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Foam Mat Dried Tomato Pulp: Drying rate and Quantitative Characteristics

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ABSTRACT: The tomato (*Solanum lycopersicum*) is one of the well-researched vegetables due to its commercial significance and extreme perishability. Tomatoes are utilized in a variety of fresh and processed forms, including juice, puree, sauce, powder, and tinned. The aim of this paper is to analyze the foaming properties and drying characteristics of tomato pulp. The effects of gram flour content (0, 5, 10, 15, and 20% w/w), methyl cellulose concentration (0, 0.125, 0.250, 0.375, and 0.50% w/w), and whipping time (5, 10, 15, 20, and 25 minutes) on the foaming characteristics (foam expansion, foam density, and foam stability) of tomato pulp were studied (5, 10, 15, 20, and 25 min). The maximum drying rates at 60, 65, 70, and 75°C were 0.17, 0.19, 0.24, and 0.24 g water/g dry matter per minute for a 2 mm drying thickness; 0.10, 0.11, 0.13, and 0.14 g water/g dry matter per minute for a 4 mm drying thickness; 0.06, 0.07, 0.08, and 0.10 for a 6 mm drying thickness; and 0.05, 0.05, 0.06, and 0.07 g water/g dry matter per minute for an 8 mm drying thickness.

Keywords: Tomato, Foaming properties, Drying characteristics, Instant mix tomato khaman powder.

I. INTRODUCTION

One of the most widely farmed and consumed fresh vegetables in the world, tomatoes are members of the Solanaceae family (Table 1). They are utilized in a variety of fresh and processed forms, including juice, puree, sauce, powder, and canned. Tomatoes are grown in more countries than any other vegetable. India produces 7% of the world's total tomato harvest, making it the country's second-largest vegetable crop [1-6]. The top 10 tomato-producing countries include China, India, the United States, Turkey, Egypt, Italy, Iran, Spain, and Brazil. According to India's National Horticulture Board (NHB), tomato production in India for 2017-18 was approximately 19.74 million tonnes. The largest producer of tomatoes in India is Andhra Pradesh, followed by Madhya Pradesh as the second-largest producer.

In the year 2018-19, the average area and yield of tomatoes in the Panchmahal district were 385 hectares and 8,139 metric tonnes, respectively, according to the Director of Horticulture, Government of Gujarat. The size of a tomato is determined based on the maximum diameter of its equatorial section, and for round and ribbed tomatoes, it is 35 mm. The locally available tomato variety (Navin) was purchased from the Godhra market. This experiment was conducted at the Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Anand Agricultural University, in Godhra, Gujarat, India.

In the kitchen, dried tomato powder can be used as a substitute for raw tomatoes in any dish. However, manufacturing high-quality fresh tomato products requires sophisticated equipment. Therefore, in today's competitive market, there is a pressing need for innovators to develop affordable processing and packaging methods that still deliver durable and user-friendly products [7-9]. Tomato powder can enhance various food items such as soups, instant sauce premixes, ketchups, sambar and rasam mix, puddings, bakery goods, health foods, sweets, biscuits, baby foods, candies and snacks [10-12]. When extracting moisture from different vegetables, it is crucial to minimize damage to the product's quality due to their structural composition.

Tomatoes have a short shelf life at room temperature and are highly perishable. They are abundantly available throughout the growing season but scarce during the off-season. Inadequate processing facilities and a limited time frame result in significant income losses for the country.

Table 1: Scientific classification of tomato [1].

Sr. No.	Kingdom	Plantae
1	Division of Tomato	Magnoliophyta
2	Class of Tomato	Magnoliopsida
3	Subclass of Tomato	Asteridae
4	Order of Tomato	Solanales
5	Family of Tomato	Solanaceae
6	Genius of Tomato	*Solanium L.*
7	Species of Tomato	*Solanum lycopersicum L.*

The demand for dehydrated tomatoes is rapidly increasing on both local and foreign markets, primarily driven by their utilization in convenience foods. As a result, there is a pressing need to develop improved methods for processing and preserving this vital crop [13]. From this perspective, drying is an effective approach as it reduces volume and transportation costs while delivering a high-quality product at an affordable price. Therefore, drying enables farmers to maximize their harvest and production, making it the most suitable and relatively inexpensive method to meet the demand [14].

