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Development and quality evaluation of nutritionally fortified fruit bars

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Abstract
The escalating global demand for health-promoting, convenient snack products has spurred considerable interest in the development of functional fruit-based formulations. This investigation was designed to develop and comprehensively evaluate a nutritionally fortified fruit bar utilizing three principal ingredients: date palm pulp (*Phoenix dactylifera L.*), cassava flour (Manihot esculenta Crantz), and cocoa-based chocolate powder. Date palm fruits serve as exceptionally rich sources of natural sugars, dietary fibre, essential minerals, and bioactive phenolic compounds. Cassava flour, recognized for its high starch content and gluten-free nature, contributes desirable textural and structural properties to the matrix. Chocolate powder, derived from cocoa beans, substantially enriches both the sensory profile and the antioxidant composition of the product through its abundance of flavonoid compounds.

Four distinct treatment formulations (T_0 through T_3) were developed by systematically varying the proportions of the three core ingredients. Each formulation was rigorously assessed for physicochemical properties, proximate nutritional composition, antioxidant activity, shelf stability, and sensory acceptability using standardized methodologies. Results demonstrated that progressive fortification with cassava flour and chocolate powder significantly enhanced the nutritional density, textural firmness, and consumer palatability of the fruit bars. The optimal formulation, designated T_3 (70% date pulp, 20% cassava flour, 10% chocolate powder), achieved the highest scores across all sensory parameters and demonstrated superior nutritional characteristics, including elevated protein, dietary fibre, and energy values. These findings conclusively validate the commercial viability and nutritional merit of locally sourced ingredient combinations for the production of shelf-stable, functional snack foods.

Keywords: Date palm fruit, cassava flour, cocoa chocolate powder, functional food product, fortified fruit bar, nutritional quality, sensory evaluation, antioxidant activity, shelf-stable snack

Introduction

The global food industry has witnessed a pronounced paradigm shift in consumer preferences, with an increasing proportion of the population prioritizing nutritional quality, functional benefits, and convenience in their dietary choices. Ready-to-eat snack foods occupy a particularly significant segment of the modern food market, and among these, fruit-based bars have gained remarkable traction due to their inherent nutritional density, extended shelf life, ease of consumption, and versatility in formulation. These products serve dual purposes: satisfying immediate energy requirements while delivering health-promoting bioactive compounds (Sharma *et al*., 2019; Nasser *et al*., 2020) [14, 18].

Date palm (*Phoenix dactylifera L.*) ranks among the most ancient and economically significant cultivated fruit crops in the world. Domesticated over 5,000 years ago in the arid regions of the Middle East and North Africa, the date fruit continues to serve as a primary dietary staple for millions across tropical and subtropical regions. Its extraordinary nutritional profile — encompassing high concentrations of readily digestible sugars (glucose, fructose, and sucrose), dietary fibre, B vitamins, potassium, calcium, magnesium, zinc, selenium, and a diverse array of phenolic antioxidants — renders it an ideal candidate for functional food development (Al-Farsi and Lee, 2008; Vayalil, 2012) [4, 21].

Beyond its nutritive composition, the rheological properties of date pulp, including its natural viscosity and adhesiveness, make it a superior binding agent and natural sweetener in processed food matrices.

Cassava (*Manihot esculenta Crantz*) is among the most widely cultivated tropical root crops globally, serving as a critical food security crop for hundreds of millions of people across Sub-Saharan Africa, Latin America, and Asia. As a gluten-free starch source, cassava flour exhibits several functional properties that are particularly valuable in food product development, including high water absorption capacity, gel-forming ability, and excellent binding and thickening characteristics (Charles *et al*., 2005; Nwosu *et al*., 2014) [7, 15]. The incorporation of cassava flour into fruit bar formulations has been shown to substantially improve structural cohesiveness, chewability, and overall textural integrity, while simultaneously increasing the caloric density and carbohydrate contribution of the product.

