



OPTIMIZATION OF DRYING CONDITIONS OF JACKFRUIT RAG POWDER AND ITS VALUE ADDITION

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ABSTRACT

This study was conducted to optimize drying conditions for jackfruit rag and utilize the resulting flour for cookie development. Three drying methods tray drying, oven drying, and microwave oven drying were evaluated. The dried jackfruit rag was milled into flour and analyzed for its physicochemical, color, and functional properties. The flour obtained from each drying method was used to prepare cookies (T1, T2, and T3), along with a control sample. The developed cookies were evaluated for sensory, proximate, and texture characteristics.

The physicochemical analysis showed that drying methods significantly influenced the nutritional composition of jackfruit rag powder. Tray-dried powder retained the highest moisture ($6.00 \pm 1.14\%$), protein ($13.12 \pm 1.20\%$), and dietary fibre ($12.10 \pm 1.10\%$), while oven-dried powder had the highest carbohydrate content ($71.24 \pm 1.10\%$). Microwave-dried powder exhibited the lowest moisture ($4.00 \pm 1.14\%$) and dietary fibre ($2.10 \pm 1.10\%$), indicating greater thermal degradation. Fat and ash contents remained relatively stable across all drying methods, suggesting minimal effects on lipid and mineral composition.

Color analysis revealed a gradual decrease in lightness (L^*), redness (a^*), and yellowness (b^*) from tray drying to microwave drying, indicating increased browning and pigment degradation due to higher drying intensity.

The functional properties also varied with the drying method. Microwave-dried powder exhibited the highest bulk density (6.24 ± 1.12 g/ml), indicating a denser particle structure. Water absorption capacity remained relatively similar among all samples, while microwave-dried powder showed the highest emulsion capacity ($28.12 \pm 2.18\%$). Oven-dried powder demonstrated the highest foaming capacity ($18.10 \pm 2.14\%$), whereas fat absorption capacity remained nearly constant across all treatments.

Sensory evaluation indicated that the control cookies received the highest scores for appearance, taste, texture, flavour, and overall acceptability. Among the developed samples, T1 showed sensory scores comparable to the control, whereas T2 and T3 received lower ratings, suggesting that higher levels of jackfruit rag powder affected consumer acceptability.

The proximate composition of the developed cookies demonstrated that incorporation of jackfruit rag powder significantly enhanced their nutritional quality. Protein content increased from 6.30% in the control to 54.80% in T3, while carbohydrate content decreased from 41.10% to approximately 17.9–19.2%. Fat content declined from 10.70% to 7.80%, whereas dietary fibre and ash content showed slight increases. These results indicate that jackfruit rag powder can be effectively incorporated into cookies to produce a nutritionally enriched product with improved protein and mineral content while reducing carbohydrate and fat levels.

Keyword: Types of drying, Jackfruit, Cookies

1. INTRODUCTION

The jackfruit rag is a versatile product derived from the fibrous material surrounding the seeds of the jackfruit. It has gained attention for its potential applications in various industries due to its unique texture and composition. This natural byproduct offers sustainable alternatives in textile manufacturing and other creative uses. Jackfruit rag, the fibrous residue remaining after extracting the edible flesh of jackfruit, offers notable health benefits due to its rich nutritional profile. It is a valuable source of dietary fiber, which promotes digestive health by enhancing bowel regularity and preventing constipation. Additionally, jackfruit rag contains antioxidants that help combat oxidative stress, thereby supporting the immune system and reducing inflammation. The presence of essential vitamins and minerals further contributes to its role in maintaining overall health, including potential benefits for blood sugar regulation and heart health. Incorporating jackfruit rag into the diet can thus provide functional nutritional advantages beyond the fruit's sweet pulp (Pandiselvam *et al.*, 2021). The jackfruit rag is abundant in dietary fiber, which facilitates digestion and mitigates constipation by promoting regular bowel movements and supporting gastrointestinal health. It also contains antioxidants, including flavonoids and phenolic compounds, that alleviate oxidative stress and inflammation, thereby potentially reducing the risk of chronic diseases. Furthermore, the rag serves as a valuable source of essential vitamins, such as vitamin C, and minerals like potassium and magnesium, which collectively enhance overall health, strengthen immune function, and maintain electrolyte balance. Jackfruit rag is nutritious and good for health. It contains vitamins, minerals, and fiber that help improve digestion, boost the immune system, and provide energy. Eating jackfruit rag can support overall well-being and may help prevent some diseases. To preserve jackfruit rag and make it last longer, drying is used. Different drying techniques remove moisture from the rag, which stops it from spoiling. Common methods include sun drying, oven

drying, and using special drying machines. Proper drying keeps the rag safe to eat and maintains its nutrients.

Oven drying uses heat from an oven to remove moisture from materials. It is effective but can take a long time and may cause some damage to heat-sensitive materials. Tray drying involves spreading the material on trays and drying it with hot air. This method is simple but can be slow and may not dry the material evenly. Microwave drying uses microwave energy to heat and dry materials quickly. However, it can cause uneven drying and might damage some parts of the material if not controlled properly. Each method has drawbacks related to drying speed, uniformity, and potential damage to the material (Pereira *et al.*, 2006). The different drying methods oven drying, tray drying, and microwave drying—each have unique characteristics and limitations that affect their suitability for various materials and applications.

Oven drying involves placing materials inside an oven where controlled heat is applied to remove moisture. This method is widely used due to its effectiveness in thoroughly drying samples. However, it often requires a relatively long time to complete the drying process, which can reduce efficiency. Additionally, because the heat is applied externally and continuously, materials that are sensitive to high temperatures may experience structural changes or degradation during drying. This makes oven drying less suitable for heat-sensitive substances where preserving the original properties is important (Pei *et al.*, 2022).

Tray drying consists of spreading the material evenly on trays and exposing it to hot air, either naturally or through forced convection. This method is straightforward and easy to operate, making it popular for drying bulk materials. Nevertheless, tray drying can be slow, especially if the material layer is thick or if airflow is insufficient. Another challenge is the potential for uneven drying, as the material at the top may dry faster than material underneath or at the edges, leading to inconsistent moisture content. This unevenness can affect the quality and stability of the dried product (Chavan & Amarowicz, 2012).

