

Techno-Economic Evaluation of Nigerian Stored Products Research Institute's Parabolic-Shaped Solar Dryer for Production of High-Quality Cassava Flour

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Abstract

Cassava (*Manihot esculenta*) is a staple crop that plays a crucial role in food security and industrial applications. However, its high moisture content makes it highly perishable, necessitating immediate processing into stable products such as High-Quality Cassava Flour (HQCF). Traditional open sun-drying methods are inefficient due to contamination risks, weather dependency, and inconsistent drying rates, and fossil fuel-powered dryers are also costly to operate. This study evaluated the techno-economic performance of the Nigerian Stored Products Research Institute (NSPRI) Parabolic-Shaped Solar Dryer (PSSD) as an alternative drying method for HQCF production. Two different sizes (6.5 m × 4.2 m × 2.4 m with effective drying area of 17.85 m²) and (10 m × 6 m × 4 m with an effective drying area of 45.6 m²) of the NSPRI PSSDs installed at NSPRI Ibadan Zonal Office, Onireke and "STOP HUNGER" at Moniya, all in Ibadan, were evaluated in this study. This resulted in distinct drying performance and techno-economic outcomes. Sensory evaluation was also conducted on some value-added products solely from the HQCF composites, ensuring assessment of flour quality through its practical use (functional and organoleptic quality). Results from meteorological data indicate that the NSPRI PSSD maintained an average temperature of about 50°C in the two dryers and effective air distribution that resulted in 17-21% reduction in relative humidity in the dryers. Furthermore, average drying rates of 0.0573-0.0727 and 0.0687-0.0701 kg/h were obtained from samples in the small and big PSSD, respectively. The dryers have loading capacity of 1.4 kg/m² and batch capacity of 25.2 and 64.0 kg/batch for the small and big PSSD, respectively. Results of sensory evaluation indicates that the HQCF has potential for production of some value-added products at moderate substitution of up to 20%. The results show that the total revenue estimated from the market value of the dried product obtained, was N72,175.00, while the total cost, representing only the operational costs of the drying process, was N54,513.00. The fabrication cost of the dryer was excluded from the analysis. The net profit obtained was N17,662.00 with a benefit-to-cost ratio of 1.32. The economic analysis suggests that adoption of the PSSD can reduce energy costs, minimize postharvest losses, and improve profitability for small-scale cassava processors.

Categories: Food and Pharmaceutical Engineering, Renewable Energy in Agriculture, Bioprocess Engineering

Keywords: cost, drying capacity, hqcf, sensory evaluation, solar-drying technology

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Introduction

Cassava (*Manihot esculenta*) is a vital staple crop grown in many tropical and subtropical regions, and globally provides food security for over 800 million people [1]. It has the potential to adapt to diverse climatic conditions and capacity to be cultivated in poor soils, which make it an essential crop for both subsistence and commercial production [2]. In addition to its role in food security, cassava is widely used in industrial applications, particularly in the production of High-Quality Cassava Flour (HQCF), which serves as an alternative to wheat flour (as composite) in bakeries, and other utilizations in the paper, textile, and adhesive industries [3]. HQCF has been widely studied as a partial substitute for wheat flour in baked and fried products due to its affordability and local availability [4]. Sensory evaluation provides insights into consumer's acceptability of a product by assessing attributes such as color, aroma, texture, taste, and overall acceptability [5].

However, even with its numerous benefits, cassava is highly perishable due to its high moisture content (MC), which accelerates post-harvest physiological deterioration within 12 to 72 hours of harvest [6]. This rapid spoilage necessitates immediate processing into more stable products such as HQCF to prevent losses, ensure food security, and enhance economic value [7,8]. Drying is a vital step in cassava processing, traditionally carried out using open sun drying [9]. However, this method is inefficient due to contamination risks, exposure to unpredictable weather conditions, and uneven drying, leading to quality degradation [10].

Solar drying technology presents an effective and sustainable alternative to traditional sun drying. The Nigerian Stored Products Research Institute has developed a solar dryer popularly known as NSPRI Parabolic Shaped Solar Dryer. It enhances drying efficiency, protects product against contamination, and reduces drying time under hygienic condition [11]. Performance evaluations have shown that solar dryers significantly reduce MC in cassava products while maintaining quality. For instance, a study comparing the performance of solar dryers with backup incinerators reported mean location drying rate efficiencies of 98.8, 94.7, and 87.4% according to [12]. Similar comparative studies have reported variations in solar dryer efficiencies (up to 14.89%) under similar test conditions, confirming improved performance with active drying designs [13].

Economic viability is a critical factor influencing the adoption of solar dryers by small- and medium-scale processors. Financial and economic assessments of solar drying systems indicate that the total capital investment and operating costs are within variable ranges for agro-processors, with favorable benefit-cost ratios and reasonable payback periods reported in the literature. For example, a 1-tonne capacity solar-biomass hybrid dryer required a capital investment of approximately USD 5,263 and was found to be profitable with a benefit-cost ratio > 1 and a payback period of about 2.7 years [14]. These costs are justified by the long-term savings in energy expenses, reduction in drying time, and improved product quality [15]. Additionally, the reduction in post-harvest losses due to effective drying ensures that processors obtain higher market value for their products [16]. Solar drying aligns with global sustainability initiatives by utilizing renewable energy sources, reducing dependence on fossil fuels, and mitigating greenhouse gas emissions [17]. Compared to mechanical drying methods such as flash dryers, which have high energy consumption and operational costs, solar dryers offer a cost-effective and eco-friendly alternative for cassava processing [18]. The adoption of solar dryers can significantly lower production costs, making HQCF processing more accessible to small-scale farmers while reducing the carbon footprint of food processing industries [19].

Hence, processing cassava into stable products like HQCF is necessary for reducing post-harvest losses, enhancing food security, and increasing economic returns. Solar drying technology provides a viable, efficient, and environmentally friendly solution for drying cassava while maintaining product quality and reducing operational costs [20]. The widespread adoption of solar dryers in cassava-producing regions has the potential to improve livelihoods, increase profitability for small-scale processors, and support sustainable agricultural development. However, empirical data on the drying performance of locally constructed solar dryers under practical conditions remain limited. This study therefore evaluated the drying and economic performance of the NSPRI PSSD for the production of HQCF.

Materials And Methods

Collection and preparation of cassava roots

This study focused on postharvest processing. Cassava (TME 419) roots were procured at harvest maturity from an International Institute of Tropical Agriculture (IITA)-certified farmer in Akinyele Local Government Area, Ibadan, Oyo State, Nigeria. The harvesting was done on 27 January 2025, which is a peak dry season period. Agronomic details such as planting date were not

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controlled, as the crop was sourced from an established production field. The procedures used for the production of HQCF include harvesting, peeling, washing, grating, dewatering/pressing, granulating/sifting, drying, and milling (Figure 1).

