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Evaluation of Different Foaming Agents for Foam Mat Drying of Tamarind Pulp: A Comparative Study of Maltodextrin, Egg White and Whey Protein

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Abstract

The present investigation entitled "Evaluation of Different Foaming Agents for Foam Mat Drying of Tamarind Pulp: A Comparative Study of Maltodextrin, Egg White and Whey Protein" was undertaken at Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, M.P.K.V., Rahuri during the year 2023-2025. This research presents a comprehensive comparative evaluation of three foaming agents, maltodextrin, egg white, and whey protein, for the foam mat drying (FMD) of tamarind pulp, a tropical fruit with significant nutritional and economic importance but challenged by high moisture content and perishability. The study systematically assessed the impact of each foaming agent combined with hydroxypropyl methylcellulose (HPMC) stabilizer on critical drying performance parameters, including foam expansion, foam density and powder recovery. Results demonstrated that maltodextrin-HPMC exhibited superior performance with the highest foam expansion of 84.3%, the lowest foam density of 0.69 g/cm³ and the greatest powder recovery of 41.5%, significantly outperforming the protein-based alternatives. This superiority is attributed to maltodextrin's dual role as both a foaming and carrier agent, its excellent stability under the acidic conditions (pH 2.8-3.2) of tamarind pulp, and its effective surface activity facilitating enhanced air incorporation and drying efficiency. The addition of HPMC stabilizer significantly enhanced powder yield, evidencing a strong synergistic effect. The study's findings underscore maltodextrin-HPMC as a highly effective and commercially viable system for producing high-quality tamarind pulp powder through foam mat drying, offering reduced drying time, improved energy efficiency, and extended shelf life while preserving the nutritional and sensory qualities of tamarind. This work establishes a clear scientific foundation for industrial adoption and future optimization of FMD technology for tamarind and similarly challenging acidic fruit matrices, thereby contributing to minimizing post-harvest losses and promoting value addition in tropical fruit processing.

Key words : Tamarind pulp, Foam mat drying, Foaming agents, Maltodextrin, Egg white protein, Whey protein isolate, Hydroxypropyl methylcellulose (HPMC), Foam expansion, Foam density, Powder recovery.

Tamarind (*Tamarindus indica* L.) is a tropical fruit belonging to the Leguminosae family, widely cultivated in tropical and subtropical regions around the world. The fruit is characterized by its unique sweet-tangy flavor profile and exceptional nutritional composition, containing high levels of tartaric acid (8-18%), reducing sugars (25-45%), dietary fiber, vitamins, minerals, and bioactive compounds including polyphenols and antioxidants (Hamacek *et al*., 2013; Shivashankara *et al*., 2011). India is the largest global producer of tamarind, with an annual output of approximately 1,38,000 metric tonnes, with major producing states including Karnataka, Kerala, Andhra Pradesh, Maharashtra, and Tamil Nadu (Statista, 2025).

Despite its nutritional and economic importance, fresh tamarind pulp faces significant challenges in terms of storage and preservation due to its high moisture content (35-40%), which makes it highly susceptible to microbial spoilage and enzymatic deterioration. This leads to substantial post-harvest losses, particularly during the harvest season when surplus production exceeds immediate consumption needs (Srinivas, 2007). The limited shelf life of fresh tamarind pulp creates supply-demand imbalances and necessitates the development of effective preservation technologies to ensure year-round availability while maintaining nutritional quality.

Traditional drying methods such as hot air drying, while effective in moisture removal, often result in significant quality deterioration including shrinkage, color changes, flavor loss, and reduced nutritional value due to prolonged exposure to high temperatures (Ratti, 2001). These limitations have prompted researchers to explore alternative drying technologies that can preserve product quality while achieving effective moisture removal.

Foam mat drying (FMD) has emerged as an innovative and promising alternative to conventional drying methods for processing liquid and semi-liquid food materials. This technique involves the incorporation of foaming agents into the product matrix to create a stable foam, which is subsequently spread into thin layers and dried under controlled conditions (Mounir and Allaf, 2017). The foam structure facilitates enhanced heat and mass transfer, reduces drying time, and operates at relatively lower temperatures compared to conventional methods, thereby minimizing thermal damage to heat-sensitive compounds.

