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RESEARCH ARTICLE

FROM PROCESS VARIABILITY TO PRODUCT STABILITY: EFFECTS OF TRADITIONAL PROCESSING PRACTICES ON PHYSICOCHEMICAL QUALITY OF KLUIKLUI, PEANUT OIL AND ROASTED PEANUTS IN BENIN

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Abstract

Traditional peanut processing in Benin involves diverse artisanal practices which effects on process performance and final product quality remain insufficiently quantified. This study investigated the influence of traditional processing variants on processing kinetics, mass balance, physicochemical properties, and quality of kluiklui, peanut oil, and roasted peanuts. Process monitoring was conducted with 18 experienced female processors across four municipalities in Benin. A common peanut landrace was used as raw material. For kluiklui and peanut oil production, three processing technologies combining hot- or cold-water kneading, maize flour incorporation, and manual pressing were compared through 27 production trials. For roasted peanuts, three heat-transfer practices, namely direct pan roasting, white clay (Howé), and dried maize bran (floflo), were evaluated through 27 trials. Processing durations, thermal profiles, mass flows, extraction yields, dry matter, lipid content, water activity, texture, acidity, peroxide value, browning index, and oil density were determined. Significant differences were observed among technologies for several processing operations, particularly sorting, roasting, grinding, kneading, pressing, shaping, and frying. Oil extraction efficiency also differed, with crude oil recovery ranging from 25.3 to 32.0% of paste mass. However, these differences were largely attenuated at the final-product stage. Final kluiklui yields were statistically comparable (59.5–59.8% of initial raw material), as were roasted-peanut yields (76.1–78.1%).

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Most physicochemical characteristics of roasted peanuts were not significantly affected by the heat-transfer medium. Nevertheless, some quality attributes remained technology-dependent, particularly kluiklui breaking force and the acid and peroxide values of crude peanut oil. Overall, traditional processing practices generated substantial variability in processing trajectories and intermediate products but resulted in relatively stable final-product characteristics. These findings suggest that future process improvement should focus on critical operations and quality-sensitive parameters rather than complete homogenization of traditional processing practices.

Introduction:-

Peanut (*Arachis hypogaea* L.) plays an important role in West African food systems. It provides essential dietary proteins to supplement cereal-based and tuber-based local diets (Bonuedi et al., 2025). Primary peanut products including kluiklui, roasted peanuts and traditional peanut oil, are widely consumed and marketed in Benin and neighbouring countries (Loko et al., 2020; Oguntinyinbo, 2014; Sogbossi Gbétokpanou, Jonard, et al., 2025; E. G. Videgla et al., 2016). Small-scale traditional peanut processing contributes to household economic activities, particularly in rural and peri-urban areas (Allan et al., 2023). The popular fried snack kluiklui is widely consumed by low-income Beninese urban households (E. G. Videgla et al., 2016). In southern Benin, kluiklui and roasted peanut snacks are consumed in several municipalities including those with strong peanut processing and trade activity, and those where peanut-based products are only sold and consumed, showing the dynamic of a local food system (Sogbossi Gbétokpanou, Iko Afé, et al., 2025). Traditional peanut oil is used for both culinary and commercial purposes, and is a recognized dietary commodity of the regional food economy (Ingenbleek et al., 2019).

Artisanal peanut processing relies on traditional empirical knowledge transmitted across successive generations (Abdul-Majeed, 2017). These artisanal practices involve sequential unit operations performed at small scale. The equipment used is generally simple or rudimentary, while processing conditions vary among producers (Zio et al., 2020). Such variability may concern raw materials, equipment, processed quantities and operator practices. Kluiklui and peanut oil share roasting, dehulling, grinding, manual kneading and pressing as unit operations. The partially defatted peanut dough is shaped and deep-fried to produce kluiklui. Roasted peanut production mainly involves dried seed roasting until the desired coat browning is reached (Sogbossi Gbétokpanou, Iko Afé, et al., 2025). Similar processing practices have been reported across Benin, Togo and Nigeria.

Existing literature primarily focused on describing individual processing operations (drying, roasting, grinding, etc.) and selected quality attributes of peanut products (Sithole et al., 2022; Wang et al., 2018; Xiang et al., 2025; Zhang et al., 2026). Peer-reviewed studies highlight several recurring gaps in the documentation and quantitative understanding of artisanal peanut processing systems (Bonuedi et al., 2025; Kortei et al., 2024). Comprehensive stepwise mass balances and process throughput remain poorly documented across entire processing chains, particularly under traditional processing conditions (Ali & Muhammad, 2014; Kortei et al., 2024). Although some studies quantified specific parameters, such as constituent losses or oil extraction yields, these measurements are generally reported for individual processing stages rather than integrated across the complete processing sequence (L. Gao et al., 2017; Martinez-Yusta et al., 2025). Consequently, the relationships between material flows, processing operations, intermediate products, and final product yields remain insufficiently characterized.

Intermediate masses, ingredient loss fractions, and stage-specific extraction yields remain entirely unknown. Intermediate physicochemical profiling across grinding, roasting, and frying stages is largely missing (Xiang et al., 2025). Stepwise measurements of moisture content, water activity, and browning index are not established (Chiou, 1990; Xiang et al., 2025). Similarly, textural mechanics like breaking force and distance to break lack quantitative process-stage models (Lykomitros et al., 2018).

Lipid oxidation kinetics, including acid value and peroxide value, are rarely tracked step-by-step (Honfo et al., 2010; Yaacoub et al., 2008). Quantitative effects of traditional technological variants remain unassessed under real field conditions (Karimuna et al., 2021; Muego et al., 1990). This limitation is particularly relevant to artisanal processing systems, in which processing conditions may vary considerably according to processors' practices, available equipment, raw material characteristics, and local production contexts. Such variability may influence processing kinetics, material flows, intermediate products, and ultimately the quality and yield of the final products. A quantitative understanding of these variations is therefore essential, particularly for processing systems involving multiple technological modalities.

In this context, the present study aimed to quantitatively characterize the traditional production of kluiklui, peanut oil, and roasted peanuts in Benin, with particular emphasis on processing operations, process kinetics, mass balances, and selected physicochemical characteristics of intermediate and final products. Processing follow-up will enable establishing end-to-end mass balances and measure material flows across major unit operations. The research evaluates the effect of traditional variants, including water temperature and maize flour addition. By integrating process monitoring, mass balance analysis, and physicochemical characterization, this study provides a quantitative basis for understanding variability within traditional peanut processing systems and contributes scientific evidence to inform future efforts toward appropriate process standardization.

Material and Methods:-

Study area and experimental design:-

Selection of study sites and artisanal processors:-

Field production follow-ups were carried out in four municipalities located across Southern and Central Benin (Cove, Aplahoué, Ouesse, and Abomey). These municipalities are representative of the major agricultural development poles recognized for artisanal peanut processing and commercialization of peanut. A total of eighteen female processors (nine dedicated to peanut oil and kluiklui, and nine dedicated to roasted peanut snack processing) were selected based on their extensive empirical expertise (≥ 10 years) in traditional peanut processing.

Experimental design:-

To evaluate the quantitative impact of traditional technological variants on process efficiency, mass balances, and product quality attributes, two multi-factor experimental designs were established (Figure 1):-

- Peanut oil and kluiklui processing: Processing was systematically documented three municipalities to test two key technological factors: (1) Water temperature during kneading: Cold versus warm water and (2) Cereal flour incorporation: Kneading without versus with maize flour. The operational layout comprised: Cove (cold water without flour), Aplahoué (cold water with maize flour incorporation), and Ouesse (hot water without flour). Three processors per site performed three independent, non-consecutive production trials (3 processors X 3 replications = 9 trials per site), yielding a total of 27 production runs.
- Roasted peanut processing: The experimental design evaluated the effect of heat transfer media on roasted peanut properties: direct pan-roasting (Cove), roasting using white clay powder named Howé in fongbé language (Abomey), and roasting using dry maize bran named floflo, in fongbé language (Ouesse).

Three processors per site performed three independent production trials, resulting in 27 roasting trials.

Raw materials standardization and field production follow-up:-

Collection and pre-treatment of raw peanuts:-

The characterization of the traditional processing of peanut (*Arachis hypogaea*) into kluiklui, peanut oil and roasted peanut was performed, using a commonly consumed local peanut landrace named: Fonkouin, identified during diagnostic surveys as the most used landraces, and provided by a single experienced farmer (≥ 10 years of cultivation experience) from Cove municipality (a town in Zou department, Benin) (Adjénia et al., 2026). Batches of peanuts (75 kg each) were prepared from a single produce of this farmer and sent to the study locations. Each batch was split in three by each processor for using 25 kg of peanut per trial. Raw samples were systematically collected from representative points of each bag prior processing for establishing baseline physicochemical and stability markers.

