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Accelerated shelf-life test of foam-mat dried overripe banana powder: A comprehensive study in product stability and quality

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Abstract
The experiment was conducted at the Indian Agricultural Research Institute in New Delhi. This study estimated the shelf life of control banana powder (CBP) and foam mat dried powder (FDP). both samples were stored under accelerated environments (temperature = 30 ℃, 40 ℃, and 50 ℃, relative humidity (RH) = 75%, 84%, and 92%) for twelve days. Products were evaluated by a descriptive sensory panel at four-time points for each shelf-life condition. The accelerated shelf-life test (ASLT) agreed that FDP had the highest shelf life of nine months. However, CBP had only four months of shelf-life. The results indicated that FDP has a high potential for use as an alternative complementary food and maintains quality for long storage periods.

Keywords: Accelerated, sensory descriptive, shelf life, relative humidity (RH)

Introduction
The banana (*Musa x paradisiaca* L.) is an herbaceous perennial monocotyledonous plant commonly referred to as the 'Apple of Paradise.' It belongs to the family Musaceae and the order Scitamineae and originated in the hot tropical regions of Southeast Asia, resulting from the hybridization of *M. accuminata* and *M. bulbisiana* [ref.] [1]. Postharvest loss of bananas in India reached as high as 50% in recent years [2]. Various factors, such as the dense physical structure and high sugar content of bananas, restrict moisture mobilization during drying, making it slow and challenging [3].
Foam-mat drying is a process in which liquid or semi-solid foods are whipped into stable foams and then air-dried. During hot air drying, the foam is desirable to remain stable and retain its typical open structure to facilitate rapid drying [4, 5].
In response to both regulatory requirements and consumer expectations, modern industrialized food products must transparently disclose their shelf lives – the duration during which their attributes remain at acceptable levels – on their packaging. Today's consumers seek products that not only boast superior appearance, texture, taste, and flavour but also retain their nutritional value. Consequently, food companies find it imperative to conduct kinetic studies whenever introducing a new or modified product to the market. However, executing a comprehensive shelf-life test covering the entire anticipated validity period of an industrialized product with an extended shelf-life can be resource-intensive and significantly impede its market release. To address this challenge, food scientists undertake accelerated shelf-life studies, involving subjecting the product to relatively rigorous storage conditions. The heightened storage temperatures used in these studies expedite degradation reactions, following an Arrhenius-like pattern where higher temperatures lead to faster attainment of elevated degradation levels. This strategic approach allows for a more efficient evaluation of product stability without the prolonged timelines associated with conventional shelf-life testing [6].

Materials and Methods
Preparation of banana puree
The Grand Nain variety of bananas was brought from the local market in New Delhi with firmness of 15-20 newtons (N), soft and mushy, and contained total soluble solids of approximately 20–25 °Brix. The peel develops a 60 percent brown spot, and the flesh inside turns brown or even black in some areas.

Then the pulp was separated from the fruit part manually. The whole pulp was turned into a puree using a blender (Phillips) for natural foaming and drying studies. The initial moisture content, bulk density, total soluble solids, and ascorbic acid content of the pulp were recorded.

Foaming experiment

Whey protein isolate (WPI) was used as a foaming agent, with a 7.5% (W/W) WPI foam mixed into 100 g of banana puree. The foam was uniformly distributed in trays of cabinet dryer of thickness 5 cm and allowed to dry up to 3.5% moisture content. The foam stability, expansion, and density of whey protein isolate (WPI) were determined to be 61.997%, 27.344%, and 0.640 g/cm^3, respectively. The quality characteristics of foam-mat dried overripe banana powder were assessed and revealed to be the water solubility index (33.60%), water absorption index (2.19), bulk density (0.521 g/cm3), true density (0.629 g/cm3), Carr index (17.266%), Hausner ratio (1.209), and porosity (0.173). Additionally, the color values were determined to be L (lightness), a (red/green), and b (yellow/blue) at 47.84, 25.20, and 38.14 respectively.

Accelerated shelf-life test (ASLT)

To determine the product's shelf life and changes in quality parameters, moisture, total plate count (TPC), yeast and mold count (YMC), and coliform count (CC) were assessed. The key factors, such as temperature and humidity, that influenced the shelf life of the product were identified. Accelerated conditions were created based on these factors to expedite the aging process. Three different temperatures, particularly 30 °C, 40 °C, and 50 °C, and relative humidity of 75%, 84%, and 92%, were used for sample exposure. Saturated salt solutions of NaCl, KCl, and KNO_3 were employed to create the desired relative humidities. The accelerated test was conducted for 12 days, which was a fraction of the expected shelf life. During the test, samples were periodically monitored for relevant quality parameters, including physical and microbiological analyses. Observations were recorded at intervals of 3 days in triplicate.