The research gap in the study of foam mat dried tomato pulp, focusing on drying rate and quantitative characteristics, can be summarized as the need for an innovative and cost-effective processing method that ensures the production of high-quality tomato powder. Existing drying methods for tomatoes often result in damage to the product's quality and limited shelf life. Additionally, there is a lack of research on utilizing protein-rich sources as alternatives to egg albumen in foam mat drying. This study aims to address these gaps by developing a process technology for foam mat drying of tomato pulp and by exploring the use of tomato powder as an ingredient in instant khaman mix.

The study aims to develop a process technology for foam mat drying of tomatoes using protein-rich sources as substitutes for egg albumen. Additionally, it aims to explore the utilization of tomato powder as an ingredient to enhance the value of the instant *khaman* mix.

II. METHODOLOGY

Experimental Design for Foam Mat Drying

Following set of experiments were planned and conducted for drying experiments

Sample

Table 2: Treatments combinations "for foam mat drying of foamed samples".

Treatment no.	Concentration of gram flour, % (w/w)		Concentration percentage of methylcellulose, % (w/w)		Whipping time, min	
	Coded	Uncoded	Coded	Uncoded	Coded	Uncoded
1	-1	5.00	-1	0.125	-1	10.00
2	1	15.00	-1	0.125	-1	10.00
3	-1	5.00	1	0.375	-1	10.00
4	1	15.00	1	0.375	-1	10.00
5	-1	5.00	-1	0.125	1	20.00
6	1	15.00	-1	0.125	1	20.00
7	-1	5.00	1	0.375	1	20.00
8	1	15.00	1	0.375	1	20.00
9	-1.68	1.59	0	0.250	0	15.00
10	1.68	18.41	0	0.250	0	15.00
11	0	10.00	-1.68	0.040	0	15.00
12	0	10.00	1.68	0.460	0	15.00
13	0	10.00	0	0.250	-1.68	6.59
14	0	10.00	0	0.250	1.68	23.41
15	0	10.00	0	0.250	0	15.00
16	0	10.00	0	0.250	0	15.00
17	0	10.00	0	0.250	0	15.00
18	0	10.00	0	0.250	0	15.00
19	0	10.00	0	0.250	0	15.00
20	0	10.00	0	0.250	0	15.00

Procedure

Foamed materials often undergo drying when exposed to hot air. The drying of foamed tomato pulp, ranging from 5°C above ambient to 100°C, was achieved using a tray drier (M/s Nova Instruments Private Ltd., Ahmedabad). The tray dryer is equipped with an electrical fan, sensors, and a temperature indicator cum controller unit, which is controlled by a computerized microcontroller.

The drying chamber is made of stainless steel and has dimensions of 0.86 m in length, 0.82 m in width, and 0.47 m in height, resulting in a volume of 0.331 m^3. The sample tray measures 0.81 m in length, 0.40 m in width (0.324 m^2), and 0.030 m in height. A thermocouple-based temperature indicator on the tray drier measures the air temperature inside the chamber. The tray dryer controller regulates the flow of air from the heater into the chamber.

To measure the hot air outflow, a digital anemometer (Prova Instruments Inc., Taiwan) recorded a rate of 0.03 m3/min. The weight of the tomato pulp samples was measured using a computerized weighing scale with a readability of ±0.001 g.

This setup ensures precise control and measurement of the drying process, enabling accurate data collection for further analysis.

Fig. 1. Tray dryer.

The digital tray drier (Fig. 1) was used to dry tomato pulp samples with thicknesses of 2, 4, 6, and 8 mm at temperatures of 60, 65, 70, and 75°C. The selection of temperature ranges and drying thicknesses was based on a previous study [15]. Sample weight loss was tracked using digital weighing balances. The temperature and thickness ranges of the study were monitored at 10-minute intervals. The sample tray was removed from the drying chamber, weighed using a computerized weighing balance located within 1.5 m of the drying unit, and then returned to the chamber. The weighing process took approximately 8-10 seconds.

Modelling the drying of foamed tomato pulp is of great importance. Simulating the dehydration of food particles in beds requires significant computational time, so equipment design models should be simplified. An apparatus with a certain number of beds and specific depths containing thin layers of particles is necessary for investigating thin-layer dehydration and updating equipment design. In this study, experimental data from foamed tomato pulp drying was fitted into twelve different variants for drying thin layers.