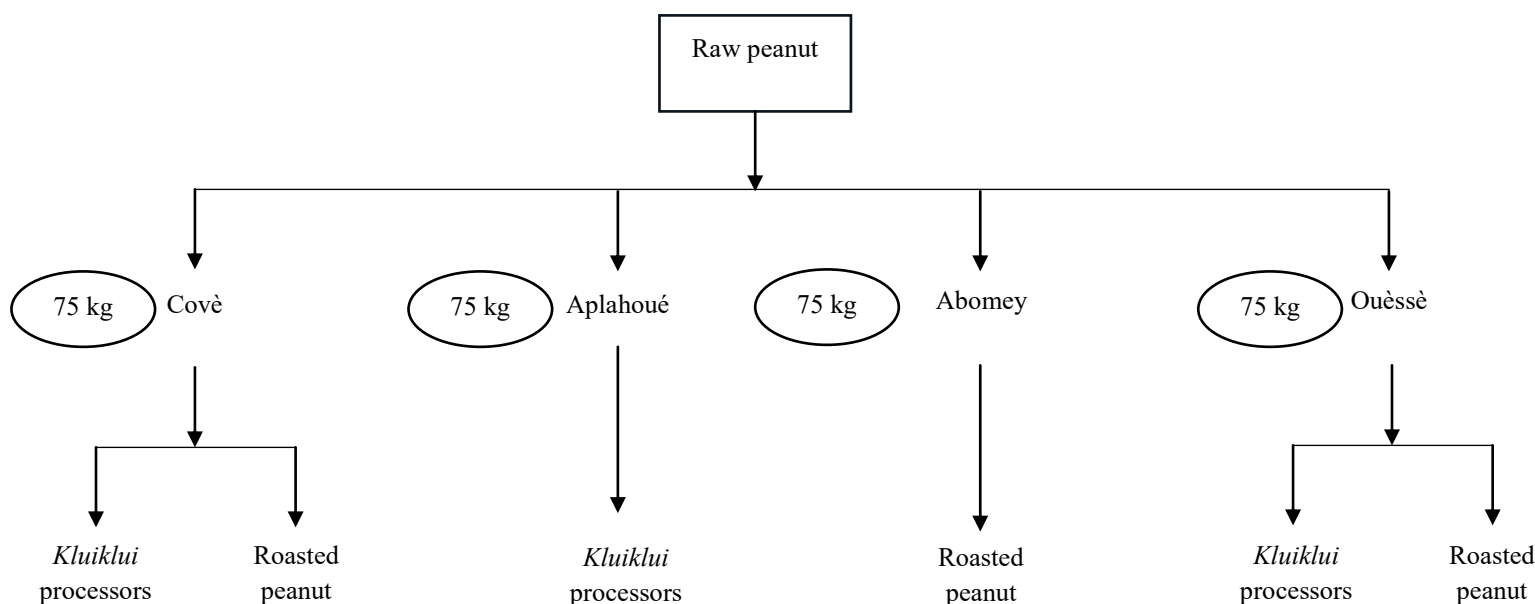


Figure 1: Raw peanut sampling

Technological characterization of kluiklui, peanut oil and roasted peanut traditional producing:-

Peanuts (25 kg) were provided to 18 peanuts processors randomly selected in different areas for processing into kluiklui and peanut oil ($n = 9$) and roasted peanut ($n = 9$), according to their own traditional procedures. The follow-up was conducted using a questionnaire that was filled with enumerator observations and the responses from the processors. Data were collected on processing steps, production schedule, experience with peanut production, seasonality of the activity, as well as sociodemographic backgrounds. Temperature during roasting and frying processes including combustion temperature in combustion place, temperature at the contact point of pan with seed, and core product temperature were recorded at each 10 min frequency with a thermocouple (Traceable digital thermocouple no.620-2006, France) according to the same method used by Assogba et al. (2020). A mass balance assessment was carried during peanuts products production. Weights of input and output at each unit operation (dried, sorted, roasted, peanut paste, added water, added salt, added maize flour, extracted crude oil, press cake, shaped dough portions, kluiklui) were recorded. Duration of drying, roasting, crushing, winnowing, grinding, kneading, shaping, and frying were also recorded.

Sample preservation and preparation for laboratory analyses:-

For laboratory analyses, 135 intermediates and 81 final products were aseptically sampled (Figure 2 & 3) and packaged in sterile containers, kept at 4 °C in portable coolers, and transferred to the laboratory for analysis. Approximate 1 kg of solid sample (kluiklui, roasted peanuts) and 500–750 mL of liquid sample (Peanut oil) was collected for analyses. Peanut oil samples were used directly for analysis. Raw peanut, Kluiklui and roasted peanuts flour samples were prepared for compositional analysis as described below. Raw peanut, kluiklui or roasted peanuts sample was grinded and homogenized using a blending device (IKA A11 Basic, Frequency 60Hz, voltage 220V, speed 28000 rpm, France) to obtain powder. Then the powdered samples were stored in a properly precleaned and dried polyethylene plastic containers until analysis.

Mass balance and processing yield calculations:-

Mass balances and transformation yields were quantitatively established across all production monitoring trials for kluiklui, crude peanut oil, and roasted peanut processing chains. To discriminate between local operational performance and cumulative product conversion, two distinct yield metrics were calculated on a wet weight basis (wb):

Stage-specific yield / Unit operation yield ($Y_{\text{stage,wb}}$): To evaluate material loss, retention, or gain at each sequential unit operation i (e.g., sorting, roasting, de-skinning, milling, kneading/pressing, shaping, and deep-frying), the stage-specific yield was computed using Eq. (1):

$$Y_{\text{stage, wb}}(\%) = \left(\frac{M_{\text{out},i}}{M_{\text{in},i}} \right) \times 100 \quad (1)$$

where $M_{\text{out},i}$ (kg) is the mass of intermediate product recovered at the exit of unit operation i , and $M_{\text{in},i}$ (kg) is the mass of material fed into unit operation i .

Overall product yield ($Y_{\text{product, wb}}$): To determine the global conversion efficiency relative to the raw material, the cumulative product yield was calculated using Eq. (2):

$$Y_{\text{product, wb}}(\%) = \left(\frac{M_{\text{final}}}{M_{\text{raw}}} \right) \times 100 \quad (2)$$

where M_{final} (kg) is the final mass of the target finished product (fried kluiklui cakes, extracted crude peanut oil, or roasted peanut kernels), and M_{raw} (kg) is the initial mass of raw decorticated peanut seeds ($M_0 = 25.0\text{kg}$) introduced at the beginning of the processing batch.

Because artisanal operations induce substantial water transfer (evaporation during roasting and deep-frying, water addition during brine soaking or dough kneading), all yields were normalized and expressed on a dry matter basis (db) using Eq. (3):

$$Y_{\text{db}}(\%) = Y_{\text{wb}} \left(\frac{DM_{\text{product}}}{100} \right) \quad (3)$$

where $Y_{\text{wb}}(\%)$ is the corresponding wet basis yield (either $Y_{\text{stage,wb}}$ or $Y_{\text{product, wb}}$), and $DM_{\text{product}}(\%)$ is the dry matter content of the evaluated intermediate or finished product fraction, determined gravimetrically by oven-drying to constant weight at $103 \pm 2^\circ\text{C}$.

Calculation of theoretical oil yield and extraction efficiency:-

Three parameters characterize oil extraction. The first is the theoretical oil yield, which represents the maximum quantity of oil that can be extracted from the raw material. It is calculated using Equation (4):

$$H_{\text{th}}(\text{kg}) = \left(\frac{m_{\text{RM}} \times T_{\text{O}}}{100} \right) \quad (4)$$

where H_{th} is the theoretical oil yield (kg), m_{RM} is the mass of raw material (kg), and T_{O} is the oil content of the raw material (%).

The mass yield R_m is the ratio of the mass of oil extracted to the initial mass of raw material. It is expressed as a percentage using Equation (5):

$$R_m(\%) = \left(\frac{m_{\text{o}}}{m_{\text{RM}}} \right) \times 100 \quad (5)$$

where m_{o} is the mass of oil extracted (kg).

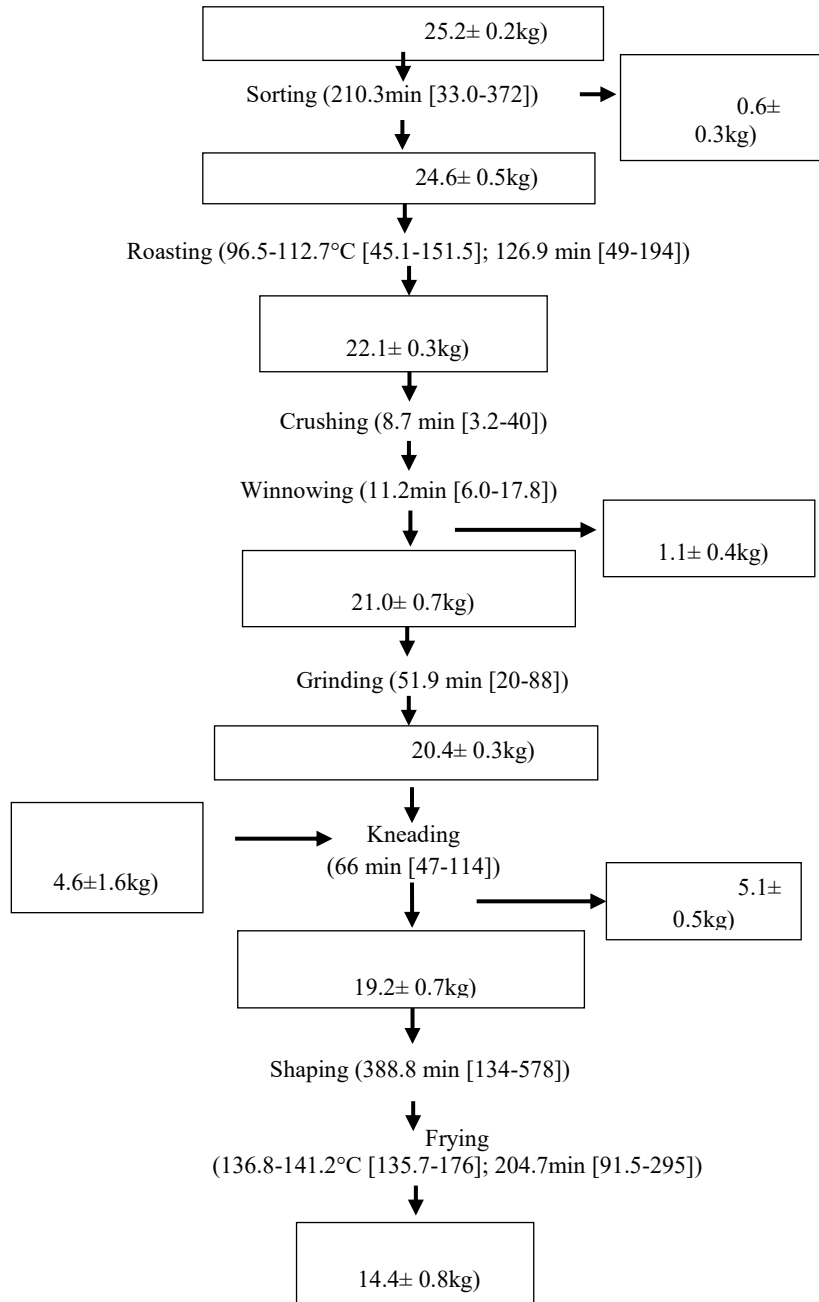
The effective yield R_e compares the oil extracted with the theoretical oil yield. It measures the efficiency of the extraction process, as shown in Equation (6):

