Effect of Drying on Extraction of Anthocyanins from *Syzygium cumini* (Jamun)

A thesis submitted in partial fulfilment of the requirement for the award of the degree of

MASTER OF SCIENCE

IN

BIOTECHNOLOGY

Submitted by

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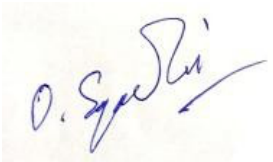
(July 2023)

CERTIFICATE

This is to certify that the thesis entitled **"Effect of Drying on Extraction of Anthocyanins from *Syzygium cumini* (Jamun)",** submitted by **Ms. Amritpreet Kaur (302101004)** in the partial fulfilment of the requirement of the award of the degree of Master of Science in Biotechnology at Thapar Institute of Engineering and Technology (TIET), Deemed to be University, Patiala is a record of student's own work carried out under my supervision and guidance. This work has not been submitted in part or full to any other university or institute for the award of any other degree.



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DECLARATION

I hereby declare that the work presented in the thesis **"Effect of Drying on Extraction of Anthocyanins from Syzygium cumini (Jamun)"** in the partial fulfilment of the requirement of the award of the degree of Masters of Science in Biotechnology at Thapar Institute of Engineering and Technology (TIET), is an original and genuine work completed by me between January 2023 and July 2023. This research was carried out under the guidance and supervision of Dr. Ovais S. Qadri, an Assistant Professor in the Department ofBiotechnology, TIET. The content presented in this thesis has not been previously submitted, either in its entirety or in part, to any other educational institution or university in India or abroad for the purpose of obtaining any degree.

Place - Patiala Amritpreet Kaur

Date -29/07/23

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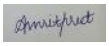

Date 29/07/23 Amritpreet Kaur

This thesis is dedicated to my father Mr. Amarjit singh, mother Mrs. Harpreet kaur, Gurnoor and Kamal for their endless love, support and encouragement.

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List of abbreviations

Acronym	Definition
A, Abs	Absorbance
C3G	Cyanidine-3-glucoside
D.m	Dry matter
D.w	Dry weight
DPPH	2,2-diphenyl-1-picrylhydrazyl
DMSO	Dimethyl sulfoxide
Et al	And others
FMD	Foam Mat Drying
FRAP	Ferric Reducing Antioxidant Power
FTIR	Fourier transform infrared spectroscopy
GAE	Gallic acid equivalent
H2O	Water
HAFMD	Hot air Foam Mat Drying
LA	Luria agar
LB	Luria broth
MFMD	Microwave Foam Mat Drying
NA	Nutrient agar
NB	Nutrient broth
PDA	Potato dextrose agar
TPTZ	2,4,6-tripyridyl-S-triazine
TMAC	Total Monomeric Anthocyanin Content
TPC	Total phenolic content
VFMD	Vacuum Foam Mat Drying
+ve	Positive
-ve	Negative

List of symbols

Acronym	**Definition**
°C	Degree Celsius
cm	Centimetre
g	Gram
kg	Kilogram
L	Litre
%	Percentage
mg	Milligram
mg/g	Milligram per gram
min	Minute
ml	Millilitre
Mg	Microgram
nm	Nanometre
pH	Potential of Hydrogen
sec	Seconds
W	Watt

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ABSTRACT

Syzygium cumini, commonly known as jambolana or Indian blackberry, is a fruit rich in anthocyanins with significant health-promoting properties. This study used conventional solvent extraction (using methanol as solvent) to compare the anthocyanin recovery from different parts of Syzygium cumini, namely its pulp, pomace, and juice. The anthocyanin content was quantified using the pH differential method, which allowed for rapid and accurate estimation of anthocyanin concentration. Additionally, the drying effects on the fruit were investigated using three different foam mat drying methods: microwave foam mat drying, hot air oven foam mat drying, and vacuum foam mat drying. Regarding the drying effects, foam mat drying was employed at three different temperatures (50°C, 70°C, and 100°C) and power levels (180W, 360W, and 540W). The drying kinetics were studied and characterized using graphical analysis. Foam properties were assessed in terms of stability, density, expansion, and moisture content. The drying method that demonstrated the most favourable results in terms of temperature or power was selected for subsequent characterization. The selected drying method was further characterized through various analyses, including total extract yield, total phenolic content (TPC), 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, ferric reducing antioxidant power (FRAP) assay, and antimicrobial tests.

1. INTRODUCTION

Syzygium cumini (**Jamun** fruit) is a berry consisting of a single seed surrounded by a flashy pulp and fruit skin. It is also known as *Syzygium jambolana*, *Eugenia jambolana* or *Eugenia cumini.* It is a native fruit of India that has been used as medicine for centuries. It belongs to the *Myrtaceae* family and is grown in tropical and subtropical regions of the Indo-Gangetic plains. Trees of this fruit are usually drought tolerant. Fruit can be grown in a wide range of climatic conditions. It is a rich source of antioxidants, calcium, phosphorous and flavonoids. *S. cumini* is an important inconsiderable fruit in India. In Gujarat, it is called as 'fruit of the gods' due to its abundance and importance. It also has various sacred values in Buddhism and Hinduism.

The human body needs a lot of micro and macronutrients, which include carbohydrates, vitamins, proteins, minerals, lipids, fats, etc. The human diet is derived from animal and plant sources. *S. cumini* fruit is one which consists a lot of nutritional value. *S. cumini* fruit is used for utilization and processing in industries. *S. cumini* fruits are consumed as fresh fruit and food products like frozen pulp, freeze-dried pulp, osmotic-dried fruit, pasta, and juice Minor fruits are a good source of nutrition and have various pharmaceutical properties. Among all seasonal fruits, it is highly perishable but nutritious. The fruit has a very high cost in the market, but it is still unexploited due to its unattainability and perishability (Ghosh et al., 2017). Fruit generally has short post-harvest activity at various temperatures, and this activity can be increased by using proper post-harvest treatments. Fruit also has economic significance as tree and fruit parts can be used for diverse purposes. In recent years, people have been shifting towards phytochemical and functional foods. *Syzygium cumini* is a potentially phytochemical-rich source of food which has gained the attention of processors for the development of functional foods (Kaur et al., 2022). Different parts of the *S. cumini* plant contain distinct phytochemicals.

Syzygium cumini consists of an antioxidant and bioactive compound, **anthocyanin**, which is a purple-colored pigment and a potential biocolorant. Pigments are the most important external factors that determine their acceptability by consumers. Pigments have been used in various industries such as cosmetics, pharmaceuticals, food etc. Food industry intensifies the character of food with the help of pigment. Synthetic colours are toxic and non-nutritious. They are also legally not allowed to use. Hence, the use of natural colorants is preferable for its health as well as other benefits. The intense colour of *S. cumini* is due to the presence of anthocyanins in it. It contains a massive amount of polyphenols, ellagic acid, and ellagitannin. Anthocyanins are water-soluble and belong to the phenolic group, flavonoids. They are recognized for their health benefits, such as anti-inflammatory, cardioprotective and hepatoprotective activities (Swer et al., 2019). It is sensitive to pH changes and temperature; thus, the choice of drying techniques is important to minimize degradation.

Drying Techniques

Drying is the process of removal of water or any other solvent from a solid, semi-solid or liquid and is one of the oldest food preservation techniques. Drying of byproducts is done before extraction to ensure efficiency, which depends upon techniques used and conditions applied for drying. Various drying methods include foam mat drying, vacuum drying, hot air oven drying and microwave drying. Drying processes provide porosity and strength to the dried material. Drying is a complex action of heat and mass transfer with several other physical and chemical transformations, which significantly impact the quality and other factors of the sample. In the food industry, it is used to increase the shelf life of food; hence food is easily transported and handled. It also ensures the safety of food items. The traditional drying methods have disadvantages such as excessive energy consumption, reduced moisture diffusivity, and extended heating time. To overcome the drawbacks, foam-mat drying can improve efficiency

by minimizing thermal degradation as liquid water is removed, thus providing stability and reduced processing time (Thuy et al., 2022).

a) Foam mat drying

Foam mat drying involves the conversion of liquid foods into stable foam and is found suitable for drying heat-sensitive, high sugar content and viscous fluids, which cannot be dried easily (Qadri et al., 2020a). A considerable amount of air and a foaming agent and stabilizer are incorporated. Foam mat drying can dry those samples that are not easily dried; moreover, it is a cheaper and more accessible operation.

b) Hot air oven drying

It is a convective drying which is done in a hot air dryer at a specific temperature. The sample is kept for a few hours to remove its moisture. It is also used to kill certain microorganisms and bacteria. It is used to dry the sample at a uniform temperature. A hot air oven is also used for sterilisation and works on the principle of conduction, convection and radiation. Heat is circulated inside the oven with the help of fans and spread evenly inside the chamber. This process is easy to operate and economical.

Applications

- Food industry: Drying of grains, nuts, seeds, and baked goods.
- Textile industry: Drying of fabrics, yarns, and fibres.
- Paper industry: Drying of paper sheets and pulp.
- Industrial applications: Drying of coatings, paints, and chemicals.

c) Vacuum drying

To dry heat-sensitive products, vacuum drying is done in a vacuum oven. The sample is kept at a certain temperature, and pressure is given. It is an ideal method to dry oxygen-sensitive materials. It can be done at a lesser temperature. This kind of drying is done in various industries such as food, pharmaceutical, plastic, chemical etc.

Applications

- Food industry: Preservation and drying of fruits, vegetables, herbs, spices, and dairy products.
- Pharmaceutical industry: Drying of sensitive drugs, herbal extracts, and pharmaceutical intermediates.
- Chemical industry: Drying of heat-sensitive chemicals, polymers, and speciality chemicals.
- Electronic industry: Removal of moisture from electronic components to prevent corrosion and maintain performance.
- Laboratory and research applications: Drying and preservation of samples anddelicate materials.
- Wood and furniture industry: Drying of timber, veneers, and wooden products.

d) Microwave drying

Microwave drying is a fast drying method with uniformity. In this kind of drying, moisture is turned into vapours with the help of heat. It can also improve the quality of drying foods. It has the advantage of high heat conduction inside the material to be dried.

Applications

- Food industry: Rapid drying of fruits, vegetables, herbs, and snacks.
- Wood industry: Drying of wood and lumber.
- Pharmaceutical industry: Drying of herbal extracts and pharmaceutical intermediates.
- Polymer industry: Drying of polymer resins and materials.
- Laboratory and research applications: Quick drying of samples and solvents.

2. Review of Literature

Syzygium cumini originated from India and Indonesia and is now grown in Southern Asia and Pacific lands. The shape of the fruit is ovoid to oblong, colour varies from dark purplish to bluish. It has juicy pulp and seeds in it. Ripe fruit can be eaten as it is or can be processed to make jam, jelly, vinegar, pickles etc. On average, the edible part of the fruit accounts for 75% of the total fruit weight. This edible portion has a moisture content of 83.7%, a fat content of 0.3%, a crude fibre content of 0.9%, a protein content of 0.7%, a carbohydrate content of 14%, and an ash content of 0.4% (Kumar et al., 2023).

In *Syzygium cumini,* many bioactive compounds are present, such as lipids, tannins, phenols, flavonoids, alkaloids etc. These bioactive compounds have various pharmacological effects, such as cardioprotective, hepatoprotective, anti-inflammatory, and anti-allergic (Arya et al., 2018). *S. cumini* fruit has more antioxidants when compared to other fruits such as banana, guava, papaya etc. It has been found that the *S. cumini* fruit has 79.21% moisture content, whereas the seed contains 52.24% moisture. Higher amounts of polyphenols are also found in *S. cumini* seed and pulp, accounting for 203 & 306 mg GAE/ 100g, respectively (Ghosh et al., 2017). Polyphenols are bioactive compounds which are used to neutralize free radicals in the body. Nutritive values of *S. cumini* have been exclusively studied on pulp and seeds. It is a good source of pectin, phenols, anthocyanin, proteins, sugars, iron and vitamin C.

Table 1- Bioactive compounds of *S. cumini*

Bioactive Compound	**Function/Health Benefits**
Anthocyanins	Antioxidant, anti-inflammatory properties
Polyphenols	Antioxidant, anti-inflammatory properties
Flavonoids	Antioxidant, anti-inflammatory properties
Carotenoids	Antioxidant, eye health benefits
Ellagic Acid	Antioxidant, potential anticancer effects

Gallic Acid	Antioxidant, antimicrobial properties
Tannins	Antioxidant, potential anticancer effects
Quercetin	Antioxidant, anti-inflammatory properties
Kaempferol	Antioxidant, potential anticancer effects
Myricetin	Antioxidant, anti-inflammatory properties
Vitamin C	Antioxidant, immune support
Vitamin A	Antioxidant, eye health benefits
Calcium	Bone health, muscle function
Potassium	Blood pressure regulation, heart health
Iron	Oxygen transport, energy production

Table 2 – Nutritive value of *Syzygium cumini*

pH	4-5
Total protein (%)	0.53-0.85
Total sugars (%)	8.43-14.31
Reducing sugars (%)	5.7-9.85
Non reducing sugars (%)	8.35-8.58
Vitamin c (%)	10.70 – 29.52
Fats (%)	0.15-0.27
Carbohydrates (%)	14.0
TSS (%)	9.0-18.6
Thiamine (mg)	0.120
Niacin (mg)	0.2-0.29
Iron (mg)	0.8-1.2
Sodium (mg)	26.2-34.1
Copper (mg)	0.23
Magnesium (mg)	4-35

S. cumini has bioactive compounds, which are secondary metabolites mostly produced naturally in the growing phase. These naturally producing secondary metabolites arise from microorganisms, plants, animals and marine.