Similar to Newton's rule of cooling, the fundamental equation used to describe thin-layer drying incorporates a single drying constant (k) that accounts for the cumulative effect of multiple transport mechanisms. Its basic form was initially proposed by Lewis [16]

$$\frac{dM}{dT} = -k\left(M - M_{eq}\right) \quad \dots (1)$$

It was assumed that M, the moisture content, depended simply on time, and the solution was integrated to produce [17-18].

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp - (k \cdot t) \quad \dots (1.2)$$

The moisture ratio (MR) was developed as a unitless representation of moisture concentration. It is calculated by dividing the amount of remaining free water that needs to be removed by the initial amount of free water, and expressing it as a ratio over time (t). The moisture ratio serves as a measure of the unfinished moisture change throughout the drying process

III. RESULT AND DISCUSSION

Physical properties of tomato. The various physical properties of tomato vegetables, such as length, width, thickness, sphericity, volume, arithmetic mean diameter, and geometric mean diameter, exhibited ranges of 53.55 to 59.73 mm, 44.08 to 49.45 mm, 39.31 to 47.54 mm, 0.77 to 0.87, 102.31 to 138.02 cm3, 47.13 to 51.92 mm, and 45.00 to 49.68 mm, respectively. The average weight of a single tomato vegetable ranged from 70.00 to 95.00 g.

Analysing Responses for "Foaming Characteristics". The responses of foaming qualities, including foam expansion, foam density, and foam stability, to changes in the independent variables (gram flour, methyl cellulose, and whipping time), are presented in Table 2. To assess the relationship between response variation and independent factors, a full second-order model was utilized. Three-dimensional response surfaces (Fig. 2-4) were generated using Design Expert Software (version 8.0.7.1) to visually illustrate the variance in responses based on the processing factors.

Table 3: Foaming Properties with different combination of treatments.

Treat ment No.	Concentration of Gram flour % (w/w)		Concentration of Methyl cellulose % (w/w)		Whipping Time, min		Foam Expansion	Foam density	Foam stability
	Coded	Uncoded	Coded	Uncoded	Coded	Uncoded	(%)	(g/cm^3)	(%)
1	-1	5.00	-1	0.125	-1	10.00	27.86	0.70	92.30
2	1	15.00	-1	0.125	-1	10.00	7.93	0.84	100.00
3	-1	5.00	1	0.375	-1	10.00	54.09	0.55	70.21
4	1	15.00	1	0.375	-1	10.00	42.85	0.59	88.88
5	-1	5.00	-1	0.125	1	20.00	18.03	0.78	91.66
6	1	15.00	-1	0.125	1	20.00	58.73	0.56	72.00
7	-1	5.00	1	0.375	1	20.00	8.20	0.89	100.00
8	1	15.00	1	0.375	1	20.00	71.42	0.55	74.07
9	-1.68	1.59	0	0.250	0	15.00	19.20	0.70	100.00
10	1.68	18.41	0	0.250	0	15.00	9.71	0.80	100.00
11	0	10.00	-1.68	0.040	0	15.00	45.16	0.57	88.88
12	0	10.00	1.68	0.460	0	15.00	45.16	0.65	80.00
13	0	10.00	0	0.250	-1.68	6.59	12.9	0.88	100.00
14	0	10.00	0	0.250	1.68	23.41	29.03	0.75	87.50
15	0	10.00	0	0.250	0	15.00	77.41	0.47	72.72
16	0	10.00	0	0.250	0	15.00	77.41	0.48	72.72
17	0	10.00	0	0.250	0	15.00	77.41	0.50	72.72
18	0	10.00	0	0.250	0	15.00	77.41	0.45	72.72
19	0	10.00	0	0.250	0	15.00	77.41	0.49	72.72
20	0	10.00	0	0.250	0	15.00	77.41	0.48	72.72