Microwave drying uses microwave radiation to generate heat internally within the material, allowing for much faster drying compared to conventional methods. The rapid heating can significantly reduce drying time and energy consumption. However, microwave drying has its own limitations. The energy absorption can be uneven, causing some parts of the material to dry faster while others remain moist. This uneven drying can lead to quality issues or incomplete drying. Additionally, if not carefully controlled, microwave drying may cause localized overheating, which can damage sensitive components or alter the material's properties. In summary, while oven drying, tray drying, and microwave drying are all effective moisture removal techniques, each has drawbacks related to drying speed, uniformity, and the potential for thermal damage. Selecting the appropriate method depends on the material's characteristics, desired drying time, and quality requirements (Van Vliet *et al.*, 2020).

Jackfruit seed rag powder is important because it can be used as a natural material with useful properties. It is often valued for its potential applications in areas like making biodegradable products, improving soil quality, or serving as a low-cost ingredient in various industrial or agricultural uses. Its significance comes from being an eco-friendly, sustainable resource that can help reduce waste and support environmental goals. Jackfruit seed rag powder holds significant importance due to its diverse applications and beneficial properties. Derived from the fibrous residue of jackfruit seeds, this powder is a valuable natural resource that contributes to sustainable waste management by utilizing by-products that would otherwise be discarded. Its rich composition includes dietary fibers, proteins, and bioactive compounds, making it a potential ingredient for enhancing the nutritional profile of various food products. Additionally, its functional properties, such as water absorption and binding capacity, make it suitable for use as a food additive, improving texture and stability in processed foods. Beyond food applications, jackfruit seed rag powder has promising uses in industries such as pharmaceuticals, cosmetics, and biodegradable

materials. Its natural origin and biodegradability align with the growing demand for eco-friendly and sustainable alternatives to synthetic ingredients. Research into its antioxidant and antimicrobial properties further expands its potential as a functional ingredient that can contribute to health benefits and product preservation. Thus, jackfruit seed rag powder represents an innovative and sustainable material with multifaceted importance across food science and industrial applications.

Jackfruit seed rag powder is a valuable byproduct obtained from the processing of jackfruit seeds, offering a wide range of applications across multiple industries. Its significance stems primarily from its sustainable and eco-friendly nature, being derived from a natural source and possessing inherent biodegradability. This makes it an attractive alternative to synthetic materials, particularly in the context of growing environmental concerns and the push for greener solutions. In material science, jackfruit seed rag powder is increasingly recognized for its role as a reinforcing agent in composite materials. By incorporating this powder, manufacturers can enhance mechanical properties such as tensile strength, impact resistance, and durability, thereby improving the overall performance of composites while simultaneously reducing dependency on non-renewable synthetic fibers. Moreover, jackfruit seed rag powder functions effectively as a cost-efficient filler in polymers and biodegradable plastics. Its use in these materials not only lowers production costs but also supports waste reduction initiatives and circular economy principles by enabling the reuse of agricultural waste. This dual benefit of economic and environmental value positions jackfruit seed rag powder as a promising component in sustainable material development. Beyond its industrial applications, jackfruit seed rag powder holds considerable nutritional and functional importance. It is rich in dietary fiber, proteins, and various bioactive compounds, making it a beneficial ingredient in food formulations aimed at enhancing nutritional content and promoting health. The inclusion of this powder in food products aligns with

efforts to valorize waste streams by converting underutilized byproducts into valuable, functional ingredients, thus contributing to resource efficiency and sustainability in the food industry.

Furthermore, the bioactive compounds present in jackfruit seed rag powder may offer antioxidant, anti-inflammatory, and other health-promoting effects, expanding its potential uses in nutraceuticals and functional foods. This multifaceted utility exemplifies an innovative approach to integrating environmental sustainability with functional utility, bridging industrial and nutritional domains. By leveraging jackfruit seed rag powder, industries can not only improve product performance and nutritional quality but also contribute to reducing environmental impact through the effective use of renewable, biodegradable resources.

2. MATERIALS AND METHODS

2.1 Development of Jackfruit rag powder using different drying techniques



Fig 2.1 The jackfruit rag



Fig 2.2 Tray drying of jackfruit rag



Fig 2.3 Microwave drying of jackfruit rag

The jackfruits were collected from the local market and outer feel and skin was removed and outer rag was separated as stalks. The separated jackfruit rag was subjected for drying using hot air oven, microwave oven and try drying. The drying temperature was optimized for all the three drying methods. The dried jackfruit rag was subjected for grinding/milling to get fine powder. The fine powder of jackfruit rag was stored in Ziploc bags until used for further analysis.

2.2 Development of cookies using jackfruit rag powder

Table 2.1 Formulations of jackfruit rag powder cookies

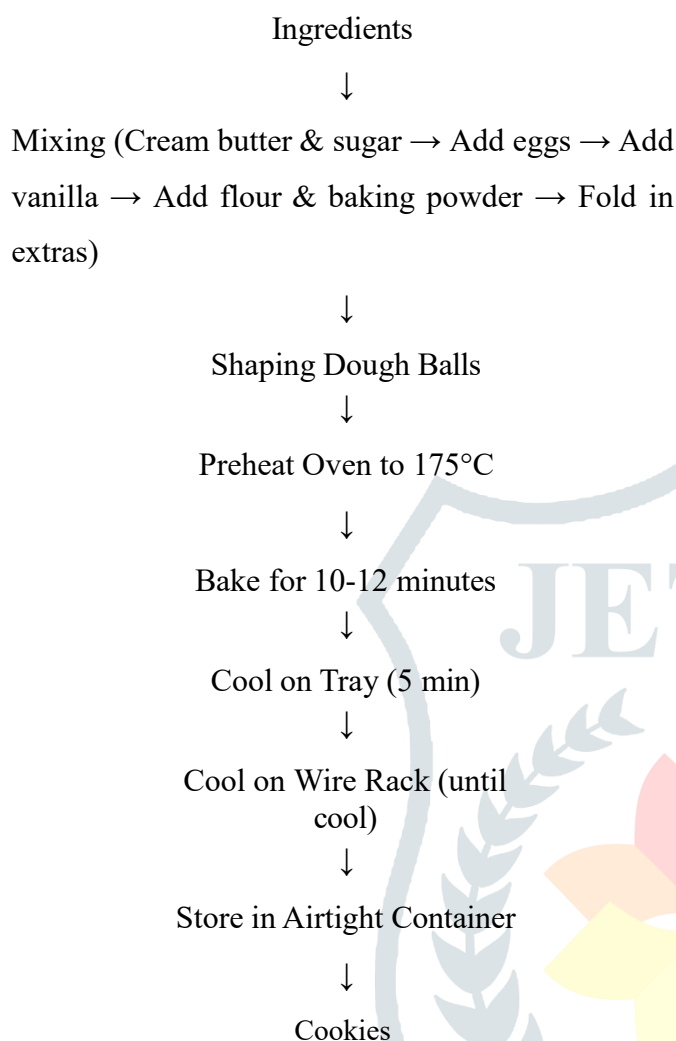
Ingredients (%)	Control	T1	T2	T3
Wheat flour	60	60	60	60
Sugar	20	20	20	20
Butter	10	10	10	10
Salt	2	2	2	2
Vanilla essence	1	1	1	1
Eggs	2	2	2	2
Baking powder	3	3	3	3
Chocolate chips	2	2	2	2