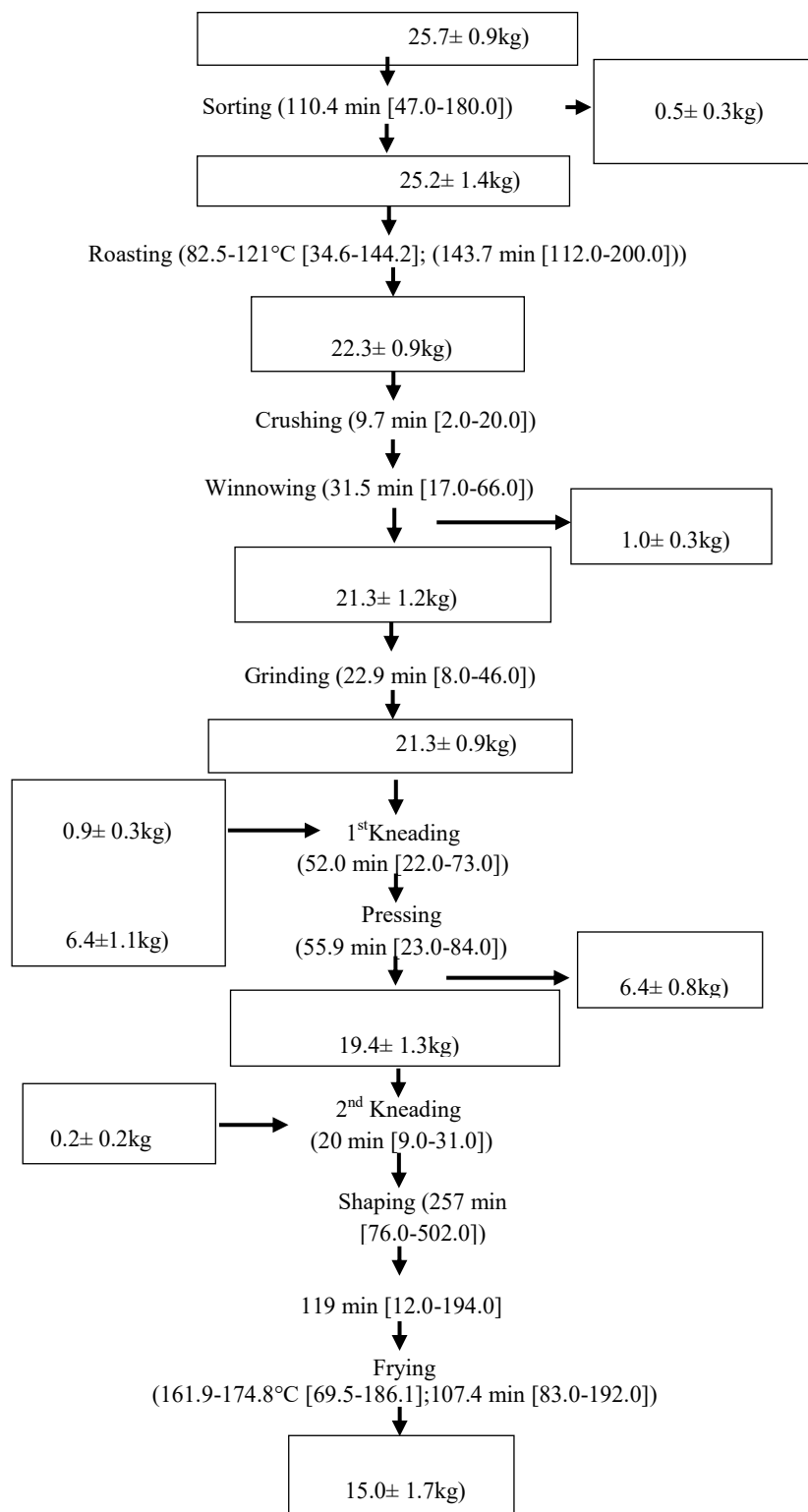
$$R_e(\%) = \left(\frac{m_{\text{o}}}{H_{\text{th}}} \right) \times 100 \quad (6)$$

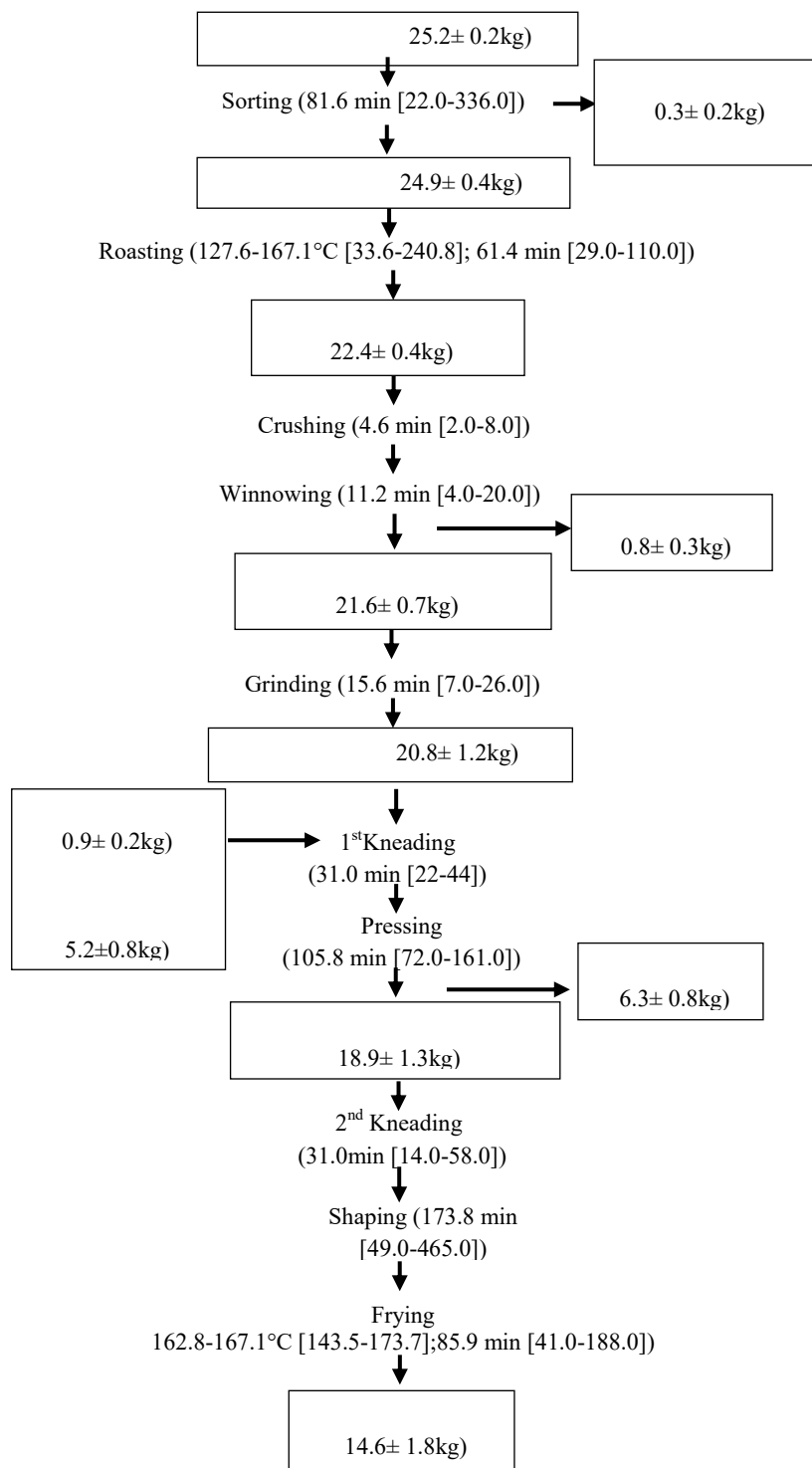
The effective yield can therefore be interpreted as the percentage of the extractable oil actually recovered. Its values range from 0 to 100%.

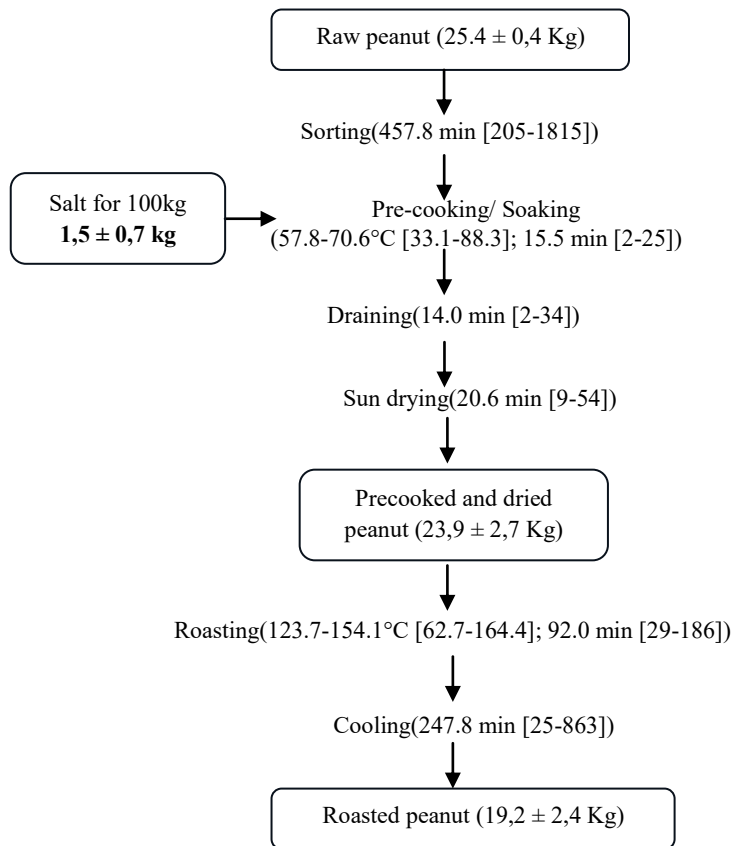
Physicochemical and textural characterization:-