To minimize the risk of sample contamination throughout processing, good hygiene and handling practices were strictly observed at every stage. Freshly harvested cassava roots were transported in clean containers and processed immediately to reduce microbial deterioration. Peeling and washing were carried out using potable water to remove adhering soil, debris, and surface contaminants. All processing equipment (grater, press, sifter, dryer, and mill) was thoroughly cleaned and sanitized before and after use to prevent cross-contamination. Dewatering and granulating were conducted on clean surfaces, while drying was performed in a controlled solar dryer environment that limited exposure to dust, insects, and other environmental contaminants. Hence, the risk of sample contamination was lowered at every stage, to ensure a quality end product. Extraneous matters and other impurities attached to the freshly harvested cassava roots were carefully removed and wholesome roots were sorted for the experiment.

The cassava roots (500 g) were thus conveyed to a cassava processing center - “Stop Hunger” at Moniya, Akinyele, LGA, Ibadan - to undergo processing. Two sizes of NSPRI PSSD were used for the evaluation: a larger size installed at STOP HUNGER, Moniya (10 × 6 × 4 m; 7.5309° N, 3.9110° E) and a smaller one installed at the NSPRI Ibadan Zonal Office (6.5 × 4.2 × 2.4 m; 7.38858° N, 3.87949° E).

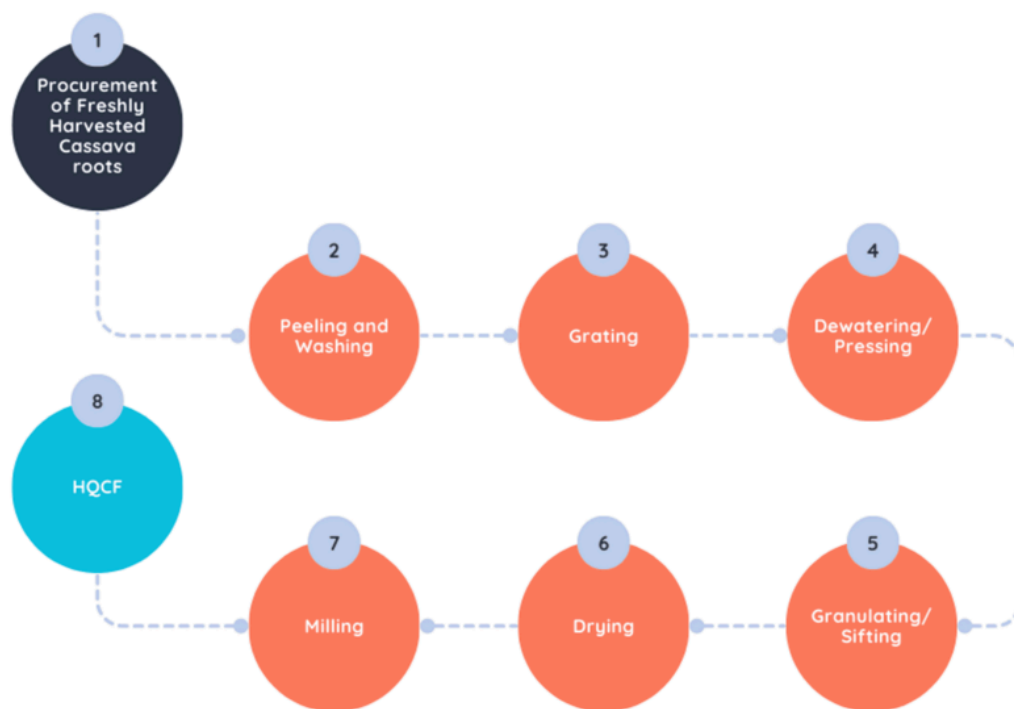


Figure 1: HQCF Production Flow chart using NSPRI PSSD

FIGURE 1: HQCF production flowchart using NSPRI PSSD

HQCF, High-Quality Cassava Flour; NSPRI, Nigerian Stored Products Research Institute; PSSD, Parabolic-Shaped Solar Dryer

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Performance evaluation of NSPRI PSSDs

Description of NSPRI PSSD

The NSPRI PSSD is a solar drying technology developed by NSPRI (Figure 2). The dryer is an immobile structure that consists of parabolic metallic frames fabricated from galvanized steel, which provides inherent resistance to corrosion and weathering; a transparent UV screen cover; a black floor; drying racks and trays; air inlet vents; and exit (aspirators). The transparent UV screen covering material reinforced with the metallic frames provides an enclosure and also transmits solar radiation heat from the sun into the drying chamber. The black floor retains heat from the solar radiation, increasing the internal temperature and enhancing the drying process; it is also insulated to prevent heat loss to the ground due to conduction. The dryer has trays arranged in two layers on sets of mobile racks positioned on rail tracks. The inlet vents are fitted with standard, fine galvanized wire mesh to prevent insects from gaining access into the dryer while allowing adequate airflow. The dryer has an access door provided at one end of the structure.

The effective dryer (loading) capacity of the NSPRI PSSD is produce-dependent and varies with factors such as crop type, initial MC, slice thickness, bulk density, and tray arrangement. Therefore, the capacity for the dryers used in this study was determined experimentally using the procedure and formula in Equation 1, and the computed values are reported in Table 3 in the Results and Discussion.



FIGURE 2: (a) Exterior view of NSPRI PSSD installed at Ibadan Zonal Office; (b) Interior view of the drying chamber during the evaluation

NSPRI, Nigerian Stored Products Research Institute; PSSD, Parabolic-Shaped Solar Dryer

Instrumentation and Measurement

The following instruments were used in this study to monitor drying time, weight loss, and meteorological data during drying: a clock; a digital sensitive weighing scale (ATM - A110C (platinum) digital precision scale; resolution: 0.01 g; accuracy: ± 0.01 g); temperature and relative humidity sensors (TEKCOPLUS THTK-6, K-Type 4-channel thermocouple, resolution: 0.1 °C; accuracy: ± 1 °C) and Temptop logger TemLog 20H (accuracy: T ± 0.5 °C; R.H $\pm 3\%$); a solarimeter (resolution: 1 W/m²; maximum: 1999 W/m²; accuracy: ± 10 W/m²); and an airflow meter (resolution: 0.1 m/s; accuracy: ± 1 m/s).

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The experiment was done in triplicates. The total weights of cassava mash in both the small and big PSSD were 28 kg and 64 kg, respectively. Each tray in both solar dryers weighed 1 kg. The weights of the unfermented cassava mash loaded into the PSSD and the dried product at the end of drying were recorded. Moisture loss of the products was monitored at regular intervals of 30 minutes. Dryer capacity was determined using Equation 1.

$$\text{Dryer Capacity (Loading density)} = \frac{\text{Weight of fresh product loaded in the dryer (kg)}}{\text{Effective drying area of the drying trays (m}^2\text{)} \times \text{drying thickness (m)}} \quad (1)$$

Preparation of the Dryer

To ensure efficient energy and product quality delivery in the dryer, all trays were thoroughly cleaned to prevent product contamination, and the covering material was cleaned to remove dust (inside and outside) prior to the commencement of the drying experiment. A no-load preheating period of one hour was achieved before the commencement of the experiment to allow thermal heating of the PSSD. The drying experiment was conducted daily from 9:00 to 18:00 (GMT), corresponding to the effective sunshine period under solar drying conditions, as commonly reported in the literature [20]. The initial MC and dry matter were determined according to standards [21]. Thereafter, weight loss was used in estimating the MC (Equation 2).

$$MC_t = \frac{W_t - W_d}{W_d} \quad (2)$$

The MC conversion to dimensionless moisture ratio (MR) was done by application of the non-exponential portion of the thin layer expressions considered [22]. Hence, MCs attained for all samples were thus converted to MR using Equation 3.

$$MR = \frac{M - M_e}{M_o - M_e} \quad (3)$$

Where, M denotes moisture content at time t (% db), Mo denotes initial moisture content (% db), Me denotes equilibrium moisture content (% db), MR denotes moisture ratio and t is the drying time (hr).