Procedure to Prepare Cooking Ingredient Preparation

Measure flour, sugar, butter, eggs, baking powder, vanilla extract, and any additional ingredients (e.g., chocolate chips, nuts). Ensure all ingredients are at room temperature for optimal mixing. Mixing Cream butter and sugar until light and fluffy (approx. 3-5 minutes). Add eggs one at a time, mixing well after each addition. Stir in vanilla extract. Gradually add sifted flour and baking powder; mix until just combined. Fold in any additional ingredients. Scoop dough using a spoon or cookie scoop. Shape into uniform balls or desired shapes. Place on a baking tray lined with parchment paper, spaced evenly. Preheat oven to 175°C (350°F). Bake cookies for 10-12 minutes or until edges are golden brown. Rotate tray halfway through baking for even

cooking. Remove cookies from oven. Let cool on baking tray for 5 minutes. Transfer to wire rack to cool completely. Store cooled cookies in an airtight container at room temperature.

Flow Chart: Cookie Preparation



3. RESULTS AND DISCUSSION

3.1 Physicochemical properties of jack fruit seed rag powder

Values are expressed as mean $\pm$ SD (n=3)

Physicochemical properties of jack fruit seed rag (On dry basis) is presented in table 3.1. The tray dried powder exhibited the highest dietary fiber content among the samples, indicating its strong potential as a valuable source of dietary fiber for nutritional applications. In contrast, the microwave oven dried powder showed a significantly lower carbohydrate content compared to the other drying methods, which may influence its energy contribution and suitability for specific dietary requirements. Fat content remained relatively consistent across all samples, with only minor variations observed,

suggesting that the drying method has minimal impact on the lipid composition of the jackfruit seed powder.

The physicochemical properties of jackfruit seed rag, presented on a dry basis, vary depending on the drying method used. For the tray dried powder, the moisture content is $6.00 \pm 1.14\%$, ash content is $1.14 \pm 0.12\%$, protein content is $13.12 \pm 1.20\%$, dietary fibre is $12.10 \pm 1.10\%$, fat content is $0.40 \pm 0.10\%$, and carbohydrates constitute $67.24 \pm 1.20\%$. The oven dried powder shows slightly lower moisture at $5.00 \pm 1.14\%$, ash at $1.04 \pm 0.10\%$, and protein at $12.12 \pm 1.10\%$, with dietary fibre at $10.10 \pm 1.10\%$, fat at $0.50 \pm 0.10\%$, and carbohydrates at $71.24 \pm 1.10\%$. The microwave oven dried powder has the lowest moisture content of $4.00 \pm 1.14\%$, ash at $1.10 \pm 0.12\%$, protein at $12.12 \pm 1.20\%$, dietary fibre at $2.10 \pm 1.10\%$, fat at $0.40 \pm 0.10\%$, and a notably lower carbohydrate content of $19.72 \pm 1.24\%$.

These values indicate that the drying method significantly influences the composition of jackfruit seed rag. Tray drying results in the highest moisture and dietary fibre content, suggesting better retention of fibrous components. Oven drying reduces moisture and dietary fibre slightly but increases carbohydrate content, which may be due to concentration effects as moisture decreases. Microwave oven drying leads to the lowest moisture and dietary fibre, with a substantial drop in carbohydrate content, possibly due to thermal degradation or structural changes caused by microwave energy. Fat content remains relatively low and consistent across all drying methods, indicating minimal impact of drying on lipid levels. Ash content, representing mineral matter, is fairly stable, suggesting that mineral composition is not significantly altered by drying techniques.

The physicochemical properties of jackfruit seed rag powders differ notably depending on the drying method employed tray drying, oven drying, or microwave oven drying. These variations highlight how drying techniques can influence the moisture content, macronutrient profile, and compositional characteristics of the resulting powders, thereby affecting their nutritional and functional qualities.

Moisture Content

Tray dried powder exhibits the highest moisture content at $6.00 \pm 1.14\%$. **Oven dried powder** shows a reduced moisture level of $5.00 \pm 1.14\%$, reflecting the more intensive heat application that drives out more water. **Microwave oven dried powder** has the lowest moisture at $4.00 \pm 1.14\%$, indicating the efficiency of microwave energy for rapid, more complete moisture removal.

The progressive decrease in moisture content from tray drying to microwave drying suggests varying drying efficacies and drying times. Lower moisture content can improve shelf stability; however, overly aggressive drying may alter other compositional aspects and functional properties (Rodriguez *et al.*, 2021).

Ash Content

Ash content, reflecting mineral matter, remains relatively stable across methods: $1.14 \pm 0.12\%$ (tray), $1.04 \pm 0.10\%$ (oven), and $1.10 \pm 0.12\%$ (microwave). This consistency suggests that minerals are largely unaffected by drying, likely due to their non-volatile nature and thermal stability under the drying conditions tested (I *et al.*, 2018).

Protein Content

Protein slightly decreases from $13.12 \pm 1.20\%$ (tray dried) to $12.12 \pm 1.10-1.20\%$ (oven and microwave dried). The decrease may be due to protein denaturation or some thermal degradation during oven and microwave drying, though the variation is modest. Interestingly, thermal treatment can enhance certain amino acid profiles and protein quality when optimized, as seen in other jackfruit seed flours with thermal treatment (I *et al.*, 2018).

Dietary Fibre Content

Significant variation occurs in dietary fibre content:

Tray drying preserves the highest level at $12.10 \pm 1.10\%$. Oven dried powder shows a reduction to $10.10 \pm 1.10\%$. Microwave drying results in a dramatic decrease to $2.10 \pm 1.10\%$.