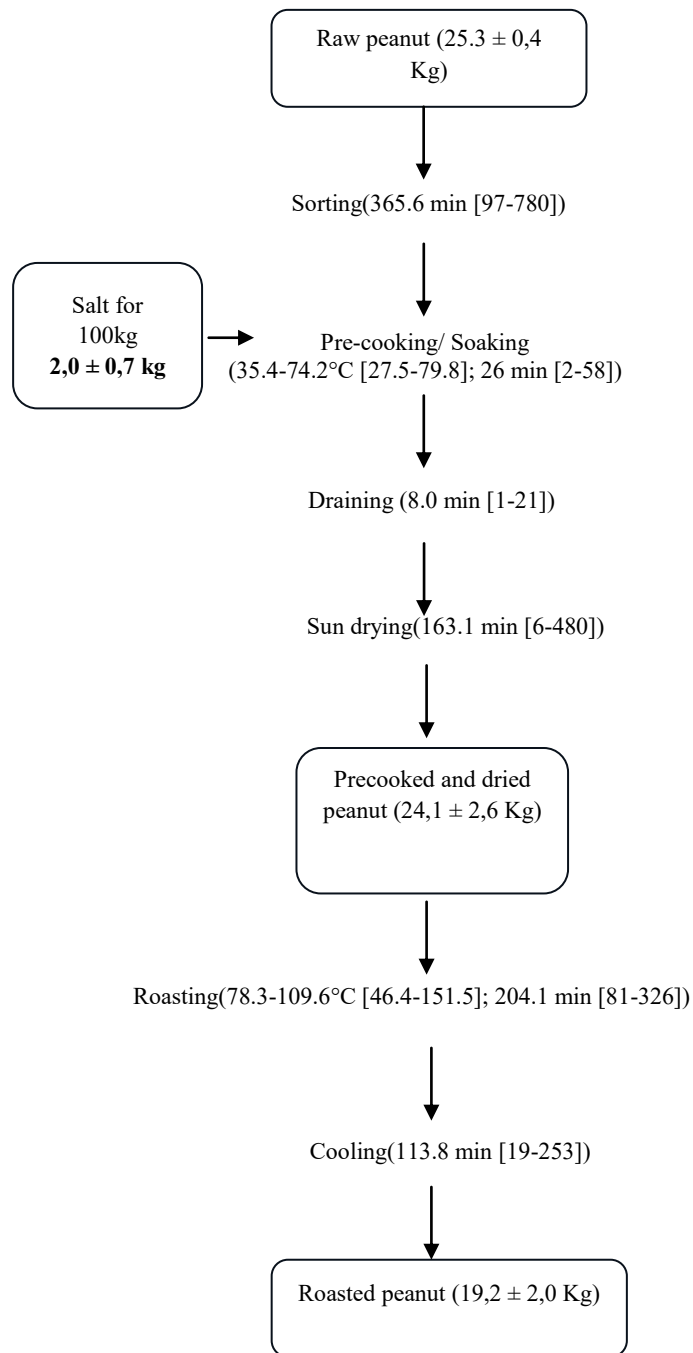
The dry matter content of raw, kluiklui and roasted peanuts flour was determined by oven-drying at $103 \pm 2^\circ\text{C}$ to constant weight (ISO1442, 1997). Crude fat content was assessed through the Randall's method (ISO11085, 2015) using petroleum ether ($40\text{--}60^\circ\text{C}$) as solvent until constant reflux was achieved. Water activity was assessed using the HygrolabRotronic C1 Aw-meter, in accordance with ISO21807 (2004). Texture of kluiklui samples (breaking force in N and fracturability) was determined using a Texture Analyzer (TA-XT Plus, Stable Micro Systems) equipped with a 3-point bending rig. Instrumental settings were as follows: pre-test speed, 1.5 mm/s; test speed, 1.0 mm/s; post-test speed, 10.0 mm/s; and travel distance, 10.0 mm following sample contact. Measurements were performed using a 5-kg load cell, with the support span fixed at 20.0 mm. Distance to break which refers to the brittleness of the kluiklui based on the distance that the probe had moved (downward) inside the kluiklui sample before it fractured. Twenty replicates were performed by sample.

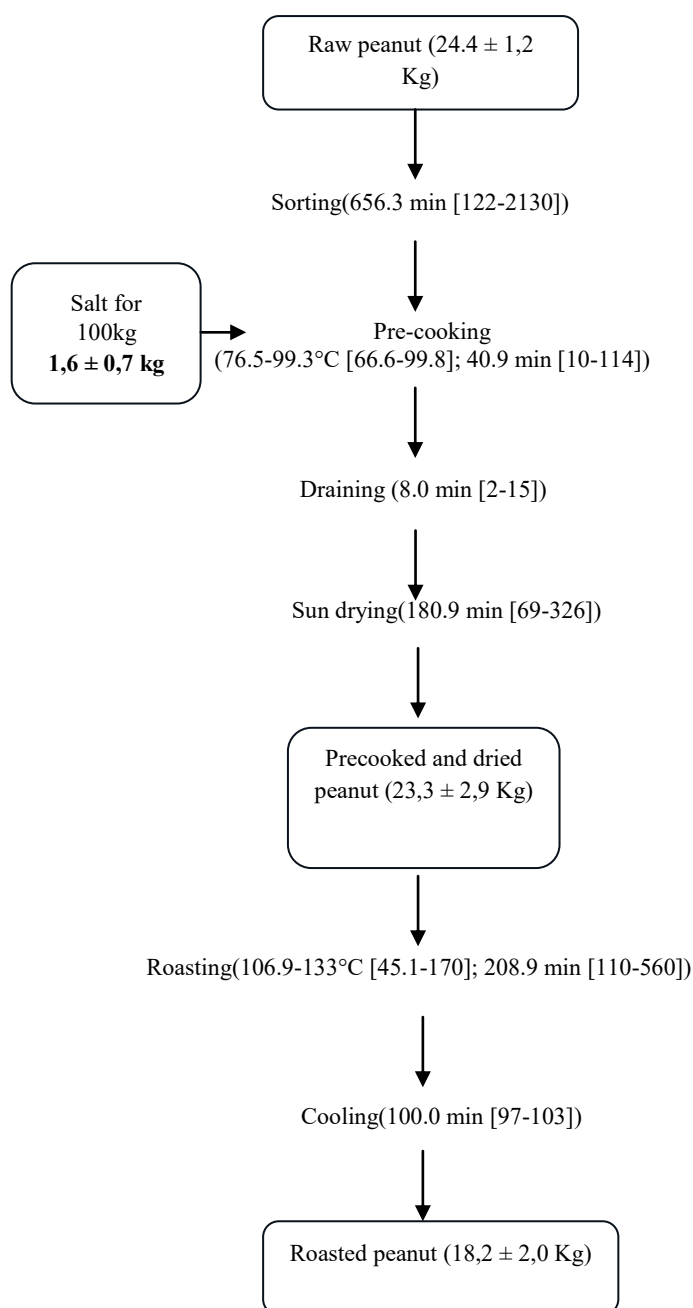
Tech. 1: Hot water without flour added

Tech. 2: Cold water with flour added

Tech. 3: Cold water without flour added

Tech. 1:Roasting with white clay

Tech. 2: Roasting without heat carrier

Tech. 3: Roasting with dried maize bran

Non-enzymatic browning index of peanut oil was measured according to Zhang et al. (2022). Peanut oils were diluted with n-hexane (1:10, w/v) and the absorbance of 420 nm was determined with a Perkin Elmer Lambda 45 UV/VIS spectrophotometer (Massachusetts, USA).

Specific gravity of peanut oil was assessed by Nelkon and Parker (1995) method. A known volume of 100ml the oil was weighed in a beaker and the mass (g) noted.

The oil specific gravity was calculated as follows:-

$$\text{Oil Specific gravity (S.G.)} = \frac{\text{Oil mass (g)}}{\text{oil volume (ml)} \times \text{water density}}$$

Peroxide (PV) and free fatty acid (FFA) of oils was performed by a photometric method using a CDR FoodLab® portable analyzer. To test PV and FFA, 5 µL and 2.5 µL oil, respectively, were placed in the prefilled cuvettes with relevant reagents and the colour intensity was measured. For peroxide value, the analytical principle is based on the

oxidation of ferrous ions (Fe^{2+}) to ferric ions (Fe^{3+}) by lipid peroxides present in the sample, followed by spectrophotometric measurement of the resulting coloured complex at 505 nm (Tian & Dasgupta, 1999). Peroxide values were automatically calculated by the instrument using an internal calibration model and expressed as milliequivalents of active oxygen per kilogram of oil (meq O_2/kg oil) (Okere et al., 2022; Tahmasbian et al., 2021). For acidity analysis, the instrument measures free fatty acids and provides a result as a percentage of oleic acid. The colour intensity was measured at 505 nm for PV samples and at 630 nm for FFA samples. The PV was expressed as meq O_2/kg oil and FFA and presented as a percentage of oleic acid. All measurements were performed in triplicate and the results expressed per 100 g of dry matter (DM).

Data Analysis:-

All processing parameters, field measurements, and laboratory analytical data were compiled in Microsoft Excel 2019 and analyzed using R software (version 4.4.2). Data were tested for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene’s test. One-way and multi-factor Analysis of Variance (ANOVA) were performed to evaluate the main effects of water temperature, flour incorporation, heat transfer media, as well as their interactive effects on process yields, lipid quality indices, and texture. Mean structuration was conducted using Tukey post-hoc tests. For non-normally distributed data, non-parametric Kruskal–Wallis or Wilcoxon rank-sum tests were applied. Statistical significance was established at a threshold of $P = 0.05$.