The coefficients of x_1, x_2, and x_3 in the model are positive, suggesting that an increase in gram flour, methyl cellulose, and whipping time may lead to an increase in foam expansion of tomato pulp. The positive coefficients for the model terms x_1x_2 and x_1x_3 indicate a potential interaction effect between gram flour and methyl cellulose, as well as gram flour and whipping time, which could further enhance foam expansion. On the other hand, the negative coefficient for the model term x_2x_3 suggests that the foam expansion may decrease with the combined effect of methyl cellulose and whipping time. Additionally, the negative coefficients for the model terms x_1^2, x_2^2, and x_3^2 indicate that both insufficient and excessive amounts of gram flour, methyl cellulose, and whipping time may decrease foam expansion

$$\text{Foam expansion} = + 77.01 + 4.16x_1 + 4.69\,x_2 + 3.72\,x_3 + 3.90\,x_1\,x_2 + 16.89\,x_1\,x_3 - 7.29\,x_2\,x_3 - 19.65\,x_1^2 - 8.80\,x_2^2 - 17.35\,x_3^2 \qquad \ldots(1.3)$$

Table 4: Analysis of variance for foam expansion for tomato pulp.

Source	Model terms Co efficient	"Sum of squares"	"df"	"Mean Square"	F Value	Prob>F
Constant	77.010					
x_1	4.160	236.150	1	236.150	1.96	0.1917
x_2	4.690	300.020	1	300.020	2.49	0.1456
x_3	3.720	188.790	1	188.790	1.57	0.2391
x_1x_2	3.900^{ns}	121.760	1	121.760	1.01	0.3384
x_1x_3	16.890**	2281.160	1	2281.160	18.94	0.0014
x_2x_3	-7.290^{ns}	424.720	1	424.720	3.53	0.0898
x_1^2	-19.650***	5566.130	1	5566.130	46.21	< 0.0001
x_2^2	-8.800*	1115.240	1	1115.240	9.26	0.0124
x_3^2	-17.350***	4338.720	1	4338.720	36.02	0.0001
Complete model						
Regression		13007.050	9	1445.230	12.00	0.0003
Lack of Fit		1204.440	5	240.890		
Pure Error		0.000	5	0.000		
Residual		1204.440	10	120.440		
Total		14211.490	19			
R^2		0.9152	Adequate Precision			10.067
Adjusted R^2		0.8390				

Relevance: *P 0.05, **P 0.01, and ***P 0.001. ns: not significant, df: degrees of freedom
x_1 = gram flour, x_2 = methyl cellulose, and x_3 = whipping time

The analysis of variance of Equation 1.3 reveals that the interaction term between gram flour and whipping time (x_1x^3) is highly significant, as indicated by the F-value of 18.94 and a P-value of 0.0014. Additionally, the square terms of gram flour (x_1^2), methyl cellulose (x_2^2), and whipping time (x_3^2) are also significant, with F-values of 46.21, 9.26, and 36.02, respectively. The corresponding P-values for these terms are less than 0.0001 ($P<0.001$), 0.0124 ($P<0.05$), and 0.0001 ($P<0.01$), indicating their statistical significance.