The success of foam mat drying is critically dependent on the selection of appropriate foaming agents, which play a pivotal role in foam formation, stability, and the quality characteristics of the final dried product. Foaming agents function by reducing surface tension at the air-liquid interface, enabling air incorporation and foam formation. The choice of foaming agent significantly influences foam expansion, foam density, drying efficiency, and powder recovery, which are key performance indicators in foam mat drying operations.

Various foaming agents have been investigated for foam mat drying applications, including protein-based agents such as egg white and whey protein, and carbohydrate-based agents like maltodextrin. Egg white, rich in albumin proteins, is known for its excellent foaming properties due to its ability to denature and form stable interfacial films around air bubbles (Li *et al*., 2021). Whey protein isolate, containing -lactoglobulin and -lactalbumin, exhibits superior solubility and foaming characteristics, making it an attractive option for foam mat drying applications (Karim and Wei, 2016). Maltodextrin, a partially hydrolyzed starch derivative, functions not only as a foaming agent but also as a carrier and stabilizer, offering unique advantages in terms of powder flow properties and storage stability (Arnold, 2018).

The effectiveness of foaming agents in foam mat drying is typically evaluated based on several critical parameters. Foam expansion, defined as the percentage increase in volume after foaming, indicates the air incorporation capacity and directly affects drying efficiency. Foam density, representing the mass per unit volume of the foam, reflects the lightness and porosity of the foam structure. Powder recovery, expressed as the percentage of dried powder obtained relative to the initial wet foam weight, indicates the overall efficiency of the drying process and product yield.

While previous studies have investigated foam mat drying of various fruit pulps, limited research has been conducted specifically on tamarind pulp, particularly regarding the comparative evaluation of different foaming agents. The unique physicochemical properties of tamarind pulp, including its high acidity (pH 2.8-3.2), viscosity, and sugar content, present specific challenges that may influence foaming agent performance differently compared to other fruit matrices.

Therefore, the present study aimed to conduct a comprehensive comparative evaluation of three different foaming agents, maltodextrin, egg white, and whey protein, for foam mat drying of tamarind pulp. The study focused on determining the optimal foaming agent based on foam expansion, foam density, and powder recovery parameters, with the ultimate goal of identifying the most suitable foaming agent for producing high-quality tamarind pulp powder through foam mat drying technology.

Materials and Methods

Raw Materials : Fresh, mature tamarind pods free from physical damage, mold, and insect infestation were procured from the university farm at Mahatma Phule Krishi Vidyapeeth, Rahuri, India. The pods were manually shelled, and seeds and fibrous materials were removed to obtain clean tamarind pulp. The extracted pulp was homogenized using a brush pulper (Model: FPP-100, Jas Enterprises, Ahmedabad, India) to achieve uniform consistency.

Foaming Agents and Stabilizer : Three different foaming agents were selected based on preliminary literature review and their proven effectiveness in foam mat drying applications:

Maltodextrin (MD) : Food-grade maltodextrin (DE 10-15) was procured from Thermo Fisher Scientific India Pvt. Ltd., Mumbai. Maltodextrin is a polysaccharide derived from controlled hydrolysis of starch and is widely recognized as safe (GRAS) by the FDA with no specific daily intake limitations (FDA, 1995).

Egg White Powder (EW) : Spray-dried, pasteurized egg white powder containing approximately 80-82% protein was obtained from Hi-Media Chemicals, Mumbai. The powder was stored under refrigerated conditions (4°C) until use.

Whey Protein Isolate (WP): Food-grade whey protein isolate containing minimum 90% protein was procured from Qualigens Fine Chemicals, Mumbai. The protein isolate was stored in moisture-proof containers at ambient temperature.