Results and Discussion:-

In-process operational kinetics: durations and thermal profiles:-

Kluiklui and peanut oil processing chain: Phase separation, dough rheology, and thermal loads:-

Processing durations and thermal profiles differed significantly among the traditional technologies, particularly during kneading, pressing, shaping and frying of kluiklui (Table 1a). Technology 1 (Tech.1), based on hot-water kneading ($76.6 \pm 9.8^\circ\text{C}$) without a subsequent pressing step, required the longest kneading time (104 ± 45.1 min), shaping time (388.8 ± 158.7 min) and frying time (204.7 ± 72.5 min). These longer durations were associated with higher fire ($541.4 \pm 84.4^\circ\text{C}$) and frying temperatures ($103.4 \pm 30.7^\circ\text{C}$) than those recorded for Tech. 2 and Tech. 3. Conversely, kneading duration was significantly reduced in cold-water variants, dropping to 66.6 ± 25.2 min in Tech. 2 and 51.7 ± 24.1 min in Tech. 3 ($p < 0.05$).

These operational divergences illustrate the technological trade-off between thermal destabilization and mechanical expression during traditional oil extraction (Ali & Muhammad, 2014; Muego et al., 1990; Rivera et al., 2025). Aqueous extraction of peanut oil requires breaking the oil-in-water emulsion to coalesce dispersed oil droplets (Ali & Muhammad, 2014; Wang et al., 2016). While hot-water kneading thermodynamically promotes lipid release by reducing oil viscosity and weakening protein–lipid interactions (Muego et al., 1990), Tech. 1 omits any pressing step and relies exclusively on manual shearing to separate the oil phase. Conversely, cold-water technologies (Tech. 2 and Tech. 3) introduce a dedicated manual pressing stage specifically designed to express an additional 15–20% of crude oil beyond what is initially released during primary kneading. Consequently, the mechanical expression step in cold-water technologies effectively compensates for the thermodynamic advantage of hot-water extraction, explaining the absence of significant differences in cumulative oil extraction yields between hot- and cold-water systems.

Dough shaping represented the most time-consuming unit operation across all technologies, but was dramatically more protracted in Tech. 1 (~6.5 h vs. ~2–4 h in Tech. 2 and 3). This pronounced discrepancy is directly governed by dough rheology and residual fat management. In Tech. 1, processors are compelled to leave substantially higher residual fat in the cake (as evidenced by the significantly higher lipid content of Tech. 1 press-cake, $p < 0.05$; Table 2a) to preserve the cohesion and plasticity required for rolling dough portions without structural crumbling. However, handling this high-oil, warm paste requires meticulous, repetitive manual care, drastically inflating shaping time. In sharp contrast, while manual pressing in Tech. 2 and Tech. 3 yields a heavily defatted, rigid cake, processors systematically recondition the matrix during a subsequent second kneading step by incorporating controlled amounts of water. This water addition rehydrates and plasticizes the defatted dough, providing optimal viscoelasticity that allows rapid portioning and shaping. Within the cold-water variants, pressing duration differed significantly between Tech. 3 (105.8 ± 33.5 min) and Tech. 2 (55.9 ± 17.6 min, $p < 0.05$). Importantly, this variation cannot be attributed to maize flour incorporation, as flour is introduced during the second kneading step (post-pressing) and at a negligible level ($\approx 1\%$ w/w). Instead, this divergence may reflect deliberate procedural differences in dewatering intensity. In Tech. 3, processors implement more exhaustive, prolonged pressing to maximize oil extraction prior to rehydration and dough conditioning. In other side, processors in Tech. 3 implement an intermediate pressing duration and sun-drying operation of shaped dough portions (averaging ~1 h under ambient

sunlight) prior to deep-frying. This combining step serves as an integrated moisture-reduction strategy to minimize frying spatter and stabilize cake geometry. Finally, the protracted deep-frying duration (204.7 ± 72.5 min) and intense fuelwood combustion (> 540 °C) recorded in Tech. 1 represent an energetic compensation for initial moisture retention. Because Tech. 1 bypasses mechanical pressing and intermediate drying, the shaped dough enters the frying bath with significant higher moisture content (76.2 ± 1.8 %, Table 3a). Since water vaporization is the rate-limiting kinetic step during deep-fat frying (Meng et al., 2019; Zhao et al., 2017), processors must maintain sustained, vigorous boiling to drive moisture below the safe conservation limit ($a_w < 0.40$). Thus, while Tech. 1 eliminates the physical labor of pressing equipment, it transfers the operational burden onto dough shaping time, frying duration, and fuelwood consumption.

Table 1a. Operating durations and thermal profiles — Kluiklui / oil production

Unit operation / parameter	Unit	Tech. 1 (Hot water, no pressing) (N=9)	Tech. 2 (Cold water + flour, pressing) (N=9)	Tech. 3 (Cold water, no flour, pressing) (N=9)	Sig. (p value <0.05)
Operation durations					
Sorting	min	$210.3 \pm 133.6a$	$110.4 \pm 43.8ab$	$81.6 \pm 98.6b$	*
Roasting	min	$126.9 \pm 60.2a$	$143.7 \pm 29.0a$	$61.4 \pm 28.7b$	*
Crushing	min	$8.7 \pm 11.8a$	$9.7 \pm 7.8a$	$4.6 \pm 2.0a$	NS
Winnowing	min	$11.2 \pm 4.0b$	$31.5 \pm 15.3a$	$11.2 \pm 5.6b$	*
Grinding	min	$51.9 \pm 25.1a$	$22.9 \pm 12.9b$	$15.6 \pm 7.2b$	*
Kneading	min	$104 \pm 45.1a$	$66.6 \pm 25.2ab$	$51.7 \pm 24.1b$	*
Pressing	min	NA (no pressing)	$55.9 \pm 17.6a$	$105.8 \pm 33.5b$	*
Shaping	min	$388.8 \pm 158.7a$	$257 \pm 124.2ab$	$173.8 \pm 140.4b$	*
Sun-drying	min	N/A	$77.5 \pm 18.8a$	N/A	*
Frying	min	$204.7 \pm 72.5a$	$107.4 \pm 37.5b$	$85.9 \pm 48.3b$	*
Whole process	min	$1316.3 \pm 367.7a$	$972.2 \pm 215.2b$	$571.1 \pm 201.2c$	*
Thermal profiles					
Roasting pan temp.	°C	$107.3 \pm 21.1b$	$106.6 \pm 26.4b$	$143 \pm 58.6a$	*
Fire temp., roasting	°C	$484.1 \pm 90.5a$	$467.4 \pm 103.9a$	$472.1 \pm 90.5a$	NS
Roasted kernel temp.	°C	$82 \pm 28.3ab$	$86 \pm 26.4a$	$80 \pm 27.4b$	*
Fire temp., frying	°C	$541.4 \pm 84.4a$	$484.3 \pm 87.5b$	$527.9 \pm 69a$	*
Frying oil-bath temp.	°C	$103.4 \pm 30.7a$	$106.9 \pm 33.8a$	$99.1 \pm 39.3a$	NS

Legend: Tech. 1 = hot-water kneading, no pressing (Kluiklui/oil chain); Tech. 2 = cold-water kneading + maize flour, with pressing; Tech. 3 = cold-water kneading, no flour, with pressing. Values are Mean $\pm$ SD; n given per group. Means in the same row followed by different superscript letters differ significantly ($p < 0.05$, Tukey HSD). NS = not significant ($p \geq 0.05$). N/A = Not Applicable

Roasted peanut processing chain: Thermal regimes, drying endpoint control, and yield dynamics:-

The traditional roasted peanut process demonstrated a significant different pattern of technological adaptation across processing variants (Table 1b). The nature of the heat-transfer medium significantly influenced pre-cooking duration (9.3 to 40.9 min), sun-drying duration (20.6 to 180.9 min), pre-cooked kernel temperature (53.7 to 96.5°C), roasting pan/heat media temperature (103.0 to 126.9 °C), fire temperature during roasting (474.4 to 543.9 °C) and roasted kernel temperature (93.6 to 109.6°C) ($p < 0.05$). Conversely, the operational durations of sorting, soaking, draining, roasting, and whole process did not differ significantly among heat carriers ($p > 0.05$). These quantitative data demonstrate that heat-carrier selection fundamentally alters the thermal transfer mechanism and kinetic energy input without perturbing the overall temporal schedule established by traditional processors.

Prior to roasting, pre-treatment unit operations exhibited marked procedural divergence. For dry maize bran (floflo), processors exclusively applied a boiling/pre-cooking pre-treatment at substantially higher temperatures (up to 96.5 °C) and durations (up to 40.9 min) compared to the milder soaking or gentle hydrothermal treatments recorded for bare pan and white clay (Howé) technologies (53.7–62.5°C). This intense hydrothermal pre-cooking (up to 96.5 °C) in the floflo process plasticizes cotyledon tissues and facilitates deep brine penetration. Crucially, although subsequent sun-drying times fluctuated widely (from ~20 min up to ~3 h) due to diurnal solar variations and initial moisture uptake, the resulting pre-treated and dried kernels converged to statistically indistinguishable dry matter contents ($p > 0.05$). This invariance reveals the precision of traditional sensory endpoint assessment: processors

empirically evaluate seed surface tactile dryness, sound during manual agitation, and seed coat detachment to terminate sun-drying at a standardized dehydration plateau, thereby standardizing kernel initial moisture prior to the thermal roasting stage (Casulli et al., 2019; Chiou et al., 1991).

During the roasting phase, heat-transfer media induced distinct thermal regimes. Kernel roasting temperatures were significantly higher when using dried maize bran (floflo) (110.7 °C) than direct pan roasting (93.6 °C), a pattern mirrored by fire combustion intensity, which reached 543.9 °C for floflo compared to temperatures for Howé (480°C) and direct pan systems (474.4°C). While bare metal or earthenware pans deliver focal conductive heat transfer susceptible to localized hot spots, particulate media provide a semi-fluidized bed effect characterized by diffuse conductive-convective heat exchange (Bagheri et al., 2016; Kortei et al., 2024). In the case of floflo, this organic granular medium possesses a lower bulk thermal conductivity than mineral clays; consequently, processors sustain an exceptionally fierce fire (>540 °C) to overcome bed insulation and maintain adequate conductive-convective flux through the biomass layer into the kernels.