Drying rate (dr) was determined using Equation 4 [23].

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad (4)$$

Where, Mt is the initial weight of the sample (g), $M_{t+\Delta t}$ is the weight of the dried sample at time, $t + \Delta t$, Δt is drying time.

Composite Flour Formulation and Sensory Evaluation of Value-Added Products

Composite flour samples of wheat and HQCF were formulated considering 10:90, 20:80, 30:70 (HQCF:wheat flour) and 100% wheat flour. The substitution levels were selected based on previous studies reporting acceptable functional and sensory properties of wheat-cassava flours within this range. The composites were used to produce five different products (Bread, Cake, Cookies, Puff-Puff, Chin-Chin). Sensory evaluation was conducted on the produced value-added items to assess the acceptability of the HQCF composite products using a 9-point hedonic scale according to [24]. The assessment was aimed at determining consumer's preference based on key sensory attributes, including appearance, aroma, taste, texture, and overall acceptability.

Products Preparation

HQCF-based products were prepared using standardized recipes to ensure uniformity in ingredient composition and processing.

Cake: Batter was prepared by creaming sugar and fat, then adding eggs, milk, and wheat-HQCF composite flour. The batter was poured into molds and baked at 180 °C until fully cooked and lightly browned.

Chin-Chin: Dough was made by mixing wheat-HQCF composite flour, sugar, eggs, fat, and water into a stiff dough, rolled and cut into small pieces, then deep-fried until golden and crisp.

Cookies: A firm dough was prepared from wheat-HQCF composite flour, sugar, eggs, and fat, shaped into small rounds, and baked at 175 °C until crisp and lightly browned.

Puff-Puff: Soft dough was made from wheat-HQCF composite flour, sugar, yeast, and water, allowed to ferment briefly, then scooped and deep-fried until puffed and golden.

Bread: Dough was prepared by mixing wheat-HQCF composite flour, yeast, sugar, water, and salt, allowed to ferment, then baked at 180 °C until fully risen and golden.

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The samples were coded with three-digit random numbers to prevent bias according to [25]. They were served at optimal consumption temperature and in equal portion on white disposable plates to maintain consistency.

Panelist Selection

A total of 15 untrained consumer panelists, representative of the target population, were engaged to evaluate the sensory attributes of the composite flour products. Although trained panelists can provide more precise measurements of specific sensory attributes, untrained consumers are more representative of actual product end-users and provide valuable insight into overall acceptability and preference. In addition, the number of untrained panelist is relatively small; however, this panel size is consistent with preliminary consumer acceptability studies and provides sufficient insight into product preference trends. All participants were screened to ensure they had no known allergies or dietary restrictions related to cassava-based products, also they were screened prior to the evaluation using a brief questionnaire to confirm the absence of known allergies or dietary restrictions related to cassava-based products. Although the screening was not performed by medical personnel, it ensured the safety and relevance of participant responses in the sensory evaluation. The panelists were properly briefed on the evaluation procedure without revealing the research objective to minimize bias according to [26].

Sensory Evaluation Procedure

The sensory evaluation was conducted in a well-lit, ventilated, and odor-free room to avoid external influences. Panelists were seated individually to prevent discussion or influence from others. Each panelist received a sensory evaluation form containing a 9-point hedonic scale for rating the following sensory attributes: Appearance, Aroma, Taste, Texture, and Overall acceptability. The scale ranged from 1 (Dislike Extremely) to 9 (Like Extremely) according to [27,28] as shown in Table 1.

Score	Description
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

TABLE 1: The 9-point hedonic scale for rating the sensory attributes of HQCF products
HQCF, High-Quality Cassava Flour

Economic evaluation of NSPRI PSSD for production of HQCF

The economic analysis of the NSPRI PSSD was conducted using standard economic assessment tools as described in [29,30]. The analysis included:

- 1. Variable costs: raw materials, labor, and energy.

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2. Fixed costs: capital investment in the dryer.

3. Revenue: income from the sale of HQCF.

Economic indicators, including total cost, net revenue, and benefit-cost ratio, were calculated using standard procedures. The results are presented in Tables 5-7. Relevant assumptions used in the calculations have also been specified to ensure reproducibility.

Fixed Cost Estimation

Fixed cost consisted of depreciation of processing equipment, namely:

NSPRI Parabolic Shaped Solar Dryer (PSSD)

Milling machine

Processing utensils

Depreciation cost was calculated using the straight-line depreciation method according to the expression in Equation 5.

$$D = (C - S)/N \quad (5)$$

Where:

D = Annual depreciation (₦/year)

C = Initial cost of equipment (₦)

S = Salvage value (₦)

N = Useful life (years)

Total Fixed Cost (TFC) was computed as expressed in Equation 6.

$$TFC = \sum D$$

Total Cost

$$TC = TVC + TFC \quad (6)$$

Where:

TC = Total cost (₦)

TVC = Total Variable Cost (₦)

TFC = Total Fixed Cost (₦)

Gross Margin

Gross margin was calculated using the expression in Equation 7.

$$GM = TR - TVC \quad (7)$$

Where:

GM = Gross Margin (₦)

TR = Total Revenue (₦)

Net Profit

Net Profit was estimated using the expression in Equation 8.

$$NP = TR - TC \quad (8)$$

Benefit-Cost Ratio

Benefit-Cost Ratio was calculated using Equation 9.

$$BCR = (TR)/(TC) \quad (9)$$

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A BCR greater than 1 indicates economic viability.

Data Collection and Analysis

The sensory ratings were collected and compiled for statistical analysis. Mean scores and standard deviations were computed for each sensory attribute. Analysis of Variance (ANOVA) was performed using SPSS version 22 to determine significant differences between samples, following procedures described in [31,32]. The results were presented in tabular and graphical formats for easier interpretation.

Results

Meteorological data in the PSSDs and ambient

Table 2 presents the average meteorological data recorded in the PSSDs and ambient environment at the two locations, while Table 3 summarizes the dryer capacity and drying rate of unfermented cassava mash in the NSPRI PSSDs.