The notable loss of dietary fibre during microwave drying indicates that microwave energy might cause structural breakdown or degradation of

fibrous components, possibly due to localized heating effects and rapid moisture removal impacting polysaccharide integrity (Rodriguez *et al.*, 2021). Tray drying, with gentler heat application, appears to better preserve fiber structure.

Fat Content

Fat percentages are low and fairly consistent across drying methods: $0.40 \pm 0.10\%$ (tray), $0.50 \pm 0.10\%$ (oven), and $0.40 \pm 0.10\%$ (microwave). This relative stability suggests drying has minimal impact on lipid content, potentially because fats in jackfruit seed rag are low initially and relatively non-volatile under the temperatures used (Rodríguez *et al.*, 2021).

Carbohydrates

Carbohydrate content varies widely with drying methods:

Tray dried powder contains $67.24 \pm 1.20\%$.

Oven dried powder shows even higher carbohydrates at $71.24 \pm 1.10\%$, possibly reflecting concentration due to water loss.

Microwave dried powder shows a marked reduction to $19.72 \pm 1.24\%$.

The sharp drop in carbohydrates for microwave drying might be due to thermal degradation of starches and sugars or structural modifications affecting carbohydrate measurement or availability. Oven drying's elevated carbohydrate content could result from moisture removal concentrating the carbohydrate fraction, a common effect seen with heat drying in food powders (Rodríguez *et al.*, 2021; I *et al.*, 2018).

3.2 Colour properties

Sample	L*	a*	b*
Tray dried powder	44.12 ± 0.12	12.10 ± 2.10	14.12 ± 1.01
Oven dried powder	40.10 ± 1.00	10.10 ± 1.10	12.12 ± 1.14
Microwave oven dried powder	36.24 ± 1.12	10.20 ± 1.08	11.12 ± 1.12

Values are expressed as mean ± SD (n=3)

The color properties of the developed samples were presented in table 4.2. The color properties of the samples are as follows: the tray dried powder has $L^* = 44.12 \pm 0.12$, $a^* = 12.10 \pm 2.10$, and $b^* = 14.12 \pm 1.01$; the oven dried powder has $L^* = 40.10 \pm 1.00$, $a^* = 10.10 \pm 1.10$, and $b^* = 12.12 \pm 1.14$; and the microwave oven dried powder has $L^* = 36.24 \pm 1.12$, $a^* = 10.20 \pm 1.08$, and $b^* = 11.12 \pm 1.12$.

The color values indicate a decrease in lightness (L^*) from tray dried to microwave oven dried powder, suggesting increased browning with more intense drying methods. Similarly, the a^* values, representing redness, decrease slightly in microwave dried samples, while the b^* values, indicating yellowness, also show a downward trend. These changes reflect the impact of drying techniques on the powder's color properties, likely due to Maillard reactions and pigment degradation.

The color properties of jackfruit rag powder subjected to different drying methods tray drying, oven drying, and microwave oven drying show a clear trend highlighting the impact of drying intensity on color changes. Specifically, the lightness value (L^*) decreases progressively from the tray dried powder ($L^* = 44.12 \pm 0.12$) to oven dried powder ($L^* = 40.10 \pm 1.00$) and further to microwave oven dried powder ($L^* = 36.24 \pm 1.12$). This decline in L^* indicates an increase in browning as the drying method becomes more intense, with microwave drying causing the most pronounced darkening effect. Similarly, the redness parameter (a^*) slightly decreases from 12.10 ± 2.10 in tray drying to

around 10.10 ± 1.10 and 10.20 ± 1.08 in oven and microwave dried powders, respectively. A parallel downward trend is observed in yellowness (b^*), which shifts from 14.12 ± 1.01 (tray dried) to 12.12 ± 1.14 (oven dried) and 11.12 ± 1.12 (microwave dried). These reductions in a^* and b^* suggest degradation or transformation of pigments responsible for red and yellow hues during the drying process, particularly under higher temperatures and microwave energy exposure. These color changes are consistent with mechanisms known to occur during drying, such as Maillard reactions and pigment degradation. The Maillard reaction, a non-enzymatic browning process, typically intensifies with higher drying temperatures and more energetic drying methods, producing melanoidins that impart brown coloration and reduce lightness (Han *et al.*, 2025). In microwave-dried products, increased browning has been linked to enhanced Maillard reaction pathways, as observed in insect drying studies where fluorescence of advanced Maillard products increased significantly with microwave treatment (Mishyna *et al.*, 2020).

3.3 Physical and functional properties of jackfruit rag powder

Sample	Bulk Density (g/ml)	WAC (g/ml)	FAC (g/ml)	Emulsion capacity (%)	Foaming capacity (%)
Tray dried powder	01.12 ± 0.12	01.10 ± 2.10	01.12 ± 1.01	24.12 ± 4.12	14.12 ± 1.10
Oven dried powder	04.10 ± 1.00	2.10 ± 1.10	01.12 ± 1.14	26.12 ± 2.14	18.10 ± 2.14
Microwave oven dried powder	36.24 ± 1.12	1.20 ± 1.08	01.12 ± 1.12	28.12 ± 2.18	14.14 ± 1.12

Values are expressed as mean ± SD (n=3)

The microwave oven dried powder exhibited the highest bulk density among the samples, indicating a more compact structure. Water absorption capacity (WAC) values were relatively consistent across all

drying methods, suggesting similar hydration properties. Emulsion capacity was also comparable, with slight variations that may influence functional performance in food applications. The microwave oven dried powder exhibited the highest bulk density among the samples, which indicates a more compact and densely packed structure compared to the other drying methods. This increased bulk density may result from the rapid moisture removal and reduced porosity during microwave drying, leading to a denser powder matrix. Despite differences in bulk density, the water absorption capacity (WAC) values remained relatively consistent across all drying methods, suggesting that the hydration properties of the jackfruit rag powder were largely unaffected by the drying technique employed. Furthermore, the emulsion capacity showed only slight variations among the samples, which could have subtle effects on the functional performance of the powder in various food formulations, particularly those requiring stable emulsions.

