International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; 9(7): 1285-1291
www.biochemjournal.com
Received: 16-05-2025
Accepted: 19-06-2025

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Tray dried gluten free smoothie mix powder: A nutrient dense ready to reconstitute beverage

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i7p.4925

Abstract
An instant smoothie powder was developed using tray-drying technology with oats (40%) and foxtail millet (30%) as the main ingredients. Honey was used as a natural sweetener, without the inclusion of any preservatives or artificial colouring agents. The product demonstrated high sensory acceptability, achieving an 85% likeness score. It exhibited low moisture content (5%) and reduced water activity, contributing to improved microbial stability and an extended shelf life. Rich in crude fibre, the powder serves as a potential dietary fibre source, with the tray-drying process (conducted at 60°C for 5 hours) preserving the nutritional integrity of the ingredients. The reconstitution ability of the powder was confirmed with a solubility rate of 94%, indicating excellent instant mixing characteristics. SEM (Scanning Electron Microscopy) analysis revealed the powder's rheological behaviour and surface morphology, highlighting its high hygroscopic nature which increases the risk of lump formation. This drawback can be mitigated through the addition of anti-caking agents and use of properly sealed packaging. The product is best reconstituted in a 1:2.5 (powder: water) ratio, providing a desirable consistency. While no additional sweetener is required, users may optionally enhance sweetness by adding sugar or drizzling honey. With its high nutritional value, excellent solubility, and convenience, this smoothie powder represents a healthy and ready-to-use beverage option for modern consumers.

Keywords: Smoothie powder, tray drying, oats, foxtail millet, solubility, shelf life

Introduction
Breakfast is usually the first meal of the day, and arguably the most important. Breakfasts vary widely in different cultures around the world, often include a carbohydrate source such as cereal or rice, fruits and/or vegetables, protein like dairy beverages. Regular consumption of breakfast is associated with a range of benefits, including better mental health in adults and adolescents (Smith, 1998, 2002b, 2005; O'Sullivan *et al.*, 2008) [25, 26, 27, 23], improved nutrition (Barton *et al.*, 2005) [6], success in weight loss (Lightowler and Henry, 2009) [19], satiation, moderation of total energy intake throughout the day and healthier lifestyle behaviours (Cho *et al.*, 2003; FosterSchubert *et al.*, 2008; O'Sullivan *et al.*, 2008; Clegg and Shafat, 2010) [8, 15, 23, 9]. Farshchi *et al.* (2005) [14] reported that Skipping breakfast affects postprandial insulin sensitivity and fasting lipids, and it may cause weight gain if the increased caloric intake is maintained. Every day, one in three Indians skip breakfast, with more women than men doing so. According to a poll, 42% of Mumbai residents either skip breakfast or search for a quick snack. (Majithia, *et al.*, 2010; de la Hunty A, Ashwell M.2007) [20, 10].

Smoothie is a thick, smooth, blended, sweetened, chilled beverage made with milk, fresh pureed fruits or vegetables and grain (cereal or millet or legume) flours that serves as a convenient vehicle for appropriate nutrient consumption appealing to all age groups with fresh fruit flavour and balanced nutrition. Smoothie can serve as a convenient breakfast, for all categories of people especially for those who skip breakfast due to lack of time in morning. Based on the available literature and considering the nutritive value of different food groups, smoothies could be prepared using diverse ingredients from dairy, pulses, millets, cereals, fruit, vegetables etc. Smoothie consumption has augmented in recent years due to the perceived health benefits, as the awareness regarding benefits of consuming at least five servings of fruit or vegetables per person every day in reduce the risk of lifestyle diseases is increasing. Smoothies contain different vitamins, antioxidants, polyphenols and fibre depending on the fruit/vegetable and grain flours used.

