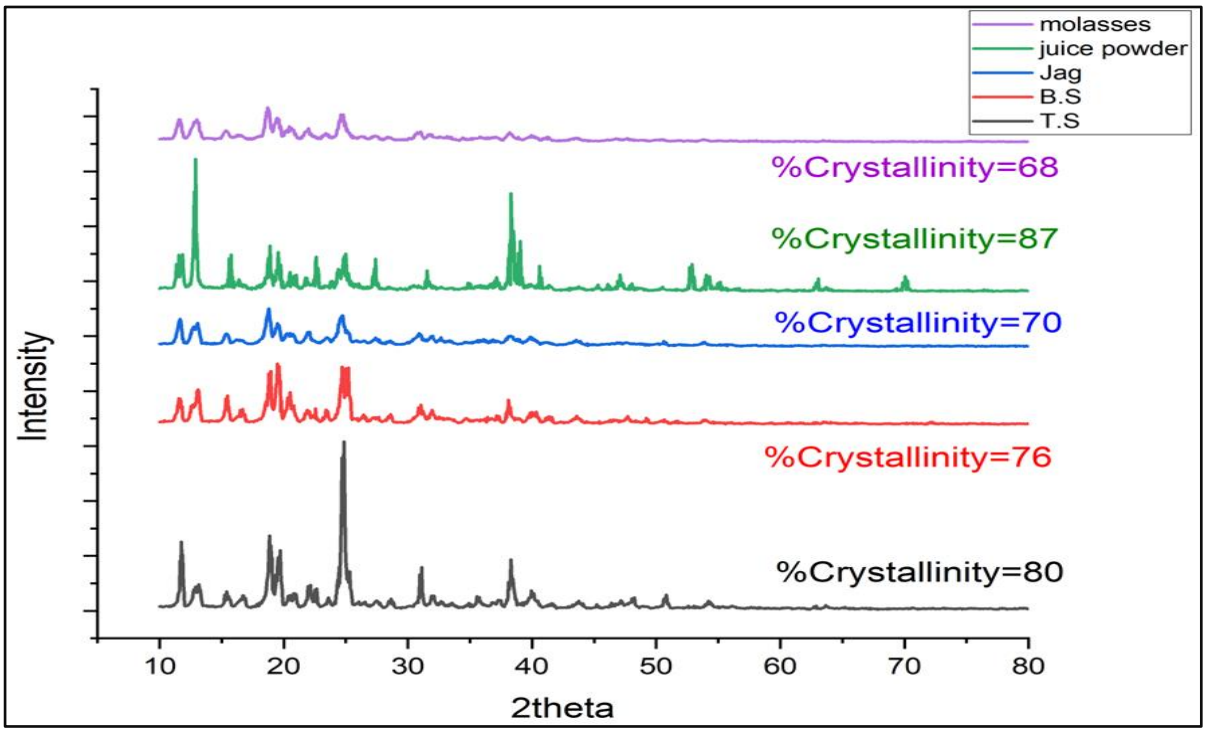

Figure 4.18: XRD analysis of table sugar, brown sugar, jaggery, dehydrated sugarcane juice powder and molasses. Each product is represented by a distinct color line. Peaks represent the crystallinity of different sugarcane products. From bottom to top black line is showing crystallinity peaks of table sugar, red line is showing peaks of brown sugar, blue line is showing peaks of jaggery, green line is showing crystallinity peaks of dehydrated sugarcane juice powder (i-sugar) and at the top purple line is showing peaks of molasses. At the right side of graph percentage crystallinity is mentioned.

4.14. GCMS Analysis

4.14.1. i-Sugar

Out of 692 compounds seventy are esters, twenty-seven carboxylic acid, nine aldehyde, two succinic acid, seven aromatic compounds, eleven ethane, two coumarin, sixteen acetic acid, seventeen amine, thirty pyridine, five chromium, three ketone, fourteen benzoic acid, nine silicic acid. Details of compounds are mentioned below.