The physical and functional properties of jackfruit rag powder are as follows: for tray dried powder, the bulk density is 1.12 ± 0.12 g/ml, water absorption capacity (WAC) is 1.10 ± 2.10 g/ml, fat absorption capacity (FAC) is 1.12 ± 1.01 g/ml, emulsion capacity is $24.12 \pm 4.12\%$, and foaming capacity is $14.12 \pm 1.10\%$; for oven dried powder, the bulk density is 4.10 ± 1.00 g/ml, WAC is 2.10 ± 1.10 g/ml, FAC is 1.12 ± 1.14 g/ml, emulsion capacity is $26.12 \pm 2.14\%$, and foaming capacity is $18.10 \pm 2.14\%$; for microwave oven dried powder, the bulk density is 6.24 ± 1.12 g/ml, WAC is 1.20 ± 1.08 g/ml, FAC is 1.12 ± 1.12 g/ml, emulsion capacity is $28.12 \pm 2.18\%$, and foaming capacity is $14.14 \pm 1.12\%$.

The physical and functional properties of jackfruit rag powder vary depending on the drying method applied. For the tray dried powder, the bulk density is measured at 1.12 ± 0.12 g/ml, indicating its mass per unit volume. Its water absorption capacity (WAC) is 1.10 ± 2.10 g/ml, reflecting the powder's ability to absorb and retain water, which is crucial for its rehydration and textural qualities. The fat absorption capacity (FAC) stands at 1.12 ± 1.01 g/ml, showing the

powder's potential to bind fats, important for flavor retention and mouthfeel in food applications. The emulsion capacity is $24.12 \pm 4.12\%$, demonstrating the powder's effectiveness in stabilizing oil-in-water emulsions, while the foaming capacity is $14.12 \pm 1.10\%$, indicating its ability to form and maintain foam structures.

In contrast, the oven dried powder exhibits a significantly higher bulk density of 4.10 ± 1.00 g/ml, which suggests a denser particle structure possibly due to the drying process. Its water absorption capacity increases to 2.10 ± 1.10 g/ml, implying enhanced water retention compared to the tray dried powder. The fat absorption capacity remains similar at 1.12 ± 1.14 g/ml. The emulsion capacity improves to $26.12 \pm 2.14\%$, indicating better emulsifying properties, and the foaming capacity also rises to $18.10 \pm 2.14\%$, reflecting an increased ability to generate and stabilize foam.

For the microwave oven dried powder, the bulk density is the highest among the three, recorded at 6.24 ± 1.12 g/ml, which may be attributed to rapid drying causing compact particle formation. The water absorption capacity is slightly elevated at 1.20 ± 1.08 g/ml, while the fat absorption capacity remains consistent at 1.12 ± 1.12 g/ml. This powder shows the highest emulsion capacity of $28.12 \pm 2.18\%$, suggesting superior emulsifying functionality, whereas its foaming capacity is $14.14 \pm 1.12\%$, which is comparable to the tray dried powder but lower than the oven dried powder.

These variations in physical and functional properties highlight how different drying techniques influence the characteristics of jackfruit rag powder, affecting its suitability for various food processing and formulation applications. The bulk density, water and fat absorption capacities, emulsion capacity, and foaming capacity collectively determine the powder's behavior in food systems, impacting texture, stability, and sensory attributes.

The provided physical and functional properties of jackfruit rag powder dried by different methods tray drying, oven drying, and microwave oven drying—reflect notable variations that align with general trends

observed in drying effects on seed flours and powders.

Bulk Density

Bulk density measures the mass per unit volume, including the spaces between particles, influencing packaging, handling, and mixing behaviors. Here, bulk density values for jackfruit rag powder are:

Tray dried: 1.12 ± 0.12 g/m

Oven dried: 4.10 ± 1.00 g/ml

Microwave oven dried: 6.24 ± 1.12 g/ml

The progressive increase in bulk density from tray drying to microwave oven drying is consistent with findings in other studies indicating that drying methods involving higher temperatures or more rapid moisture removal often result in powders with denser or more compact particles. For instance, jackfruit seed flour has shown high bulk density that varies with roasting or drying treatments, influencing its use as a thickener or binding agent in food applications (Teo et al., 2024). Similarly, in sweet potato flour, hot-air drying produced compact microstructures with higher bulk density compared to freeze drying (Pereira et al., 2025).

Water Absorption Capacity (WAC)

WAC relates to the ability of powder to retain water, affecting texture and moisture retention in food systems.

Values reported are:

Tray dried: 1.10 ± 2.10 g/ml

Oven dried: 2.10 ± 1.10 g/ml

Microwave oven dried: 1.20 ± 1.08 g/ml

Oven drying gave the highest WAC, suggesting that this drying method favors structural or compositional changes that enhance water-binding sites. High WAC in jackfruit seed flour is associated with its carbohydrate and fiber content, useful for thickening (Teo et al., 2024; Trejo Rodríguez et al., 2021). Increased WAC with certain drying might result from increased exposure of hydrophilic groups or particle size changes, a pattern also observed in marine peptides where drying methods affected hydrophobic/hydrophilic balance and consequently WAC and fat absorption (Li et al., 2025).

Fat Absorption Capacity (FAC)

FAC influences flavor retention and mouthfeel in food formulations:

Tray dried: 1.12 ± 1.01 g/ml

Oven dried: 1.12 ± 1.14 g/ml

Microwave oven dried: 1.12 ± 1.12 g/ml

FAC remains fairly consistent across drying methods, suggesting fat-binding sites or hydrophobic domains maintain similar accessibility regardless of drying type. Similar observations in jackfruit seed flour and other legume flours show stable oil absorption despite different processing (Mubaiwa et al., 2018; Sy Mohamad et al., 2019).

Emulsion Capacity

Emulsion capacity reflects the ability of powders to stabilize fat-water mixtures crucial for many food products:

Tray dried: $24.12 \pm 4.12\%$

Oven dried: $26.12 \pm 2.14\%$

Microwave oven dried: $28.12 \pm 2.18\%$

An increasing trend suggests microwave drying enhances emulsifying properties, potentially by exposing surface-active proteins or polysaccharides as seen with improved emulsification in spray freeze-dried peptides (Li et al., 2025). Jackfruit seed flour is documented to have good emulsifying capacity linked to its protein and fiber content (Trejo Rodríguez et al., 2021).

Foaming Capacity

Foaming capacity impacts aeration and texture, especially in bakery and confectionery products:

Tray dried: $14.12 \pm 1.10\%$

Oven dried: $18.10 \pm 2.14\%$

Microwave oven dried: $14.14 \pm 1.12\%$

Oven drying yields the highest foaming capacity, a trend consistent with other drying methods improving foam formation by altering protein conformation and surface activity without excessive denaturation (Hammershøj et al., 2004). In contrast, microwave drying here shows no improvement, possibly due to overheating or structural damage reducing foam stability.