Due to its important role in promoting affordable, balanced meals and dietary variety, millet has the ability to solve both food and nutritional security in India. Vital amino acids, dietary fiber, minerals such as calcium, iron, manganese, phosphorus, potassium, and magnesium, flavonoids, polyphenols, and E and B-complex vitamins are all abundant in millets, which are more nutritious than other grains. Because of their nutritional advantages, they are now known as nutria-millets or nutria-cereals. It has been said that milk is nature's almost ideal food. A balanced diet is achieved by combining the nutrients found in milk with those found in vegetables, fruits, and grains like cereals and lentils. Cereals make up a large portion of human caloric and protein intake, especially in underdeveloped nations, and are the least expensive form of food energy. Other nutrients such dietary fiber, vitamins, minerals, isoflavanoides, polyphenols, and tocopherols are also present in millets and legumes. (J Awasthi *et al.*, 2025) [5].
Despite the fact that tiny millet, is more nutritious than grains, its use is restricted. The laborious nature of its processing is the main deterrent to its production and usage. Nonetheless, the development of suitable processing technologies is necessary to rekindle the lost interest in this millet because of its enormous potential. The current study is aimed to select the optimum levels of ingredients to formulate a breakfast smoothie, by incorporating the goodness of millets. Also make the product convenient to use and store by using suitable drying technology based on sensory evaluation.

Materials and Methods

Selection of raw materials

The raw materials required for the preparation of the product such as cereals that is steel cut oats (*Avena sativa* L), millet such as foxtail millet (*Setaria italica*), curd, almonds (*Prunus dulcis*), cinnamon powder (*Cinnamomum burmanni*) and skimmed milk powder were purchased from the local market of Kalpetta.

Selection of the Best Formulation for Smoothie

Sixteen preliminary trials were conducted to select the most suitable ingredients for this product. During the pretrials, it has been found that steel cut oats and foxtail millet gives the proper consistency to the product. The best combination of oats and millets were selected based on the high concentration of nutrients, colour, flavour, consistency, and taste of the smoothie. Skimmed milk powder and water (60:80 ratio) was selected as the most suitable medium for the grinding of the product after four preliminary trials.

Preparation of fresh smoothie

For the preparation of fresh cereal smoothie, the good quality raw materials were selected. The required amount of raw ingredients was weighed for preparation 150 g of instant powder. Steel cut oats and foxtail millet (40:25) is consider as the major ingredients, and the remaining are SMP, honey, almonds, curd and cinnamon powder were taken as 60 g, 60 ml, 5 g, 50 ml and 2 g respectively.
Cooking of oats and foxtail millets (40:25) were done. Cooking of oats helps to reduce its phytic content and make it easier to digest. The process was carried out at a temperature of 100 °C for 10 min. The cooking of foxtail millet is done under pressurized condition in a cooker for 20 min. The second step of preparation was soaking and refrigeration. The cooked and drained oats and foxtail millet were soaked in curd (50 ml) for overnight will improve its nutritional properties and flavour. Blending is the third step, in which the soaked mix and pealed almond which is soaked in water is blended in a food processer by the addition of 80 ml of reconstituted SMP in water. The other ingredients are added subsequently during the blending process.

Preparation of smoothie powder

One of the objectives of the project was to make the product in the powder form, so that the product becomes convenient and shelf stable. The blended fresh smoothie about 25ml, was spread evenly on a stainless-steel tray (12 5/8" x 19 1/8). After the pretrials it was concluded that tray drying is the best method for the prepared product. The temperature required for the adequate drying of the product was 60℃ for 5 hrs. The dried product in the trays were scraped with a metal scrapper and powdered. After drying and powdering, the weight of the tray-dried powder was measured and it was sealed in appropriate packages and stored under the refrigerated condition.

Preparation of Instant Smoothie

About 15g of the prepared instant smoothie powder was dissolved in 100 ml of cool water. It can be consumed directly without any further addition or any treatments.