2.1 Anthocyanins

Anthocyanins are coloured pigments (blue, red, purple, yellow) in the phenolics present in fruits and vegetables having antioxidant properties. A total of 77 anthocyanins have been found, while five were found to be with pure standards in plums (Ali et al., 2022). Anthocyanin content is measured through the pH differential method, which is based on the conversion of structure with a change in pH (Maran, Sivakumar, et al., 2014). Major anthocyanins of *S. cumini* are malvidin, petunidin, delphinidin, peonidin, and pelargonidin. Anthocyanins are considered very important due to their health benefits and other antioxidant properties.

- **Structure**

Marquart, in 1835 gave the term anthocyanin, which is derived from two Greek words that are Anthos - flower and Kyanos - blue. Sir Robert Robinson and Professor Richard Willstatter were awarded the noble prize for their notable work with anthocyanins. Anthocyanins possess a fundamental structure referred to as the flavonoid backbone, which comprises two aromatic rings labelled A and B, connected by a heterocyclic ring denoted as C (Ongkowijoyo et al., 2018). This flavonoid backbone serves as the central structure of the anthocyanin molecule. Glycosylation is a common occurrence in anthocyanins, where one or more sugar molecules are attached to the flavonoid backbone. This process of glycosylation allows for the addition of sugars at different positions within the molecule, leading to various types of anthocyanins with distinct characteristics. The incorporation of sugar molecules into anthocyanins affects their solubility in water, stability, color, and bioavailability. It is important to note that the structure of anthocyanins can differ based on the specific type and plant source, as various

substitutions and modifications on the flavonoid backbone contribute to the diverse range of anthocyanin structures observed in plants. The specific sugar moieties attached can vary among different anthocyanins. Common sugar groups include glucose, galactose, and xylose. Anthocyanins can have various substitutions, which can occur on the rings or side chains of the molecule. Anthocyanins are flavonoids with a $C_6C_3C_6$ carbon group. Its basic structure is 2-phenylbenzopyrylium of flavylium salt. They are the salts of polymethoxy and polyhydroxy-derived glycosides.

- **Health benefits**

Anthocyanins have emerged as important nutraceuticals due to the oxygen atoms' positive charge, which is believed to show higher antioxidant properties. They have a role insubsiding chronic and degenerative diseases. They also have a role in curing diseases like cancer, visual ability and certain viruses. The role of anthocyanins in cardiovascular diseases has been studied in various animal trials. Extraction from coloured cereals revealed that anthocyanins help regulate glycaemic and lipid profiles. They also have a positive impact on cardiovascular and cancerous diseases under in vivo and in vitro conditions. Anthocyanins also play an imperative role in anti-ageing, obesity control, retinal disorders and hepatoprotection (Farooq et al., 2020). Anthocyanins have an effect on the digestive system and are also a diuretic.

- **Bio colorant**

Colour is an important parameter of quality in the food industry. It affects customers' preferences and choices. Biocolorants are usually plant-originated. Anthocyanidins, carotenoids, chlorophyll, and flavonoids are the most preferred biocolourants in the food industry. Anthocyanins offer a wide range of colours, ranging from red and purple to blue. The specific hue depends on the pH of the solution in which they are used. Anthocyanins are utilized as natural colorants in the food and beverage industry to add attractive colours to a variety of products, including juices, candies, jams, yoghurts, and baked goods. Anthocyanins also find

applications in the cosmetic and pharmaceutical sectors for coloring cosmetic products, pharmaceutical tablets, and capsules. The shift towards natural color trends in the food industry is driven by several advantages, including enhanced food safety, improved nutritional value, and enhanced sensory properties (Nabi et al., 2023).

2.2 Extraction

The extraction of bioactive compounds plays a significant role in manufacturing phytochemical-rich products. The extraction methods commonly used for anthocyanins from plant material are not specific and result in pigment solutions containing significant quantities of other compounds, such as sugars, sugar alcohols, organic acids, amino acids, and proteins (Jampani et al., 2014). Due to the negative effects of synthetic colors, it becomes important to develop an efficient method for the extraction of biologically active compounds that provide the potential to make natural colorants. Anthocyanins are becoming popular and potential plant-based colorants. Hence, determining the exact temperature, time, and solid-liquid ratio is crucial to obtain the maximum yield. Anthocyanins, when subjected to high pH and heat, degrade easily. There are various extraction methods being used. Conventional solvent extraction is an economical and traditional method for extraction. Conventional solvent extraction is a well-established technique for extracting bioactive compounds, including anthocyanins. It has been widely used and studied in various applications, providing a reliable and robust approach for anthocyanin extraction. The polar nature of anthocyanin molecules enables their extraction using various polar solvents such as acetone, methanol, water, and alcohol, allowing flexibility in choosing the most suitable solvent based on the target anthocyanins and desired extraction efficiency. The solvents penetrate the plant material, dissolve the anthocyanins, and extract them effectively, resulting in a high extraction yield. It is generally a cost-effective method compared to more advanced extraction techniques. The

equipment and materials required for this method are readily available and affordable, making it a practical option for anthocyanin extraction from S. *cumini* on both laboratory and industrial scales. It minimizes the risk of anthocyanin degradation or modification during the extraction process, ensuring the retention of their structural and functional properties. Extraction is carried out using acidified alcohols such as methanol, ethanol, acetone, and glycerol. Methanol is found to give maximum recovery of anthocyanins than ethanol (Johnson et al., 2020). Also, in a study conducted by Sasikumar et al. (2021), of all the solvents tested for anthocyanin extraction, the methanol extract displayed the highest concentration of anthocyanins.

The conventional agitated bed extraction method was performed in an incubator shaker. The agitation helps in maximizing the contact between the solvent and the fruit pulp, facilitating the efficient extraction of anthocyanins. The extraction process is typically carried out at controlled temperature and time conditions to optimize the yield and quality of the extracted anthocyanins. It was done for at least 2 hours and then filtered with Whatman filter paper.The sample was stored in a refrigerator. 58.92 to 284.09 mg C_3G $100g^{-1}$ anthocyanin was observed in agitated bed extraction (Mattos et al., 2022).

2.3 Drying

The effect of the drying technique applied plays a massive role in anthocyanin extraction from *Syzygium cumini*. Anthocyanin is sensitive to degradation hence there is a need to impose stringent demands on it. Drying makes it more stable and can provide more anthocyanin recovery. To obtain more anthocyanin recovery from an extract after the drying process, it's important to consider techniques that minimize degradation and maximize the preservation of these delicate compounds. According to Hardy & Jideani (2017), the main goal of food dehydration is to extend the shelf life of products by minimizing microbial activity and preventing product deterioration. By removing moisture from food, dehydration creates an

environment that inhibits the growth of microorganisms and helps maintain the quality of the product for a longer period.

In a study by (Eliasson et al., 2017), a higher proportion of anthocyanin was observed in the microwave and hot air drying. Grape was dehydrated at different temperatures after doing foam mat drying, and it was found that 70°C is a suitable temperature at which most anthocyanin is recovered. At 80°C, it was found that drying time was the least (Tavares et al., 2019).

2.3.1 Foam mat drying

Foam mat drying is an alternative method employed for removing water from liquid materials and pureed substances. It involves the creation of a stable foam by incorporating an edible foaming agent and whipping the liquid material. The foam is then spread onto a sheet or mat for drying. To optimize foam stability and drying efficiency, different additives such as methylcellulose (0.25% to 2%) and egg white (3% to 20%) are commonly utilized. These additives can be used alone or in combination to improve the effectiveness of the foam mat drying process. This technique is particularly suitable for drying heat-sensitive, viscous, or sticky products that cannot be efficiently dried using other drying methods (Hardy & Jideani, 2017).

2.3.1.1 Theory of foam formation

As described by Eisner et al. (2007), foam is a complex system found in food and beverages that consists of two distinct phases: the dispersed phase (gas bubbles) and the continuous phase (liquid). These phases are separated by a thin liquid layer known as the lamellar phase, which forms the walls of the bubbles. In food and beverages, foam is composed of a combination of gases, liquids, solids, and surfactants, which play a crucial role in stabilizing the foam structure and maintaining its integrity. Foams consist of gas bubbles that are surrounded by a structure

called the plateau border. This film acts as a boundary between the bubbles and provides stability to the foam by preventing the bubbles from collapsing or merging with each other. Proteins and surfactants play significant roles in influencing the texture and stability of foams. They contribute to the retention and improvement of foam stability. Surfactants have the ability to migrate rapidly towards thinner regions of the bubble walls, known as the lamella. On the other hand, proteins bind to the interface between the gas and liquid phases, interacting with the lamella through various forces such as electrostatic or hydrophobic interactions, hydrogen bonds, or covalent linkages. These interactions help in enhancing the stability of the foam structure. Indrawati et al. (2008) suggested that foams are inherently unstable due to thermodynamic factors, but the addition of surface-active agents like proteins provides kinetic stability during foaming. Proteins lower surface tension, facilitating foam formation and stabilizing the system by altering the forces between foam bubbles. They also improve interfacial rheology, enhancing the resistance to bubble collapse and maintaining the foam structure.

2.3.1.2 Effect of FMD on TMAC

The effect of foam mat drying on the concentration of total anthocyanins in plant-based foods was studied. The findings showed that an increase in egg white and methylcellulose concentration led to a decrease in total anthocyanin content, likely due to a dilution effect. However, an increase in drying temperature from 50 to 65 °C resulted in an increase in total anthocyanin level, attributed to a shorter drying time that exposed the compounds to heat for a shorter duration. On the other hand, a further increase in temperature from 65 to 80 °C caused a decrease in total anthocyanin content, likely due to the thermal degradation of anthocyanins, as temperatures above 65 °C were found to be detrimental to these compounds (Reis et al., 2021).

Djaeni et al. (2018) concluded that with Roselle extract, drying was effectively carried out using ovalbumin and glycerol monostearate as the foaming agent and foam stabilizer under different drying air conditions. The results indicated that the drying time of the roselle extract with the foaming agent was three times faster compared to conventional drying without foam. Moreover, the drying time decreased with higher air temperatures and lower air relative humidity. These conditions allowed for the retention of antioxidant activity and color in the dried roselle extract. Nine anthocyanins were detected in *S. cumini* and then dehydrated. Juice extraction leads to 40% more degradation of anthocyanin than fruit with FMD. When drying time was compared, it was found that at 80°C, 32% of anthocyanins were degraded.

2.3.2 Hot air oven foam drying

Hot air oven foam drying is a specific technique that combines foam formation with the use of a hot air oven for the drying process. In this method, a foam is created using a suitable foaming agent, and the foam is then spread out as a thin layer on a tray or surface. The tray is then placed inside a hot air oven, where the foam undergoes drying. The hot air circulating inside the oven removes moisture from the foam layer. The heat accelerates the evaporation of water or solvent present in the foam, leading to the drying of the foam.

A study conducted on bananas by Sankat & Castaigne (2004) concluded that the drying process of banana foam mats was significantly influenced by the foam's physical properties, specifically its density and thickness. Increasing the air temperature notably decreased the drying time, even at higher temperatures of 75 °C and 90 °C. However, the airflow conditions and sugar content of the foam mats obtained through osmotic pre-treatment did not have a significant impact on the drying process. Forced convection conditions were found to be more effective than natural convection for drying the foam mats.

Hot air oven foam drying offers advantages such as controlled drying conditions, uniform drying, and the ability to preserve the structure and properties of the foam. It is used in various

industries, including food, pharmaceuticals, and cosmetics, the production of powdered ingredients, dried products, and stable foams with specific functionalities. The drying temperature used in hot air oven foam drying can vary depending on the specific application and the characteristics of the material being dried. Typically, the drying temperature for hot air oven foam drying falls within the range of 40 °C to 100 °C. However, the exact temperature setting may be adjusted based on factors such as the desired drying rate, the moisture content of the foam, and the thermal stability of the foam or the compounds it contains. It is important to carefully control and optimize the drying temperature to ensure effective drying while minimizing the risk of over-drying or thermal degradation of the foam or its components.

Tavares et al. (2019) conducted a study on grape juice where after determining the foam formulation, the foam was dehydrated using hot air at three different temperatures: 60 °C, 70 °C, and 80 °C. The resulting powdered products were obtained in approximately 6.25 ± 0.25 hours at 60°C, 3.17 ± 0.29 hours at 70°C, and 2.67 ± 0.24 hours at 80°C. As the temperature increased, the drying time decreased. Specifically, compared to the drying time at 60°C, the mean drying time at 70°C was reduced by approximately 39%, while the drying time at 80°C was reduced by approximately 52%.

2.3.3 Vacuum oven foam drying

Vacuum oven foam mat drying is a specific method that combines foam formation with the use of a vacuum oven for the drying process. This technique involves the creation of a foam using a suitable foaming agent, followed by spreading the foam as a thin layer on a tray or surface. The tray with the foam is then placed inside a vacuum oven, where the drying process takes place under reduced pressure.

In a study conducted by (Sramek et al., 2015), foamed tomato paste formulation was subjected to vacuum drying and it concluded that rapid vacuum drying at 50 °C yielded the highest

retention of color and carotenoids compared to other drying methods. Vacuum foam drying is advantageous over convective air drying due to reduced carotenoid degradation, isomerization, and color changes. Elevated temperatures and higher oxygen exposure during convective air drying tend to result in greater degradation and changes. In contrast, vacuum foam drying enables the production of high-quality tomato powders with maximum retention of nutritional content and visual appeal.