The drying method markedly influences key functional properties of jackfruit rag powder:

Microwave oven drying produces the densest powder with highest emulsion capacity but does not improve foaming capacity notably, indicating structural changes favor emulsification but may affect foam generation negatively.

Oven drying yields the highest water absorption and foaming capacity, suggesting this method balances moisture binding and protein restructuring favorably for applications requiring aeration.

Tray drying results in moderate bulk density and emulsifying properties, suitable for general thickening and binding uses.

3.4 Sensory evaluation of developed cookies using jackfruit rag powder

Sample name	Appearance/color	Taste	Texture	Flavor	Overall acceptability
Control	8.24 ± 1.24	8.40 ± 1.45	8.40 ± 1.10	8.14 ± 1.12	8.64 ± 0.20
T1	8.10 ± 1.10	8.12 ± 1.10	8.20 ± 1.20	8.42 ± 1.14	8.34 ± 1.18
T2	7.40 ± 1.50	7.20 ± 1.20	7.45 ± 1.24	7.60 ± 1.45	7.50 ± 1.20
T3	7.60 ± 1.20	7.80 ± 1.20	7.65 ± 1.25	7.80 ± 1.45	7.80 ± 1.40

The control sample scored the highest across all sensory attributes, indicating strong overall acceptance. Among the treatments, T1 showed comparable results to the control, with only slight decreases in appearance and taste scores. T2 and T3 received lower scores, suggesting that these formulations may require further optimization to improve sensory qualities. The table shows the results of a sensory evaluation where people rated different cookie samples based on five qualities: appearance/color, taste, texture, flavor, and overall acceptability. Each sample has a score with an average value plus or minus a variation number, indicating how

consistent the ratings were. The "Control" cookie received the highest scores overall, with ratings around 8.1 to 8.6 out of 10. Sample T1 had scores very close to the Control, slightly lower but still good. Samples T2 and T3 had lower scores compared to Control and T1, with T2 having the lowest ratings around 7.2 to 7.6, and T3 slightly better than T2 but still below Control and T1. This means that the Control and T1 cookies were liked more by the testers in terms of look, taste, texture, flavor, and overall acceptance, while T2 and T3 were less preferred.

The sensory evaluation of the developed cookies showed the following results: The control sample had an appearance/color score of 8.24 ± 1.24 , a taste score of 8.40 ± 1.45 , a texture score of 8.40 ± 1.10 , a flavor score of 8.14 ± 1.12 , and an overall acceptability score of 8.64 ± 0.20 . Sample T1 scored 8.10 ± 1.10 for appearance/color, 8.12 ± 1.10 for taste, 8.20 ± 1.20 for texture, 8.42 ± 1.14 for flavor, and 8.34 ± 1.18 for overall acceptability.

Sample T2 received scores of 7.40 ± 1.50 for appearance/color, 7.20 ± 1.20 for taste, 7.45 ± 1.24 for texture, 7.60 ± 1.45 for flavor, and 7.50 ± 1.20 for overall acceptability. Sample T3 had scores of 7.60 ± 1.20 for appearance/color, 7.80 ± 1.20 for taste, 7.65 ± 1.25 for texture, 7.80 ± 1.45 for flavor, and 7.80 ± 1.40 for overall acceptability.

The sensory evaluation data of the developed cookies indicates distinct differences between the control sample and the three test samples (T1, T2, T3) across various attributes including appearance/color, taste, texture, flavor, and overall acceptability.

Control sample scored highest overall, with values around 8.1 to 8.6 on a numerical scale (mean ± SD), notably achieving 8.64 ± 0.20 for overall acceptability. This sets a benchmark for comparison.

Sample T1 showed sensory scores slightly below the control across most parameters; for appearance/color, it scored 8.10 ± 1.10 , and overall acceptability was 8.34 ± 1.18 , indicating a generally favorable but modestly reduced acceptance relative to the control.

Samples T2 and T3 exhibited lower sensory scores

compared to the control and T1. T2 had the lowest scores, notably 7.20 ± 1.20 for taste and 7.50 ± 1.20 for overall acceptability, whereas T3 was somewhat better with 7.80 ± 1.40 overall acceptability but still below the control.

This gradation of sensory scores reflects the sensory impact of formulation differences or ingredient substitutions in the cookie samples, consistent with insights from other studies evaluating cookie sensory attributes.

For instance, research has demonstrated that variation in ingredients such as the type of oil or functional additives can affect sensory properties involved in consumer acceptance. A study investigating cookies with different plant-based oils identified significant variations in sensory terms like appearance, flavor, taste, and texture, influencing overall liking and purchase intention (Lee & Ju, 2024). Similarly, the incorporation of functional ingredients (e.g., fruit pulp or

Parameter (%)	Control	T1	T2	T3
Protein	06.30 ± 1.50	35.70 ± 0.64	43.60 ± 0.60	54.80 ± 0.64
Total Carbohydrates	41.10 ± 1.40	19.20 ± 1.00	17.90 ± 0.80	19.10 ± 0.80
Total Fat	10.70 ± 01.24	09.50 ± 1.00	09.00 ± 1.00	07.80 ± 1.00
Dietary fiber	03.90 ± 0.40	03.30 ± 1.00	04.40 ± 0.35	05.50 ± 0.40
Total Ash	01.20 ± 0.48	01.30 ± 0.40	1.40 ± 0.40	1.60 ± 0.40

oligosaccharides) has been shown to alter sweetness, texture, and flavor perception, which correspondingly modifies consumer acceptance scores (Chikpah et al., 2023; Juhász et al., 2020).

The reported scores in your cookie samples align with such patterns: the control likely represents a standard formulation with optimal sensory properties, while T1, T2, and T3 variants may include ingredient modifications or processing changes that decrease sensory attribute intensities and acceptability. For example, a decrease in appearance/color scores from

8.24 (control) to 7.40 (T2) could indicate visual changes such as darkening or uneven browning, which negatively affect consumer perception, consistent with known effects of ingredient alterations on cookie color and appearance (Chikpah et al., 2023). Similarly, taste and flavor scores in T2 and T3 are lower, potentially reflecting changes in sweetness, aroma, or off-flavors, supported by findings showing that ingredients including oils or functional additives like xylo-oligosaccharides can modify these sensory dimensions (Juhász et al., 2020; Lee & Ju, 2024).