Evaluation of Quality Parameters

Sensory Evaluation

Sensory evaluation of samples was carried out by a consumer panel using 9-point hedonic scale developed by Peryam and Pilgrim (1957) with required modification. Instant smoothie samples (about 25 ml) were served in transparent glasses. Consumer acceptability test was conducted with a 9-point hedonic scale to evaluate attributes such as color, flavor, appearance, texture, taste, and overall acceptance with individual scores from 9 (like extremely) to 1 (dislike extremely).

Evaluation of Powder Properties

Bulk density, Solubility and tapped density

Bulk density and tapped density were measured according to the method proposed by Caliskan and Dirim in 2011. With minor adjustments, the procedure outlined in Sri Lankan Standard (SLS) 668: 1984 was used to measure the instant smoothie's solubility in a duplicate. A dried centrifuge tube was filled with approximately 2.5 g of instant green smoothie powder. After adding water and giving the tube a good shake, the tube was centrifuged. The supernatant solution was then pipetted into a moisture container that had been dried and weighed. It was first stored in a water bath before being dried in an oven (OF-22G, Korea).To determine the solid in the liquid supernatant, the weight was measured in grams per milliliter. Ultimately, the following equation was used to calculate the residue's weight and solubility.

$$\text{Solubility (\%)} = [(m_4-m_2)-Y(m_3-m_4)] \times 100/m1$$

Where m_1 is the weight of the sample (g), m_2 is the weight of dried 50ml centrifugal tube (g), m_3 is the weight of the centrifugal tube with wet sediment (g), m_4 is the weight of the centrifugal tube with dry sediment (g), and Y is the supernatant liquid in g per ml

Particle size and powder properties
To study the particle size and powder properties the sample is analysed by scanning electron microscopy (SEM). As a device for examining particle surfaces SEM offers the general options listed below: Depending on the sample, surface feature imaging ranges from 10,000 to 100,000; feature resolution ranges from 3 to 100 nm; This microscope, when fitted with a backscattered detector, enables us to image second phases on unetched surfaces when the second phase has a different average atomic number, evaluate the crystallographic orientations of grains as small as 2-10 m, and observe grain boundaries on unetched surfaces. This enables us to assess individual grains, precipitated phases, and dendrites; determine the chemistry of features on the particle surface down to micron sizes; and assess surface gradients in chemical composition over distances of about one meter.

Viscosity
A Brookfield DV-II + programmed viscometer (Brookfield Engineering Laboratories Inc., Middleboro, USA) was used to measure the viscosity. A 250 ml beaker with a 6.5 cm diameter was filled with about 140 ml of the product. The speed of Spider 2 was 10 rpm. The duration of the measurement was 30 seconds. Before and after the stress test, the viscosity was measured.

Water Holding Capacity
Water Holding Capacity was determine using the method described by RA Anderson-1982. One gram of the sample was added to 10ml of distilled water in a pre-weighed tube and centrifuged at 4,000 rpm for 20 min on a VWR Centrifuge (Model Micro Star R30, USA). The clear supernatant was discarded and the centrifuge tube was weighed with the sediment. The amount of water bound by the sample was determined by difference and expressed as the weight of water bound by sample.

Specific heat capacity
The specific heat capacity of a food product can be predicted, based on product composition and the specific heat capacity of individual product components. The following expression was proposed:

$Cp = \varepsilon$(C psi. m si)

Where each factor on the right side of the equation is the product of the mass fraction of a product solids by removing the term for the water fraction. Choi and Okos (1986) evaluated the product components' specific heat value. By eliminating the term for the water fraction, the specific heat capacity of the product solids can be predicted using the equation above. Product enthalpy and apparent specific heat can be predicted using these specific heat magnitudes for the product solids.

$C_p = 4.180X_w + 1.711X_p + 1.98X_f + 1.547X_c + 0.908X_a$; KJ/Kg℃

where the fractions Xw, Xp, Xf, Xc, and Xa stand for water, protein, fat, and carbohydrates, respectively.