2.3.4 Microwave foam drying

Microwave foam mat drying refers to the process of using a microwave oven to remove moisture from a foam mat. It involves placing the foam mat inside the microwave and utilizing its heating capabilities to speed up the drying process. In an experiment conducted by Qadri & Srivastava (2017), the study examined the drying process and quality of guava powder dried using a microwave foam mat technique. In this method, a foam was created using 8% egg albumin as the foaming agent, and the foamed guava pulp was then dried using microwave power levels of 480W, 560W, 640W, 720W, and 800W. The thickness of the foam was varied at 3mm, 5mm, and 7mm. The utilization of microwave-assisted foam mat drying for guava powder production significantly reduced the drying time and improved the quality of the final product.

Zheng et al. (2011) did foam mat drying on household microwave, and the analysis and optimization of parameters for microwave-assisted foam mat drying (MAFM) were conducted for the dehydration process of blackcurrant pulp. The parameters studied included microwave power, pulp load, drying time, and pulp thickness. Increasing the microwave power and reducing the pulp load were found to expedite the dehydration process of blackcurrant pulp using microwave foam mat drying (MFMD). Additionally, the thickness of the pulp had a significant positive impact on the content of both vitamin C and anthocyanins in the

blackcurrant pulp. The optimized parameters for MAFM drying of blackcurrant pulp were identified as follows: microwave power of 560 W, pulp load of 65 g, drying time of 8 minutes, and pulp thickness of 4.46 mm. These findings suggest that MFMD shows promise as a potential method for dehydrating blackcurrant pulp.

2.4 Review of characterization

Aqil et al. (2012) conducted a study and discovered that the *S. cumini* pulp powder had a polyphenolic content of 1.15%. However, after enrichment, the polyphenol content increased to 1.77%. Upon hydrolysis, the polyphenol content was reduced to 1.31%. The extracts derived from the pulp demonstrated a scavenging capability of 50% of the DPPH (2,2-diphenyl-1-picrylhydrazyl) compound. Comparatively, the seed extracts of the *S. cumini* fruits exhibited significantly higher FRAP (Ferric Reducing Antioxidant Power) values than the pulp extracts ($P < .001$). The *S. cumini* pulp powder was found to contain 0.54% anthocyanins.

The anthocyanin content in the hot air-dried *S. cumini* powder was found to be 259.89 ± 0.48 mg per 100 g. The hot air-dried *S. cumini* powder exhibited a relatively lower content of total phenols, measuring at 3.67 g gallic acid equivalents (GAE) per 100 g. Furthermore, it displayed a lower antioxidant activity, measured at 83.53%. Throughout the storage period, there was a significant decrease ($p \leq 0.05$) observed in the levels of bioactive compounds and antioxidant activity in both the control and supplemented samples (Kapoor & Ranote, 2016).

Coates (2000) offers an elucidation of the occurrence of functional groups as depicted in FTIR spectra. The infrared spectrum is significantly influenced by the physical state of the sample and the molecular, chemical, and physical environments in which it exists. The formation of an infrared spectrum occurs when electromagnetic radiation is absorbed by a molecule, specifically by certain chemical bonds within the molecule. This absorption happens at frequencies that correspond to the vibrations of those specific chemical bonds. If the infrared

spectrum appears to be uncomplicated, it suggests that the compound being analyzed could be a low-molecular-weight organic or inorganic compound. Examples of such compounds include simple salts with common molecular ions like carbonate, sulfate, nitrate, or ammonium, as well as covalent species such as chloroform, dichloromethane, methanol, or water. Another group of compounds that should be noted are simple polymers, including polyethylene and polytetrafluoroethylene. These polymers demonstrate straightforward spectra, particularly when obtained from thin films. Hydrogen bonding is likely present and can be observed in hydrates, aqueous solutions, alcohols, ammonium compounds, amino compounds, and similar systems. Certain inorganic compounds, including hydrated species, can display a combination of broad and very narrow bands in their infrared spectra.

There are some gaps in the literature:

In recent years, plant pigments have been looked at as potential natural food colors in addition to their health benefits. The effect of drying on various quality characteristics has been explored extensively. However, there is a lack of research determining the effect of dehydration on the extraction of anthocyanins from different foods. There is little information on using foam mat drying techniques specifically for the dehydration of *Syzygium cumini* fruit matrices, which may result in a higher recovery of anthocyanins. This study aims to dehydrate the *Syzygium cumini* fruit pulp using the FMD method to assess the effect on the extraction yield of the total anthocyanin content. Further, the extracted anthocyanins will be characterized.

The objectives of our study are as follows:

- To compare the extraction yield of different forms of *S. cumini* pulp (whole pulp, pomace, and juice).
- To study the effect of foam mat drying on the recovery of anthocyanin from *S. cumini*.
- To determine antioxidant and antimicrobial properties of the extracted anthocyanins.

3. Methods

3.1 Extraction based on anthocyanin recovery of pulp, juice and pomace

3.1.1 Sample Preparation

Ripened fruits of *Syzygium cumini* were bought from the local market of Patiala, Punjab, India, whereas the extraction and drying process was carried out at Thapar Institute of Engineering and Technology.

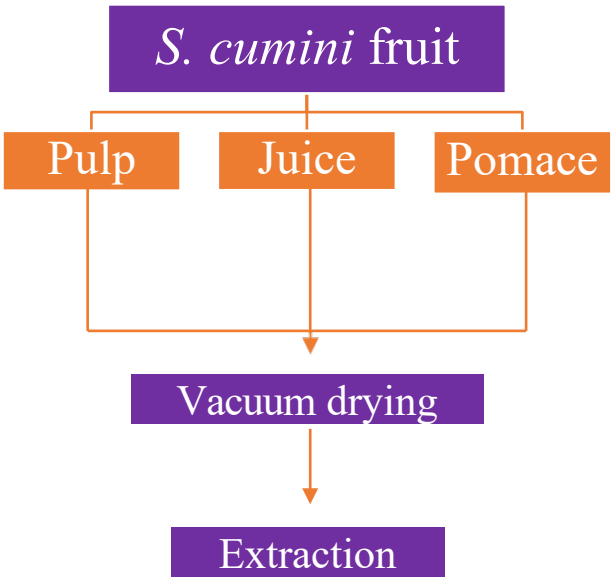

Fig 1: extraction of pulp, juice and pomace

- Blanching – The Fruit of *Syzygium cumini* was washed with tap water at 38°C and dipped in boiling water, followed by cold water. It is done to stop the enzymatic activity. It also helps in removing microorganisms from the fruit's surface.
- Pulping – It is carried out by removing seeds from the pulp. This step is done manually. The pulp was then stored in the freezer refrigerator at -18°C.
- Filtration – The obtained pulp was then divided into two equal parts where on one side, the pulp itself was used for analysis, and on the other hand, the pulp was used to extract juice in the stomacher-homogenizer for 30 minutes, and the remaining pomace was filtered

through muslin cloth with 40 mesh size. So, the fruit's three products (pulp, juice, and pomace) were stored for further analysis.

- Drying – The pulp, juice, and pomace of the *S. cumini* fruit were further dried in a vacuum dryer for 7-8 hours and checked the moisture content. On drying, the pulp, juice, and pomace were ground to powder, sealed & stored in aluminium packs in the refrigerator until further procedure.

Fig 2: Separation of pulp from seeds

• Extraction – The powdered samples were utilized for anthocyanin extraction in an incubator shaker for 2 hours at 37 °C with 100 ml acidified methanol (5% HCl) addition in the sample-to-solvent ratio of 1:20. The extracts were then filtered. Analysis for anthocyanin recovery was then carried out.

Fig 3: Juice and pomace after extraction

3.1.2 Effects of Drying on anthocyanin extraction

Three primary drying techniques were considered for comparison on the basis of their anthocyanin recovery. The drying techniques were combined with the foaming of the powdered fruit sample. Thus, the foam mat drying.

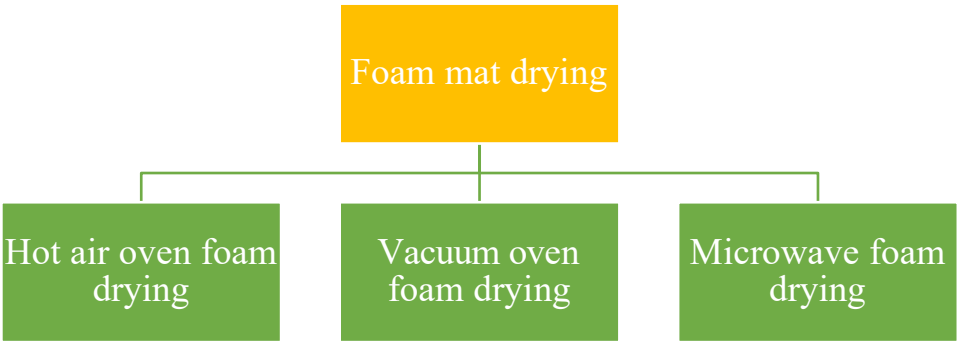

Fig 4: Different drying methods

3.1.2.1 Foam mat drying

- **Preparation of foam**

Foaming of the sample was obtained by making a 50 g slurry from the pulp after blanching and adding 25 ml of distilled water to it. After the slurry preparation, 500 mg (0.75%) methylcellulose was added as a stabilizer and 7.5 g (10%) egg albumin to act as a foaming agent, as suggested by (Kadam & Balasubramanian, 2011). The ingredients were mixed and foamed using a hand mixer. The foam was spread on plates for further drying. A uniform layer of foam was spread all over the plate. According to (Qadri et al., 2020b), it is done to increase the surface of mass transfer and decrease the drying time.

- **Foam characteristics**

As Sahu et al. (2022) suggested, foam possesses different parameters on which it is described.

i. Foam expansion

In this process rise of volume during foaming is checked. During foaming, volume expansion was important to ensure the formation of foam. It was measured by the difference between the initial volume of pulp with the final volume of foam.

$$\text{Foam expansion, FE}(\%) = \frac{V_1 - V_0}{V_0} \times 100$$

Where, V_1 is the final volume of foam

V_0 is the initial volume of pulp

ii. Drainage volume

The stability of foam is important to ensure proper drying throughout the process. The Drainage volume was measured by taking 100 ml of foam in a measuring cylinder and kept in the refrigerator for 24 hours without disturbance. After 24 hours, the volume of foam drained was measured.

$$\text{Drainage volme, DV}(\%) = \frac{V_t}{V_0} \times 100$$

Where, V_t is the volume of foam after 24 hours

V_0 is the volume of foam initially

iii. Foam density

The density of the foam was measured by pouring the foam sample into a 100 ml measuring cylinder without breaking the foam structure. The mass of the foam is measured, and volume was also noted.

$$\text{Foam density, FD}(g/cm3) = \frac{M_s}{V_s}$$

Where, M_f is the mass of foam (g)

V_f is the volume of foam (cm^3)

- **Moisture content**

Moisture content is measured to check the amount of water in the foam present. It was done by keeping 14 g of the sample in Aczet moisture balance MB50. Moisture balance is a device which measures the percentage of water content present in the sample.

Fig 5: Processing of foam

3.1.2.2 Microwave foam drying

The foamed slurry, weighing 14 grams and placed on a Petri plate, was kept at a consistent thickness of 30 mm. The microwave was operated at three different power levels: 180 W, 360 W, and 540 W. The slurry was poured into two separate Petri dishes. The foamed sample was then subjected to microwave treatment, and its weight loss was measured every minute. Additionally, the time taken for the sample to completely dry was noted.

3.1.2.3 Vacuum foam drying

The vacuum foam drying was carried out on two moisture Petri dishes, and a 14 g sample was poured with a 30 mm thickness. Then the temperature of the vacuum oven was set at 50 °C, 70

°C, and 100 °C consecutively. Weight loss was noted after every 15 minutes, total time taken for drying was indicated for all three temperatures.

3.1.2.4 Hot air oven foam drying

The foaming sample, which weighed 14 g and had a thickness of 30mm, was placed on a moisture plate. It was then subjected to consecutive temperature levels of 50°C, 70°C, and 100°C in a hot air oven. During this process, the plates were left in the oven, and weight loss measurements were taken every 15 minutes. Additionally, the total drying time was recorded after the sample had completely dried. All the dried samples were then cooled in a desiccator. The dried sample was scraped from the dishes, powdered, sealed, and stored for anthocyanin extraction.

3.1.3 To determine antioxidant and antimicrobial properties of the extracted anthocyanins.

The foam-mat dried sample was then further analyzed for its anthocyanin recovery to compare the effect of different drying methods applied. Other tests will also be conducted, such as phenolic content, antioxidant, and antimicrobial assays.

3.1.3.1 Total Anthocyanin content (TAC)

The extract was quantified for its anthocyanin content with the pH differential method (Maran, Sivakumar, et al., 2014). The extract (1ml) was mixed with 4ml sodium acetate (pH 4.5) and 4ml potassium chloride (pH 1.0) separately. The mixtures were equilibrated for 1 hour, and absorbance was observed at 520 and 700nm.

$$A = (A_{520} - A_{700})_{pH\ 1.0} - (A_{520} - A_{700})_{pH\ 4.5}$$

$$TAC = \frac{A \times MW \times DF \times 1000}{\epsilon \times 1}$$

Where, A - absorbance, MW- molecular weight, DF- Dilution factor, ϵ - molar absorptivity of cyanidin-3-glucoside.