Cocoa-derived chocolate powder represents one of the most widely consumed and scientifically well-characterized functional food ingredients. The therapeutic and health-promoting attributes of cocoa are primarily attributed to its exceptionally high content of polyphenolic compounds, particularly flavan-3-ols (catechin and epicatechin), procyanidins, and anthocyanins, which collectively exert potent antioxidant, anti-inflammatory, vasodilatory, and cardioprotective effects (Katz *et al*., 2011; Crozier *et al*., 2011) [8, 12]. In addition to its functional significance, chocolate powder imparts characteristic flavor complexity, aromatic richness, and appealing color to food products, thereby greatly enhancing consumer acceptability.

Despite the well-documented individual attributes of these three ingredients, limited systematic research has explored their synergistic combination in a single fortified fruit bar product. Previous investigations have examined date-based confections (Hamada *et al*., 2002) [11], cassava-enriched snack products (Sobowale et al., 2013) [20], and cocoa-fortified bars (Afoakwa, 2010) [2] independently, but comprehensive studies integrating all three components remain scarce. This research gap forms the fundamental motivation for the present study.

Accordingly, the present investigation was undertaken with the specific objective of formulating a nutritionally superior, sensorially appealing, and shelf-stable fortified fruit bar from date pulp, cassava flour, and chocolate powder, and to systematically evaluate its physicochemical, nutritional, antioxidant, and sensory characteristics with a view to identifying the most optimal formulation for potential commercial application.

Nutritional and Functional Properties of Date Palm Fruits

Date palm fruits have been extensively investigated for their nutritional composition and health-promoting bioactive constituents. Al-Farsi *et al*. (2005) [3] reported that Omani date varieties contain 72–80% total sugars on a dry weight basis, with glucose and fructose as the predominant monosaccharides. Total dietary fibre content ranges from 6.4 to 11.5%, which contributes to satiety promotion and glycemic regulation. A comprehensive review by Vayalil (2012) [21] highlighted the presence of carotenoids, sterols, and procyanidins in date fruits and their documented roles in oxidative stress reduction, anti-tumor activity, and hepatoprotective effects. The use of date paste and pulp as natural sweeteners and binders in energy bars and cereal-based snacks has been validated by multiple studies (Hamada *et al*., 2002; Renjhen *et al*., 2008) [11, 17].

Functional Characteristics of Cassava Flour in Food Systems

The functional properties of cassava flour have been thoroughly characterized by several investigators. Defloor *et al*. (1998) [9] demonstrated that cassava starch exhibits high paste viscosity, excellent clarity, and strong gel-forming capability, which are desirable characteristics for snack bar applications. Nwosu *et al*. (2014) [15] evaluated the water absorption index (WAI) and water solubility index (WSI) of fermented and unfermented cassava flour and reported significant improvements in binding capacity and textural attributes upon incorporation into composite food products. Adebowale *et al*. (2008) [1] further confirmed that cassava flour-enriched food bars exhibited significantly improved cohesiveness, springiness, and chewiness compared to control formulations, underscoring its technological utility in the snack food sector.

Cocoa and Chocolate Powder in Functional Food Development

The incorporation of cocoa and chocolate powder into food products for the dual purposes of flavor enhancement and functional enrichment has been widely investigated. Crozier *et al*. (2011) [8] quantified the flavonoid content of various cocoa-containing products and demonstrated that cocoa powder contains among the highest concentrations of epicatechin (up to 196 mg/100 g) of any commonly consumed food. Keen (2001) [13] reviewed clinical evidence for cardiovascular benefits of regular cocoa consumption, attributing these effects primarily to flavanol-mediated nitric oxide production and platelet aggregation inhibition. In the context of snack bar development, Afoakwa (2010) [2] reported that inclusion of cocoa powder at 10–15% concentration significantly elevated both total polyphenol content and DPPH radical scavenging activity of composite cereal bars.

Fortified Fruit Bars: Development and Evaluation Trends

The development of fortified fruit bars has attracted increasing research attention over the past decade. Sharma *et al*. (2019) [18] developed mango-oat energy bars fortified with chia seeds and reported significant improvements in omega-3 fatty acid content and sensory acceptability at a 10% chia seed inclusion level. Nasser *et al*. (2020) [14] formulated energy bars from fig paste, rolled oats, and flaxseed and demonstrated that the optimal formulation provided approximately 350 kcal/100 g with excellent scores for texture, taste, and overall acceptability. Studies by Renjhen *et al*. (2008) [17] on mixed fruit bars incorporating guava and papaya pulp established baseline data on moisture, water activity, and microbial stability, providing a useful reference framework for the present investigation.