Thermal conductivity
The inherent characteristic of a substance that links to its capacity to conduct heat is called thermal conductivity. Conduction is the process of transferring energy within a material without the material moving as a whole. When there is a temperature differential in a solid (or stationary fluid) medium, conduction occurs. Higher molecular motions correspond to conductive heat flow, which happens in the direction of decreasing temperature. When molecules collide with one another, energy is transferred from the more energetic to the less energetic ones. Under steady state conditions and when the heat transfer is solely reliant on the temperature gradient, thermal conductivity is defined as the amount of heat (Q) transferred through a unit thickness (L) I in a direction normal to the surface of a unit area (A) as a result of a unit temperature gradient (dt T). In equation form this becomes the following:

Thermal conductivity = heat × distance/(area × temperature gradient)

$\lambda = Q \times L/ (A \times \Delta T)$

The majority of food products' thermal conductivity varies depending on their physical structure and water content. Numerous methods proposed for predicting thermal conductivity do not take structural orientation into account and instead rely on moisture content. The following is the Chois and Okos Model for predicting thermal conductivity.

$K = 0.58X_w + 0.155X_p + 0.25X_c + 0.16X_f + 0.135X_a$, W/m°$k$

Where
X_w is Water fraction, X_p is Protein fraction, X_f is Fat fraction X_c is carbohydrate fraction, X_a is ash fraction

Colour estimation
The colour of the powder product is measured by using Hunters colorimeter by following Colour Hunter L, a, b versus CIE 1976 L*a*b* standards.

Evaluation of Proximate Composition.
Moisture content, ash content, crude protein content, crude fibre content, and crude fat content, titratable acidity, reducing and non-reducing sugar of the instant smoothie sample were measured using the AOAC (2023) [4] method. Carbohydrate content was calculated by reducing the other compositions

Analysis of Mineral Content
The mineral contents, including iron (Fe) and sodium (Na), were determined using an Atomic Absorption Spectrometer (ICE 3500, UK). Prior to analysis, the instant smoothie powder samples were digested using a microwave digestion system (MARS 6, USA). Calibration standards were prepared, and the mineral concentrations were quantified in accordance with the standard method recommended for atomic absorption spectroscopy. AOAC (2023) [4]

Results and Discussion
Product Development
Smoothies are semiliquid beverage with smooth consistency, with different ingredients oats, foxtail millet and almonds. Skimmed milk powder reconstituted in water was selected as the liquid medium for blending. Smoothie in powder form provides better shelf-life and customer convenience.
Preliminary trials were conducted for selecting ingredients for manufacturing of cereal smoothie. Suitability of

ingredients like skimmed milk powder, oats, foxtail millet and honey and their addition rate were evaluated after subjecting the samples for sensory analysis (colour, flavour, texture and overall acceptability). Preliminary trials were conducted in four phases and overall, sixteen different combinations were evaluated by hedonic method. The best combination was selected on the bases of varying the quantities of SMP and foxtail millet and by fixing the proposition of oats, curd, honey and cinnamon powder. On the basis of the trial's product containing 60g of SMP along with 25g of Foxtail millet obtained maximum sensory score and was selected as the final product.

Development of the Instant Smoothie powder

For converting smoothie into powder form and facilitating the long-term preservation, tray drying was applied. Initially, the product is pre heated in a water bath at a temperature of 50℃, and then, exposed to a controlled temperature of 60℃ for 5 hours.

Proximate composition

Table 1: The proximate composition and nutritional parameters of instant smoothie. (AOAC 22ed edition, 2023)

SI. No	Parameter	Result (%)
1	Moisture	5.26
2	Protein	16.88
3	Fat	7.22
4	Total Ash	3.34
5	Carbohydrate	62.9
6	Reducing sugar	18.0
7	Non-Reducing sugar	16.2
8	Dietary Fibre	3.20
9	Iron	7.71
10	Sodium	94.5

Millet based smoothie with 16.8% protein can be considered a good source of protein when comparing with similar products like mango smoothie (2.25%) (Hevin *et al.*, 2024), Little Millet smoothie (7.81%) (Neeharika & Suneetha, 2024) [22]. 100 ml of instant smoothie sample provides the considerable amounts of Iron and Sodium as shown in the above table. 100 ml (15 g of instants smoothie powder) of cereal smoothie sample covers 7.71% and 94.5% of the Reference Nutrient Intake (RNI) (adults) for Fe, and Na respectively. The total fat content of the end product is about 7±0.22%.