Location/Dryer		Solar Radiation (W/m ²)	Air Velocity (m/s ²)	Temperature (°C)	Relative Humidity (%)
Moniya	PSSD	445 ± 156	1.84 ± 1.19	50.14 ± 7.47	36.45 ± 10.95
	Ambient	564 ± 178	2.77 ± 1.35	40.13 ± 8.03	46.52 ± 8.06
NSPRI Ibadan	PSSD	763 ± 298	2.29 ± 1.31	49.61 ± 9.18	40.33 ± 17.64
	Ambient	955 ± 356	2.34 ± 1.22	38.73 ± 5.61	48.71 ± 17.57

TABLE 2: Average meteorological data in the PSSDs and ambient in the two locations

NSPRI, Nigerian Stored Products Research Institute; PSSD, Parabolic-Shaped Solar Dryer

Solar drying behavior of the unfermented cassava mash for production of HQCF

Two NSPRI PSSDs located at different local government areas within Ibadan were included in this study to compare drying performance under slightly different site conditions. Using two dryers allows assessment of the consistency, reliability, and generalizability of the dryer design across locations, while accounting for variations in solar radiation, microclimate, and operational factors. The results presented in Table 3, and Figure 3 reflect this comparative evaluation.

PSSD Size	Location	Average Drying Rate (kg/h)	Loading Capacity (kg/m ²)	Dryer Capacity (kg/batch)
Small	NSPRI Ibadan, Onireke	0.0650 ± 0.0077	1.41	25.20
Big	STOP HUNGER, Moniya	0.0694 ± 0.0007	1.40	64.00

TABLE 3: Dryer capacity and drying rate of unfermented cassava mash in the NSPRI PSSDs

NSPRI, Nigerian Stored Products Research Institute; PSSD, Parabolic-Shaped Solar Dryer

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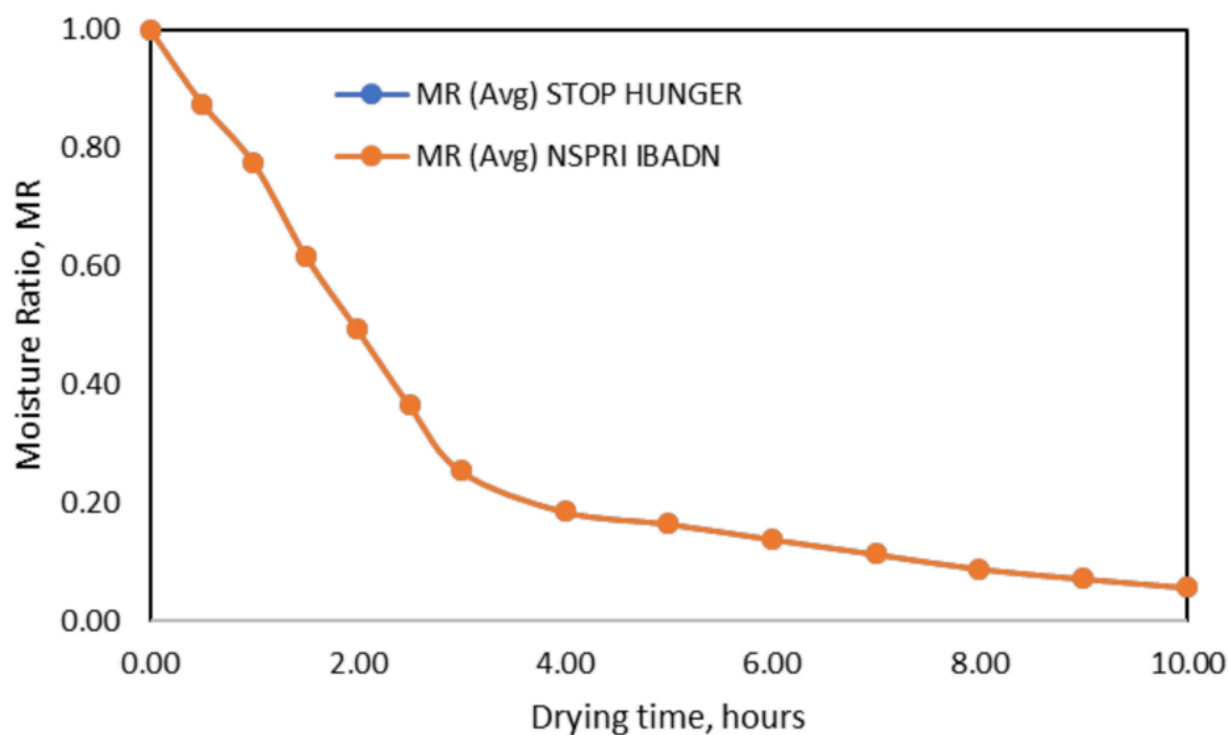


FIGURE 3: Experimental moisture ratio curve for unfermented cassava mash using NSPRI PSSDs

NSPRI, Nigerian Stored Products Research Institute; PSSD, Parabolic-Shaped Solar Dryer

The overlapping curves indicate very similar drying behavior between the two PSSDs.

Sensory Evaluation of HQCF/Wheat Value-Added Products

The products evaluated in this study include cake, chin-chin, cookies, puff-puff, and bread. Cake is a soft, sweet baked product commonly served as a dessert or snack. Chin-chin is a popular West African fried snack, slightly sweet with a crisp exterior and soft interior. Cookies are small baked biscuits with a crunchy texture, while puff-puff is a deep-fried dough snack, soft and mildly sweet, often served as street food. Bread is a leavened wheat-based staple with a soft, elastic crumb, widely consumed in meals or sandwiches.

This analysis presents the sensory results obtained for Cakes, Chin-Chin, Cookies, Puff-Puff, and Bread.

Result of Sensory Evaluation for Cake

- Color: The highest score was recorded in the 30% HQCF sample (7.62), indicating that 30% HQCF substitution can enhance or maintain the appearance of cakes produced from the composite flour.
- Aroma: The 30% HQCF sample (6.77) had the highest aroma rating, suggesting that HQCF does not significantly alter the cake's fragrance despite the substitution ratio.
- Texture: The 30% HQCF sample scored highest value of 6.46, implying that HQCF substitution up to this level does not negatively impact cake texture.
- Taste and Acceptability: The best ratings were recorded at 30% HQCF, indicating that this level of substitution maintains sensory quality. The results are shown in Table 4.

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HQCF Level (%)	Color	Aroma	Texture	Taste	Acceptability
0 (100% Wheat)	7.40 ± 1.53 ^a	6.50 ± 1.28 ^a	6.20 ± 1.81 ^a	6.45 ± 1.46 ^a	6.60 ± 1.32 ^a
10	7.55 ± 1.92 ^a	6.65 ± 1.54 ^a	6.30 ± 1.33 ^a	6.60 ± 1.52 ^a	6.75 ± 1.72 ^a
20	7.58 ± 1.23 ^a	6.70 ± 1.17 ^a	6.40 ± 1.62 ^a	6.72 ± 1.49 ^a	6.90 ± 1.96 ^a
30	7.62 ± 1.87 ^a	6.77 ± 1.62 ^a	6.46 ± 1.77 ^a	6.85 ± 2.91 ^a	7.00 ± 1.64 ^a

TABLE 4: Sensory evaluation of cake produced from HQCF-wheat composite flour (mean ± SD)

Values are expressed as mean ± standard deviation. Means with different superscripts within a column are significantly different ($p < 0.05$). HQCF, High-Quality Cassava Flour

The sensory evaluation results showed a progressive increase in mean scores for color, aroma, texture, taste, and overall acceptability with increasing HQCF substitution up to 30%, although the differences were not statistically significant ($p < 0.05$). This indicates that HQCF can replace wheat flour up to 30% in cake production without compromising sensory quality.