3.1.3.2 Total extract yield (TEY)

The total extraction yield was calculated by weighing three petri plates separately, and a 10ml sample was added to each petri dish. They were kept in a hot air oven for 2 hours for solvent removal. After 2 hours, the dishes were again weighed (Swer et al., 2018). Subtracted the initial weight and final weight of the dishes to obtain the total extract yield.

$$\text{Totalyield}(\%\text{drybase}) = \frac{\text{extractweight}}{\text{weight of the sample}} \times 100$$

3.1.3.3 Total phenolic content (TPC)

In the 0.2ml diluted sample, 25ml folin-ciocalteau reagent was added. Incubated the mixture for 5 minutes at room temperature. After incubation, added 2 ml of sodium carbonate (7.5g/100 ml). Then the solution was mixed and incubated for 2 hours at room temperature. The absorbance was measured at 754 nm against distilled water as blank. On plotting the gallic acid curve, total phenolic content was calculated. To prepare a standard curve for gallic acid, a stock solution was made using 100 mg of gallic acid in methanol. Seven different dilutions were prepared by adding distilled water to gallic acid. Added 5 ml folin reagent and 4 ml sodium carbonate in all the test tubes. The sample was incubated at 20 °C for 30 minutes, and absorbance was noted at 754 nm. C value was calculated after plotting the Excel.

3.1.3.4 Antioxidant assay - DPPH (1,1-diphenyl-2-(2,4,6-trinitrophenyl) hydrazine)

Free radical scavenging activity for *S. cumini* was obtained spectrophotometrically against DPPH. In the 0.1 ml diluted sample (1:4), added 3.9 ml of methanolic DDPH. The sample was allowed to stand for 30 minutes at 37 °C in the dark. The absorbance was measured at 517nm against methanol as blank. The test was performed in triplicates recommended by (Swer et al., 2018).

$$\text{DPPH}(\%) = \left(\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}}\right) \times 100$$

3.1.3.5 Antiradical assay - FRAP (ferric reducing antioxidant power)

FRAP assay was conducted according to the method given by Zannou & Koca, 2022). FRAP reagent was made with acetate buffer (300 mM, pH 3.6), TPTZ (0.031 mg in 10 ml of 40 mM HCl), and ferric chloride (20 mM) in a 10:1:1 ratio. In the 0.1ml diluted sample (1:100), 3ml FRAP reagent was added. After 4 minutes, the absorbance at 593 nm against FRAP as blank was recorded. The test was performed in triplicates.

3.1.3.6 Antimicrobial assays

- **Antibacterial assay**

The growth of bacteria was checked by the agar diffusion method. In a flask, a 200 ml medium (Luria broth, nutrient broth) was measured. Sterilized the flask with the medium in an autoclave at 121 °C for 15 minutes. In each flask, a bacterial sample was grown for 24 hours, and Agar plates were prepared on the other hand. On every plate, grown bacterial culture was spread 100 microliters each. Wells were made on each plate, and an alcoholic *S. cumini* sample was added. A control was prepared with ampicillin as positive control and DMSO as negative control. Then it was incubated for 24 hours, and the zone of inhibition was measured.

- **Antifungal assay**

In 3 flasks, 200 ml potato dextrose broth was made each and kept in an autoclave for 15 minutes at 121 °C. In each flask, fungal samples (3 different fungi were taken) were added and kept in a growth room for a few days. In PDA sterile plates, a molten medium was added. The fungal sample was spread on each plate. Wells were made, and poured 20 microliters of anthocyanin with DMSO (100 mg/ml) to it. The control PDA plates were prepared with fungal culture and allowed to diffuse. The plates were incubated for a few days, and the diameter was measured (Salamon et al., 2021).

$$I = \left[\frac{C - T}{C}\right] \times 100$$

Where, I is inhibition (%), C is the colony diameter of the mycelium on the alcoholic control plate (mm), and T is the colony diameter of the mycelium on the test Petri plate (mm).

4. Results and Discussion

4.1 Extraction of juice, pulp, pomace

Syzygium cumini fruit was extracted to obtain juice, pulp and pomace. Samples were dried at 70°C in a vacuum oven. It was found that 500g of fresh pulp yielded 32g of powder. A separate 500g fresh pulp was filtered to obtain juice and pomace, and after drying, 18.95g juice powder and 14g pomace powder were recovered.

The extraction process involved a solid-to-liquid ratio of 1:20, the addition of 5% HCl, and a temperature of 37°C in an incubator shaker. The extraction duration ranged from 30 to 60 minutes. Das et al. (2023) conducted an extraction of bioactive compounds from *S. cumini* using the traditional agitated bed method. The predominant compounds obtained from this method were anthocyanins and flavonoids, which are known to have beneficial properties.

When anthocyanin yield was compared after extraction, pulp had the maximum anthocyanin compared to juice and pomace. It was observed that juice had minimum anthocyanin recovery with 221.12±4.85 mg/100g fresh weight as compared to pulp 329.72±4.1mg/100g fresh weight) and pomace (300.80±17.14mg/100g fresh weight), which could be because when a sample is filtered with a muslin cloth, pomace is left on the cloth and juice is filtered out, pigment gets separated into two and hence, loss in recovery. Pulp typically contains more anthocyanins than juice and pomace due to the higher concentration of these compounds in the pulp. When fruits are processed, such as during juicing, the anthocyanins present in the fruit are released into the liquid phase. However, some of these compounds may remain trapped in the solid parts, such as the pulp or pomace. While juice extraction can yield a clear liquid, it may have a lower concentration of anthocyanins compared to the original fruit. On the other hand, pulp retains a significant amount of the fruit's solid content, including the anthocyanin-rich tissues. Therefore, when the pulp is extracted or separated from the juice, it contains a

higher concentration of anthocyanins. This is a primary cause that pulp is often considered a valuable source of these compounds. While pomace can still contain some residual anthocyanins, its concentration is generally lower compared to the original pulp. Additionally, the extraction process used for obtaining juice can further reduce the anthocyanin content in pomace.

A study conducted by de Carvalho et al. (2017) suggested that the extracted juice contained only 40% of the total anthocyanin content found in the *S. cumini* fruit. Past research on pasteurized *S. cumini* (jambolana) pulp indicated reductions in anthocyanin content of approximately 8.5% (Branco et al., 2016). According to Kaur et al. (2022), the pomace contains substantial quantities of beneficial bioactive compounds, minerals, and antioxidants. However, once the juice has been extracted, the pomace typically loses its value for the processors (figure 10).

The temperature should be optimized at a lower degree because a certain temperature will cause softening of plant tissues, which will stimulate the movement of molecules and penetrates the solvent into the plant tissue. Hence, solubility and diffusivity increase the extraction yield, which is not possible at a higher temperature because anthocyanins are heat-sensitive pigments, as suggested by (Maran, et al., 2014).

Fig 6: Pulp, juice, and pomace after extraction

Total anthocyanin was calculated for all 3 samples (figure 11) by the pH differential method, and it was found that pulp had most of the anthocyanin.

Table 3: TAC of pulp, pomace, and juice

Pulp	329.72±4.1mg/100g fresh weight
Juice	221.12±4.85mg/100g fresh weight
Pomace	300.80±17.14mg/100g fresh weight

4.2 Effects of Drying on anthocyanin extraction

Syzygium cumini was dried by converting it into foam and then three different drying techniques at different temperatures and power. The foam was given hot-air assisted foam mat drying, Vacuum-assisted foam mat drying, and Microwave-assisted foam mat drying. Hot air oven drying and vacuum drying were done at 50°C, 70°C, and 100°C, microwave drying was done at 180 W, 360 W, and 540 W. Foam mat thickness was maintained at 3mm, and weight was 14 g in each plate having 10 cm diameter. Drying was continued until less than 10% moisture content was left in the sample. The overall optimization was done to get the maximum recovery of anthocyanin after extraction. Foam mat drying is an efficient method of drying because due to more surface area-to-volume ratio and pores present in foam help build mass transfer efficiency and reduce drying time.

Fresh *S. cumini* was taken from the local market of Patiala and was blanched to reduce enzyme activity. The pulp was separated from the seed to make a proper slurry for foaming. As the recommendation given by Kadam & Balasubramanian (2011), foam mat drying was done by taking egg albumin as a foaming agent, and methylcellulose acted as a stabilising agent. The slurry was whipped by a hand blender at high speed of 1500rpm for 10 minutes to make stable foam. Then it was subjected to drying on plates with 3mm thickness. All three drying processes

were done at desired temperature and power for optimization. The dried sample was scraped from plates and kept in the refrigerator at 4 °C for further studies.

Fig 7: Stable foam in plate

Foam characteristics

Foam is a dispersion of gas bubbles within a liquid or solid matrix, resulting in a lightweight and porous material. Foam mat drying is a method used for drying or dehydrating various food products, including fruits, vegetables, and other materials. It involved the formation of a foam layer from a liquid or puree and subsequent drying of the foam to remove moisture. Several parameters played a crucial role in the foam mat drying process:

- Foam expansion

The expansion of foam was described by comparing the volume of *S. cumini* with egg albumin and the volume of foam after whipping, as described by Sahu et al. (2022). A foam expansion of 102.66% foam was achieved with 10% egg albumin. A higher dose of the foaming agent makes more foam expansion. While foaming, foam agents move from the aqueous layer to the air-liquid phase, which may have led to a decrease in surface tension. As the addition of foaming agents increases, higher foam expansion was observed in *S. cumini*.

- Drainage volume

Foams are fragile in nature, they can lose their stability after some time, so there is a need to check the drainage volume of foam as foams can easily drain out even in one minute. As they are delicate, the study of foam becomes difficult. During the drying procedure, the foam should maintain its property in order to maintain its surface area and capillary effect. Whipping for 10 minutes got the stable foam with methylcellulose, which had a positive effect on its stabilization. The drainage volume of *S. cumini* was found to be 91% after 24 hours of keeping it in a refrigerator. The drainage volume of the foam was 9 ml which proved to be highly stable. This is comparatively equal to the experiment performed by Sahu et al. (2022) in which 95.02% was the highest stability in foam.

- Foam density

The density of the foam is another critical parameter. Higher foam density can result in longer drying times, while lower foam density may lead to unstable foam structure. Controlling foam density helps in achieving desired drying characteristics. In the foam mat drying method, the density of the foam is typically influenced by factors such as the use of different foaming aids and the speed and duration of whipping. However, even when the whipping time and speed are kept constant, the foam stabilizer and the amount of pulp present can still impact the foam density. The foam density of *S. cumini*-egg albumin was found to be 0.58g/cm^3, which agrees

with the study of Sahu et al. (2022), which recommends that *S. cumini* foam have 0.3g/cm^3-0.6g/cm^3 foam density.

- Moisture content

Monitoring the moisture content of the foam during drying is essential. It helps in determining the progress of drying and ensures that the final product meets the desired moisture specifications. The ideal moisture content after drying is considered to be 10% - 15%, where 90.708% was the moisture content of foam before drying. The assessment of other properties, process design, quality determination, handling, and packaging of any food material or agricultural produce necessitates knowledge of the moisture-dependent characteristics of the material (Bajpai et al., 2020). The moisture content of foam was determined by a moisture analyser which provides heat to evaporate the moisture from the sample; as the sample gets dried, the balance notes its weight until its equilibrium is attained. The initial weight and weight loss during drying were compared and measured in % (Kowalska et al., 2018).

Three primary parameters (drying rate, moisture content, and total anthocyanin content) were considered to analyse the drying efficiency of all three drying techniques.

a) Hot air foam drying

Hot air foam drying is a drying method that combines the use of a hot air with foam formation to remove moisture from materials. The process involved generating foam by introducing a foaming agent or solution into the material before subjecting it to a hot air oven. Drying was carried out at three different temperatures; 50 °C, 70 °C and 100 °C. The process aimed to produce dried *S. cumini* with improved shelf life and reduced water content.

Drying rate

The drying rate is the time at which the substance or material takes to reduce moisture. In the case of hot air drying, drying weight was taken every 15 minutes; at 100 °C highest drying rate

of 0.18gH_2O/g d.m/min is seen at a minimum time of 100 min, as seen in Fig (15). While in the case of 50 °C, 0.07gH_2O/g d.m/min is the maximum drying rate with 250 min as the drying time. It can be observed that at the highest temperature, the least time is taken, while at low temperature, more time takes place. Similar results were seen in the experiment conducted on bananas by Falade & Okocha (2012), in which temperatures 60 °C to 80 °C were taken and found out that at 70 °C, it took 170 minutes which is near to our results with 130 minutes. Similar results can be seen in Tavares et al. (2019). Extended drying periods in hot air drying can result in significant deterioration of the product's quality characteristics. Paul & Das (2018) suggested that by minimizing the drying duration, it is possible to better preserve the quality attributes of the final product. Hot air drying causes the drying process to occur from the outer surface towards the inner regions of the material being dried.