The energy value of the powder is 271.36 Cal/g. This finding indicates that the smoothie powder has a significant crude fiber and carbohydrate content. A higher fiber content is advantageous from a nutritional perspective. When compared to the ash content of freeze-dried pumpkin powder (4:11±0:08) published in (Caliskan and Dirim *et al.*, 2015) [11], this powder had less ash.

Quality Evaluation of Instant Smoothie

Organoleptic evaluation

The developed instant smoothie was evaluated for the sensory attributes of appearance, colour, flavour, consistency, body, texture, and overall acceptability. Actual likeness of the instant smoothie sample is at the margin of 85% when considering the colour, appearance, and overall acceptability. Depending on the consumer's inclination, adding sugar or honey when dissolving the instant powder in cold water could lessen the slightly bitter flavor. Neeharika *et al.* (2020) [21] observed that addition of fruit juices enhanced the sensory acceptability of little millet-based smoothie.

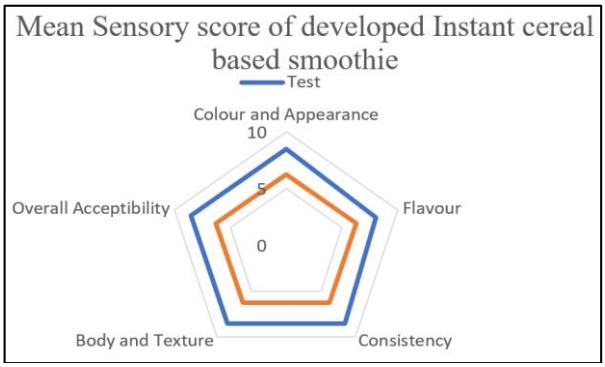

Fig 1: The radar chart corresponding to the sensory analysis of developed instant smoothie powder (60 SMP,25 Foxtail millet). This chart indicates the mean rank of appearance, colour, appearance, body, texture, consistency and overall acceptability for the developed instant smoothie powder.

Physio chemical properties of smoothie powder

The initial pH of the fresh and reconstituted smoothie was almost similar, 4:22±0:020 and 4:50±0:0385 respectivelyThe fresh smoothie's initial moisture content was 88.12%, and after 94.53% of the water was removed through tray drying, the instant smoothie mix's final moisture content was 5.26%. This outcome is marginally greater than the moisture content of freeze-dried mango powder (4%), as reported by Dirim and Çalışkan (2012) [12], and freeze-dried pumpkin powder (3.93%). According to Dirim and Çalışkan (2012) [12], the water activity level of freeze-dried pumpkin powder is higher than that of instant green smoothie powder, which was found to have a water activity of 0.197. A dry product's water activity is a more accurate indicator of its shelf stability. The product's durability against enzyme activation, lipid oxidation, browning, and hydrolytic processes was validated by its extremely low water activity content.

Particle size analysis and study of cohesiveness and flowability property of product by SEM

One of the most significant physical characteristics that influences a powder's flowability is its particle size. For wheat flour, the mean particle size, tensile strength, angle of repose, and cohesiveness of the flour are all negatively correlated. The intermolecular interactions are stronger, the particles are more compact, and the degree of contact area increases with decreasing particle size. Variations in the cohesive qualities of powders are also influenced by the features of the particle surface. Due in part to the rough surface features of soft powder particles, soft powders are more cohesive than hard powders (Kuakpetoon *et al.*, 2001) [18]

Through mechanical connections and Van der Waals forces, particle surface roughness can regulate interparticle interaction. Particles with smooth surfaces can interact with one another because of their large contact area (figure 2). It was discovered that a major factor in the cohesion of the flour particles was the amount of wheat fat. A portion of the flour systems' inherent cohesion was eliminated during defatting. Smoothie powder particles are not round, according to SEM photos; Amunugoda *et al.* (2020) [2] found the same thing with spray-dried ginger powder.