This thermal intensity directly governed stage-specific roasting yields. Calculated relative to pre-cooked kernel mass, the roasting yield decreased significantly as roasting temperature severity increased ($p < 0.05$): direct pan roasting achieved the highest yield ($85.3 \pm 4.9\%$), followed by Howé clay ($82.5 \pm 3.6\%$), while floflo yielded the lowest recovery ($79.8 \pm 3.8\%$). The elevated kernel temperatures (110.7°C) and vigorous thermal regime of the floflo variant accelerated moisture evaporation and non-bound water flashing, coupled with heightened testa embrittlement and subsequent cuticle shedding during roasting (Shi et al., 2016; Xiang et al., 2025). In contrast, direct pan roasting at lower core temperatures (93.6 °C) limited excessive deep dehydration during the pan residence phase. Remarkably, despite these operational and stage-yield discrepancies, the cumulative mass yield of roasted peanuts and final physicochemical quality markers (total dry matter, lipid content on a dry matter basis, and water activity, a_w) were statistically equivalent across all heat-transfer media ($p > 0.05$). All processing variants consistently drove final water activity below the critical threshold ($a_w < 0.35$), ensuring effective microbial lethality and chemical stability against hydrolytic spoilage (Olaime et al., 2020; Yu, 2023). Nevertheless, field observations revealed that kernels roasted with Howé clay reportedly experience accelerated post-roast softening during ambient storage compared to direct pan or floflo products. This phenomenon can be explained by surface microstructural and sorption mechanisms: fine mineral aluminosilicate clay particles adhering to the seed coat and microporous fractures induced by rapid mineral-to-seed thermal shocks can enhance localized surface hygroscopicity, accelerating moisture re-adsorption under the high relative humidity conditions characteristic of Southern Benin (Lee & Resurreccion, 2006; Martínez-Navarrete & Chiralt, 1996). This qualitative post-roast divergence underscores that while empirical processing achieves compositional parity at the exit of the pan, protective packaging remains essential to maintain textural crispness in clay-roasted snacks.

Table 1b. Operating durations and thermal profiles — Roasted peanut chain

Unit operation / parameter	Unit	White clay (Howé) (N=9)	No heat carrier (Direct pan) (N=9)	Dried maize bran (Floflo) (N=9)	Sig. (p value <0.05)
Operation durations					
Sorting	min	457.8 ± 554a	365.6 ± 237.3a	656.3 ± 597.7a	NS
Pre-cooking	min	9.3 ± 6.0b	26 ± 5.6ab	40.9 ± 31.9a	*
Soaking	min	6.2 ± 9.3a	20.7 ± 32.3a	NA	NS
Draining	min	15.0±14.0a	8.0±7.2a	8.0±5.8a	NS
Sun-drying	min	20.6±18.8b	163.1±154.9ab	180.9±101.3a	*
Roasting	min	92 ± 53.4a	204.1 ± 113.2a	208.9 ± 142.9a	NS
Whole process	min	672.4±604.6a	714.9 ± 507.1a	1452.7 ± 968.1a	NS
Thermal profiles					
Pre-cooked kernel temp.	°C	61.5 ± 15.4b	53.7 ± 15.7b	96.5 ± 31.5a	*
Soaked kernel temp.	°C	54.3 ± 18.1a	62.5 ± 9.3b	N/A	*
Roasting pan/media temp.	°C	126.9 ± 30.4a	103 ± 32.7b	118.3 ± 30.5a	*
Fire temp., roasting	°C	480 ± 65.0b	474.4 ± 84.5b	543.9 ± 84.7a	*
Roasted kernel temp.	°C	109.6 ± 32.3a	93.6 ± 25.2b	110.7 ± 36.8a	*

Legend: Values are Mean $\pm$ SD ($n = 9$ production batches per heat carrier). Different superscript letters within a row denote significant differences ($p < 0.05$); NS = not significant; N/A =not applicable. White clay (Howé), No heat carrier (direct pan), Dried maize bran (floflo) = roasted peanut heat-transfer media.

Mass balance and extraction yields: intermediate variability and final convergence:-

Mass balance and yield of kluiklui and oil production:-

Stepwise mass-balance tracking demonstrated that all three artisanal processing technologies shared equivalent mass flows during upstream unit operations, diverged significantly during phase separation, and ultimately converged at the finished-product stage (Table 2a). The masses of raw peanuts, sorted peanuts, and peanut paste did not differ significantly among Tech. 1, Tech. 2, and Tech. 3 ($p > 0.05$).

The first major bifurcation in material flows occurred at the liquid–solid phase separation stage, leading to significant variations in crude oil extraction recovery ($p < 0.05$). Technology 1 achieved a crude oil recovery of 5.1 ± 0.5 kg, corresponding to a stage yield of $25.3 \pm 1.3\%$ relative to the initial paste mass. In sharp contrast, cold-water processing with pressing in Tech. 2 and Tech. 3 yielded 6.4 kg ($32.0 \pm 3.9\%$) and 6.3 kg ($29.3 \pm 3.2\%$) of crude oil, respectively. This quantitative disparity is directly governed by the presence or absence of mechanical extraction. Traditional aqueous peanut oil extraction depends on destabilizing the dispersed lipid-protein emulsion to promote lipid droplet coalescence (Ali & Muhammad, 2014; Wang et al., 2016). While hot-water addition in Tech. 1 thermodynamically lowers oil viscosity, relying solely on manual shearing without pressing leaves a substantial fraction of coalesced oil entrapped within the interstitial capillary network of the proteinaceous matrix. Conversely, manual pressing in Tech. 2 and Tech. 3 provides an external mechanical driving force that expels this capillary-bound oil, increasing stage oil recovery by 4 to 7 percentage points.

The divergence in oil recovery directly dictated the yield of intermediate defatted paste. Expressed as a percentage of initial paste mass, the defatted-paste yield differed significantly among technologies ($p < 0.05$), peaking in Tech. 1 at $128.1 \pm 6.7\%$, compared to $120.0 \pm 5.7\%$ in Tech. 2 and $122.1 \pm 3.6\%$ in Tech. 3. Notably, all values substantially exceeded 100%. This apparent mass expansion reflects the net mass gain associated with the incorporation of exogenous process water (and minor quantities of table salt) during kneading to induce phase inversion and dough conditioning (Muego et al., 1990; E. A. G. Videgla et al., 2016). The significantly higher defatted-paste ratio observed in Tech. 1 (128.1%) stems from a dual accumulation mechanism: the total retention of added kneading water combined with the unexpressed residual lipid fraction. In Tech. 2 and Tech. 3, the pressing operation expels both crude oil and a fraction of free water, yielding a drier, heavily defatted press-cake that is only moderately re-expanded during the second kneading step. Thus, the kneading–extraction stage represents the critical technological crossroad where water addition, flour incorporation, and mechanical expression dictate the partitioning of oil and water between intermediate fractions.

Despite these substantial intermediate deviations in liquid retention and phase separation, the final cumulative yield of kluiklui snacks exhibited remarkable convergence across all three technologies. Finished kluiklui yields represented $59.5 \pm 3.4\%$ for Tech. 1, $59.8 \pm 6.8\%$ for Tech. 2, and $59.6 \pm 7.5\%$ for Tech. 3 of initial raw peanut seed mass ($p > 0.05$). This statistical parity demonstrates that operational divergences generated during oil extraction are progressively neutralized during subsequent unit operations. Deep-fat frying is fundamentally a coupled heat and mass transfer process governed by moisture vaporization and counter-current oil absorption (Bouchon, 2003; Meng et al., 2019). Because the shaped dough portions in Tech. 1 entered the frying bath with higher initial water and fat contents, processors sustained a substantially longer frying cycle (204.7 min) under fierce fuelwood combustion ($>540^\circ\text{C}$). This extended thermal exposure acted as an energetic compensator, driving out surplus moisture via intense steam flashing until the matrix reached a terminal dehydration plateau. Conversely, dough portions in Tech. 2 and Tech. 3, which had already undergone mechanical dewatering and intermediate sun-drying, required significantly shorter frying times to achieve the same target moisture level. Consequently, the operational trade-off between mechanical dewatering (cold water + press) and prolonged thermal vaporization (hot water without press) resulted in an identical conversion efficiency of raw peanuts into marketable kluiklui cakes. From a techno-economic standpoint, however, this yield equivalence highlights a major efficiency trade-off. While Tech. 1 eliminates the capital requirement for pressing utensils and yields an identical kluiklui mass, it does so at the cost of sacrificing marketable crude peanut oil (25.3% vs. 29.3 and 32.0%) while inflating fuelwood expenditure and labor time during shaping and deep-frying.

Table 2 a. Stepwise operation yields and final effective yields — Kluiklui / oil production

Parameter	Unit	Tech. 1 (Hot water, no pressing) (N=9)	Tech. 2 (Cold water + flour, pressing) (N=9)	Tech. 3 (Cold water, no flour, pressing) (N=9)	Sig.
Masse balances					
Unprocessed peanut	kg	25.2 ± 0.2a	25.7 ± 0.9a	25.2 ± 0.2a	NS
Sorted peanut	kg	24.6 ± 0.5a	25.2 ± 1.4a	24.9 ± 0.4a	NS
Roasted peanut	kg	22.1 ± 0.3a	22.3 ± 0.9a	22.4 ± 0.4a	NS
Dehulled peanut	kg	21 ± 0.7a	21.3 ± 1.2a	21.6 ± 0.7a	NS
Peanut paste	kg	20.4 ± 0.3a	21.3 ± 0.9a	20.8 ± 1.2a	NS
Water mass	kg	4.6 ± 1.6b	6.4 ± 1.1a	5.2 ± 0.8ab	*
Maize flour mass	kg	NA	0.2 ± 0.2	NA	-
Salt mass	kg	0.2 ± 0.1a	0.2 ± 0.1a	0.2 ± 0.0a	NS
Peanut oil mass	kg	5.1 ± 0.5b	6.4 ± 0.8a	6.3 ± 0.8a	*
Partially defatted peanut paste	kg	19.2 ± 0.7a	19.4 ± 1.3a	18.9 ± 1.3a	NS
Shaped peanut paste	kg	18.1 ± 1.7a	20.1 ± 1.9a	18.8 ± 1.6a	NS
Kluiklui	kg	14.4 ± 0.8a	15 ± 1.7a	14.6 ± 1.8a	NS
Production yields					
Unprocessed peanut-to-Dehulled yield	%	90.3 ± 1.2b	87.9 ± 1.4c	92.4 ± 1.9a	*
Dehulled-to-peanut paste yield	%	93.8 ± 1.4b	98.0 ± 4.4a	96.8 ± 2.2ab	*
Oil-extraction yield (% of paste)	%	25.3 ± 1.3b	32 ± 3.9a	29.3 ± 3.2a	*
Defatted-paste ratio (% of paste)	%	128.1 ± 6.7b	120 ± 5.7a	122.1 ± 3.6ab	*
Kluiklui yield (% of defatted paste)	%	78.7 ± 4.0a	80 ± 7.6a	83.9 ± 10.4a	NS
Oil yield on raw material (Rm; % of raw material)	%	20.3 ± 2.1b	25.1 ± 3.3a	25 ± 3.2a	*
Effective oil-extraction efficiency (Re)	%	38.4 ± 13.3a	46.3 ± 18.4a	45.7 ± 15.8a	NS
Final Kluiklui product yield (KK, % raw material)	%	59.5 ± 3.4a	59.8 ± 6.8a	59.6 ± 7.5a	NS