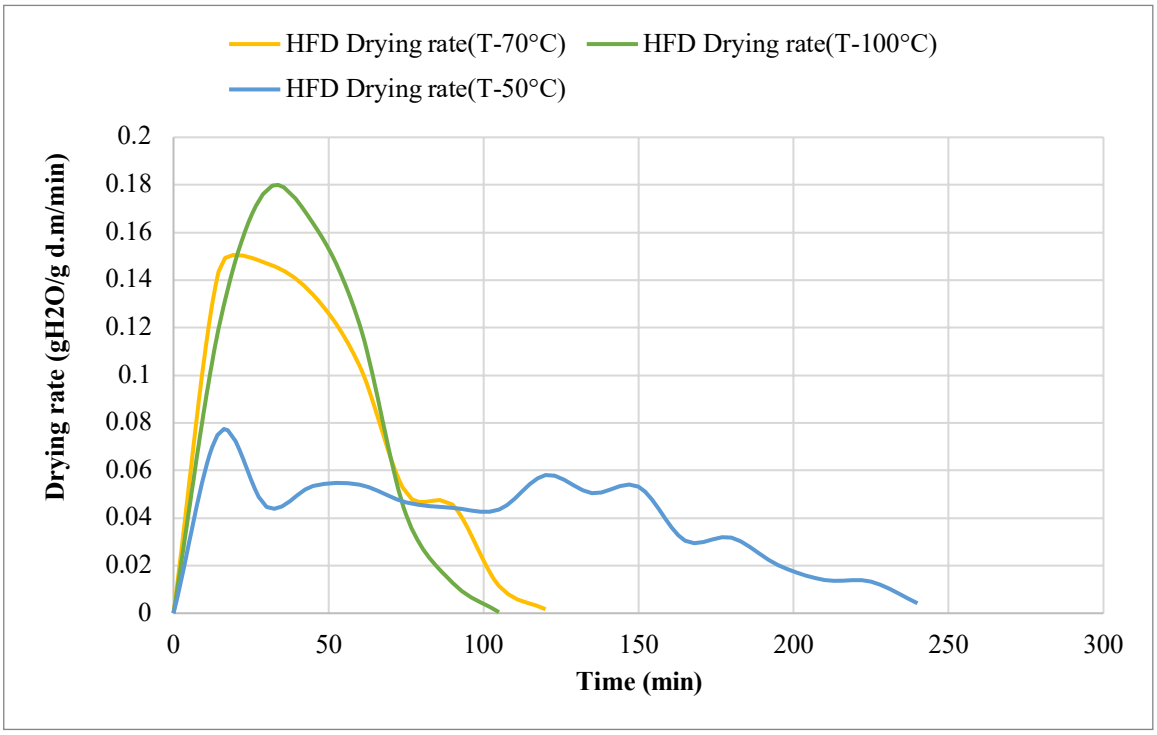

Fig 8: Drying rate of hot air oven foam drying ate 50 °C, 70 °C, 100 °C

Moisture content

Initially, the moisture content decreased steadily. However, as the hot air foam drying (HAFD) process progressed, the rate of moisture removal became slower during the final phase. This was primarily due to the challenges posed by the moisture present in the sample, which hindered its efficient removal. After 90 minutes, 70 °C and 100 °C were almost dried, but 50 °C had 50% moisture content with 4.429 g of H20/g of dry weight in it. According to Pu & Sun (2017), the evaluation of a drying system's performance depends on its capacity to effectively reduce the moisture content of products to a desired level while minimizing any negative impact on product quality.

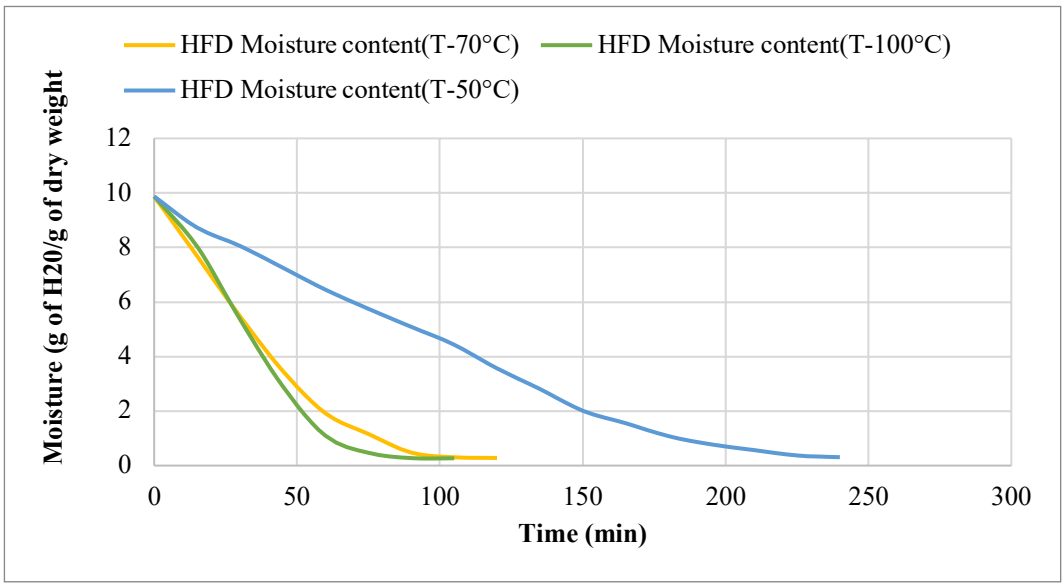

Fig 9: moisture content of hot air foam drying at 50 °C, 70 °C, 100 °C

Total anthocyanin content

Hot air foam drying was used as a method for anthocyanin extraction from various *S. cumini* fruit. Anthocyanin recovery was checked for all three temperatures, and it was found that in the case of lower temperatures, more anthocyanin was recovered with almost 420.41±5.84 mg/100g fresh weight because anthocyanins are sensitive to heat and may degrade or undergo chemical changes at higher temperatures. By using lower temperatures, the risk of thermal degradation or loss of anthocyanin compounds is minimized, leading to higher recovery.

However, recovery of anthocyanins at 100 °C was more than 70 °C this could be because at higher temperatures, lesser drying time takes place and hence, leads to lesser degradation of anthocyanin. A test conducted on a plant-based food material by (Reis et al., 2021) concluded that a hot air temperature of 40 °C – 60 °C yields more anthocyanin.

Table 4: TAC (mg/100g fresh weight) for hot air foam drying

50 °C	420.41±5.84
70 °C	356.23±6.90
100 °C	372.64±12.656

b) Vacuum foam drying

In vacuum foam drying, the material is placed in a vacuum chamber, and the pressure is reduced. This reduction in pressure lowers the boiling point of water, causing the moisture within the material to evaporate more readily. The foam structure allows for better diffusion of moisture from the interior of the material to its surface, facilitating faster and more uniform drying. A vacuum oven operates by utilizing low-pressure conditions to facilitate the drying, heating, or processing of materials. It was done at 3 different temperatures that are 50 °C, 70 °C and 100 °C. A vacuum oven offers controlled low-pressure conditions and precise temperature control, making it suitable for drying heat-sensitive materials or substances that require a specific environment for processing or preservation.

Drying rate

Vacuum drying (VD) is an appropriate method for drying heat-sensitive products. This technique involves removing moisture under reduced pressure conditions. Due to the absence of oxygen, it is particularly suitable for preserving the quality of oxygen-sensitive food materials (Paul & Das, 2018). In the case of *S. cumini*-egg albumin foam drying vacuum oven was used at pressure -12 psi, at three temperatures, 50 °C, 70 °C, and 100 °C and drying time

was noted. It was observed that at 50°c and 70°c drying rate was 0.07 and 0.16 gH2O/g d.m/min, respectively. It was also seen that time taken by 70°and 100°c was almost near, but drying rate had a huge difference. However, 50 °C took the highest time with almost 240min. Similar results were seen in the test conducted by Thuwapanichayanan et al. (2008), in which it took 120- 300 minutes for the drying process of bananas.

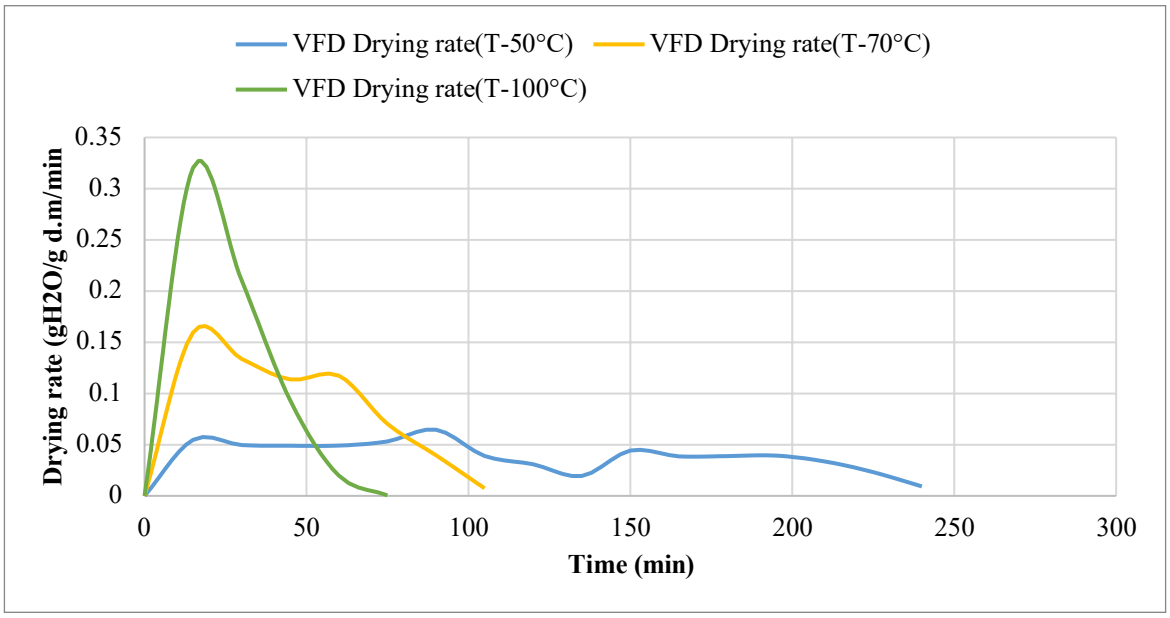

Fig 10: drying rate of vacuum foam drying at 50 °C, 70 °C, and 100 °C

Moisture content

Vacuum drying is a commonly employed method for reducing moisture content in materials. Interestingly, the highest amount of time is required when using the lowest temperature, while the lowest time is needed when employing a temperature of 50°C, followed by 70°C. The difference in time between 70°C and 100°C is minimal, and the corresponding graph reflects this trend, as there is a rapid decrease in moisture content initially, followed by a plateau where no further water loss occurs. On the other hand, when using a temperature of 50°C, the time required to lower the moisture content is the longest, with a gradual decrease observed throughout the process. The vacuum environment plays a crucial role in effectively removing moisture from the material by facilitating foam formation. This process enables efficient

extraction of moisture, leading to a significant reduction in the final product's moisture content. Vacuum drying is a widely utilized technique, offering flexibility in terms of temperature settings.

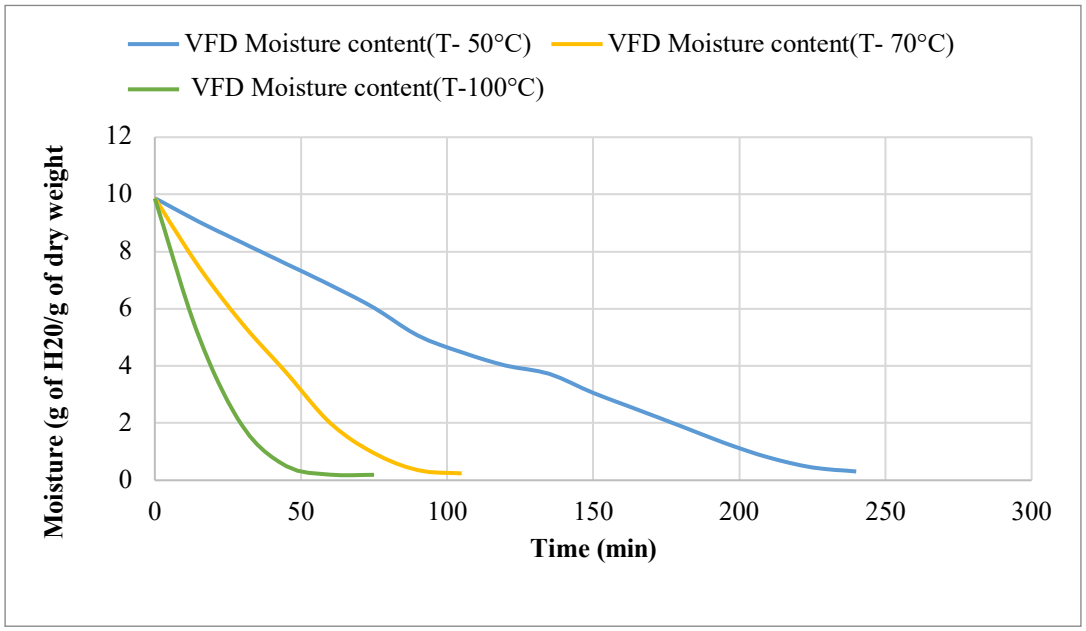

Fig 11: Moisture content in vacuum foam drying at 50 °C, 70 °C, and 100 °C

Total anthocyanin content

Vacuum foam drying is a technique that can be used to extract anthocyanins from plant materials, such as *S. cumini*. This process involves exposing the foam derived from S. cumini to reduced pressure conditions, which aids in the removal of moisture. Interestingly, it has been observed that a higher temperature during the drying process leads to a lower recovery of anthocyanins, with a value of 340.35±1.25 mg/100g fresh weight. Conversely, the highest anthocyanin recovery occurs at lower temperatures. The pH differential method is employed to assess the retrieval of anthocyanins. In a study conducted by de Carvalho et al. (2017), anthocyanin recovery in jambolana foam drying ranged from 155.2 mg/100g to 229.8 mg/100g at temperatures between 60°C and 80°C.

Table 5: TAC (mg/100g fresh weight) for vacuum oven foam drying

50 °C	421.58±5.94
70 °C	413.23±6.93
100 °C	340.35±1.25

c) Microwave foam drying

The microwave foam drying technique for *S. cumini* entails utilizing microwave radiation and foam formation to eliminate moisture from the fruit. Various power settings, such as 180 W, 360 W, and 540 W, are employed in this process. Microwave foam drying is known for its rapid drying speed. The foamed *S. cumini* fruit is exposed to microwave radiation, which generates heat by causing the water molecules present within the fruit to vibrate, resulting in internal heating. The drying process continues until the desired moisture content is attained. The specific duration of the drying process can vary depending on factors such as the initial moisture content of the fruit, the composition of the foam, the microwave power level used, and the desired quality of the final dried *S. cumini* product.