The moisture content has a significant impact on cohesion because grain flours are moisture sensitive. Powders have a tendency to absorb water molecules when the relative humidity of the surrounding air rises. This can lead to the formation of liquid bridges between powder particles, increasing powder cohesion and decreasing flowability. The ability of flours to adsorb water has been the subject of numerous investigations. Cohesion, wall friction, and the effective angle of wall friction have all been observed to increase with an increase in moisture content (Teunou *et al*., 1999) [28].

Particle surfaces may become more-sticky with increased moisture content, increasing the particles' adherence to the wall surface. It has also been hypothesized that water adsorbed onto a particle's surface tends to breakdown soluble components and create liquid bridges between particles, which causes cohesion and challenging flow. Due to a decrease in moisture content that may lessen particle cohesion, wheat flour's flowability increases as the temperature rises while maintaining a constant relative humidity (Teunou *et al.*, 1999) [28]. Fractions of sucrose powder with particle sizes smaller than 200 µm began to show signs of flow problems, such as a higher cohesion index and a greater propensity to caking (Dozan, 2014) [13].

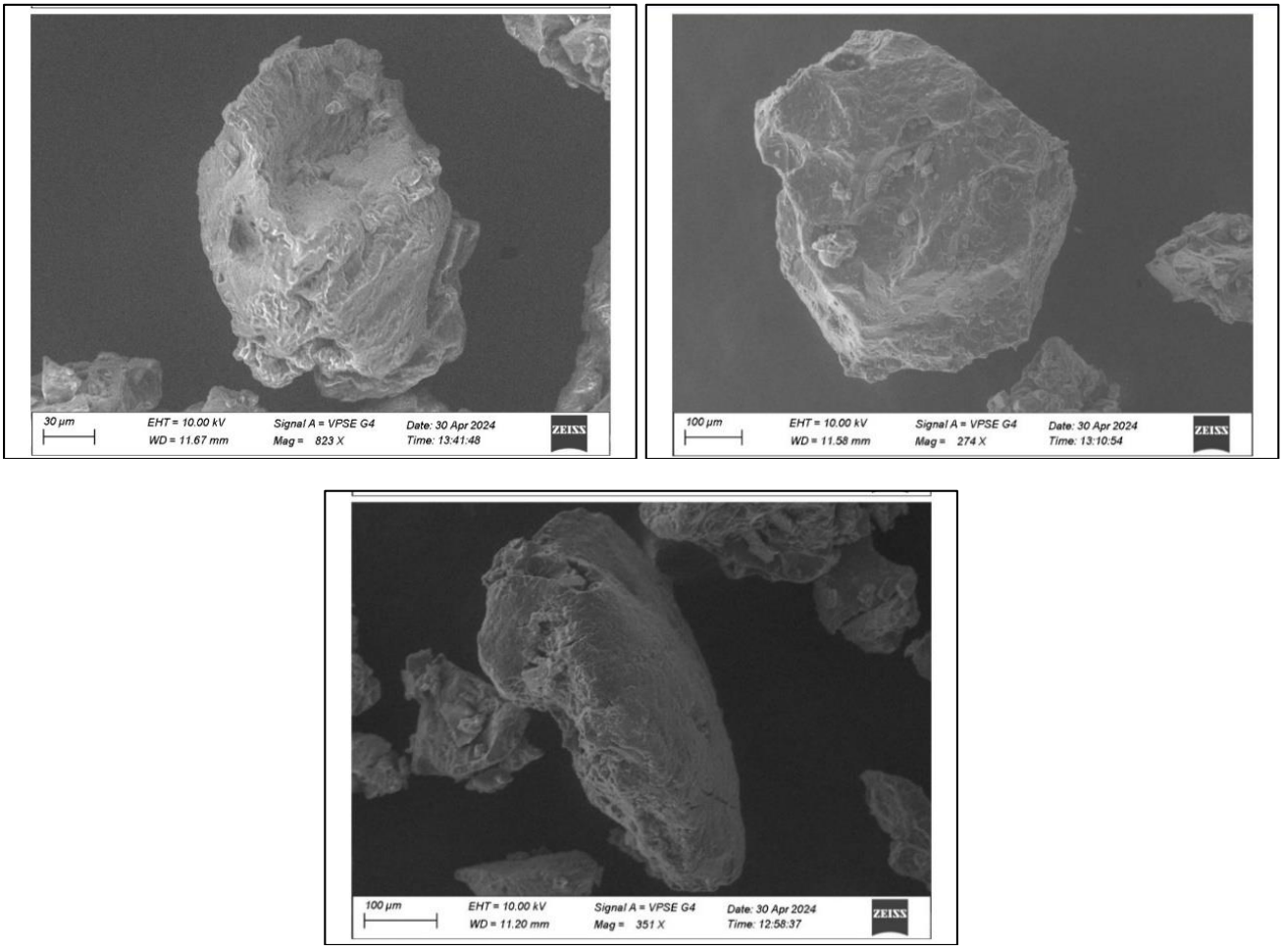

Fig 2: Surface properties of smoothie powder (SEM)

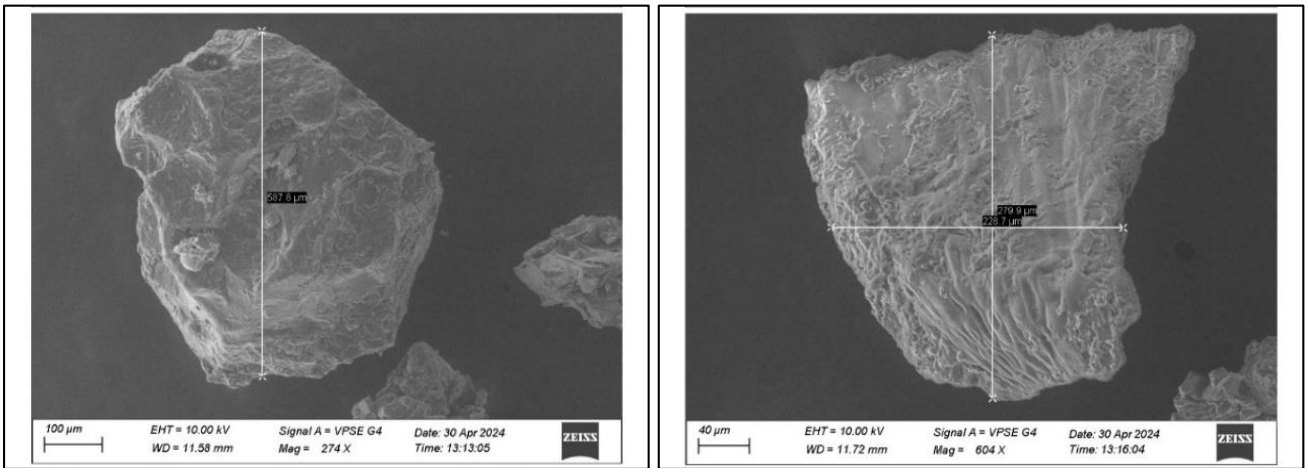

Fig 3: Particle size of smoothie powder (SEM).