The absence of significant differences may be attributed to the functional characteristics of cake systems. Unlike bread, cake requires limited gluten network development; therefore, partial dilution at 30% substitution does not critically impair structure or mouthfeel. The stable texture scores observed suggest that starch gelatinization and batter aeration were not adversely affected. Cassava flour possesses relatively high starch content and favorable pasting properties, which contribute to crumb softness and structural stability in cake formulations. Additionally, its water absorption capacity supports adequate batter viscosity, thereby maintaining product quality despite wheat substitution.

The findings are consistent with earlier reports by [26] and [27], who observed that cassava-wheat composite flours up to 30% substitutions maintained acceptable sensory attributes in baked products.

From a policy perspective, these results support the objectives of Nigeria's Cassava Bread Initiatives, which were introduced to promote partial substitution of wheat flour with HQCF in bakery products. Demonstrating that HQCF can be incorporated at 30% without significant sensory penalty strengthens the technical feasibility of such national substitution policies.

Economically, increased utilization of HQCF in bakery applications has important implications for reducing wheat import dependency, conserving foreign exchange, and stimulating local cassava value chains. Given that wheat is largely imported into Nigeria, while cassava is abundantly produced locally, composite flour technology provides a strategic pathway for agro-industrial development and rural income generation.

Furthermore, the sensory stability observed in this study may be linked to the quality of HQCF processing. Proper drying and processing conditions are critical to achieving low residual moisture, uniform particle size, minimal enzymatic browning, and absence of off-flavors. Efficient drying enhances flour whiteness, improves storage stability, and preserves functional properties such as pasting behavior and hydration characteristics, all of which influence sensory performance in baked products. Therefore, optimized drying systems are essential to ensure consistent product quality in composite flour applications.

Overall, the results demonstrate that when properly processed and dried, HQCF can serve as a technically viable and economically strategic partial substitute for wheat flour in cake production up to 30% inclusion level.

Result of Sensory Evaluation for Chin-Chin

· Color: The highest score (8.00) was found in the 20% HQCF sample, indicating that moderate HQCF levels enhance the appearance of the chin-chin product.

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- Aroma, Texture, and Taste: All samples showed comparable ratings, suggesting that HQCF substitution levels considered in this study do not significantly impact aroma, texture, and taste attributes of the produced chin-chin.
- Acceptability: The 20% HQCF sample had the highest acceptability rating (7.79), and it was at par with 100% wheat flour chin-chin. The results are shown in Table 5.

HQCF Level (%)	Color	Aroma	Texture	Taste	Acceptability
0 (100% Wheat)	7.85 ± 1.72 ^a	7.20 ± 1.41 ^a	7.10 ± 1.66 ^a	7.25 ± 1.17 ^a	7.60 ± 1.27 ^a
10	7.95 ± 0.98 ^a	7.15 ± 1.15 ^a	7.05 ± 1.18 ^a	7.20 ± 1.24 ^a	7.70 ± 1.22 ^a
20	8.00 ± 1.61 ^a	7.18 ± 0.92 ^a	7.12 ± 1.40 ^a	7.28 ± 1.18 ^a	7.79 ± 1.63 ^a
30	7.90 ± 1.22 ^a	7.10 ± 1.34 ^a	7.00 ± 1.62 ^a	7.15 ± 1.52 ^a	7.65 ± 1.47 ^a

TABLE 5: Sensory evaluation of chin-chin produced from HQCF-wheat composite flour (mean ± SD)

Values are expressed as mean ± standard deviation. Means with different superscripts within a column are significantly different (p < 0.05). HQCF, High-Quality Cassava Flour

Sensory evaluation of chin-chin produced from HQCF-wheat composite flour showed no significant differences (p < 0.05) in color, aroma, texture, taste, or overall acceptability at substitution levels up to 30%. Mean scores were slightly higher at 20% substitution but the differences were not significant, indicating that HQCF can be incorporated without compromising product quality.

Chin-chin's structural properties explain this stability. As a low-moisture fried snack, its crispness depends largely on starch gelatinization and moisture loss rather than gluten elasticity. Cassava starch supports desirable crunch and compensates for partial wheat protein reduction. Proper drying of HQCF ensures low moisture, minimal browning, uniform particle size, and good pasting behavior, all of which enhance frying performance and sensory quality. This finding agrees with [26] and [27].

These results support Nigeria's Cassava Bread Initiative, highlighting the potential of HQCF to reduce wheat import dependence, stimulate local cassava value chains, and promote affordable, acceptable snack products.

Result of Sensory Evaluation for Cookies

- Color, Aroma, and Texture: Ratings remained consistent across samples, indicating that HQCF substitution as considered in this study did not significantly alter cookies' color, aroma, and texture.
- Taste and Acceptability: The highest ratings were observed at 20% HQCF, showing that a moderate substitution level such as 20% can maintain product quality. The results are shown in Table 6.

HQCF Level (%)	Color	Aroma	Texture	Taste	Acceptability
0 (100% Wheat)	7.60 ± 1.43 ^a	7.05 ± 1.76 ^a	7.10 ± 1.62 ^a	7.20 ± 1.73 ^a	7.30 ± 1.51 ^a
10	7.58 ± 1.18 ^a	7.00 ± 1.15 ^a	7.08 ± 1.39 ^a	7.25 ± 1.42 ^a	7.35 ± 1.24 ^a
20	7.62 ± 1.39 ^a	7.02 ± 1.09 ^a	7.12 ± 1.47 ^a	7.40 ± 1.83 ^a	7.45 ± 1.17 ^a
30	7.55 ± 1.23 ^a	6.98 ± 1.17 ^a	7.05 ± 1.54 ^a	7.15 ± 1.51 ^a	7.25 ± 1.48 ^a

TABLE 6: Sensory evaluation of cookies produced from HQCF-wheat composite flour (mean ± SD)

Values are expressed as mean ± standard deviation. Means with different superscripts within a column are significantly different (p < 0.05). HQCF, High-Quality Cassava Flour

Furthermore, the results in Table 6 indicate that substituting wheat flour with HQCF up to 30% does not significantly affect the sensory quality of cookies. Color, aroma, texture, taste, and overall acceptability remained stable across all substitution levels. Cookies' structural stability can be attributed to the short dough system, where gluten development is less critical than in cakes, and starch from HQCF helps maintain crispness and mouthfeel. Slight variations in taste and acceptability (peaking at 20%) may reflect an optimal balance between wheat gluten and cassava starch.

Up to 30% HQCF can replace wheat flour in cookie production without negatively impacting consumer perception, supporting its use in local bakery formulations and cassava value addition.

Result of Sensory Evaluation for Puff-Puff

- Color and Aroma: The highest scores were recorded in 30% HQCF substitution for production of puff-puff with color and aroma having 7.52 and 7.19 points, respectively. This suggests that HQCF enhances these two attributes.
- Texture: The best-rated sample was 100% wheat flour (7.19), but differences across samples were minimal.
- Taste and Acceptability: While puff-puff made with 100% wheat was most preferred, 10% HQCF still maintained a high acceptability score. The results are shown in Table 7.