Objectives of the Study

The present investigation was conducted with the following specific objectives:

- To formulate a series of fortified fruit bars incorporating different proportions of date palm pulp, cassava flour, and cocoa-based chocolate powder.
- To determine the physicochemical characteristics of the developed fruit bars, including moisture content, pH, total soluble solids, and water activity.
- To evaluate the proximate nutritional composition, including protein, fat, crude fibre, total carbohydrates, and gross energy values.
- To assess the total phenolic content (TPC) and antioxidant activity (DPPH radical scavenging) of the formulated products.
- To conduct sensory evaluation and determine the relative acceptability of each formulation among a semi-trained consumer panel.
- To identify the most nutritionally superior and sensorially acceptable formulation suitable for scale-up and potential commercial production.

Materials and Methods

1. Procurement and Preparation of Raw Materials

Fresh, fully mature date fruits of the Medjool variety, food-grade cassava flour, natural cocoa-based chocolate powder (10–12% fat, Dutch-processed), refined cane sugar, food-grade citric acid (anhydrous), pectin (high-methoxyl, DE > 60%), and potable water were procured from certified suppliers in the local market. All reagents and chemicals employed for laboratory analyses were of analytical reagent (AR) grade unless otherwise specified.

1.1 Preparation of Date Palm Pulp

Fresh date fruits were carefully sorted to exclude damaged, over-ripe, or insect-infested specimens. The selected fruits were thoroughly washed under potable running water to remove surface dust, debris, and microbial contaminants. Pits were manually extracted and discarded. The deseeded flesh was then processed in a laboratory-grade electric blender (Philips HR2056, 600W) with a controlled addition of distilled water (1:0.5 w/v, fruit to water ratio) until a smooth, homogeneous pulp of uniform consistency was obtained. The resulting pulp was passed through a 0.5 mm mesh screen to remove any residual fibrous material or seed fragments prior to use in formulation.

1.2 Preparation of Cassava Flour

Commercially available cassava flour was assessed for moisture content and found to be within the acceptable range (< 13% w/w). The flour was sieved through a 250-µm mesh sieve to ensure uniform particle size distribution before incorporation into the fruit bar matrix. No additional heat treatment was applied, as the flour was confirmed to be low in residual cyanogenic glucosides (< 10 ppm HCN equivalent) by the manufacturer's certificate of analysis.

2. Experimental Design and Treatment Formulations

A Completely Randomized Design (CRD) with twelve replications were employed and with the formulations (T_0, till T_{12}) were prepared, as detailed in **Table 1**. The control treatment (T_0) consisted of 100% date pulp with no added cassava flour or chocolate powder. The twelve experimental treatments incorporated progressively higher levels of cassava flour and chocolate powder substitution, while maintaining a constant total ingredient mass of 500 g per batch.

3. Treatment Combination of Control

Table 1: Formulation Composition of Fortified Fruit Bar Treatments (per 500 g batch)

Treatment	Date pulp	Soya flour	Chocolate powder
T_0	80	15	5

Treatment Combination of Experimental

Treatment	Date Pulp	Cassava flour	Chocolate
T_1	80	8	12
T_2	76	13	11
T_3	72	18	10
T_4	68	23	9
T_5	64	28	8
T_6	62	31	7
T_7	61	33	6
T_8	59	36	5
T_9	58	38	4
T_{10}	54	43	3
T_{11}	53	45	2
T_{12}	51	48	1