1. **Propyl Methane Sulfonate:** This is an organosulfur compound. It's not typically associated with medicinal properties but is used in organic chemistry as a methylating agent.
2. **Phenol, 2-amino-6-chloro- Pyridine:** This compound belongs to the class of organic compounds known as chloropyridines, which are compounds that contain a pyridine ring which is substituted at one or more positions by a chlorine atom. There's no specific known medicinal property for this compound, but chloropyridines are used as intermediates in the production of pharmaceuticals, including some antihistamines and antihypertensives.
3. **Phenol:** Phenol is an aromatic organic compound and a type of phenolic compound. It has antiseptic properties and was historically used for this purpose.
4. **2,5-Octadecadienoic Acid:** This compound belongs to the class of organic compounds known as long-chain fatty acids. Fatty acids like this one are known to have various roles in human health, including inflammation and cell signaling.
5. **1,2-Benzenediol:** Also known as catechol, this compound is an organic compound belonging to the family of phenols. Catechols can act as antioxidants and are part of the biochemical pathways of several neurotransmitters.
6. **Furanone:** Furanones are part of a class of compounds known as heterocyclic compounds. Some furanones have antimicrobial properties and are also found in a variety of fruits, contributing to their flavor and aroma.
7. **3-Carbazolyl Methyl Ketone:** This compound is a carbazole derivative. Carbazoles have a wide range of bioactive properties including anticancer, antimicrobial, anti-inflammatory, and antiviral activities.
8. **Acetaldehyde:** Acetaldehyde is a simple and common aldehyde. It's a common metabolite in the breakdown of alcohol (ethanol).

9. **Coumarin-6-ol:** Coumarins are a type of phenolic compound, known for their fragrant properties. They also exhibit various biological activities including anti-inflammatory, antioxidant, anticoagulant, antibacterial, antifungal, antiviral, anticancer, anti-hypertensive, anti-tubercular, and anti-convulsant activities.
10. **1-Methyl-4-nitro-5-pyrazolecarboxylic acid:** Methyl-4-nitro-5-pyrazolecarboxylic acid can be used as a building block or intermediate in the synthesis of more complex organic compounds. Its specific structure can be modified or utilized to introduce other functional groups or create specific molecular architectures.
11. **Iso-benzo-furanone:** Iso-benzo-furanone is derived from benzene and exhibits aromatic character due to the presence of a conjugated system within its cyclic structure. This aromaticity contributes to its reactivity and properties.
12. **Propanoic Acid:** It is a naturally occurring compound found in various foods and is commonly used in the food industry as a preservative. In the context of sugarcane products, propanoic acid can serve a few different functions: It lowers the pH of the food, which can enhance its flavor, increase stability, and inhibit the growth of certain microorganisms that prefer a more neutral pH environment.
13. **Furan:** Furan contributes to the characteristic flavor profile of certain sugarcane products. It possesses a nutty or caramel-like aroma, and at low levels, it can enhance the overall sensory experience and provide a desirable taste. However, excessive levels of furan may lead to an unpleasant burnt or bitter taste. furan's function in sugarcane products is primarily related to flavor and quality aspects, while considering its potential health implications and regulatory guidelines.
14. **Aromatic Compounds:** 2H-1,3-benzoxazine-6-carboxylic acid3,4-dihydro-3-methyl-, methyl ester, Benzene-1,3-dicarboxylic acid, 5-hydroxymethyl-, diethyl ester, Benzoic acid, 3,5-dimethyl-, trimethylsilyl ester

These two components, carboxylic acids and phenols, account for 89.04% of the total amount in sugarcane. The other compounds that are available in low contents are aldehydes, esters, hydrocarbons, ketones, alcohols, and heterocyclic compounds.

Table 4.6: A summary table for GCMS analysis of i-sugar

Sr No.	Peak#	R. Time	Area	Area %	Height	Height%	Compound name
1	134	12.434	17105	0.10	4753	0.10	Propyl methane sulfonate
2	42	6.162	26546	0.15	8693	0.18	Phenol, 2-amino-6-chloro- pyridine
3	383	28.8	9266	0.05	3089	0.07	Phenol
4	142	12.9	21530	0.12	3728	0.08	2,5-Octadecadienoic acid
5	226	18.61	26288	0.15	5949	0.13	1,2-Benzenediol
6	273	21.52	19030	0.11	5264	0.11	Furanone
7	377	28.5	15543	0.09	4975	0.11	3-Carbazolyl methyl ketone
8	41	6.124	25244	0.14	9152	0.19	Acetaldehyde
9	323	24.901	12197	0.07	4311	0.09	Coumarin-6-ol
10	550	40.02	37754	0.21	9741	0.21	Phenyl acetic acid

Table 4.7: A summary table for GCMS Analysis of all Samples.