Hydroxypropyl Methylcellulose (HPMC) : HPMC was used as a foam stabilizer across all treatments. It is a semi-synthetic, water-soluble polymer derived from cellulose, recognized for its excellent stabilizing properties in foam systems (Sharma *et al*., 2016).

Experimental Design : A completely randomized design was employed with three treatments corresponding to the three foaming agents. Each treatment was replicated three times to ensure statistical reliability. The treatment combinations were: T_1 : Egg white (10%) + HPMC (4%), T_2 : Whey protein (10%) + HPMC (4%) and T_3 : Maltodextrin (10%) + HPMC (4%)

The concentrations of foaming agents and stabilizer were selected based on preliminary trials and literature recommendations for similar fruit pulps (Ekpong *et al*., 2016).

Foam Preparation : For each treatment, 100 g of homogenized tamarind pulp was taken in a mixing bowl. The respective foaming agent (10% w/w) and HPMC stabilizer (4% w/w) were added to the pulp. The mixture was subjected to mechanical whipping using a blender (Parul Engineering Private Limited, Pune, Maharashtra, India) in conjunction with compressed air injection (2 HP High Pressure Air Compressor, Boss Air Compressor, Pune, Maharashtra, India) for 10 minutes at ambient temperature (25±2°C) to achieve stable foam formation.

Foam Mat Drying : The prepared foam was spread uniformly on pre-treated aluminum trays to achieve a consistent thickness of 1.5

cm. The trays were placed in a tray dryer (Biotechnics, India) operated at 60°C with an air velocity of 2.0 m/s. Drying was continued until the foam mat reached a constant weight, indicating the achievement of desired moisture content (6% wet basis).

Powder Preparation : The dried foam mats were cooled to ambient temperature and ground using a laboratory mixer (Model: FPM-150, Jas Enterprises, Ahmedabad, India) to obtain fine, free-flowing powder. The powder was sieved through a 60-mesh screen to ensure uniformity and stored in airtight containers for analysis.

Evaluation Parameters

Foam Expansion (%) : Foam expansion was calculated as the percentage increase in volume after whipping, using the following formula (Ekpong *et al*., 2016):

$$\text{Foam expansion (\%)} = [(V_1 - V_0)/V_1] \times 100$$

Where, V_0 = Initial volume of tamarind pulp before whipping (cm^3) and V_1 = Final volume of foam after whipping (cm^3)

Foam Density (g cm^{-3}) : Foam density was determined by dividing the mass of the foam by its volume (Ekpong *et al*., 2016):

$$\text{Foam density (g cm}^{-3}\text{)} = M/V_1$$

Where, M = Mass of the foam (g) and V_1 = Volume of the foam (cm^3)

Powder Recovery (%) : Powder recovery was calculated as the percentage of dried powder obtained relative to the initial weight of wet foam (Ekpong *et al*., 2016):

$$\text{Powder recovery (\%)} = (W_2/W_1) \times 100$$

Where, W_1 = Initial weight of wet foam (g) and W_2 = Weight of dried powder (g)

Results and Discussion

Foam Expansion : The foam expansion values for different foaming agents are presented in Table 1. Significant differences ($p < 0.05$) were observed among the treatments, with maltodextrin-HPMC combination (T_3) exhibiting the highest foam expansion of 84.3%, followed by whey protein-HPMC (T_2) at 79.6%, and egg white-HPMC (T_1) at 74.8%.

The superior performance of maltodextrin in terms of foam expansion can be attributed to its unique physicochemical properties and mechanism of foam formation. Unlike protein-based foaming agents that rely primarily on protein denaturation and interfacial film formation, maltodextrin functions through a combination of surface activity and film-forming properties. The partially hydrolyzed starch chains in maltodextrin possess both hydrophilic and hydrophobic segments, enabling effective reduction of surface tension at the air-liquid interface and facilitating enhanced air incorporation (Arnold, 2018).