4. Manufacturing Procedure

The manufacturing protocol was standardized across all treatment batches to ensure reproducibility. The weighed quantity of date pulp was transferred to a stainless-steel jacketed cooking vessel and heated over a medium flame with continuous stirring. Pre-weighed quantities of cassava flour and chocolate powder were thoroughly blended together in a dry bowl to ensure homogeneous mixing before gradual incorporation into the heating pulp. Sugar, pectin, and citric acid (dissolved in a minimal quantity of water) were sequentially added during cooking with constant agitation. The mixture was concentrated to a final total soluble solids content of 75–80°Brix as determined by a calibrated hand refractometer (Atago N-1E). The hot concentrated mass was uniformly spread to a thickness of approximately 5 mm on pre-greased stainless-steel trays using a calibrated spreading frame. The spread product was then subjected to control drying in a forced-air cabinet dryer at 55–60°C for 8–10 hours until the moisture content was reduced below 15% (w/w). After cooling to ambient temperature, the dried sheets were cut into standardized rectangular bars (30 g ± 0.5 g per bar, dimensions: 8 cm × 3 cm × 1 cm) using a stainless-steel guillotine cutter. Individual bars were packed in heat-sealed low-density polyethylene (LDPE) pouches and stored under ambient conditions (25 ± 2°C, RH 60–65%) pending analysis.

5. Analytical Methods

5.1 Physicochemical Analysis

All physicochemical parameters were determined in triplicate. Moisture content was determined gravimetrically by oven-drying at 105°C to constant weight (AOAC Method 925.09). Ash content was measured by muffle furnace incineration at 550°C for 6 hours (AOAC Method 923.03). The pH of a 10% (w/v) homogenate in distilled water was measured using a calibrated digital pH meter (Mettler Toledo FE20). Total soluble solids (TSS) were measured directly using a temperature-compensated hand refractometer and expressed as °Brix. Water activity (ac) was determined using a water activity meter (Decagon AquaLab Series 4TE) at 25°C.

5.2 Proximate Composition

Proximate analysis was conducted according to the standard AOAC (2019) [5] methods. Crude protein was determined by the Kjeldahl nitrogen method (N × 6.25 conversion factor, AOAC Method 2001.11). Crude fat was extracted by the Soxhlet method using petroleum ether (AOAC Method 920.85). Crude fibre was determined by acid-alkali digestion (AOAC Method 962.09). Total carbohydrates were calculated by difference [100 – (moisture + ash + protein + fat + fibre)]. Gross energy was calculated using Atwater factors (4 kcal/g protein, 4 kcal/g carbohydrate, 9 kcal/g fat).

5.3 Total Phenolic Content and Antioxidant Activity

Total phenolic content (TPC) was quantified using the Folin-Ciocalteu colorimetric method as described by Singleton and Rossi (1965) [19], with results expressed as mg gallic acid equivalents per 100 g dry weight (mg GAE/100 g DW). Antioxidant activity was assessed by the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay as described by Brand-Williams *et al*. (1995) [6], and results were expressed as percent inhibition at a concentration of 1 mg/mL methanolic extract.

6. Sensory Evaluation

Sensory evaluation was conducted by a panel of ten semi-trained evaluators (5 male, 5 female; age range 22–45 years) from the Department of Food Science and Technology, following written informed consent. Panelists were familiarized with the product category through a brief orientation session. Coded samples (three-digit random codes) were presented in random order on white ceramic plates in a standard sensory evaluation laboratory under white fluorescent lighting. Panelists were instructed to rinse the mouth with potable water between samples. The following sensory attributes were evaluated using a structured 9-point hedonic scale (9 = Like Extremely; 1 = Dislike Extremely): color and appearance, aroma, flavor, texture, taste, and overall acceptability.

7. Shelf Life Assessment

To evaluate the storage stability of the most acceptable formulation (T_3), packaged bars were stored under two conditions: (a) ambient temperature (25 ± 2°C, RH 60–65%) and (b) refrigerated conditions (4 ± 1°C). Moisture content, water activity, microbial load (total plate count and yeast and mold count per AOAC, 2019), and sensory scores were monitored at 0, 15, 30, 45, and 60 days of storage.

8. Statistical Analysis

All experimental data were subjected to one-way analysis of variance (ANOVA) using a Completely Randomized Design (CRD). Mean comparisons were performed using the Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$. Statistical analyses were performed using SPSS Version 26.0 (IBM Corporation, Armonk, NY). Data are presented as mean ± standard deviation of three independent replications.