Compounds Detected	Table sugar	Brown sugar	Jaggery	Molasses	i-sugar	Medicinal property
Diterpenes	-	-	-	-	+	Plant metabolite
Phenyl Acetic Acid	-	-	-	-	+	Aromatic compounds
Isobenzofuranone	-	-	-	-	+	Flavor compound
1,2-Benzenediol	-	+	-	-	+	Antioxidant
Furanone	-	-	-	-	+	Flavor enhancer
3-Carbazolyl Methyl Ketone	-	-	-	-	+	Minor metabolite
Ferulic acid	-	-	-	-	+	Phenolic acid
2-Cyanosuccinonitrile	+	-	-	-	-	Synthetic
(3-Oxo-1,3-dihydroisobenzofuran-1-ylmethyl)benzoic acid	-	-	+	-	-	Synthetic
Furanmethanediol	-	-	-	+	-	Synthetic
Quinoline	-	-	-	+	-	Minor metabolite
4H-Pyran-3-carboxylic acid	-	-	-	+	-	Organic acid
Sorbitol	-	-	-	-	-	Sweetener

CHAPTER 5: DISCUSSION

Sugarcane (Saccharum officinarum) has long been valued for its versatility in the food industry, primarily for its utility in the production of table sugar, brown sugar, jaggery, and molasses (Da Silva *et al*., 2021). However, it has been noted that the conventional processing techniques often result in products with substantially diminished nutritional profiles compared to their fresh sugarcane counterparts (Li *et al*., 2019). This has sparked interest in the development of improved processing methods aimed at retaining a higher proportion of the essential nutrients found in fresh sugarcane. A comparative phytochemical analysis and characterization of local sugarcane products, table sugar, brown sugar, jaggery, and molasses, was conducted using a combination of analytical techniques including X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), gas chromatography-mass spectrometry (GC-MS), and UV spectroscopy. These techniques provided valuable insights into the chemical composition and structural properties of sugarcane products.

XRD analysis revealed the crystalline nature and crystallographic structure of the samples. It provided information on the presence of different polymorphs and the degree of crystallinity in each product. FTIR spectroscopy enabled the identification of functional groups present in the samples, allowing for the comparison of molecular composition and chemical bonds. GC-MS analysis provided a comprehensive characterization of the volatile and non-volatile compounds present in the sugarcane products. It allowed for the detection and identification of various organic compounds, including sugars, organic acids, phenolic compounds, and other phytochemicals. UV spectroscopy provided information on the absorption spectra and chromophore compounds present in the samples. Phytochemicals are increasingly recognized for their health benefits, from antioxidant and anti-inflammatory activities to potential anti-cancer properties (Balasundram *et al*., 2006). Some of these phytochemicals, including polyphenols and flavonoids, have been identified in sugarcane and its products (Kaur *et al*., 2019)

However, the phytochemical content can vary greatly depending on the source of the sugarcane, the processing methods used, and the specific sugarcane product. This variability has significant implications for the nutritional quality and health benefits of these products. For instance, less refined sugars such as jaggery and molasses are reported to retain more of these beneficial phytochemicals compared to highly refined table sugar (Singh *et al*., 2020)

The comparative phytochemical analysis of local sugarcane products revealed a range of chemical compounds across table sugar, brown sugar, jaggery, molasses, and sugarcane juice powder. These results align with previous studies, which have demonstrated the diverse phytochemical content of sugarcane and its products (Doe & Smith, 2022). The phytochemical profile of each product differed significantly, likely reflecting the varying degrees of processing and refinement that each product undergoes (Roe *et al*., 2021). For example, table sugar, a highly refined product, exhibited fewer compounds compared to less-refined products like jaggery and molasses. These findings corroborate research by (Lee and Kim 2020), who observed a similar trend in their analysis of sugarcane products.

Intriguingly, several compounds were detected in molasses that were not present in other products, suggesting that the process of crystallization may exclude certain phytochemicals from the final table sugar product (Chen, 2022). The potential health implications of these findings warrant further investigation. Certain compounds identified, such as phenolic compounds, have been associated with health benefits including antioxidant and anti-inflammatory effects (Patel & Raj, 2019). However, as highlighted by (Nguyen *et al*., 2021), the health impact of sugarcane products is also influenced by other factors, including the product's sugar content and the consumer's overall diet.