HQCF Level (%)	Color	Aroma	Texture	Taste	Acceptability
0 (100% Wheat)	7.40 ± 0.98 ^a	7.00 ± 1.26 ^a	7.19 ± 1.31 ^a	7.35 ± 1.68 ^a	7.50 ± 1.32 ^a
10	7.48 ± 1.41 ^a	7.05 ± 1.28 ^a	7.10 ± 1.17 ^a	7.30 ± 1.23 ^a	7.45 ± 1.28 ^a
20	7.52 ± 1.76 ^a	7.10 ± 1.47 ^a	7.05 ± 1.21 ^a	7.20 ± 1.85 ^a	7.30 ± 1.17 ^a
30	7.52 ± 1.68 ^a	7.19 ± 1.12 ^a	7.00 ± 1.18 ^a	7.10 ± 1.16 ^a	7.20 ± 1.25 ^a

TABLE 7: Sensory evaluation of puff-puff produced from HQCF-wheat composite flour (mean ± SD)

Values are expressed as mean ± standard deviation. Means with different superscripts within a column are significantly different (p < 0.05). HQCF, High-Quality Cassava Flour

Furthermore, the sensory evaluation results of puff-puff in Table 7 indicate that puff-puff can tolerate up to 30% HQCF substitution without compromising quality.

Color and aroma remained stable across all levels, showing that HQCF did not impart any undesirable visual or olfactory changes. Texture and taste were not significantly affected, suggesting that the frying process and the short gluten network in puff-puff compensate for partial wheat protein dilution. Overall acceptability remained high (7.20-7.50), indicating that consumers perceive puff-puff with 30% HQCF similarly to that of the 100% wheat flour.

Puff-Puff is a fried, low-gluten product, so structural and sensory quality relies mainly on starch gelatinization and moisture loss during frying, rather than strong gluten development. The starch-rich HQCF contributes to slight crispness while maintaining softness inside, which supports stable acceptability scores.

HQCF can replace wheat flour by up to 30% in puff-puff production, offering opportunities for cassava value addition and reduction in wheat import dependence without compromising sensory quality.

Results of Sensory Evaluation for Bread

- Color, Aroma, and Texture: The highest ratings were observed in 100% wheat samples, followed closely by 20% HQCF.
- Taste and Acceptability: The acceptability of bread decreased with increasing HQCF levels, with 100% wheat flour being the most preferred. The results are shown in Table 8.

HQCF Level (%)	Color	Aroma	Texture	Taste	Acceptability
0 (100% Wheat)	7.80 ± 1.11 ^a	7.50 ± 1.52 ^a	7.40 ± 0.78 ^a	7.60 ± 1.27 ^a	7.70 ± 1.65 ^a
10	7.65 ± 1.41 ^a	7.35 ± 1.23 ^a	7.30 ± 1.27 ^a	7.40 ± 1.35 ^a	7.50 ± 1.12 ^a
20	7.55 ± 1.32 ^a	7.25 ± 1.35 ^a	7.20 ± 1.19 ^a	7.30 ± 1.12 ^a	7.35 ± 1.27 ^a
30	7.30 ± 1.24 ^b	7.00 ± 1.27 ^b	6.90 ± 1.14 ^b	6.95 ± 1.25 ^b	7.00 ± 1.22 ^b

TABLE 8: Sensory evaluation of bread produced from HQCF-wheat composite flour (mean ± SD)

Values are expressed as mean ± standard deviation. Means with different superscripts within a column are significantly different ($p < 0.05$). HQCF, High-Quality Cassava Flour

The sensory evaluation of cake, chin-chin, cookies, puff-puff, and bread produced from HQCF-wheat composite flour revealed that HQCF substitution up to 30% generally maintained acceptable sensory quality, although the degree of tolerance varied among products.

Cake, chin-chin, cookies, and puff-puff exhibited no significant differences ($p > 0.05$) in color, aroma, texture, taste, or acceptability for 30% HQCF. Slight increases in mean scores were observed for cake and chin-chin at 20-30% substitution, likely due to the mild color and flavor of HQCF enhancing appearance and aroma without compromising texture [26]. Cookies and puff-puff showed stable sensory attributes across all substitution levels, which can be explained by their low-gluten or short dough systems, where structure and crispness rely mainly on starch gelatinization and MC rather than gluten development. Proper HQCF processing and drying ensure low residual moisture, uniform particle size, and minimal off-flavors, supporting sensory stability in these products [27].

Bread, in contrast, demonstrated a gradual decline in all sensory attributes with increasing HQCF, with 30% substitution significantly lower than the control. Bread is highly dependent on gluten for dough elasticity, gas retention, and crumb structure; partial replacement with HQCF weakens the gluten network, resulting in a softer texture, reduced aroma, and slightly altered color [27]. Standard Deviation values indicate some panelist variation, but the downward trend is clear. Substitution up to 20% appears acceptable without formulation adjustments, whereas higher levels may require functional additives (e.g., vital wheat gluten or hydrocolloids) to maintain quality.

Across all products, HQCF contributed positively to starch functionality, providing crispness in fried snacks and a soft crumb in cakes, while minimally affecting taste and aroma. This demonstrates that product type dictates tolerance to HQCF, with gluten-dependent products (bread) being most sensitive and low-gluten or fried products (chin-chin, puff-puff) being more adaptable.

From a policy perspective, these results support Nigeria's Cassava Bread Initiative, which promotes partial replacement of wheat with HQCF to reduce wheat import dependence. Economically, the findings suggest that HQCF incorporation can stimulate local cassava value chains, conserve foreign exchange, and promote affordable, acceptable bakery and snack products. Optimized drying and processing of HQCF are critical to preserving functional properties such as pasting behavior and water absorption, which directly influence product sensory quality.

Result of Economic Evaluation for the Production of HQCF

Tables 9-11 show the results for the economic evaluation for the production of HQCF. It is to be noted that revenue estimation was based on the market price of HQCF per kilogram.

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Variable Cost (VC)	Amount (N)
Cost of cassava tubers	32,500
Transportation	2,500
Labor (for other processing operations)	3,000
Cost of peeling	2,000
Grating	2,000
Dewatering	3,000
Total Variable Costs (TVC)	45,000

TABLE 9: Economic evaluation result for production of HQCF (variable cost)

HQCF, High-Quality Cassava Flour

Revenue	Amount (N)
Proceeds from sales of HQCF (46.45 kg @ N 1,500/kg)	69,675
Proceeds from sales of cassava peel	2,500
Total Revenue (TR)	72,175

TABLE 10: Economic evaluation result for production of HQCF (revenue)

HQCF, High-Quality Cassava Flour

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Fixed Costs (FC)	Amount (N)
Depreciated cost of PSSD	6,462
Depreciated cost of milling machine	2,112
Depreciated cost of utensils	939
Total Fixed Costs (TFC)	9,513
Total Costs (TC = TVC + TFC)	54,513
Gross Margin (TR-TVC)	27,175
Net Profit (TR-TC)	17,662
Benefit-Cost Ratio	1.32

TABLE 11: Economic evaluation result for production of HQCF (fixed cost)

HQCF, High-Quality Cassava Flour; PSSD, Parabolic-Shaped Solar Dryer

Discussion

Meteorological data in the PSSDs and ambient

Temperature Readings in the Ambient and PSSDs

The average temperature recorded in the big NSPRI PSSD at Moniya was 50.14 ± 7.47 °C, while the corresponding ambient temperature was 40.13 ± 8.03 °C (Table 2). This resulted in an average temperature difference Δ of 10.01 °C between the dryer chamber and the ambient environment.