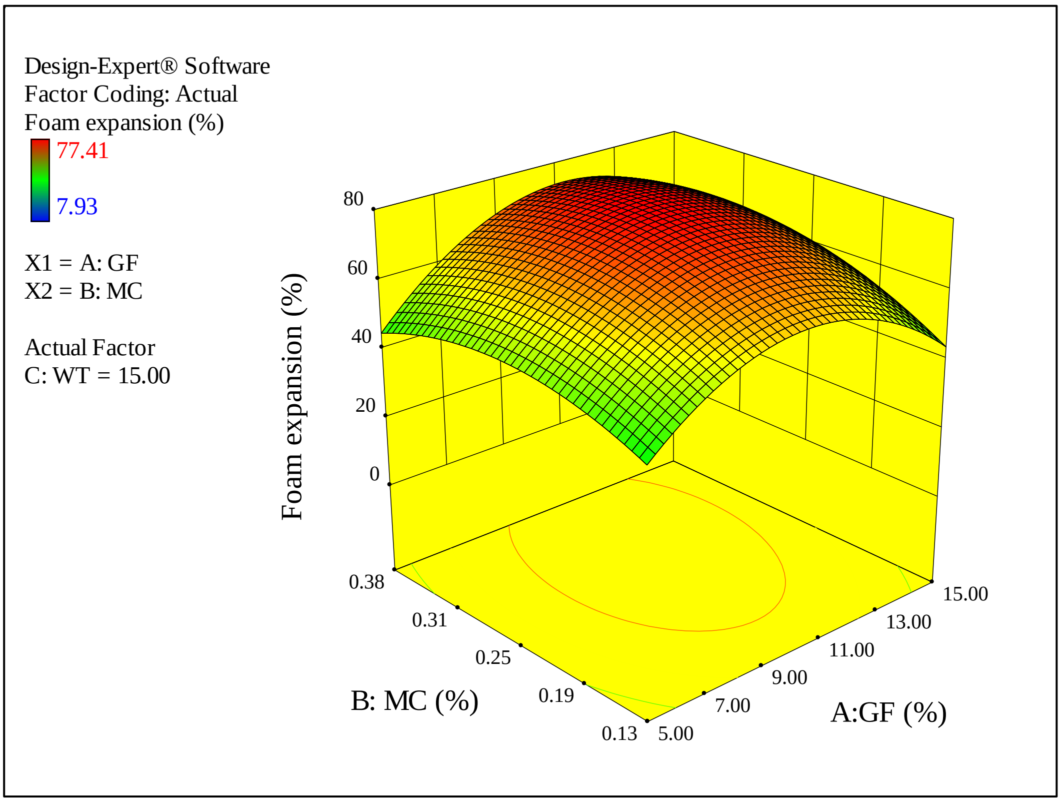

Fig. 2. Variation of foam expansion with respect to gram flour (GF) and methylcellulose (MC) in tomato pulp

It may be seen from Fig. 2 that the foam expansion of tomato pulp increases with the increase in methylcellulose.

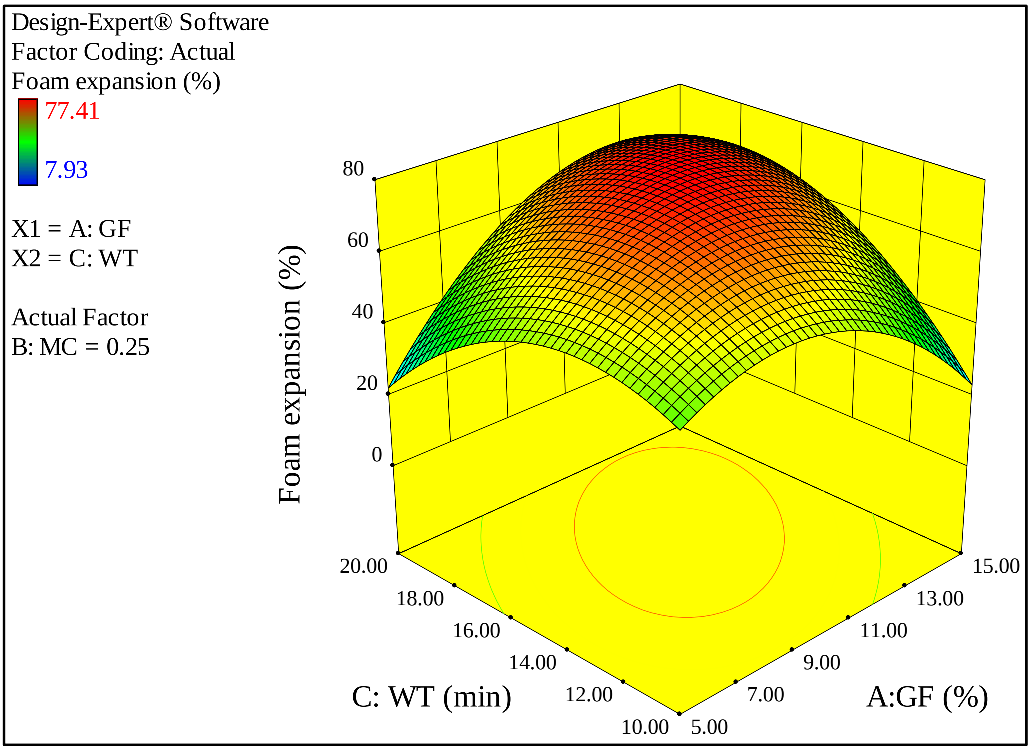

Fig. 3. Variation of foam expansion related to gram flour (GF) & whipping time (WT) in tomato pulp.