Results and Discussion

1. Physicochemical Characteristics

The physicochemical properties of the developed fruit bars are presented in Table 2. Statistically significant differences ($p < 0.05$) were observed among treatments for all parameters evaluated.

Table 2: Physicochemical Properties of Fortified Fruit Bar Treatments (Mean ± SD, n = 3)

Treatment	Moisture (%)	Ash (%)	pH	TSS (°Brix)	Water Activity (aw)
T_0	16.8 ± 0.21^a	2.1 ± 0.05^a	5.71 ± 0.02^a	76.2 ± 0.35^a	0.68 ± 0.01^a
T_1	15.4 ± 0.18^b	2.4 ± 0.04^b	5.63 ± 0.03^b	77.1 ± 0.28^b	0.65 ± 0.01^b
T_2	14.7 ± 0.17^c	2.7 ± 0.06^c	5.58 ± 0.02^c	77.9 ± 0.31^c	0.63 ± 0.01^c
T_3	13.9 ± 0.15^d	3.0 ± 0.05^d	5.50 ± 0.02^d	78.6 ± 0.29^d	0.61 ± 0.01^d

Means within a column bearing different superscript letters are significantly different ($p < 0.05$, DMRT).

Moisture content declined progressively from 16.8% in T_0 to 13.9% in T_3 ($p < 0.05$), a trend consistent with the increasing proportion of cassava flour, which possesses superior water-binding capacity due to its high amylopectin content. The water absorbed by starch granules during cooking remains tightly bound, becoming less available for free moisture expression. These values are within the internationally recommended safe moisture range (< 18% w/w) for intermediate-moisture fruit-based confectioneries (Codex Alimentarius, 2019). Ash content increased significantly with fortification (2.1 to 3.0%), reflecting the combined mineral contribution of cassava flour (phosphorus, calcium) and chocolate powder (magnesium, iron, zinc). The pH values ranged from 5.50 to 5.71 across treatments, indicating.

A mildly acidic product matrix conducive to microbial stability. Total soluble solids increased significantly with increasing fortification, from 76.2°Brix (T_0) to 78.6°Brix (T_3), reflecting the higher solid content contributed by the incorporated ingredients. Water activity (aw) declined with increasing fortification, reaching a minimum of 0.61 for T_3, which is well below the critical threshold for bacterial growth (aw = 0.85) and mold/yeast proliferation (aw = 0.70), suggesting good shelf stability at ambient temperature.

2. Proximate Nutritional Composition

The proximate composition of the fortified fruit bars is presented in Table 3. All nutritional parameters exhibited significant treatment effects ($p < 0.05$), with T_3 demonstrating the most favorable nutritional profile across all components evaluated.

Table 3: Proximate Nutritional Composition of Fortified Fruit Bars (g/100 g, dry weight basis; Mean ± SD, n = 3)

Treatment	Protein (%)	Fat (%)	Crude Fibre (%)	Carbohydrates (%)	Energy (kcal/100 g)
T_0	2.3 ± 0.08^a	0.6 ± 0.04^a	3.1 ± 0.12^a	76.4 ± 0.52^a	316 ± 3.2^a
T_1	2.8 ± 0.09^b	1.2 ± 0.06^b	3.8 ± 0.14^b	78.2 ± 0.49^b	330 ± 3.8^b
T_2	3.2 ± 0.10^c	2.1 ± 0.07^c	4.3 ± 0.15^c	79.5 ± 0.44^c	342 ± 4.1^c
T_3	3.6 ± 0.11^d	2.8 ± 0.08^d	4.9 ± 0.16^d	80.1 ± 0.41^d	355 ± 3.9^d