At NSPRI Ibadan, which is located a few kilometers from Moniya, the average temperature recorded in the small PSSD was 49.61 ± 9.18 °C, while the ambient temperature was 38.73 ± 5.61 °C. The calculated temperature difference Δ for the small PSSD was 10.88 °C.

Although the temperature difference recorded at NSPRI, Ibadan (10.88 °C) was slightly higher than that observed at Moniya (10.01 °C), both values fall within a similar thermal range. This similarity is expected due to the close proximity of the two locations and their comparable meteorological conditions.

The positive temperature differentials recorded at both locations confirm that the PSSDs effectively elevated the drying air temperature above ambient conditions. This fulfills the fundamental objective of solar dryer design - achieving higher internal temperatures to enhance moisture removal rates and reduce drying time under hygienic conditions. Similar thermal performance trends have been reported in related solar drying studies [33,34].

Relative Humidity Readings in the Ambient and PSSDs

The average relative humidity obtained at Moniya in the big PSSD and ambient were 36.45 ± 10.95 and $46.52 \pm 8.06\%$, respectively; while the small PSSD and ambient at NSPRI Ibadan recorded 40.33 ± 17.64 and $48.71 \pm 17.57\%$ as shown in Table 2. The PSSD at Moniya caused a percentage reduction in relative humidity of about 21% when compared with ambient readings; while a 17% reduction in the average relative humidity of the ambient was recorded in the PSSD installed at NSPRI Ibadan. This reduction in relative humidity in the dryers indicates the efficiency of the heat energy available in the dryers in removing moisture from the product. This decrease was therefore not independent but directly linked to the temperature rise observed

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within the dryer. The inverse relationship between air temperature and relative humidity explains the improved drying potential inside the PSSD, as lower relative humidity enhances moisture removal from the product. Researchers have reported a series of findings on drop in humidity level when using solar dryers to dry agricultural products according to [35].

Solar Radiation Readings in the Ambient and PSSDs

The average solar radiation obtained in the PSSD and ambient at Moniya were 445 ± 156 and 564 ± 178 W/m², respectively; while 763 ± 298 (PSSD) and 955 ± 356 W/m² (ambient) were obtained at NSPRI Ibadan (Table 2).

The covering material of the PSSD caused a reduction in transmitted solar radiation of approximately:

- * 21% at Moniya (Big PSSD)
- * 20% at NSPRI Ibadan (Small PSSD)

This reduction is attributed to reflection and absorption losses through the transparent glazing material of the dryer.

Although NSPRI Ibadan recorded higher solar radiation values than Moniya (both ambient and PSSD), the drying chamber temperatures were relatively similar:

- * Moniya PSSD: 50.14 ± 7.47 °C
- * NSPRI Ibadan PSSD: 49.61 ± 9.18 °C

This observation suggests that solar radiation intensity alone did not solely determine the internal dryer temperature. Other interacting factors such as:

- * Dryer geometry and size
- * Heat retention capacity
- * Air velocity
- * Relative humidity
- * Thermal mass of internal components

may have influenced heat accumulation and equilibrium temperature within the drying chambers.

Notably, despite the larger PSSD being installed at NSPRI Ibadan, the chamber temperature did not increase proportionally with the higher solar radiation. This indicates that the larger system may have experienced greater convective heat losses or required more energy to reach thermal equilibrium due to increased internal air volume.

Therefore, the similarity in temperature between the two dryers does not necessarily imply higher heat trapping efficiency in the larger PSSD, but rather reflects the combined effect of radiation transmission, airflow, and heat loss mechanisms. Similar observations have been reported in related solar drying studies [34,35].

Air Velocity Readings in the Ambient and PSSDs

The average air velocities obtained in the PSSD and ambient were 1.84 ± 1.19 and 2.77 ± 1.35 m/s respectively at Moniya; while at NSPRI Ibadan 2.29 ± 1.31 and 2.34 ± 1.22 m/s were obtained in the PSSD and ambient respectively as shown in Table 2. The air flow rates recorded in the two PSSDs depict the functionality and efficiency of the air distribution system of the dryers, similar results were reported by [34,35].

Estimation of Dryer Capacity (Loading Density)

The respective capacity determined for the two sizes of the NSPRI PSSD are calculated below. The two dryers have a loading capacity of 1.4 kg/m², and a dryer batch capacity of 25.2 and 64.0 kg/batch for the small ($6.5 \times 4.2 \times 2.4$ m) and big ($10 \times 6 \times 4$ m) PSSD, respectively as shown in Table 3.

- (i). Capacity determination for small PSSD ($6.5 \times 4.2 \times 2.4$ m):

$$\text{Loading Capacity per Square Metre} = \frac{(0.8 \times 14) + (1.0 \times 14) \text{ kg}}{(0.75 \times 0.75 \times 14) + (0.95 \times 0.75 \times 14) \text{ m}^2}$$

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$$\text{Loading Capacity per Square Metre} = \frac{25200 \text{ kg}}{17.50 \text{ m}^2} = 1.41 \text{ kg/m}^2$$

$$\text{Dryer Capacity} (6.5 \times 4.2 \times 2.4 \text{ m}) = \text{Effectivedrying} \times \frac{\text{drying capacity}}{\text{m}^2} = 17.85 \times 1.41 = 25.2 \text{ kg/batch}$$

(ii). Capacity determination for big PSSD (10 × 6 × 4 m):

$$\text{Loading Capacity per Square Metre} = \frac{(1.0 \times 64 \text{ kg})}{0.95 \times 0.75 \times 64 (\text{m}^2)} = \frac{64 \text{ kg}}{45.60 \text{ m}^2} = 1.40 \frac{\text{kg}}{\text{m}^2}$$

$$\text{Dryer Capacity} = \text{Effectivedrying} \times \text{drying capacity/m}^2 = 45.60 \times 1.40 = 64 \text{ kg/batch}$$