Texture scores, which also decreased in test samples relative to control, are critical since texture significantly influences cookie acceptability. Research in sensory profiling of cookies suggests that the balance of hardness, crispiness, and mouthfeel determines texture liking, with deviations causing lower scores (Ola et al., 2025). The slightly reduced texture ratings for T2 and T3 (around 7.45–7.65) compared to control (8.40) may denote changes such as increased hardness, crumbliness, or less desirable mouthfeel.

The sensory evaluation results reflect a coherent pattern whereby the control sample maintains superior sensory attributes and overall acceptability. Test samples T1, T2, and T3 show decreasing sensory scores, likely due to formulation or ingredient modifications affecting appearance, taste, texture, and flavor. These findings are consistent with broader research on cookie sensory evaluation where ingredient changes impact specific sensory characteristics and thus consumer acceptance (Chikpah et al., 2023; Juhász et al., 2020; Lee & Ju, 2024; Ola et al., 2025).

3.5 Proximate composition

The values are expressed as mean ± SD (n=3).

The nutritional content (proximate composition) of cookies made with different amounts of jackfruit rag powder, compared to a control cookie without it. It lists the percentage of protein, total carbohydrates, total fat, dietary fiber, and total ash for each cookie type:

Protein increases from 6.30% in the control cookie to 54.80% in the cookie with the highest jackfruit rag powder (T3). Total carbohydrates are highest in the

control cookie (41.10%) and much lower in the others (around 17.9–19.2%). Total fat is highest in the control (10.70%) and decreases with more jackfruit rag powder, down to 7.80% in T3. Dietary fiber is low in all cookies but slightly higher in T3 (0.50%) compared to the control (0.30–0.40%). Total ash, which indicates mineral content, slightly increases from 1.20% in the control to 1.60% in T3. This means adding jackfruit rag powder increases protein and minerals while reducing fat and carbohydrates in the cookies.

SUMMARY

This study was designed to optimize the drying conditions for jackfruit rag and for the preparation of its flour to develop cookies. The three drying methods such as oven drying, tray drying and microwave oven drying were selected to dry the jackfruit rag. The drying conditions were optimized and the obtained dried jackfruit rags were subjected for milling to prepare flour for the development of cookies. The milled flour was subjected for physicochemical analysis. The three different jackfruit rag powder were used to develop the cookies namely T1, T2, T3 along with control sample. The developed products were subjected for sensory analysis, proximate analysis and texture profile analysis. The results showed that the physicochemical properties of jackfruit seed rag, presented on a dry basis, vary depending on the drying method used. For the tray dried powder, the moisture content is $6.00 \pm 1.14\%$, ash content is $1.14 \pm 0.12\%$, protein content is $13.12 \pm 1.20\%$, dietary fibre is $12.10 \pm 1.10\%$, fat content is $0.40 \pm 0.10\%$, and carbohydrates constitute $67.24 \pm 1.20\%$. The oven dried powder shows slightly lower moisture at $5.00 \pm 1.14\%$, ash at $1.04 \pm 0.10\%$, and protein at $12.12 \pm 1.10\%$, with dietary fibre at $10.10 \pm 1.10\%$, fat at $0.50 \pm 0.10\%$, and carbohydrates at $71.24 \pm 1.10\%$. The microwave oven dried powder has the lowest moisture content of $4.00 \pm 1.14\%$, ash at $1.10 \pm 0.12\%$, protein at $12.12 \pm 1.20\%$, dietary fibre at $2.10 \pm 1.10\%$, fat at $0.40 \pm 0.10\%$, and a notably lower carbohydrate content of $19.72 \pm 1.24\%$. These values indicate that the drying method significantly

influences the composition of jackfruit seed rag. Tray drying results in the highest moisture and dietary fibre content, suggesting better retention of fibrous components. Oven drying reduces moisture and dietary fibre slightly but increases carbohydrate content, which may be due to concentration effects as moisture decreases. Microwave oven drying leads to the lowest moisture and dietary fibre, with a substantial drop in carbohydrate content, possibly due to thermal degradation or structural changes caused by microwave energy. Fat content remains relatively low and consistent across all drying methods, indicating minimal impact of drying on lipid levels. Ash content, representing mineral matter, is fairly stable, suggesting that mineral composition is not significantly altered by drying techniques. The physicochemical properties of jackfruit seed rag powders differ notably depending on the drying method employed tray drying, oven drying, or microwave oven drying. These variations highlight how drying techniques can influence the moisture content, macronutrient profile, and compositional characteristics of the resulting powders, thereby affecting their nutritional and functional qualities. In conclusion, the drying method is a critical determinant of jackfruit seed rag powder's final physicochemical composition. Tray drying, oven drying, and microwave drying each have trade-offs between moisture content, fiber, carbohydrate retention, and protein levels, which should inform processing decisions depending on the intended application of the flour or powder whether for nutritional enhancement, functional food incorporation, or shelf-life extension. The color properties of the developed samples were presented in table 4.2. The color properties of the samples are as follows: the tray dried powder has $L^* = 44.12 \pm 0.12$, $a^* = 12.10 \pm 2.10$, and $b^* = 14.12 \pm 1.01$; the oven dried powder has $L^* = 40.10 \pm 1.00$, $a^* = 10.10 \pm 1.10$, and $b^* = 12.12 \pm 1.14$; and the microwave oven dried powder has $L^* = 36.24 \pm 1.12$, $a^* = 10.20 \pm 1.08$, and $b^* = 11.12 \pm 1.12$. The color values indicate a decrease in lightness (L^*) from tray

dried to microwave oven dried powder, suggesting increased browning with more intense drying methods. Similarly, the a^* values, representing redness, decrease slightly in microwave dried samples, while the b^* values, indicating yellowness, also show a downward trend. These changes reflect the impact of drying techniques on the powder's color properties, likely due to Maillard reactions and pigment degradation.

The microwave oven dried powder exhibited the highest bulk density among the samples, indicating a more compact structure. Water absorption capacity (WAC) values were relatively consistent across all drying methods, suggesting similar hydration properties. Emulsion capacity was also comparable, with slight variations that may influence functional performance in food applications. The microwave oven dried powder exhibited the highest bulk density among the samples, which indicates a more compact and densely packed structure compared to the other drying methods. This increased bulk density may result from the rapid moisture removal and reduced porosity during microwave drying, leading to a denser powder matrix. Despite differences in bulk density, the water absorption capacity (WAC) values remained relatively consistent across all drying methods, suggesting that the hydration properties of the jackfruit rag powder were largely unaffected by the drying technique employed. Furthermore, the emulsion capacity showed only slight variations among the samples, which could have subtle effects on the functional performance of the powder in various food formulations, particularly those requiring stable emulsions.