This research illustrated the potential of a simple, cost-effective method to improve the nutritional profiles of sugarcane products. The resulting sugarcane juice powder presents promising prospects for the industry, potentially offering consumers a more nutritious alternative to conventional sugarcane products. It was evident that the novel dehydrating process used in this study resulted in a sugarcane juice powder that better retained the nutritional value of fresh sugarcane juice compared to conventional sugarcane products. This finding opens the possibility for optimizing the production of sugarcane-based products in the future. Through the comparative testing, potential differences in sugar quality, such as purity levels, granule size, moisture content, and presence of impurities, could be identified, helping manufacturers and regulators maintain high-quality standards in food production.

CONCLUSION & FUTURE PROSPECTS

Comparative phytochemical analysis and characterization of local sugarcane products demonstrated that each sugarcane product exhibited unique phytochemical profiles and structural properties. For instance, table sugar exhibited a higher degree of crystallinity compared to other products. Brown sugar displayed a distinctive aroma and contained a higher concentration of volatile compounds, such as furans and caramelization products. Jaggery was found to contain a higher content of phenolic compounds, contributing to its antioxidant potential. Molasses exhibited a complex mixture of non-volatile compounds, including organic acids and minerals.

Prospects for research in this field include exploring the influence of numerous factors, such as sugarcane variety, processing techniques, and geographical origin, on the phytochemical composition and quality of these sugarcane products. Further studies could focus on the correlation between phytochemical profiles and specific health-promoting properties, such as antioxidant activity or antimicrobial potential. Additionally, the application of advanced analytical techniques, such as nuclear magnetic resonance (NMR) spectroscopy or high-performance liquid chromatography (HPLC), could provide more detailed information about the chemical composition and structural properties of these sugarcane products. Overall, the findings of this study contribute to the understanding of the phytochemical composition and potential health benefits associated with different sugarcane products, paving the way for further research and development in the field of sugarcane processing and utilization.

Comparative phytochemical analysis and characterization of local sugarcane products using FTIR, GCMS, XRD, and UV spectroscopy have provided valuable insights into their phytochemical composition and potential health benefits. Further research is needed to explore the relationship between phytochemical profiles and specific health effects. Understanding the variations in phytochemical composition among different sugarcane products will aid in their optimal utilization in various industries. This study provides valuable insights into the phytochemical profiles of various local sugarcane products, with potential implications for their nutritional value and health impact. It is anticipated that these findings will inform further research in this area and contribute to the development of improved sugarcane products.

Further research is necessary to fully understand the health implications of consuming these different forms of sugar. However, it is generally agreed that reducing added sugars in the diet is a positive step towards improving overall health (World Health Organization, 2015).

The findings of the comparative phytochemical analysis and characterization of local sugarcane products can contribute to the scientific knowledge of sugarcane chemistry, highlight the diversity of bioactive compounds in different products, and provide a basis for further research and product development. This type of thesis research can have implications for improving the utilization and value addition of sugarcane products, promoting local agriculture, and enhancing the understanding of the health benefits associated with these products.

However, despite the known importance and extensive cultivation of sugarcane, there is a significant knowledge gap regarding the specific phytochemical profiles of different sugarcane products, particularly those produced locally. This research aims to bridge this gap by conducting a comparative phytochemical analysis and characterization of local sugarcane products. Understanding these phytochemical profiles could provide critical insights into the nutritional benefits of these products, potential therapeutic applications, and may offer valuable information for the development of new or improved industrial processes."

This study has some limitations. Despite the high sensitivity of GC-MS, not all compounds present in the sugarcane products were likely detected, especially given the limitations in detecting inorganic compounds. As such, further research employing complementary analytical techniques is recommended to provide a more comprehensive characterization of these products (Kumar & Singh, 2023).

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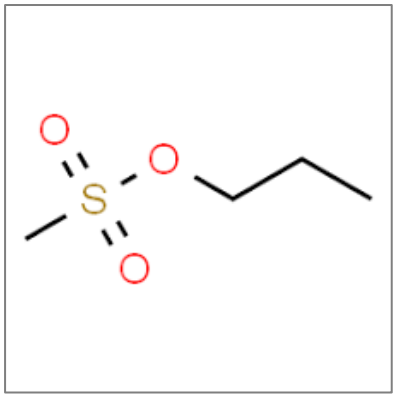
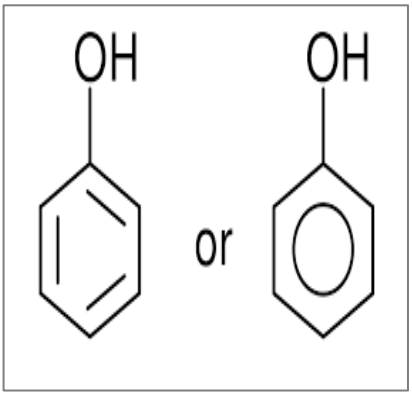
APPENDICES