Powder Properties of the Product

To ascertain the powder qualities, the instant powder's quality parameters, including bulk density and tap density, were evaluated. According to the determined powder parameters, its bulk density and tapped density are 0.5±0.0424 g/ml and 0.3±0.0327 g/ml, respectively. In comparison to the bulk densities of freeze-dried pumpkin powder (0:113±0:0006 g/ml) and sumac extract (0.267-0.282 g/ml), as reported by Caliskan and Dirim *et al.* (2015) [11], it is a higher value. Because high-density products are easier to store in tiny containers than low-density products (Quispe-Condori, M. D. A. Saldaña, *et al.*, 2011) [24], this increased bulk density is crucial for powder storage and packaging.

According to the SEM technique, the powder's characteristics showed that it had excellent cohesion and flowability. A powder's flowability is a gauge of its free-flow properties. For handling, packaging, measurement, shipping, bag filling and emptying, storage, and choosing parameters for mixing and conditioning, manufacturers and consumers depend heavily on the proper flow of powder (Dirim and Çalıskan, *et al.*, 2015) [11]. For describing the wettability and flowability of milk protein powders in their consolidated condition, the work of cohesion and work of adhesion are trustworthy markers (An & Zheng, 2024) [3].

The instant smoothie powder had a 96.50% solubility rate. Caliskan and Dirim *et al.* (2015) reported that the freeze-dried guava powder was 96% soluble when compared to other drying techniques [11]. In general, freeze-dried powder has superior solubility than powder made using conventional drying techniques. When evaluating a powder's capacity to reconstitute with water, its solubility is the most crucial characteristic.

Estimation of colour by Hunter colorimetry

Colour has been shown of primary importance in the judgment of food, ultimately influencing the acceptance or rejection of food. The colour was measured by determining

Table 2: Colour determination of smoothie mix powder

	Product	Control
l*	76.01	75.62
a*	3.76	3.74
b*	24.75	24.57

Hunter L (lightness), a (redness/greenness) and b (yellowness/blueness) values of smoothie.

Lightness (L*), red/ greenness (a*), and yellow/ blueness (b*) values of the

Product are shown in the above Table 2.

Evaluation of microbial stability of the product: Total plate count

The danger of microbial proliferation is significantly increased by the unit operations of smoothie preparation, which entail many damage pressures such peeling, chopping, shredding, or blending (N. Castillejo, *et al.*, 2017) [7]. Because to tray drying, instant smoothie powder has improved microbiological stability. After drying, the fresh smoothie's water content dropped to a very low level, making it unsuitable for microbe survival. Tray drying reduced the total number of plates by 85.6% (6.36 log units) and 100%, respectively.

Nutritional label

Nutrition Facts

2 Serving per Container

Serving size 1 packet (100g)

Amount per serving

Calories 393

	% Daily Value*
Total fat 7g	**24%**
Cholesterol 0mg	**0%**
Total Carbohydrate 62g	**19%**
Reducing Sugar 18g	-
Dietary Fibre 3g	10%
Protein 16g	**28%**
Fe 7mg	-
Na 94mg	-

Conclusion

A novel instant smoothie powder containing Oats and Foxtail millet in ratios of 40% and 30%, respectively was developed, using the tray-drying technique, without using any preservatives and colouring agent.

The product's overall sensory acceptance reached an 85% likeness level. The smoothie powder's extremely low moisture content (5%), which gives the product a longer shelf life and improved microbiological stability. The product's greater crude fiber content makes it a valuable source of fiber. The final product's nutritional value was unaffected by the tray-drying method. Its good reconstitution properties as an instant powder were validated by about 94% of its solubility. As a result, consumers may be presented with the instant smoothie powder as a convenient and healthful option.

The SEM analysis of the instant smoothie powder reveals its rheological properties and also it shows its surface characteristics. Due to particle property the powder is highly hydroscopic and chances of lump formation is high. By the addition of anti-caking agents this property can be reduced. The product has good rheological and solubility property for the reconstituting process a ratio of 1:2.5 gives better consistency. There is no need for further addition of sugar or honey to the product, for more sweetness consumers can add a spoon of sugar or honey according to their preference. Overall, the instant smoothie mix developed has good nutritional and sensory properties making it an ideal choice for a fast-track life of the current times.

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