Solar drying behavior of the unfermented cassava mash for production of HQCF

Moisture Ratio and Drying Rate

The MR followed an exponential decrease, in line with the drying behavior of unfermented cassava mash. A rapid decrease in MR (from 1.00 to 0.49 within 2 hours) was observed (Figure 3) and this indicates efficient removal of surface moisture using the NSPRI PSSDs, similar to results found by [36] in cassava drying experiments. The slower MR decline after 3 hours suggests that internal diffusion of moisture dominates, requiring longer drying times to reach the desired HQCF MC of ≤12%, as recommended by the Food and Agriculture Organization [37]. Unfermented cassava mash has an inherently high initial MC due to its starchy nature. Results of data generated indicated that the MC of pressed mash decreased from 98.22 to 5.51%db within 10 hours. Initial rapid drying was observed (0-2 hours) as the MC reduced significantly from 98.22 to 49.75%db, indicating that there was evaporation of free water from the cassava mash. This aligns with the findings of [38], who reported that the drying rate of cassava mash is highest at the beginning when moisture is more freely available. Afterwards, the falling rate period was observed (3-10 hours), and the MC decreased at a slower rate, reaching 5.51% at 10 hours. This is typical for starch-rich materials like cassava, as bound water requires longer drying times to be removed, as reported by [39]. Table 3 shows the drying rate of unfermented cassava mash in the PSSDs at both NSPRI Ibadan and STOP HUNGER, Moniya. Average drying rates of 0.0650 ± 0.0077 and 0.0694 ± 0.0007 kg/h were recorded for sample dried in the small PSSD (at NSPRI Ibadan) and big PSSD (at Stop Hunger, Moniya), respectively. This result is in conformity with the findings of [40].

Sensory evaluation of HQCF/wheat value-added products

Sensory Evaluation for Cakes

Cakes with HQCF substitution of up to 30% maintained good sensory characteristics as shown in Table 4, particularly in color and texture, similar results were obtained by [41].

Sensory Evaluation for Chin-Chin

HQCF can be incorporated into the production of Chin-Chin up to 20% as shown in Table 5, without negatively affecting consumer preference and product acceptability, similar results were obtained by [42].

Sensory Evaluation for Cookies

HQCF up to 20% did not negatively impact cookies' sensory properties as illustrated in Table 6, making it a suitable substitution ratio in composite flour for the production of cookies, similar results were reported by [43].

Sensory Evaluation for Puff-Puff

Puff-puff made with 100% wheat was most preferred; however, there was a high acceptability score for 10% HQCF as shown in Table 7.

Sensory Evaluation for Bread

Bread tolerates HQCF up to 20% as illustrated in Table 8, before experiencing a significant decline in consumers' preference.

However, several studies support the findings of this sensory evaluation. The study by [42] reported that HQCF can replace wheat in bakery products up to 20% without significant adverse sensory effects. Also, the studies by [43,44] reported that moderate levels of HQCF enhance texture and crispiness in snacks like cookies and chin-chin, aligning with the current results. The studies by [45, 46] also noted that HQCF incorporation up to 30% in baked products maintains sensory acceptance in some formulations. Lastly, the research in [47] observed that HQCF improves crispiness in cookies and chin-chin, further supporting the findings in this study. Hence, the sensory evaluation of the value-added products from (NSPRI PSSD produced) HQCF

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indicates that moderate substitution (10-20%) maintains or enhances sensory properties in most baked and fried products. However, higher levels of substitution (30%) are better suited for certain products, like cakes and puff-puff, without significantly compromising consumer preference. The results align with existing literature [48,49] further reinforcing HQCF's potential as a partial wheat flour substitute in food formulations, and the suitability of NSPRI PSSD for production of HQCF.

Result of the economic analysis

Tables 9, 10, and 11 show the cost of items involved in the production of the HQCF, the revenue (income) as well as the profit accruable to HQCF production using NSPRI PSSDs.

The depreciation cost of the processing equipment showed that the PSSD accounted for the highest annual fixed cost (N6,462), followed by the milling machine (N2,112) and utensils (N939). This indicates that the dryer represents the major capital investment component in HQCF production.

The result in Table 9 shows that the total revenue (TR) generated was N72,175.00 while the total cost (TC) as shown in Table 10 was N 54,513.00. The Total Fixed Cost (N9,513) was relatively low compared to the Total Cost (N54,513), showing that variable costs constituted the larger proportion of production expenses. This suggests that operational inputs such as raw materials and labor had greater influence on total production cost than equipment depreciation.

The cost of fresh cassava roots constituted about 60% of the total cost incurred in the production of HQCF. The gross margin obtained was N 27,175.00 and this implies that an average HQCF producer using NSPRI PSSD could earn a gross profit of N 27,175.00 per production of 250 kg of cassava roots. Furthermore, the gross margin of N27,175.00 indicates strong operational efficiency, as revenue sufficiently covered variable costs with a substantial surplus.

The net profit obtained was N 17,662.00 with a benefit-to-cost ratio of 1.32 as shown in Table 11. In addition, the net profit confirms that the enterprise is financially profitable after accounting for both fixed and variable costs. The benefit-cost ratio further supports the economic viability of HQCF production. This implies that for every N 1.00 invested, N1.32 is realized, yielding a return of N0.32 per N1 invested, indicating that high-quality cassava flour production with the said technology is profitable. The study by [50] reported a similar result in the literature.

Overall, the results demonstrate that HQCF production using the PSSD is economically sustainable and profitable under the conditions of this study.

While the present study focused on the techno-economic evaluation of the NSPRI PSSD for HQCF production, comprehensive physicochemical, nutritional, and functional quality assessments of HQCF produced using the same drying system have been previously reported by the authors [51]. Those findings confirmed that the PSSD effectively preserves quality attributes and ensures food safety. Therefore, this study complements the earlier work by establishing the technical performance and economic viability of the technology for sustainable HQCF production.

Conclusions

The study demonstrated that the NSPRI PSSD significantly improved the drying efficiency and economic viability of HQCF production. Compared to traditional open-sun drying, the NSPRI PSSD offers controlled drying conditions, reducing contamination risks and ensuring consistent moisture removal. The system balances and maintains stable solar radiation absorption, air distribution, temperature, and relative humidity control to optimize drying performance. Economic evaluation reveals that the investment in solar drying technology is justified by reduced energy costs, higher product quality, and minimized post-harvest losses. The adoption of NSPRI PSSD can enhance the profitability of small-scale cassava processing businesses while supporting environmental sustainability by reducing dependence on fossil fuels. In addition, the sensory evaluation of HQCF products indicates that moderate substitution (10-20%) maintains or enhances sensory properties in most baked and fried goods. However, higher levels of substitution (30%) are better suited for certain products, like cakes and puff-puff, without significantly compromising consumer preference. Therefore, a cost-effective and green-energy based dryer (NSPRI PSSD) that has potential for hygienic production of HQCF should be adopted by small- and medium-scale processors in the business of cassava flour production for increased return on investment, national food security, and environmental sustainability.

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Comprehensive evaluation of the physicochemical, nutritional, and functional quality attributes of HQCF produced using the NSPRI PSSD has been previously reported in our earlier Cureus Journal of Engineering, part of Springer Nature publication; therefore, the present study concentrated on the economic viability and operational performance of the drying system.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Consent was obtained or waived by all participants in this study. Ethics Review Committee of the Nigerian Stored Products Research Institute (NSPRI) issued approval Not applicable. This study was approved by the Nigerian Stored Products Research Institute, Ibadan Zonal Office. Consent was obtained from all participants prior to their inclusion in the study. All procedures performed in this study involving human participants during the sensory evaluation were in accordance with the ethical standards of the institution. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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