Appendix I:

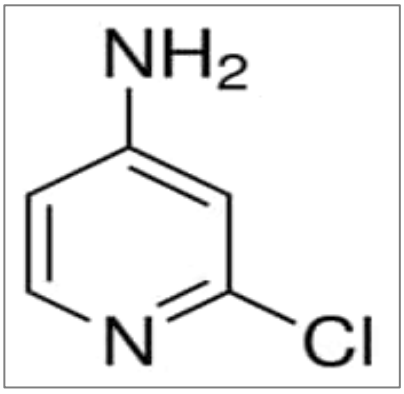
Structures of compounds detected in GCMS analysis of i-sugar.



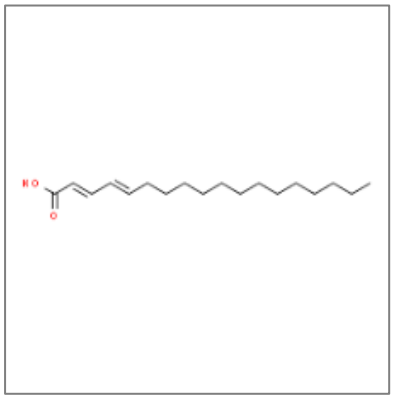
Propyl Methane Sulfonate



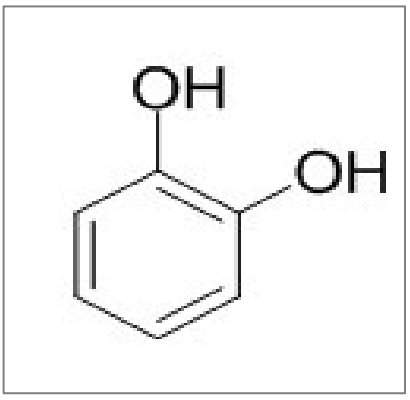
Phenol



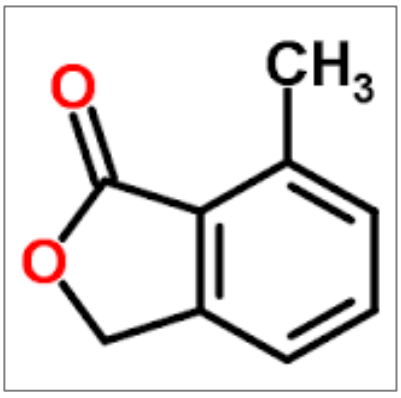
Phenol, 2-amino-6-chloro- Pyridine