The progressive increase in protein content from 2.3% (T_0) to 3.6% (T_3) is attributable to the protein contribution of both cassava flour (~1.5–2.0% protein) and chocolate powder (~5–7% protein). While these values are modest in absolute terms, they represent a 57% relative enhancement over the control, which is nutritionally significant for a confectionery product category typically regarded as protein-poor. Fat content increased substantially from 0.6% (T_0) to 2.8% (T_3), primarily owing to the cocoa butter naturally present in chocolate powder. This fat fraction, consisting predominantly of stearic and oleic acids, is associated with neutral to beneficial effects on cardiovascular risk markers. Dietary fibre content increased from 3.1% (T_0) to 4.9% (T_3), exceeding the minimum threshold for a “source of fibre” nutrition claim (3 g/100 g, Regulation EU 1924/2006) across all fortified treatments. This improvement is attributable to the combined insoluble fibre contributions of cassava flour and cocoa solids. Gross energy values ranged from 316 to 355 kcal/100 g across treatments, classifying the product as a moderate-to-high energy snack appropriate for active consumers and children. These findings are in good agreement with those reported for similar functional snack bar products by Sharma *et al*. (2019) and Nasser *et al*. (2020) [14, 18].

3. Total Phenolic Content and Antioxidant Activity

The total phenolic content (TPC) and DPPH radical scavenging activity of the fruit bars are presented in Table 4.

A highly significant positive correlation (r = 0.97, $p < 0.001$) was observed between TPC and antioxidant activity across all treatments.

Table 4: Total Phenolic Content and Antioxidant Activity (Mean ± SD, n = 3)

Treatment	TPC (mg GAE/100 g DW)	DPPH Scavenging (% inhibition)
T_0	186.4 ± 4.2^a	42.1 ± 1.8^a
T_1	218.7 ± 5.1^b	52.3 ± 2.1^b
T_2	267.3 ± 5.8^c	63.8 ± 2.4^c
T_3	312.5 ± 6.3^d	74.6 ± 2.7^d

TPC increased markedly and significantly from 186.4 mg GAE/100 g DW in T_0 to 312.5 mg GAE/100 g DW in T_3 ($p < 0.05$), an enhancement of approximately 68% attributable predominantly to the phenolic-rich cocoa fraction. This is consistent with published data for cocoa powder TPC values ranging from 250 to 450 mg GAE/100 g (Crozier *et al.*, 2011) [8]. Correspondingly, DPPH radical scavenging activity increased from 42.1% (T_0) to 74.6% (T_3) inhibition at 1 mg/mL, placing T_3 within the range of commercially marketed antioxidant snack bars. The baseline phenolic activity observed in T_0 is consistent with the known polyphenol content of date pulp (proanthocyanidins, hydroxycinnamic acids), as documented by Al-Farsi and Lee (2008) [4]. These results strongly suggest that the combination of date pulp and chocolate powder creates a synergistically enhanced antioxidant matrix, which may confer meaningful health benefits upon regular consumption.

4. Sensory Evaluation

The mean sensory scores assigned by the evaluation panel are presented in Table 5. T_3 was the most preferred formulation across all sensory parameters evaluated.

Table 5: Sensory Evaluation Scores of Fortified Fruit Bars (9-Point Hedonic Scale; Mean ± SD, n = 10 panelists)

Treatment	Color & Appearance	Aroma	Flavor	Texture	Taste	Overall Acceptability
T_0	7.1 ± 0.3^a	6.9 ± 0.4^a	7.0 ± 0.3^a	6.8 ± 0.4^a	7.2 ± 0.3^a	7.0 ± 0.3^a
T_1	7.8 ± 0.3^b	7.4 ± 0.3^b	7.6 ± 0.3^b	7.4 ± 0.3^b	7.7 ± 0.3^b	7.6 ± 0.3^b
T_2	8.2 ± 0.3^c	8.0 ± 0.3^c	8.1 ± 0.3^c	7.9 ± 0.3^c	8.0 ± 0.3^c	8.1 ± 0.3^c
T_3	8.7 ± 0.2^d	8.6 ± 0.2^d	8.8 ± 0.2^d	8.6 ± 0.2^d	8.7 ± 0.2^d	8.7 ± 0.2^d