Legend: Values are Mean ± SD, n = 9 per technology. Different superscripts within a row denote significant differences ($p < 0.05$); NS = not significant.

Masse balance and yield of roasted peanut chain:-

Compared to the liquid–solid phase separation dynamics observed in the kluiklui chain, the traditional roasted peanut process exhibited substantially greater stability and continuity in mass allocation across all processing variants (Table 2b). Initial decorticated seed inputs, sorted clean kernel masses, and final roasted peanut yields showed no statistically significant differences among the three heat-transfer media ($p > 0.05$). Across all trials, cumulative finished product yields relative to the initial raw material ($Y_{\text{product, db}}$) converged into a narrow window ranging from 76.1% to 78.1%. The only significant divergence in material flow occurred strictly at the roasting operation itself ($p < 0.05$). Stage-specific roasting yield ($Y_{\text{product, db}}$), defined as the mass ratio of roasted kernels recovered relative to soaked or pre-cooked kernel inputs, varied significantly according to the heat carrier: direct pan roasting achieved the highest mass retention ($85.3 \pm 4.9\%$), followed closely by white clay (Howé, $82.5 \pm 3.6\%$), whereas dry maize bran (floflo) treatment resulted in significantly lower mass recovery ($79.8 \pm 3.8\%$). This localized operational disparity may be directly linked to the hydrothermal history imposed prior to roasting coupled with roasting thermal severity. In the floflo technology, processors perform prolonged hydrothermal pre-cooking (40.9 ± 31.9 min at $96.5 \pm 31.5^\circ\text{C}$) rather than the cold/ambient brine soaking applied in bare pan and clay systems. This pre-cooking causes swelling of starch granules, partial protein solubilization, and deeper capillary water imbibition into the cotyledons (Ijarotimi et al., 2022; Sacca, 2012). During subsequent pan roasting, the floflo medium operates under severe thermal conditions, with fire combustion temperatures reaching 543.9°C and internal kernel temperatures reaching 110.7°C . This elevated thermal flux induces intense flash-evaporation of unbound and

capillary-held moisture, driving moisture content from higher hydration levels down to safe shelf-stable levels below 2% db (Bagheri et al., 2016; Shi et al., 2018; Xiang et al., 2025). Furthermore, intense convective-conductive friction within the agitating biomass bed promotes testa embrittlement and cuticle dusting, compounding mass loss through skin shedding (Shi et al., 2018). In contrast, direct pan and white-clay treatments enter the roasting stage with lower initial water loads from ambient soaking, which mitigates excessive vapor flashing and preserves higher intermediate mass retention. Crucially, this operational discrepancy remained strictly localized within the roasting unit operation and did not carry over into the finished product yield ($p > 0.05$). When normalized to initial raw decorticated peanut seeds ($M_0 = 25.0$ kg), the cumulative mass conversion of raw seeds into marketable roasted kernels was completely buffered across technologies.

This overall yield parity highlights two foundational engineering principles governing traditional processing:-

- **Transient mass conservation:** The excess mass absorbed during boiling in the floflo variant consists almost entirely of process water, which is subsequently lost as vapor during roasting. Because solid-state matrix integrity is preserved unlike the kluiklui process where lipid extraction partitions macronutrients, the dry matter conversion efficiency remains conserved regardless of intermediate moisture fluxes (Xiang et al., 2025; Yu, 2023).
- **Sensory-guided endpoint regulation:** Traditional female processors consistently terminate roasting based on multi-sensory physical markers, including the acoustic frequency of expanding cotyledon cracking, surface golden-brown coloration (Maillard reaction progress), and roasted pyrazine aroma intensity (Chiou et al., 1991; Kortei et al., 2024; Lykomitros et al., 2016). This empirical vigilance ensures that all batches achieve equivalent terminal dehydration and chemical maturity, buffering against discrepancies in heat carrier mechanics.

From a practical and economic perspective, these findings demonstrate that artisanal processors can select between direct pan roasting, mineral clay (Howé), or organic agro-industrial by-products (floflo) based on local fuel availability, cookware access, or cultural preference without incurring any material penalty on overall finished product output.

Table 2b. Stepwise mass balance and yields — Roasted peanut chain

Parameter	Unit	White clay (Howé) (N=9)	No heat carrier (Direct pan) (N=9)	Dried maize bran (Floflo) (N=9)	Sig.
Masse balances					
Raw peanuts	kg	25.4 ± 0.4a	25.3 ± 0.4a	24.4 ± 1.2a	NS
Sorted peanuts	kg	21.3 ± 2a	22.1 ± 1.3a	21.9 ± 1.9a	NS
Soaking/pre-cooking water absorbed	kg	2.4 ± 0.9a	4.5 ± 2.6a	2.8 ± 2.3a	NS
Salt used	kg	0.4 ± 0.2a	0.5 ± 0.2a	0.4 ± 0.2a	NS
Pre-cooked/soaked/dried kernels	kg	23.9 ± 2.7a	24.1 ± 2.6a	23.3 ± 2.9a	NS
Roasted peanuts	kg	19.2 ± 2.4a	19.2 ± 2a	18.2 ± 2.0a	NS
Production yields					
Pre-treatment yield on raw peanut (Pre-cooked/soaked/dried kernels)	%	116.5 ± 10.9a	116.6 ± 16.7a	120.5 ± 16.0a	NS
Roasting yield on pre-treated (roasted peanut, %)	%	82.5 ± 3.6ab	85.3 ± 4.9a	79.8 ± 3.8b	*
Final product yield on raw material (Y_{products} db)	%	77.7 ± 8.8a	78.1 ± 7.6a	76.1 ± 6a	NS

Legend: Values are Mean $\pm$ SD, n = 9 batches per heat carrier. Different superscripts within a row denote significant differences ($p < 0.05$); NS = not significant.

Physicochemical dynamics and finished-product quality:-

Physicochemical dynamics and kluiklui quality:-

The physicochemical composition of the initial matrices was highly consistent across kluiklui technologies (Table 3a). Raw peanuts, roasted kernels and initial ground paste showed no significant differences in dry matter, crude lipid content (on a dry matter basis) or acid value ($p > 0.05$). This homogeneity demonstrates that subsequent analytical divergences in intermediate matrices and end-products did not originate from botanical, agronomic, or preliminary processing variations, but were exclusively driven by the downstream technological choices implemented during dough conditioning and phase separation.

The first significant physicochemical divergence appeared in the defatted paste ($p < 0.05$). Tech. 1 retained higher residual lipid in the defatted cake ($23.6 \pm 8.2\%$ db.), compared with Tech. 2 ($12.9 \pm 2.9\%$ db) and Tech. 3 ($16.0 \pm 4.4\%$ db). This pattern indicates the lower oil-extraction efficiency of Tech. 1. The shaped dough also differed in dry matter, with Tech. 1 reaching $76.2 \pm 1.8\%$, compared with $69.4 \pm 1.8\%$ for Tech. 2 and $63.0 \pm 21.5\%$ for Tech. 3 ($p < 0.05$). These differences indicate that technological variation is expressed primarily in intermediate matrices following kneading and oil extraction.

Kluiklui retained some of this technological differentiation but showed a more limited variation in composition. Residual lipid content varied slightly but significantly ($p < 0.05$) between Tech. 1 ($25.6 \pm 1.2\%$), Tech. 2 ($22.4 \pm 4.1\%$) and Tech. 3 ($25.9 \pm 10.8\%$), mirroring the combined effects of intermediate cake fat levels and frying-oil absorption dynamics (Bouchon, 2003). In contrast, dry matter, water activity and breaking deformation length (probe penetration distance prior to structural fracture) didn't vary significantly among technologies ($p > 0.05$). The invariance of water activity confirms that traditional frying endpoints achieve equivalent moisture vaporization plateaus, ensuring effective microbial stability and hydrolytic protection across all artisanal formulations (Olaimat et al., 2020; Yu, 2023).

Conversely, breaking force differed markedly among technologies ($p < 0.05$). Tech. 3 generated the hardest snack structure, requiring the highest breaking force (63.0 ± 44.0 N), followed by Tech. 2 with Tech. 2 (34.3 ± 31.0 N); $p < 0.05$, whereas Tech. 1 yielded the lowest fracture resistance (10.3 ± 4.3 N).