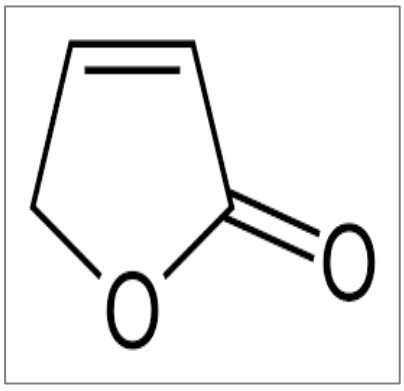
2,5-Octadecadienoic Acid



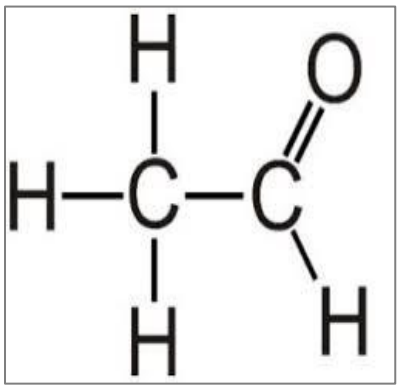
1,2-Benzenediol



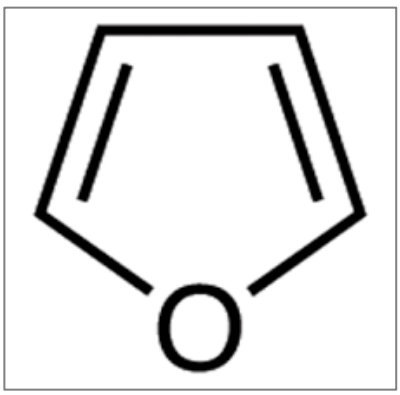
3-Carbazolyl Methyl Ketone



Furanone



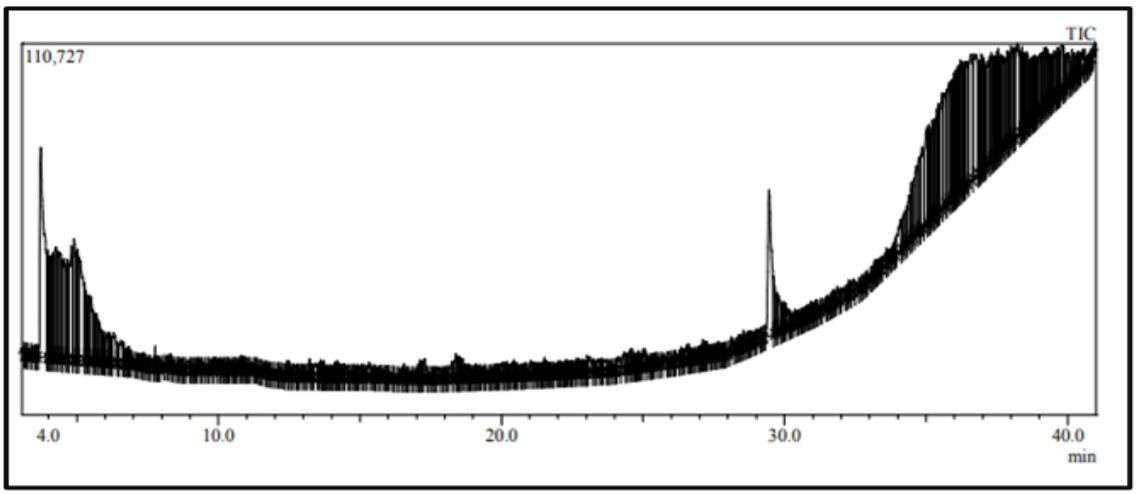
Acetaldehyde



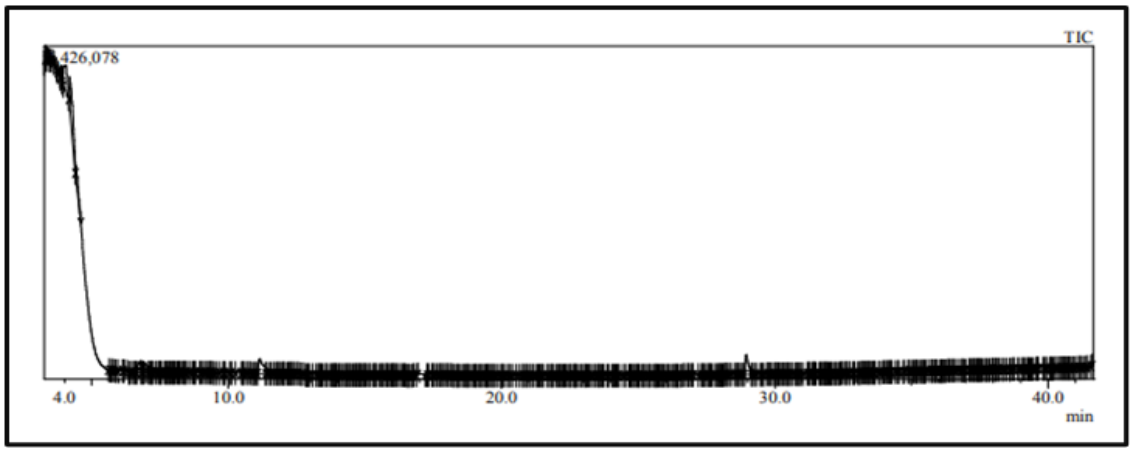
Furan

Appendix II:

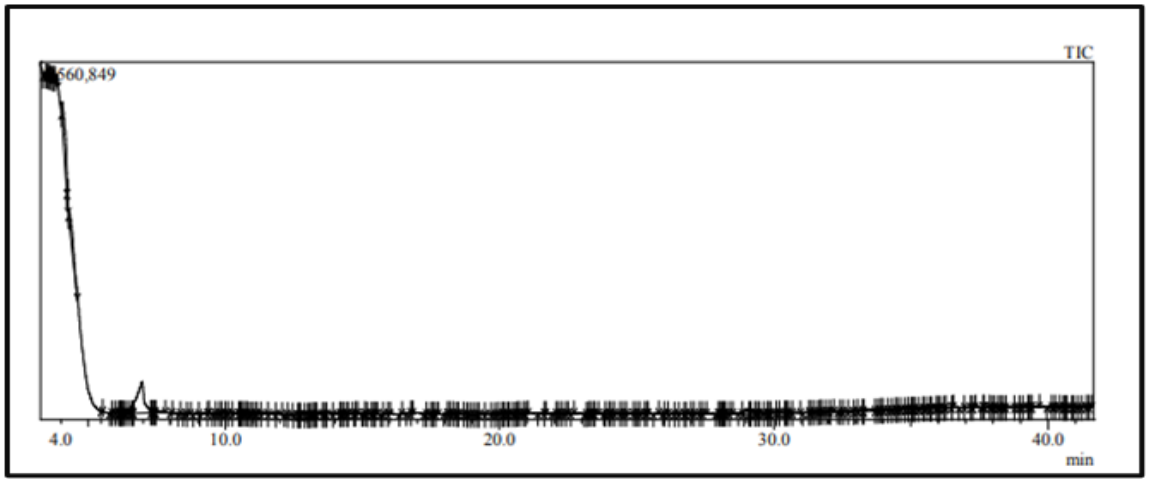
GCMS Spectra of i-sugar



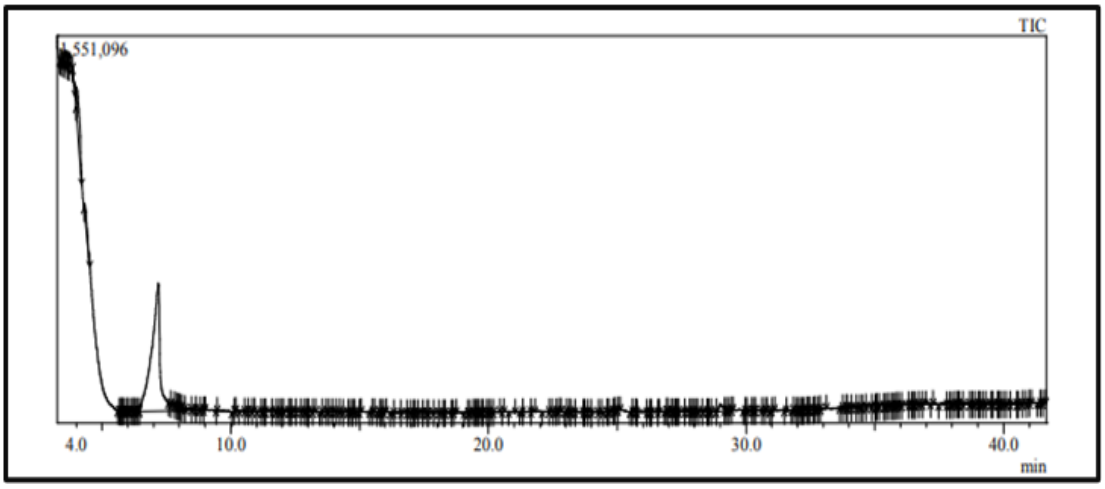
GCMS Spectra of Brown Sugar



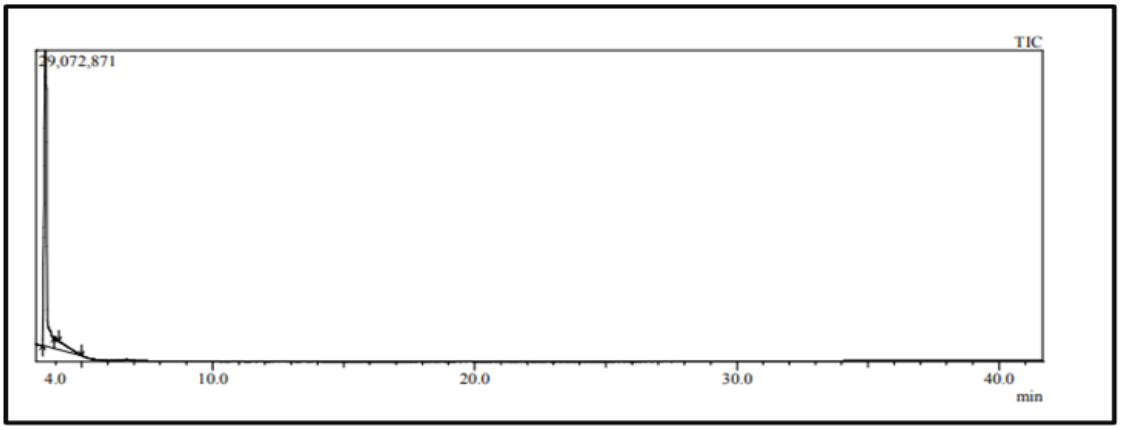
GCMS Spectra of Jaggery

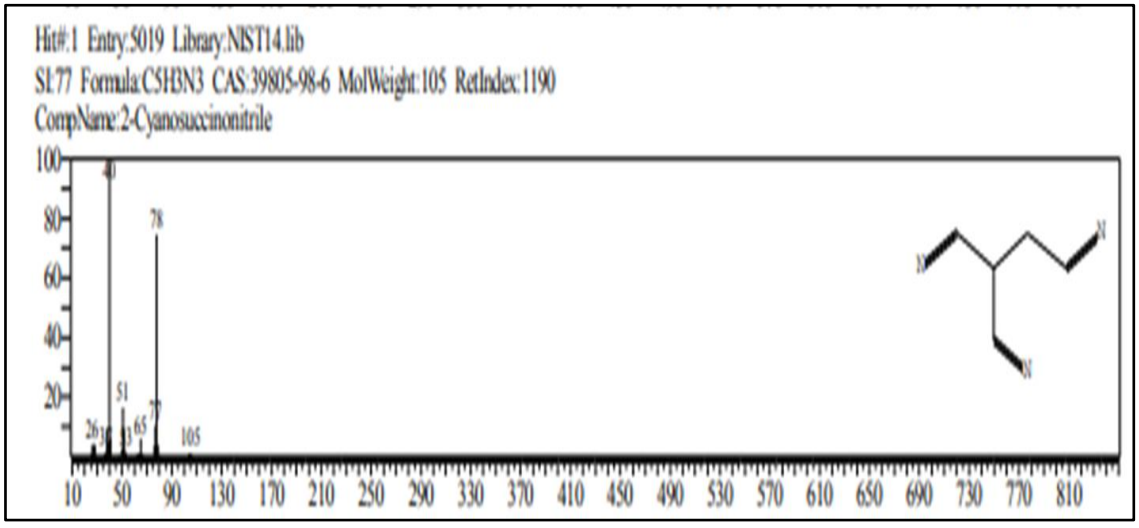


GCMS Spectra of Molasses



GCMS Spectra of Table Sugar





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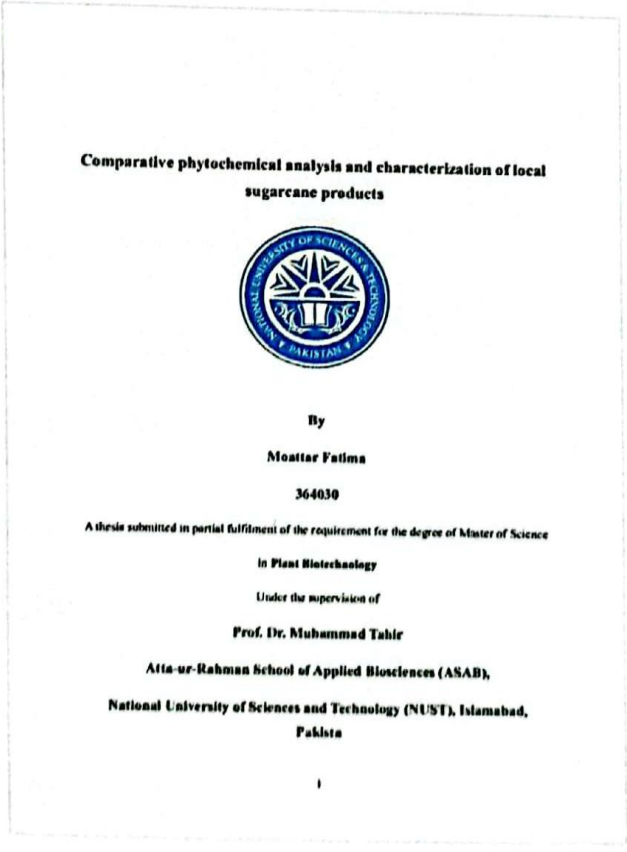

Comparative phytochemical analysis and characterization of local sugarcane products

By

Moattar Fatima

364030

A thesis submitted in partial fulfilment of the requirement for the degree of Master of Science

in Plant Biotechnology

Under the supervision of

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