The progressive increase in foam expansion from egg white (T_1) to whey protein (T_2) to maltodextrin (T_3) reflects the varying air incorporation capacities of these foaming agents. Whey protein, containing -lactoglobulin and -lactalbumin, demonstrates better foaming properties compared to egg white due to its superior solubility and surface activity in the acidic environment of tamarind pulp (Karim and Wei, 2016). The high acidity of tamarind pulp (pH 2.8-3.2) may have influenced protein functionality, with whey proteins showing better stability under acidic conditions compared to egg white proteins.

The achievement of higher foam expansion with maltodextrin is particularly significant for foam mat drying applications, as increased foam volume directly correlates with enhanced surface area for moisture evaporation, potentially leading to improved drying efficiency and reduced drying time.

Foam Density : Foam density results showed an inverse relationship with foam expansion, which is expected based on the fundamental principles of foam physics (Table 1). Treatment T_3 (maltodextrin-HPMC) recorded the lowest foam density at 0.69 g cm^{-3}, followed by T_2 (whey protein-HPMC) at 0.74 g cm^{-3}, and T_1 (egg white-HPMC) at 0.78 g cm^{-3}.

The lower foam density achieved with maltodextrin indicates the formation of a lighter, more aerated foam structure with higher air content. This characteristic is advantageous for foam mat drying as it promotes faster moisture removal through enhanced mass transfer and reduced thermal resistance. The 11.5% reduction in foam density from T_1 to T_3 demonstrates the significant impact of foaming agent selection on foam structure and properties.

The foam density values obtained in this study are comparable to those reported by Ekpong *et al*. (2016) for tamarind pulp foam mat drying using different concentrations of maltodextrin. Lower foam density is associated with better drying kinetics due to the increased porosity and reduced bulk density of the foam matrix, which facilitates easier moisture diffusion and vapor transport.

Powder Recovery : Powder recovery is a critical parameter that reflects the overall efficiency of the foam mat drying process and directly impacts the economic viability of the operation. The results presented in Table 1 demonstrate significant differences among treatments, with maltodextrin-HPMC combination (T_3) achieving the highest powder recovery of 41.5%, followed by whey protein-HPMC (T_2) at 38.9%, and egg white-HPMC (T_1) at 36.5%.

The superior powder recovery achieved with maltodextrin can be attributed to several factors. First, the excellent film-forming properties of maltodextrin contribute to better foam stability during the drying process, reducing foam collapse and material loss. Second, maltodextrin acts not only as a foaming agent but also as a carrier agent, helping to encapsulate the tamarind solids and prevent losses during drying and powder collection.

The comparison between powder recovery with and without additives (foaming agents and stabilizer) clearly demonstrates the beneficial effect of these components. For maltodextrin treatment (T_3), powder recovery increased from 29.6% without additives to 41.5% with additives, representing a 40.2% improvement. This substantial increase highlights the synergistic effect of the foaming agent-stabilizer combination in improving process efficiency.

The enhanced powder recovery with maltodextrin is also related to its ability to reduce stickiness and improve powder flow properties. Maltodextrin's high water solubility and low hygroscopicity contribute to the formation of free-flowing powders that are easier to collect

Table 1. Performance evaluation of different foaming agents for foam mat drying of tamarind pulp

Treatment	Combi-nations	Foam expansion (%)	Foam density (g cm^{-3})	Powder recovery Without additives (%)	Powder recovery With additives (%)
T_1	A + Z	74.8	0.78	26.1	36.5
T_2	B + Z	79.6	0.74	27.8	38.9
T_3	C + Z	84.3	0.69	29.6	41.5

and handle compared to powders produced with protein-based foaming agents.

Comparative Performance Analysis : The comparative analysis of all three evaluation parameters reveals a clear performance hierarchy: T_3 (maltodextrin-HPMC) > T_2 (whey protein-HPMC) > T_1 (egg white-HPMC). This ranking is consistent across all measured parameters, indicating that maltodextrin is the most suitable foaming agent for foam mat drying of tamarind pulp under the studied conditions.