Kinetic study

$$\text{Zero order reaction: } t = \frac{A0 - At}{k0}$$

$$\text{First-order reaction: } t = \frac{lnA0 - lnAt}{k0}$$

where,
t = prediction of shelf life (days)
A0 = initial quality value (Parameter's initial value)
At = value of product quality at time t k0 = constant

Result and Discussion

Table 1: Effect of temperature, RH, and storage days on the total plate count (TPC) of foam mat dried and control overripe banana powder

Days	Temperature (°C)	RH (%)					
		75		84		92	
TPC							
		CBP	FDP	CBP	FDP	CBP	FDP
0	30	24	21	24	21	24	21
3		44	47	54	60	68	74
6		112	116	120	128	135	148
9		226	229	244	249	253	264
12		253	261	263	270	259	267
0	40	24	21	24	21	24	21
3		55	62	61	66	69	73
6		119	125	125	131	142	148
9		234	240	255	261	262	268
12		254	260	270	277	272	281
0	50	24	21	24	21	24	21
3		60	69	67	82	78	82
6		126	137	131	157	151	157
9		242	250	264	275	271	175
12		244	272	276	290	270	290
*CBP- Control banana powder, FDP- Foam mat dried powder							

Table 2: Effect of temperature, RH, and storage days on the yeast and mold count (YMC) of foam mat dried and control overripe banana powder

Days	Temperature (°C)	RH (%)					
		75		84		92	
YMC							
		CBP	FDP	CBP	FDP	CBP	FDP
0	30	12	15	12	15	12	15
3		56	63	60	60	68	74
6		131	137	135	128	156	164
9		196	203	233	249	238	245
12		246	252	247	270	261	272
0	40	12	15	12	15	12	15
3		59	66	66	65	74	80
6		140	155	135	130	162	164
9		204	207	255	260	249	256
12		263	272	270	270	275	279
0	50	12	15	12	15	12	15
3		65	72	71	80	82	86
6		152	165	141	150	171	169
9		211	215	243	245	260	263
12		270	279	251	263	289	284
*CBP- Control banana powder, FDP- Foam mat dried powder							

Table 3: Effect of temperature, RH, and storage days on the moisture content of foam mat dried and control overripe banana powder

Days	Temperature (°C)	RH (%)					
		75		84			92
Moisture content (%)							
		CBP	FDP	CBP	FDP	CBP	FDP
0	30	4	3	4.12	4.58	3.58	4.56
3		21.25	16.41	24.12	23.25	25.25	25.14
6		32.58	22.25	35.18	36.24	38.12	35.68
9		44.87	35.12	46.37	48.54	48.25	49.57
12		46.47	38.02	48.56	49.08	51.12	50.18
0	40	4.25	3.56	3.12	4.36	4.54	4.07
3		18.26	14.68	20.15	21.89	22.22	24.58
6		29.62	24.21	34.12	34.15	36.69	34.19
9		41.28	40.21	45.14	47.14	45.56	44.58
12		44.27	42.57	46.48	47.5	50.21	48.25
0	50	3.75	3.7	4.58	3.78	5.21	3.56
3		16.47	15.35	19.47	20.58	21.11	22.14
6		27.59	25.41	30.49	32.49	35.12	34.25
9		38.85	34.54	44.23	44.63	41.47	41.12
12		43.43	37.56	45.02	46.02	48.6	47.69
*CBP- Control banana powder, FDP- Foam mat dried powder							

During the accelerated shelf-life study for 12 days, moisture content, total plate count (TPC), and yeast and mold count (YMC) increased. While coliform counts (CC) were absent for all samples throughout the storage period, Irrespective of RH conditions, all quality characteristics, such as moisture content, TPC, and YMC, followed a first-order reaction. The Arrhenius model was used for shelf-life prediction of control and foam mat dried powder. The predicted shelf life was 4 months, and 9 months for control, and foam mat dried powder respectively, at 30 °C and 75% RH. The findings indicated that higher temperatures and high RH during ASLT accelerated the growth of microorganisms in both the control and foam mat dried powder. The elevated temperature stimulated the metabolic activities of microorganisms, leading to increased microbial activity [7]. Foam mat dried banana powder exhibited hygroscopic properties, implying their ability to absorb moisture from the surrounding environment. When the relative humidity surpassed the moisture content of the product, it tended to attract and absorb moisture from the air, leading to an increase in its overall moisture content [8].

Conclusion

The shelf-life testing under ASLT storage conditions showed that at 30 °C and 75% RH, FDP could maintain its sensory quality for at least 9 months with no detection of off-note characteristics. The foam mat drying process may result in a powder with a unique particle structure that provides better protection against moisture reabsorption during storage. This can further contribute to the prevention of clumping and caking.

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