Drying rate

The drying rate during MFMD (Microwave Foam Mat Drying) was quantified as the amount of water lost per minute per gram of dry matter. Therefore, the unit used to express the drying rate was g H_2O/g dry weight. The drying rate of MFMD was done on different powers, that is, 180 W, 360 W, and 540 W. The drying rate was found to be highest at 540W (as shown in the figure 21). In the case of 180 W power, it took almost 30 minutes to dry the foam in a complete manner. On the other hand, only 7-12 minutes were taken by 360W and 540W to dry the foam. As the drying power increases, the drying time reduces to almost 50%. Increasing the inlet air temperature resulted in a decrease in the drying time of the foam-mat. This can be attributed by two factors. Firstly, the drop in relative humidity associated with higher temperatures creates a more favourable environment for moisture evaporation. Secondly, the increased heat supplied

to the system, while maintaining a constant air flow rate, further facilitates the quicker removal of moisture.

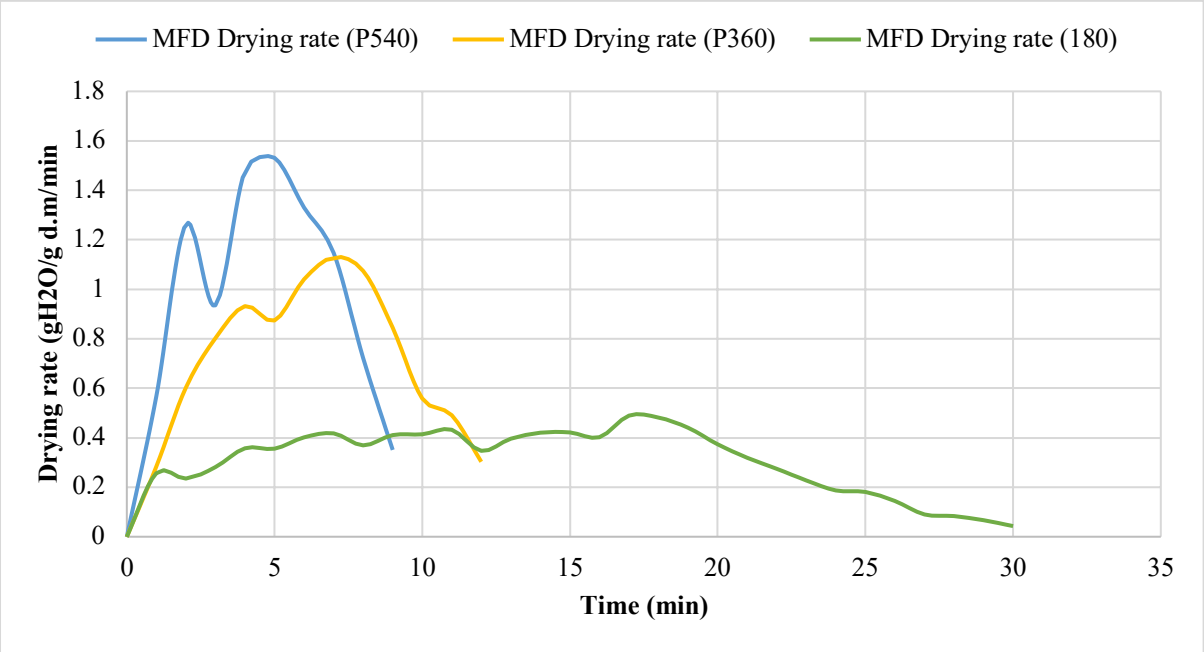

Fig 12: drying rate of microwave foam drying at 180 W, 360 W, 540 W

Moisture content

The drying process of the *S. cumini* pulp foam was influenced by the three selected parameters, namely microwave power, foam thickness, and inlet air temperature, as shown in Figures . These figures demonstrate the impact of foam thickness and inlet air temperature on the moisture content at different microwave power levels of 180W, 360W, and 540W. From the figure, it can be determined that with the decrease in drying time, moisture content also decreases till it attains 0.2g of H_2O/g of d.w. Initially, the moisture content of foam was 10 g of H_2O/g of d.w, it reduced faster in the beginning, but towards the end of the drying process, the curves exhibited a flatter slope, indicating a slower drying rate. The drying time of the foam was significantly influenced by the microwave power. The figures (22) clearly demonstrate that increasing the microwave power from 180 W to 540 W led to a substantial decrease in the drying time of the foam. The taken by 180W to attain 0.1g of H_2O/g of d.w was about 32

minutes, whereas only 10 min were taken by 540W to attain the same moisture level. Similarly, 13 minutes were taken by 360 W to achieve the same moisture level of about 0.1g of H_2O/g of dry weight.

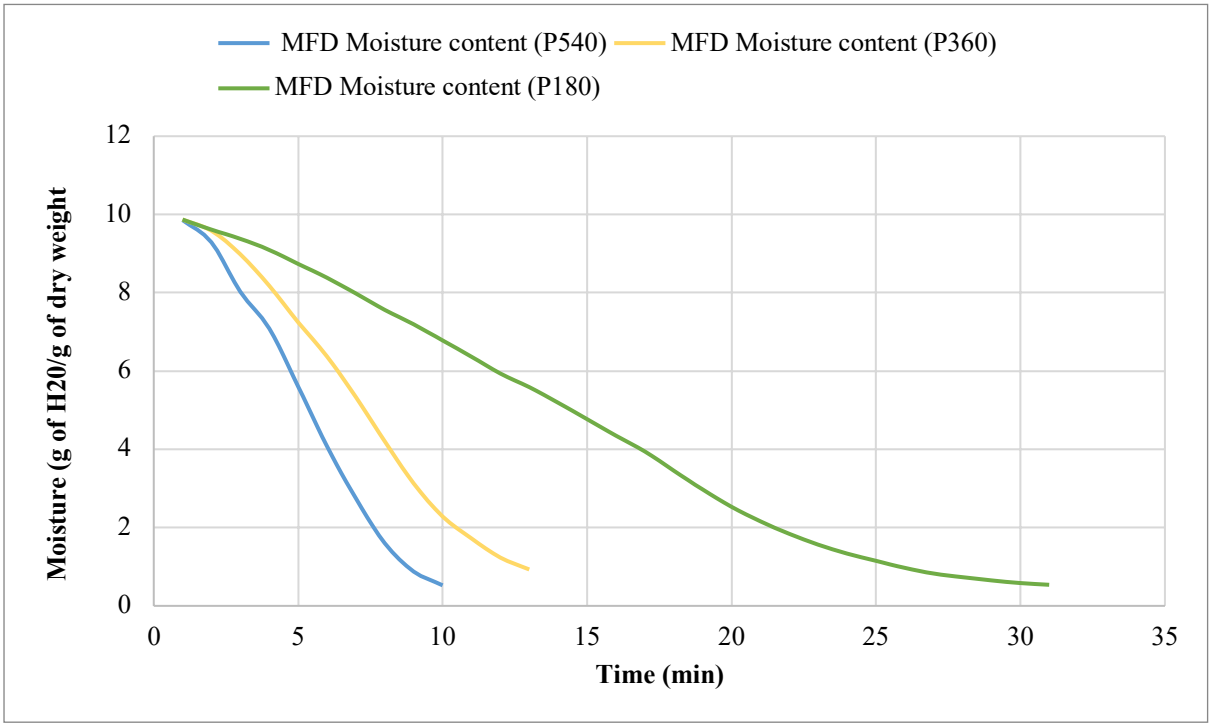

Fig 13: moisture content of microwave foam drying at 180 W, 360 W, 540 W

Total anthocyanin content

The table below illustrates the impact of microwave power on anthocyanin recovery. It clearly demonstrates that lower power levels result in higher anthocyanin recovery. For instance, at 180W power, the recovery was 491.42±6.97 mg/100g fresh weight, while at 360W power, it decreased to 473.4±11.67 mg/100g fresh weight and further declined to 421.58±16.14 mg/100g fresh weight at 540W power. This phenomenon can be attributed to the fact that lower power levels provide a gentler heating process, thereby minimizing the degradation or loss of anthocyanin compounds. Anthocyanins are known to be sensitive to high temperatures and can easily degrade under such conditions. Therefore, by utilizing lower microwave power, the potential for thermal degradation of anthocyanins is reduced, leading to a higher recovery rate.

Furthermore, lower power levels may enable more controlled and gradual moisture removal, thereby contributing to better preservation of anthocyanins. Similar outcomes were reported in an experiment conducted by Sun et al. (2020).

Table 6: TAC (mg/100g fresh weight) for microwave foam drying

180 W	491.42±6.97
360 W	473.4±11.67
540 W	421.58±16.14

Comparative study of all three drying techniques

Drying rates

The drying rates can vary depending on the specific conditions, foam composition, material properties, and equipment used for each drying method. The following data illustrates a comparison of various drying methods using different temperature and power settings. The drying process is being compared on the basis of the lower power of microwave foam drying with the lowest temperature in hot air foam drying and vacuum drying. The figure (24) shows that microwave foam drying with a power of 180 W taking time nearly 30 minutes, whereas the time taken at 50 °C for hot air oven foam drying and 50 °C for vacuum foam drying was almost 240 minutes.

The drying rate of MAFMD with power 180W is huge, with almost 0.5 gH_2O/g d.m/min. In this scenario, the graph initially shows an increase, followed by a period of stability or plateau, and then a subsequent decrease. However, in the case of hot air foam drying (HAFMD) and vacuum foam drying (VFMD), the graph demonstrates a slight increase initially, followed by a relatively constant drying rate over an extended period. An increase of up to 0.07 gH2O/g d.m/min in hot air oven foam drying and 0.06 gH2O/g d.m/min in vacuum foam mat drying

can be seen, also rate of drying kept almost the same in the stability period with little change at 100 minutes and ending drying at the same time.

Fig (25) compares the drying performance of a microwave foam drying method at a power level of 360W with hot air foam drying at a temperature of 70°C and vacuum foam drying also at a temperature of 70°C. Hot air foam drying can be seen taking the highest time with 120 minutes on the other hand, not more than 15 minutes are taken by microwave foam drying with the highest drying at 1.074 gH_2O/g d.m/min, and the highest drying rate of the other two methods is ~ 0.07 gH_2O/g d.m/min. The graphs exhibited an initial increase in slope, followed by a sudden decrease for MAFMD. Both hot air foam drying and vacuum foam drying methods showed a consistent or steady drying period without significant fluctuations.

In Fig (26), the highest drying rate is seen when compared that is 1.53 gH_2O/g d.m/min in 9 minutes of microwave foam drying with power 540W; this is the overall highest rate too in all dryings. Comparing the drying times, we can see that hot air oven foam drying took approximately 105 minutes, while vacuum foam drying took approximately 75 minutes. In terms of drying rates, vacuum drying exhibited the highest peak at 30 minutes with a rate of 0.210 gH2O/g d.m/min. On the other hand, hot air foaming maintained a constant rate of 0.177 gH2O/g d.m/min from 30 minutes to 60 minutes.

Vacuum foam drying generally offers faster drying rates compared to hot air oven foam drying. The low-pressure environment in vacuum drying promotes rapid moisture removal due to the increased moisture gradient and reduced boiling point of water. Microwave drying is considered as superior drying than hot air drying. Microwave heating presents a viable and efficient alternative for rapidly heating food, offering faster heating rates and the ability to achieve uniform temperature distribution without significant temperature differences (Bhagya Raj & Dash, 2021). Microwave drying is known for its high heating efficiency and faster drying

rates compared to conventional methods. The penetration depth of microwaves can promote more uniform heating and faster moisture removal. Therefore, microwave foam drying generally offers a faster drying rate compared to both hot air foam drying and vacuum foam drying.