The superior performance of maltodextrin can be explained by its unique combination of properties that make it particularly well-suited for foam mat drying applications. Unlike protein-based foaming agents that may be affected by the acidic environment of tamarind pulp, maltodextrin maintains its functionality across a wide pH range. Additionally, maltodextrin's role as both a foaming agent and carrier agent provides dual benefits in terms of foam formation and powder quality.

The results obtained in this study are in agreement with previous research on foam mat drying of fruit pulps. Islam *et al*. (2024) reported similar trends when comparing maltodextrin with protein-based foaming agents for jackfruit juice powder production, observing higher foam expansion and powder recovery with maltodextrin. Similarly, Ozcelik *et al*. (2019) highlighted the advantages of maltodextrin in improving foam stability and final product quality in foam mat drying applications.

Practical Implications : The identification of maltodextrin as the optimal foaming agent for tamarind pulp foam mat drying has several practical implications for industrial applications. The higher foam expansion and lower foam density achieved with maltodextrin suggest improved drying efficiency, which could translate to reduced energy consumption and processing time in commercial operations. The superior powder recovery indicates better material utilization and higher economic returns.

Furthermore, maltodextrin is generally recognized as safe (GRAS) by regulatory authorities and is widely accepted in food applications, making it suitable for commercial food processing operations. Its stability under various storage conditions and compatibility with different food matrices make it a practical choice for industrial implementation.

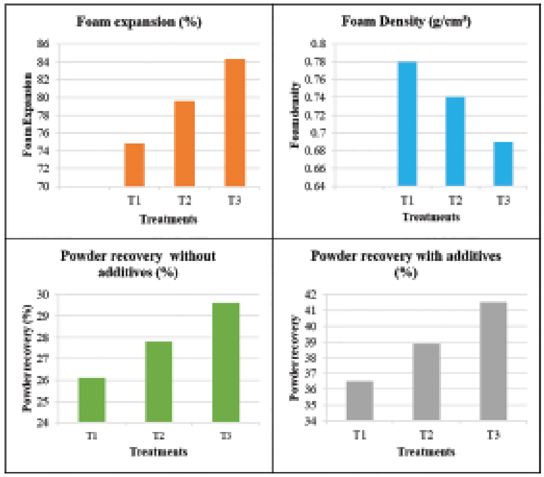
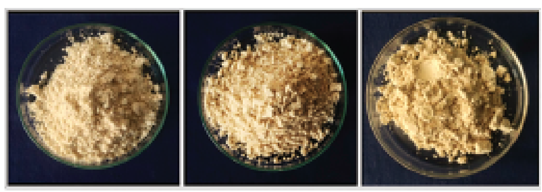


Fig. 1. Comparative effects of different foaming agents on FMD of tamarind pulp



T1 T2 T3

Plate 1. Tamarind Pulp Powders from Different Foam-Mat Drying Treatments

Conclusion

The evaluation demonstrates that maltodextrin combined with HPMC stabilizer is the superior foaming agent system for foam mat drying of tamarind pulp. Maltodextrin delivered the highest foam expansion of 84.3%, the lowest foam density of 0.69 g cm^{-3}, and the maximum powder recovery of 41.5%, outperforming egg white and whey protein. These results reflect maltodextrin's strong air incorporation capacity, optimal foam structure for efficient drying, and superior process yield. Its dual role as foaming and carrier agent, along with its stability under the acidic conditions of tamarind pulp (pH 2.8-3.2) and broad functional range, underpin this performance advantage. The addition of HPMC stabilizer significantly enhances powder recovery, with maltodextrin treatment showing a 40.2% improvement compared to without additives, indicating a notable synergistic effect. Maltodextrin's recognized safety status (GRAS), stability during storage, and compatibility with diverse food matrices make it highly suitable for commercial food processing.

These findings imply that maltodextrin-HPMC foam mat drying can improve drying efficiency, reduce energy use and processing time, and extend shelf life while preserving nutritional quality in tamarind powder production. This work establishes a clear performance hierarchy and provides a strong scientific foundation for further optimization and industrial adoption of foam mat drying technology for tamarind and similarly challenging acidic fruit pulps.

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