T_3 achieved the highest scores for all sensory attributes, with an overall acceptability score of 8.7 (classified as 'Like Very Much' to 'Like Extremely'). The deep mahogany-brown color imparted by chocolate powder contributed to a visually attractive product with greater consumer appeal relative to T_0. The characteristic cocoa aroma was identified by panelists as one of the most appealing features of T_3, with an aroma score of 8.6. Flavor was the highest-rated attribute (8.8), likely reflecting the harmonious integration of the caramel-like sweetness of date pulp with the bittersweet complexity of cocoa. Textural scores improved consistently with increasing cassava flour content, corroborating its role as a structural and binding agent that imparts a pleasingly firm, chewy consistency without excessive hardness. The control formulation T_0 received acceptable but lower scores across all parameters, with a tendency toward excessive stickiness noted by several panelists, which was substantially remediated by cassava flour addition in the experimental treatments. These results are consistent with findings by Sharma *et al*. (2019) and Nasser *et al*. (2020) [14, 18], who reported marked improvements in sensory acceptability upon incorporating cocoa powder and starchy flours into fruit bar formulations.

5. Shelf Life Performance of Optimal Formulation (T_3)

Table 6: Shelf Life Monitoring of T_3 under Ambient Storage (25°C, RH 60–65%)

Storage Period (days)	Moisture (%)	Water Activity (aw)	TPC (mg GAE/100 g)	Overall Acceptability	Total Plate Count (log CFU/g)
0	13.9 ± 0.15	0.61 ± 0.01	312.5 ± 6.3	8.7 ± 0.2	< 1.0
15	14.2 ± 0.17	0.62 ± 0.01	305.8 ± 5.8	8.5 ± 0.3	< 1.0
30	14.6 ± 0.18	0.63 ± 0.01	298.3 ± 5.5	8.3 ± 0.3	1.2 ± 0.2
45	15.1 ± 0.20	0.64 ± 0.01	289.7 ± 5.2	8.0 ± 0.3	1.8 ± 0.3
60	15.4 ± 0.21	0.65 ± 0.01	281.1 ± 4.9	7.8 ± 0.4	2.1 ± 0.4

The shelf life data for T_3 under ambient storage conditions indicate that the product maintains acceptable quality parameters throughout a 60-day storage period. Moisture content increased gradually from 13.9% at day 0 to 15.4% at day 60, yet remained well within the safe limit of 18% at all time points. Water activity showed a corresponding modest increase from 0.61 to 0.65, remaining below the mold growth threshold throughout the study period. Total phenolic content declined by approximately 10% over 60 days, which is consistent with published oxidative degradation rates for phenolic-rich food products under ambient storage (Ramirez-Jimenez *et al*., 2000) [16]. Overall sensory acceptability scores remained above 7.5 ('Like Moderately' to 'Like Very Much') through 60 days of storage. Microbial counts remained well within FSSAI (2022) acceptable limits for fruit-based confectioneries ($< 10^2$ CFU/g total plate count; < 10 CFU/g yeast and mold) throughout the storage period. These findings collectively confirm that LDPE-packaged T_3 fruit bars are shelf-stable for a minimum of 60 days under ambient tropical conditions.

Conclusion

The present study successfully demonstrated the development of nutritionally fortified, sensorially superior, and shelf-stable fruit bars through the strategic combination of date palm pulp, cassava flour, and cocoa-based chocolate powder. The systematic variation of ingredient proportions across four treatment formulations revealed clear dose-dependent improvements in nutritional density, antioxidant activity, and sensory quality with increasing levels of fortification.

Treatment T_3, comprising 70% date pulp, 20% cassava flour, and 10% chocolate powder, consistently emerged as the optimal formulation, achieving statistically significant superiority across all evaluated parameters: lowest moisture content (13.9%), highest dietary fibre (4.9%), highest total phenolic content (312.5 mg GAE/100 g), highest DPPH radical scavenging activity (74.6%), and highest overall sensory acceptability score (8.7/9.0). The product demonstrated excellent shelf stability over a 60-day ambient storage period, with microbial counts, water activity, and sensory scores all remaining within commercially acceptable limits.

These findings provide strong scientific evidence for the feasibility of developing high-quality, functional snack food products from widely available and low-cost tropical ingredients. The fortified fruit bar formulation has significant potential for application in child nutrition programs, sports nutrition, and general health-conscious consumer markets. Future research should investigate the impact of alternative packaging materials, natural preservative incorporation (e.g., rosemary extract, vitamin E), modified atmosphere packaging, and the clinical nutritional impact of regular consumption on relevant biomarkers in targeted population groups.

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