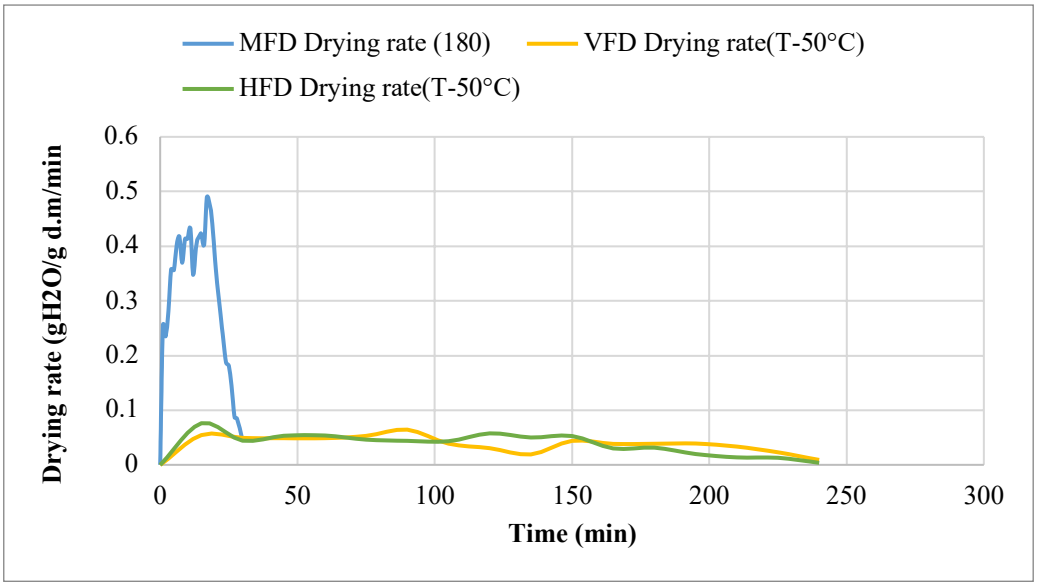

Fig 14: drying rate of all three techniques at 180W and 50 °C

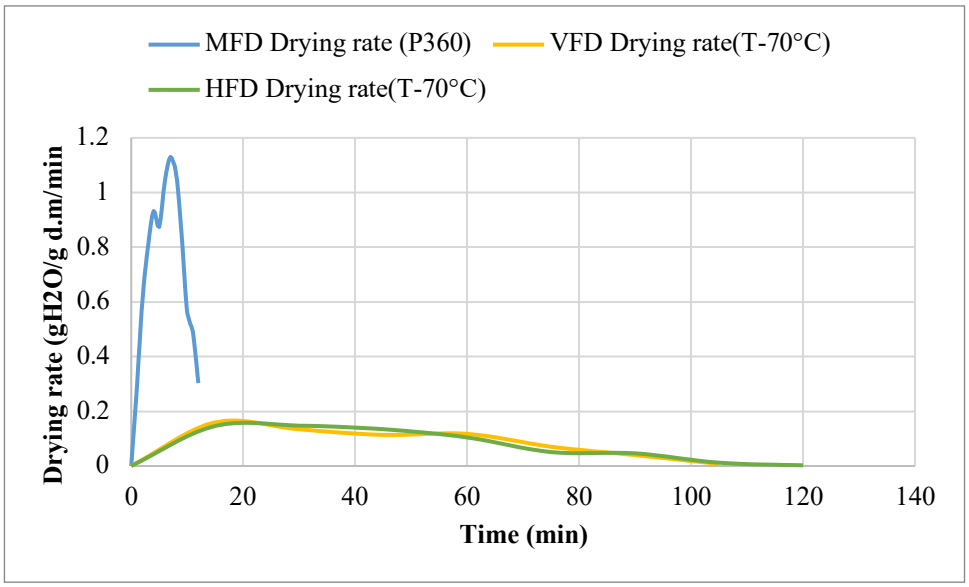

Fig 15: Drying rate of three techniques at 360W and 70 °C

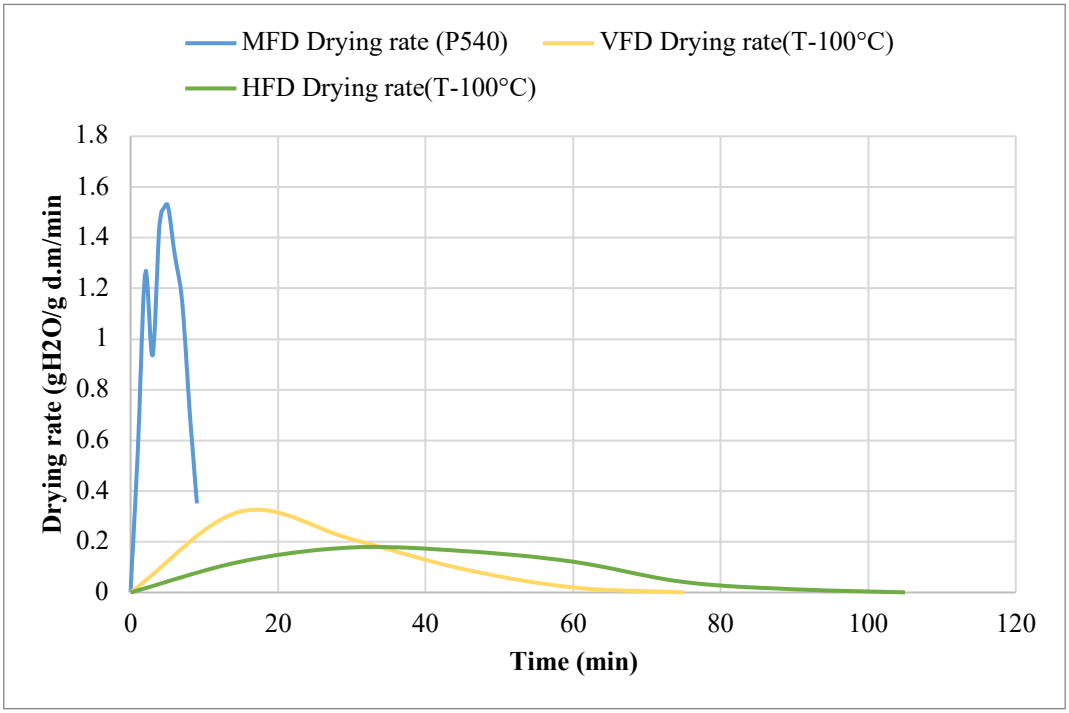

Fig 16: Drying rate of all three techniques at 540 W and 100 °C

Moisture content

The drying of S. cumini pulp- egg albumin had an effect on all three techniques that is microwave-assisted foam drying, hot air foam drying and vacuum foam drying. Moisture content was checked on three different temperatures and power. The lowest power was quantified with the lowest temperature and similarly highest power with the highest temperature. The three graphs below show the comparative study as in fig (27) The drying process resulted in a noticeable decrease in the moisture content of the sample as the drying time advanced. Eventually, the moisture content reached a stable value of 0.58 g H2O/g d.m. .This indicates that further drying did not significantly affect the moisture content of the sample. Similar results were seen in an experiment conducted by Brygidyr et al. (1977) on tomato paste foam.

It can be observed that in all the samples, the moisture content was the same initially, that is, 9.86 g of H_20/g of dry weight, but the time taken for the reduction of water from Hot air oven foam drying was the most with 240 minutes, while microwave foam drying took only 30

minutes. The graph has a constant falling rate. During this period, the drying rate gradually decreases as the moisture content of the material decreases. It signifies that the drying process is approaching completion, and the remaining moisture requires more time and energy to be removed.

In the power 360 W and 70 °C graph (fig 28), it can be determined that it took only 13 minutes for microwave drying to reach its moisture content to 0.92 g of H20/g of dry weight from 9.86 g of H20/g of dry weight. On the other hand, 120 minutes were taken for hot air foam drying and 105 minutes for vacuum foam drying to reach 0.27 g of H20/g of dry weight. In both the dryings, after 80 minutes, moisture removal was stable and was reducing very slowly, which means that very little water was left in the sample to be dried, so it was taking more time to reduce very little moisture. According to the provided figure (29), the drying times for hot air foam drying and vacuum foam drying at 100°C were 105 minutes and 75 minutes, respectively, until reaching a moisture level of 0.46 g of H2O/g of dry weight. In comparison, microwave drying was the fastest, taking only 9 minutes at 540W power and completely drying the sample at a moisture level of 0.52 g of H2O/g of dry weight.

In short, out of all dryings, microwave drying is the fastest, and hot air foam drying took the highest time. In addition to the various benefits of hot-air foam-mat drying, there is a limitation associated with this technology, which is the inefficient heat transfer within the foamed materials. However, this drawback can be addressed by employing microwave heating. Microwave heating offers volumetric heat generation, allowing for efficient and rapid heat transfer without significant thermal lag. Results were seen in a test conducted on tomato paste by Ratti & Kudra (2006). Vacuum drying is a little faster than hot air drying heat transfer through convection in hot air drying is relatively slower compared to conduction and radiation in vacuum drying. The presence of oxygen in hot air drying can also be a limiting factor, as it may

lead to oxidation and degradation of the product, requiring lower temperatures or longer drying times. On the other hand, vacuum drying creates a low-pressure environment, promoting faster evaporation and more efficient heat transfer.

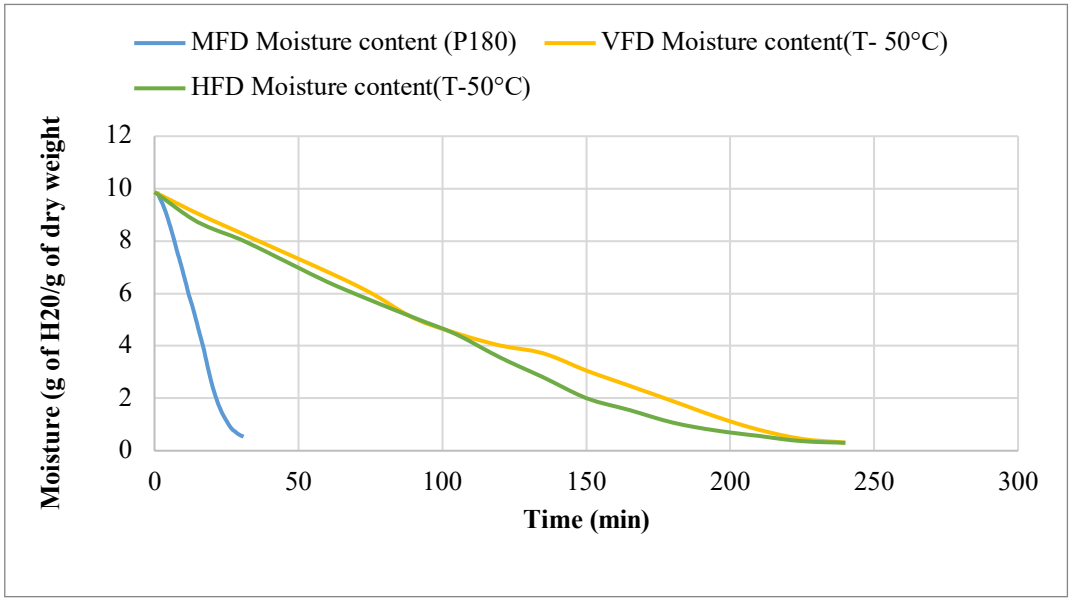

Fig 17: Moisture content if all three techniques at 180 W and 50 °C

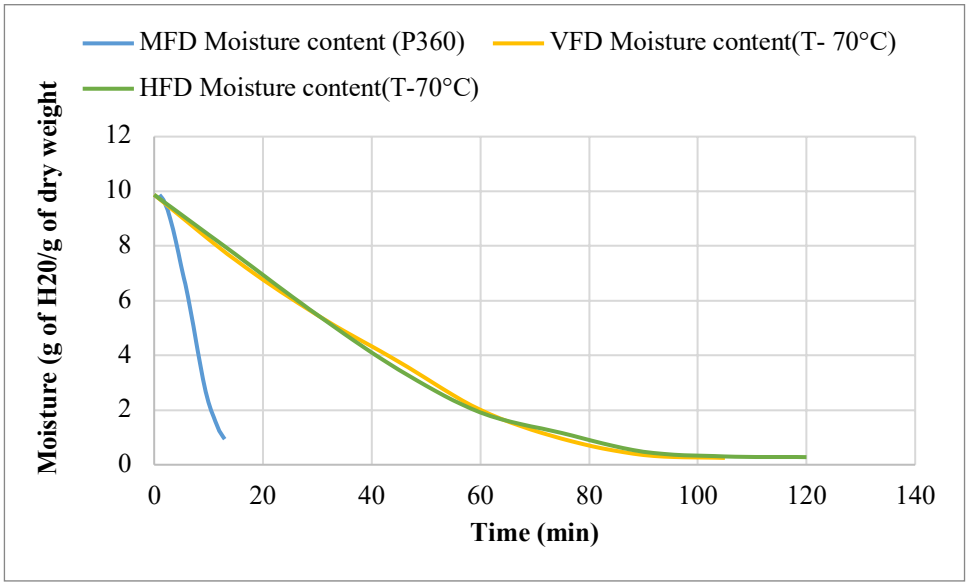

Fig 18: Moisture content of all three techniques at 360 W and 70 °C

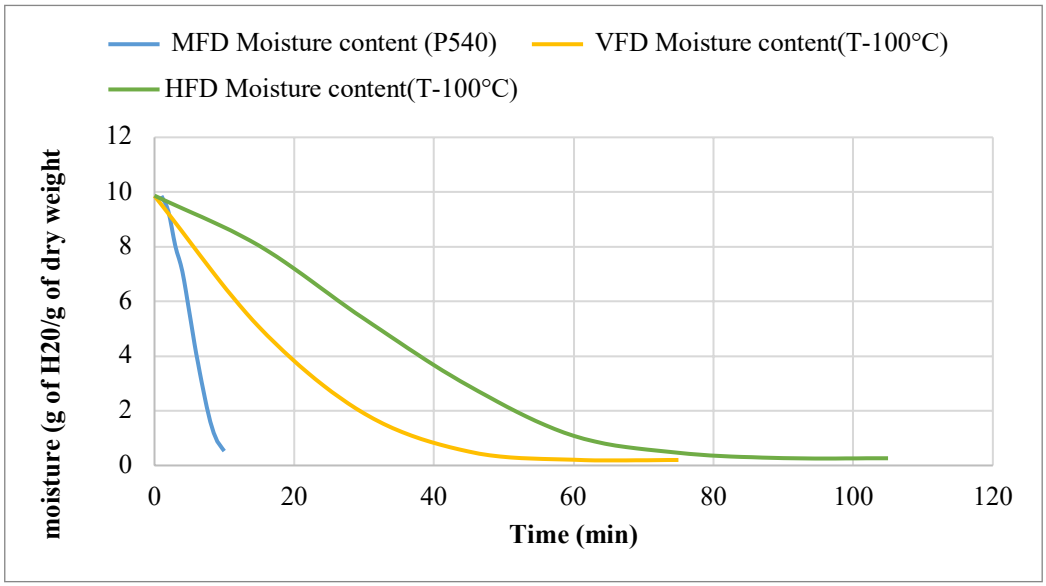

Fig 19: Moisture content of all three techniques at 540 W and 100 °C

Total anthocyanin content

Total anthocyanin content (TMAC) was compared with different drying techniques at different temperatures and power. It was observed that at 180W in microwave drying highest anthocyanin content was found, with 491.42±6.97 mg/100g fresh weight. A little or no difference in anthocyanin recovery was seen in the other two dryings at 50 °C. In Table (8) where 70 °C was taken as the temperature for hot air foam drying and vacuum foam drying, while 360W was the power taken for microwave foam drying. In all the dryings, a major difference in anthocyanin recovery was found. At a temperature of 70 °C, hot air foaming resulted in lower anthocyanin recovery, with a measured value of 356.23±6.90 mg/100g fresh weight. On the other hand, vacuum foam drying demonstrated a significant increase in anthocyanin content, with a measured value of 413.23±6.93 mg/100g fresh weight. In highest power 540W and temperature 100°C in fig (9), least anthocyanin can be seen in vacuum drying with 340.35±1.25 mg/100g fresh weight and highest in microwave foam drying with 421.58±16.14 mg/100g fresh weight.