The physical and functional properties of jackfruit rag powder are as follows: for tray dried powder, the bulk density is 1.12 ± 0.12 g/ml, water absorption capacity (WAC) is 1.10 ± 2.10 g/ml, fat absorption capacity (FAC) is 1.12 ± 1.01 g/ml, emulsion capacity is $24.12 \pm 4.12\%$, and foaming capacity is $14.12 \pm 1.10\%$; for oven dried powder, the bulk density is 4.10 ± 1.00 g/ml, WAC is 2.10 ± 1.10

g/ml, FAC is 1.12 ± 1.14 g/ml, emulsion capacity is $26.12 \pm 2.14\%$, and foaming capacity is $18.10 \pm 2.14\%$; for microwave oven dried powder, the bulk density is 6.24 ± 1.12 g/ml, WAC is 1.20 ± 1.08 g/ml, FAC is 1.12 ± 1.12 g/ml, emulsion capacity is $28.12 \pm 2.18\%$, and foaming capacity is $14.14 \pm 1.12\%$.

The physical and functional properties of jackfruit rag powder vary depending on the drying method applied. For the tray dried powder, the bulk density is measured at 1.12 ± 0.12 g/ml, indicating its mass per unit volume. Its water absorption capacity (WAC) is 1.10 ± 2.10 g/ml, reflecting the powder's ability to absorb and retain water, which is crucial for its rehydration and textural qualities. The fat absorption capacity (FAC) stands at 1.12 ± 1.01 g/ml, showing the powder's potential to bind fats, important for flavor retention and mouthfeel in food applications. The emulsion capacity is $24.12 \pm 4.12\%$, demonstrating the powder's effectiveness in stabilizing oil-in-water emulsions, while the foaming capacity is $14.12 \pm 1.10\%$, indicating its ability to form and maintain foam structures. In contrast, the oven dried powder exhibits a significantly higher bulk density of 4.10 ± 1.00 g/ml, which suggests a denser particle structure possibly due to the drying process. Its water absorption capacity increases to 2.10 ± 1.10 g/ml, implying enhanced water retention compared to the tray dried powder. The fat absorption capacity remains similar at 1.12 ± 1.14 g/ml. The emulsion capacity improves to $26.12 \pm 2.14\%$, indicating better emulsifying properties, and the foaming capacity also rises to $18.10 \pm 2.14\%$, reflecting an increased ability to generate and stabilize foam.

For the microwave oven dried powder, the bulk density is the highest among the three, recorded at 6.24 ± 1.12 g/ml, which may be attributed to rapid drying causing compact particle formation. The water absorption capacity is slightly elevated at 1.20 ± 1.08 g/ml, while the fat absorption capacity remains consistent at 1.12 ± 1.12 g/ml. This powder shows the highest emulsion capacity of $28.12 \pm 2.18\%$, suggesting superior emulsifying functionality,

whereas its foaming capacity is $14.14 \pm 1.12\%$, which is comparable to the tray dried powder but lower than the oven dried powder.

The control sample scored the highest across all sensory attributes, indicating strong overall acceptance. Among the treatments, T1 showed comparable results to the control, with only slight decreases in appearance and taste scores. T2 and T3 received lower scores, suggesting that these formulations may require further optimization to improve sensory qualities. The table shows the results of a sensory evaluation where people rated different cookie samples based on five qualities: appearance/color, taste, texture, flavor, and overall acceptability. Each sample has a score with an average value plus or minus a variation number, indicating how consistent the ratings were. The "Control" cookie received the highest scores overall, with ratings around 8.1 to 8.6 out of 10. Sample T1 had scores very close to the Control, slightly lower but still good. Samples T2 and T3 had lower scores compared to Control and T1, with T2 having the lowest ratings around 7.2 to 7.6, and T3 slightly better than T2 but still below Control and T1. This means that the Control and T1 cookies were liked more by the testers in terms of look, taste, texture, flavor, and overall acceptance, while T2 and T3 were less preferred. The sensory evaluation of the developed cookies showed the following results: The control sample had an appearance/color score of 8.24 ± 1.24 , a taste score of 8.40 ± 1.45 , a texture score of 8.40 ± 1.10 , a flavor score of 8.14 ± 1.12 , and an overall acceptability score of 8.64 ± 0.20 . Sample T1 scored 8.10 ± 1.10 for appearance/color, 8.12 ± 1.10 for taste, 8.20 ± 1.20 for texture, 8.42 ± 1.14 for flavor, and 8.34 ± 1.18 for overall acceptability. Sample T2 received scores of 7.40 ± 1.50 for appearance/color, 7.20 ± 1.20 for taste, 7.45 ± 1.24 for texture, 7.60 ± 1.45 for flavor, and 7.50 ± 1.20 for overall acceptability. Sample T3 had scores of 7.60 ± 1.20 for appearance/color, 7.80 ± 1.20 for taste, 7.65 ± 1.25 for texture, 7.80 ± 1.45 for flavor, and 7.80 ± 1.40 for overall acceptability.

The sensory evaluation data of the developed cookies indicates distinct differences between the control sample and the three test samples (T1, T2, T3) across various attributes including appearance/color, taste, texture, flavor, and overall acceptability.

The nutritional content (proximate composition) of cookies made with different amounts of jackfruit rag powder, compared to a control cookie without it. It lists the percentage of protein, total carbohydrates, total fat, dietary fiber, and total ash for each cookie type: Protein increases from 6.30% in the control cookie to 54.80% in the cookie with the highest jackfruit rag powder (T3). Total carbohydrates are highest in the control cookie (41.10%) and much lower in the others (around 17.9–19.2%). Total fat is highest in the control (10.70%) and decreases with more jackfruit rag powder, down to 7.80% in T3. Dietary fiber is low in all cookies but slightly higher in T3 (0.50%) compared to the control (0.30–0.40%). Total ash, which indicates mineral content, slightly increases from 1.20% in the control to 1.60% in T3. This means adding jackfruit rag powder increases protein and minerals while reducing fat and carbohydrates in the cookies.

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