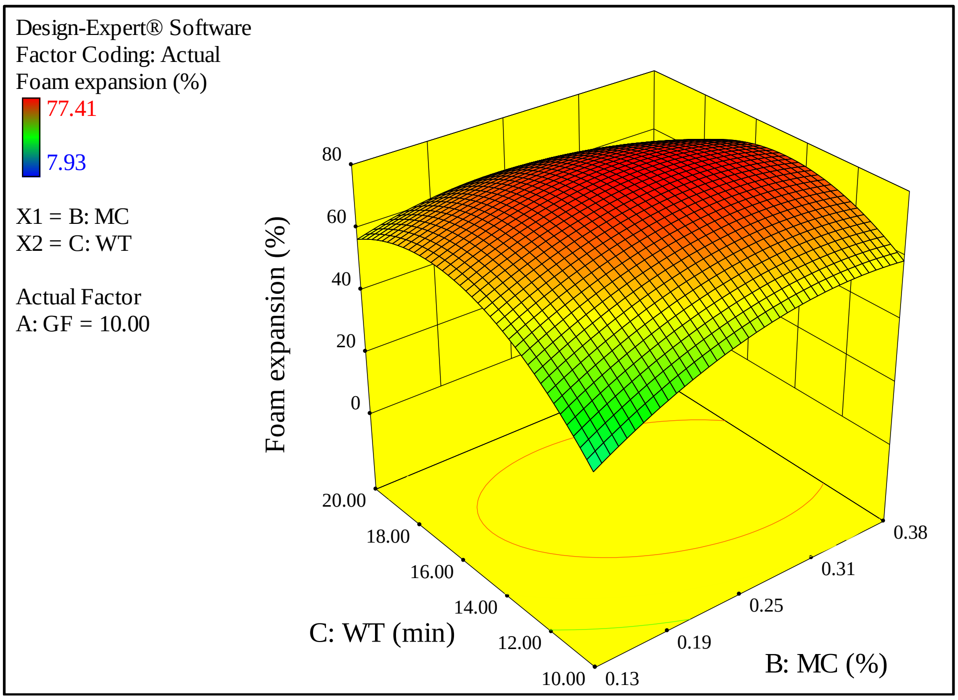

Fig. 4. Variation of foam expansion with respect to methylcellulose (MC) and whipping time (WT) in tomato pulp.

It may be seen from Fig. 3 that foam expansion of tomato pulp experienced a quadratic effect with respect to whipping time and gram flour.

It can be detected from Fig. 4 that the foam development amplified with whipping time and methylcellulose.

The drying process of foamed tomato pulp at various temperatures and thicknesses exhibited a falling rate period, accompanied by a short initial period of acceleration. Initially, the moisture loss was relatively slow but gradually increased as the drying process advanced. This decrease in drying rate was mainly attributed to the reduction in moisture content. Similar observations have been documented in studies on the drying of mango pulp [19] and foamed custard apple pulp [20]. These findings emphasize the significance of comprehending moisture migration and the drying properties of foamed fruit pulps, as they can contribute to optimizing the drying process and ensuring the preservation of the final product's quality.

IV. CONCLUSIONS

Because the thin foam surface quickly removes moisture, foamed tomato pulp dried at all temperatures and thicknesses at a decreasing rate time. Foamed tomato pulp dried in 120 to 180, 180 to 240, 270 to 380, and 350 to 500 min with drying thicknesses 2, 4, 6, and 8 mm at 60-75°C. Maximum drying rates at 60, 65, 70, and 75°C were 0.17, 0.19, 0.24 and 0.24 g water dry matter per min for a 2 mm drying thickness; 0.10, 0.11, 0.13, and 0.14 g water dry matter per minute for a 4 mm drying thickness; 0.06, 0.07, 0.08, and 0.10 for a 6 mm drying thickness; and 0.05, 0.05, 0.06, and 0.07 g water/g dry matter per minute for an 8 mm drying thickness. Twelve popular models were examined to suit foamed tomato pulp experimental data. Midilli's model had a higher R2 value (0.99531) and lower $\chi 2$ (0.0006) & RMSE (0.0138) values were lower than other models, which indicates that the model fitted very well to the experimental data.

V. FUTURE SCOPE

Future research in foam mat dried tomato pulp can focus on optimizing foam composition, improving product quality through parameter adjustments and pre-treatments, studying shelf stability and storage conditions, exploring its potential in various food applications, and investigating the effects of different factors on drying kinetics, sensory attributes, and nutritional properties. These efforts will contribute to the development of high-quality dried tomato powder with an extended shelf life, enhanced sensory characteristics, and wider market applications.

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