On comparing all the dryings, the highest anthocyanin was recovered with the lowest power, 180 W in microwave drying and least in vacuum drying at 100 °C. In contrast to the other two drying methods, vacuum drying at the highest temperature resulted in lower anthocyanin content. The reason for this can be attributed to the specific conditions and interactions during the drying process. Despite the higher temperature, vacuum drying creates a low-pressure environment that may contribute to the degradation or loss of anthocyanins. Additionally, prolonged exposure to high temperatures in vacuum drying could lead to thermal degradation of anthocyanins, resulting in reduced recovery. It is essential to optimize the drying conditions, including temperature and time, to preserve the anthocyanin content and achieve the desired product quality. On the other hand, the lowest temperatures of hot air and vacuum drying recovered the same anthocyanin content as that of the highest power of microwave drying.

Microwave drying typically operates at lower temperatures compared to hot air or vacuum drying. Anthocyanins are sensitive to heat and can degrade or undergo structural changes at elevated temperatures. By using lower drying temperatures in microwave drying, the degradation of anthocyanins can be minimized, resulting in higher recovery. Additionally, the shorter drying time in microwave drying also contributes to better anthocyanin recovery. The shorter exposure to drying conditions reduces the likelihood of degradation or loss of anthocyanins during the drying process.

In a study conducted by Xu et al. (2022), it was found that vacuum drying resulted in higher anthocyanin content compared to hot air drying. The researchers suggested that this difference could be attributed to the longer exposure to heat in hot air drying, which led to the degradation of anthocyanins. Similarly, de Carvalho et al. (2017) conducted a test on S. cumini using foam mat drying and predicted that at higher temperatures, there would be a decrease in anthocyanin recovery.

Table 7 : TAC at power 180W, 50°c(mg/100g fresh weight)

Hot air foam drying	50 °C	420.41±5.84
Vacuum foam drying	50 °C	421.58±5.94
Microwave foam drying	180 W	491.42±6.97

Table 8: TAC at 360W and 70°c (mg/100g fresh weight)

Hot air foam drying	70 °C	356.23±6.90
Vacuum foam drying	70 °C	413.23±6.93
Microwave foam drying	360 W	473.4±11.67

Table 9: TAC at 540w and 100°c (mg/100g fresh weight)

Hot air foam drying	100 °C	372.64±12.656
Vacuum foam drying	100 °C	340.35±1.25
Microwave foam drying	540 W	421.58±16.14

As in fresh sample, vacuum drying at 70°C was done it had total anthocyanin 329.72±4.1mg/100g fresh weight, while after doing microwave foam mat drying at 180W it increased to 491.42±6.97mg/100g fresh weight. So, microwave foam drying at 180W has maximum anthocyanin content so it was selected for further characterization.

6.3 Characterization

Total extract yield

The total extract yield provides an indication of the efficiency of the extraction process and can be used for comparison purposes between different extraction methods or conditions. Average extract yield was 3.76+-0.29% , A lower extract yield implies that there may be a lower

concentration or quantity of the desired compounds or substances in the extracted material. The total extract yield of anthocyanins can vary depending on several factors, including the source material, extraction method, and conditions. The yield can be influenced by the specific plant species, maturity of the plant material, extraction solvent, extraction technique, and duration of the extraction process.

Fig 20: Total extract yield of jamun pulp

Total phenolic content

The total phenol content concentration was expressed in terms of Gallic acid equivalent (GAE) $Y= 0.0169x + 0.1739$, $R^2=0.9893$ (Stalin & Swamy, 2018). TPC with microwave foam drying was found to have an absorbance of 0.218±0.019nm, and the c value was 0.052±0.022. Lower values of TPC are due to the temperature of the extraction medium increased due to the amplified direct impact of microwave energy, leading to the degradation of the bioactive substances. This rise in temperature was a result of the dipolar rotation induced by the microwave energy, which directly affected the medium and caused the deterioration of the desired compounds (Nayak et al., 2015). TPC values indicate the amount of polyphenols present in our sample, which suggests greater antioxidant activity and other health benefits. Results shown by Gardner et al. (2000) on vegetable juice were 0.293 mg/ml of GAE, which

were almost similar to our studies conducted. In a test conducted by Maran et al. (2014) had 0.039 p-values.

DPPH

The methanolic extract of S. cumini pulp foam showed significant results of DPPH free radical activity with a spectrophotometric method. 94.88±1.54 % was found in the antioxidant capacity of our sample, which was performed in triplicates at 517nm. In this assay, the DPPH radical, which is purple in color, is reduced by an antioxidant compound or substance with free radical scavenging properties. When the DPPH radical accepts an electron or hydrogen atom from the antioxidant, its color changes from purple to yellow, indicating the reduction of the free radical. A higher percentage of DPPH free radical activity suggests that the sample has a stronger ability to neutralize free radicals.

Similar results were found on a test conducted on black *S. cumini* landraces by (Gajera et al., 2017) with 53.8% to 98.2% free radical activity performed on 6 different samples. A study conducted by Zhang & Lin (2009) had very good and relatable results to our study on *Syzygium cumini* fruit.

FRAP

The FRAP assay was chosen to measure the total antioxidant-reducing capacity. The FRAP method quantifies the ability of antioxidants to reduce ferric ions (Fe3+) to ferrous ions (Fe2+) (Fredes et al.2104). The change in absorbance in the FRAP assay is directly linked to the overall reducing power of the electron-donating antioxidants present in the reaction mixture (Benzie & Strain, 1999). The FRAP assay evaluates the presence of antioxidants in the samples, which can function as reductants in a colorimetric reaction associated with redox reactions. The measurement of ferric-reducing antioxidant power was performed using a spectrophotometer, and the absorbance values obtained were 0.059nm, 0.055nm, and 0.047nm.

Antimicrobial assay

Extensive research has been conducted on the antimicrobial effects of plant phenolic compounds against human pathogens. This research aims to assess and create novel and valuable food ingredients and pharmaceutical products. Antimicrobial effects of anthocyanin have been detected on various bacterial as well as fungal samples. Polyphenolic compounds, such as anthocyanins, possess antimicrobial properties that can effectively inhibit the growth of various microorganisms, particularly pathogens. Anthocyanins exert their antimicrobial effects by inducing cell damage through diverse mechanisms, ultimately leading to the destruction of the targeted cells (Salamon et al., 2021). Cisowska et al. (2011) have shown the antimicrobial activity of anthocyanins on bilberry.

Table 10: antibacterial and antifungal effects of *S.cumini* anthocyanin

	E.coli	***Lactobacillus***	***C. gloeosporioides***	***C. gloeosporioides***	***F. lateritium***
***S. cumini* sample**	11.66±2.3mm	5.33±3.51mm	_	_	_
+ve control	17.66±0.70mm	17±1.73mm	Cottony growth	Fluffy colonies	White woolly
-ve control	_	_	_	_	_

Antibacterial test

1. ***Lactobacillus***

To check the antibacterial effect of anthocyanin on lactobacillus, nutrient agar plates were prepared, as it provided a source of nutrients for the bacteria to grow. When anthocyanins are incorporated into the NA agar, their antibacterial properties can be assessed. If the anthocyanins have antibacterial activity against the tested bacteria, they will diffuse into the surrounding agar or from the disc, creating a zone of inhibition where bacterial growth is visibly inhibited (Amaregouda et al., 2022). A little zone of inhibition was seen with 5.33±3.51mm which means

weaker antibacterial effect of lactobacillus on anthocyanins whereas in positive control a larger clear zone was developed with no such region in negative control.

Fig 21: NA plates with bacterial zones

2. E. coli

The antibacterial effect of anthocyanin against E.coli was seen with a large zone of inhibition 11.66±2.3 mm. The test was performed in luria agar plates which act as nutrient media for Escherichia coli. Anthocyanins could affect the pH or nutrient availability in the growth medium, influencing the growth. Similar results were seen in the experiment conducted by (Amaregouda et al., 2022). in which anthocyanins showed very good antibacterial activity against E.coli and this is due to significant antibacterial effect of anthocyanins on food borne pathogens. The resistance of E. coli to the juice derived from V. opulus fruits was observed to be higher in a study conducted by (Česonienė et al., 2012).

Fig 22: LA plates with bacterial zones

Antifungal test

1. ***Colletotrichum gloeosporioides***

Colletotrichum gloeosporioides is primarily known as a plant pathogenic fungus. *C. gloeosporioides*, have been found to produce mycotoxins under certain conditions. Mycotoxins are toxic compounds produced by fungi that can contaminate food and pose a health risk if consumed in high amounts. The antifungal activity of anthocyanins on *Colletotrichum gloeosporioides* was not observed in the experiment. The fungal plates that were treated with anthocyanins did not inhibit the growth of the fungus, and it displayed normal and proper growth. This suggests that anthocyanins, in the tested concentration or conditions, did not possess significant antifungal properties against *Colletotrichum gloeosporioides*.

Fig 23: PDA plates with *C. gloeosporioides* (orange)

2. ***Colletotrichum gloeosporioides* (orange)**

Colletotrichum gloeosporioides fungus did not show any inhibitory response to the presence of anthocyanins. The growth of the fungus was observed to be unaffected, and it displayed full growth even in the presence of the anthocyanins. This suggests that the tested anthocyanins did not exhibit antifungal properties against *Colletotrichum gloeosporioides* in the specific conditions of the experiment.

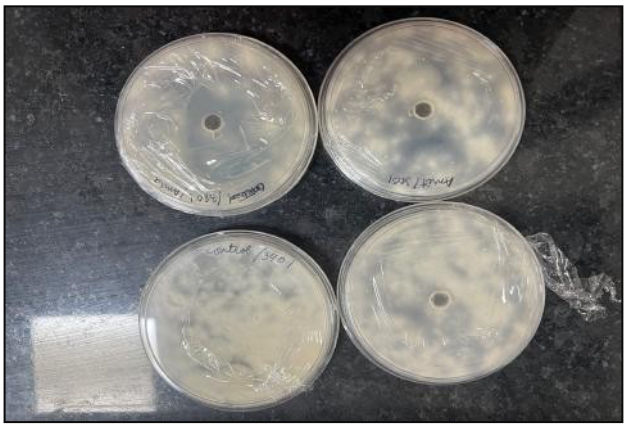

Fig 24: PDA Plates with *C. gloeosporioides*

3. Fusarium latertium

Fusarium lateritium is known to be a potential pathogen of several plant species and can cause economic losses in crop production. In the experiment conducted using anthocyanins derived from *S. cumini*, it was found that the anthocyanins did not exhibit any antifungal activity against *Fusarium lateritium*. The fungus showed no response or inhibition in its growth when exposed to the anthocyanins. This indicates that the tested anthocyanins from S. cumini did not possess significant antifungal properties against *Fusarium lateritium* under the specific conditions of the experiment.

Fig 25: PDA plates with *F. lateritium*

5. Conclusion

In conclusion, the experiment aimed to determine the anthocyanin recovery from the pulp, pomace, and juice of *Syzygium cumini*. The results showed that the pulp contained the highest amount of anthocyanins, with an average of 329.72 ± 4.1 mg/100g dry weight. Subsequently, the pulp was subjected to foam mat drying using different methods, including microwave foam mat drying, hot air oven foam mat drying, and vacuum foam mat drying. Among the drying methods, microwave foam mat drying at a power level of 180W resulted in the highest anthocyanin recovery. The anthocyanin content obtained at this power level was determined to be 491.42 ± 6.97 mg/100g, indicating a significant increase compared to the initial content. The utilization of lower power levels during microwave foam mat drying proved beneficial, as it prevented anthocyanin degradation due to reduced heat exposure. The longer drying time required at 180W was compensated by the higher anthocyanin recovery achieved. The extracts obtained from the microwave foam mat drying at 180W power were characterized to assess its properties. The total extract yield was found to be approximately 3.76 ± 0.29%, indicating the percentage of extract obtained from the drying process. The TPC, measured as a C value, was determined to be 0.052 ± 0.022 mg GAE per gram of dry weight, suggesting the presence of phenolic compounds in the extract. The extract exhibited significant DPPH activity of 94.88± 1.54%, indicating its potential as an antioxidant. The FRAP absorbance was approximately 0.055 nm, indicating its reducing power. The extract also demonstrated a significant antibacterial effect, but no significant antifungal effect was observed. These characterizations provide valuable insights into the composition and potential applications of the anthocyanin extract obtained from the microwave foam mat drying at 180W power, highlighting its antioxidant and antibacterial properties. Further exploration of its applications in the food, pharmaceutical, or nutraceutical industries is warranted.

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