This mechanical gradient is directly governed by residual fat plasticization, structural compaction, and formulation differences:-

- **Fat-mediated structural softening in Tech. 1:** In fried starch-protein matrices, lipids act as structural "shorteners" and plasticizers that disrupt cross-linked protein networks and reduce mechanical strength (Chiou et al., 1991; Owade et al., 2022). The higher residual oil content in Tech. 1 cakes, coupled with the absence of intensive mechanical compaction, produces a porous, fragile cellular structure that fractures under minimal force (10.3 N) imparting a more tender and friable bite.
- **Mechanical compaction, sun-drying, and starch reinforcement cold water technologies:** The remarkable hardness observed in Tech. 3 (63 N) stems principally from the protracted manual pressing step (105.8 min) thoroughly a significant proportion of the free oil, yielding a compact, dense protein framework. Technology 2, for its part, occupied a balanced intermediate position (34.3 N) for twofold reasons. First, processors in Tech. 2 apply ~1 h of intermediate open-air sun-drying to shaped dough rolls prior to frying, inducing surface crust pre-hardening and moisture gradients that consolidate matrix density. Second, the incorporation of maize flour ($\approx 1\%$ w/w) during secondary kneading introduces external cereal starch granules that gelatinize and retrograde during high-temperature frying, forming an interconnected structural scaffold that significantly elevates fracture resistance (Lykomitros et al., 2018; Muego et al., 1990).

Peanut oil quality: Enzymatic hydrolysis versus thermal autoxidation:-

Technological differences were more pronounced in crude peanut oil than in the finished kluiklui product, indicating a greater sensitivity of oil quality attributes to processing variations. Acid value was lowest for Tech. 1 (3.1 ± 1.5 mg KOH/g), intermediate for Tech. 2 (5.9 ± 3.3 mg KOH/g) and highest for Tech. 3 (7.9 ± 2.2 mg KOH/g; $p < 0.05$). This divergence highlights the critical role of processing temperature on endogenous enzymatic activity. In Tech. 1, kneading dough with hot water ($76.6 \pm 9.8^\circ\text{C}$) rapidly denatures endogenous peanut lipases and lipoxygenases, effectively arresting the biocatalytic cleavage of triacylglycerols into free fatty acids (Ali & Muhammad, 2014; Sanders, 2002). Conversely, cold-water kneading (Tech. 2 and Tech. 3) occurs at ambient

temperatures (28–32 °C) that coincide with near-optimal lipase kinetics. In Tech. 3, where dough handling and mechanical pressing are protracted over ~106 min, endogenous and microbial lipases remain active for extended periods in an aqueous-lipid emulsion, accelerating triacylglycerol hydrolysis and elevating free fatty acid accumulation (Honfo et al., 2011; Yaacoub et al., 2008). According to the Codex Alimentarius standard for virgin peanut oil (CXS 210, 1999), the maximum allowable AV is 4.0 mg KOH/g. Consequently, while crude oil from Tech. 1 complies fully with international standards, cold-water variants (Tech. 2 and 3) exceed this regulatory threshold due to prolonged ambient biocatalysis.

The oxidative pattern was exactly reversed. Crude oil from Tech. 1 showing the highest value (14.0 ± 4.9 meq O_2 /kg), followed by Tech. 2 (11.9 ± 3.8 meq O_2 /kg) and Tech. 3 (10.0 ± 8.8 meq O_2 /kg; $p < 0.05$). Hot-water extraction in Tech. 1 exposes unsaturated fatty acids (predominantly oleic and linoleic acids) to elevated temperatures in the presence of dissolved atmospheric oxygen during vigorous open-air kneading, accelerating the initiation and propagation of free-radical chain autoxidation to form primary lipid hydroperoxides (F. Gao et al., 2017; Wang et al., 2016). Conversely, ambient cold-water expression limits thermal oxygen activation, preserving lower primary oxidation levels. Nevertheless, all three crude oil variants complied with the Codex Alimentarius ceiling for virgin vegetable oils ($PV \leq 15.0$ meq O_2 /kg).

Other physical and chromatic attributes of crude oil—specifically volumetric bulk density ($0.914\text{--}0.916\text{g/cm}^3$), free fatty acid percentage, and spectrophotometric browning index (BI) didn't vary significantly across all technologies ($p > 0.05$). This stability demonstrates that the traditional extraction configuration selectively modulates biochemical degradation pathways (hydrolysis vs. primary peroxidation) without altering the fundamental physical state or non-enzymatic chromatic profile of the crude oil.

In marked contrast to crude oil, the residual frying oil exhibited complete cross-technological convergence across all measured parameters (Table 3a). Total dry matter, bulk density, and peroxide value showed no statistically significant differences among technologies ($p > 0.05$).

Peroxide values of the frying oils converged within a narrow range of 16.9 to 18.1 meq O_2 /kg. During deep-fat frying, the sustained thermal load (over 150 °C) in open pans induces severe thermo-oxidative stress that drives the rapid decomposition of unstable primary hydroperoxides into volatile and non-volatile secondary oxidation products (aldehydes, ketones, epoxides, and polymeric triglycerides) (Bouchon, 2003; Zhao et al., 2017). Simultaneously, continuous steam flashing generated by frying wet dough portions strips away volatile scission compounds. This dynamic equilibrium between hydroperoxide generation, thermal breakdown, and steam stripping creates a standardized thermo-oxidative steady state in the oil bath, effectively buffering and overriding any upstream oxidative differences inherited from the crude extraction phase.

Physicochemical dynamics and roasted peanut quality:-

The traditional roasted-peanut chain exhibited even greater physicochemical stability across all evaluated heat-transfer media (Table 3b). Raw peanuts, pre-treated/dried kernels and roasted peanuts showed no significant differences in dry matter, crude lipid content or water activity among heat carriers ($p > 0.05$). Raw peanuts contained 93.6–93.9% dry matter and 44.7–46.6% lipid on a dry basis. After pretreatment, dry matter increased to 79.7–82.4%, while roasted peanuts retained 39.3–43.1% lipid on a dry basis. Therefore, heat-carrier selection modified the thermal conditions of roasting without producing measurable differences in the physicochemical composition of the intermediate and final products.

The consistency of water activity ($a_w < 0.35$) across all roasted products demonstrates that the thermal regimes generated by distinct heat carriers consistently achieve the same terminal dehydration plateau. In low-moisture snack foods, water activity represents the definitive thermodynamic measure of free water availability, directly dictating chemical stability and microbiological shelf life (Islam et al., 2026; Olaimat et al., 2020). During pan roasting, heat transfer drives out capillary and multilayer moisture via flash vaporization (Chen et al., 2023; Meng et al., 2019). Operating below the critical threshold of $a_w = 0.35$ places the product in the monolayer moisture sorption zone (glassy state), which completely arrests endogenous lipase and lipoxigenase catalysis, prevents non-enzymatic hydrolytic rancidity, and inhibits the growth of xerophilic molds, including toxigenic *Aspergillus flavus* strains (Casulli et al., 2019; Martínez-Navarrete & Chiralt, 1996; Sogbossi Gbétokpanou, Jonard, et al., 2025).

Table 3a. Stepwise physicochemical properties — Kluiklui / oil chain (raw seed → finished products)

Technologic	Step	N	TMS	Lipid (% BS)	aw	Acid Index	Acidity (% Acid oleic)	Force (N)	Length (mm)	Brun Index	Peroxide value	Density volumique
Tech. 2	Abs	3	93.7 ± 1.4a	45.3 ± 4.6a	-	-	-	-	-	-	-	-
Tech. 3		3	93.5 ± 0.5a	46.6 ± 2.1a	-	-	-	-	-	-	-	-
Tech. 1		3	94.7 ± 1.2a	44.8 ± 3.5a	-	-	-	-	-	-	-	-
Tech. 2	Ato	9	98.2 ± 0.8a	-	0.4 ± 0.1a	-	-	-	-	-	-	-
Tech. 3		9	97.4 ± 0.8a	-	0.4 ± 0.1a	-	-	-	-	-	-	-
Tech. 1		9	97.7 ± 0.6a	-	0.3 ± 0.1a	-	-	-	-	-	-	-
Tech. 2	PA T	9	98.8 ± 0.6a	45.4 ± 5.2a	-	6.6 ± 1.1a	0.4 ± 0.3a	-	-	-	-	-
Tech. 3		9	98.3 ± 0.7a	44.9 ± 4.4a	-	8.7 ± 2.9a	0.6 ± 0.5a	-	-	-	-	-
Tech. 1		9	98.1 ± 0.7a	40 ± 5.6a	-	7 ± 1.5a	0.4 ± 0.2a	-	-	-	-	-
Tech. 2	PD A	9	72.9 ± 1.4a	12.9 ± 2.9b	-	-	-	-	-	-	-	-
Tech. 3		9	75 ± 2.2ab	16 ± 4.4b	-	-	-	-	-	-	-	-

Technologie	Step	N	TMS	Lipid (% BS)	aw	Acid Ind ex	Acidity (% Acid oleic)	Force (N)	Length (mm)	Brun Index	Peroxide value	Density volumique
Tech. 1		9	76.2 ± 2b	23.6 ± 8.2a	-	-	-	-	-	-	-	-
Tech. 2	Pato	9	69.4 ± 1.8a	21.5 ± 28.7a	-	-	-	-	-	-		
Tech. 3		9	63.0 ± 21.5a	36.7 ± 53.2a	-	-	-	-	-	-		
Tech. 1		8	76.2 ± 1.8b	19.5 ± 2.8b	-	-	-	-	-	-		
Tech. 2	KK T	9	97.7 ± 1a	22.4 ± 4.1a	0.3 ± 0.1a	-	-	34.3 ± 31.0ab	1.5 ± 0.4a	-	-	-
Tech. 3		9	97 ± 1.2a	25.9 ± 10.8ab	0.3 ± 0.1a	-	-	63.0 ± 44.0a	1.3 ± 0.5a	-	-	-
Tech. 1		9	96.3 ± 1.2a	25.6 ± 1.2b	0.3 ± 0.1a	-	-	10.3 ± 4.3b	1.4 ± 0.3a	-	-	-
Tech. 2	HAB	9	99.5 ± 0.5a	-	-	5.9 ± 3.3ab	0.1 ± 0.0a	-	-	0.2 ± 0.1a	11.9 ± 3.8ab	0.9 ± 0.0a
Tech. 3		9	99.7 ± 0.3a	-	-	7.9 ± 2.2a	0.1 ± 0.1a	-	-	0.1 ± 0.1a	10 ± 8.8a	0.9 ± 0.0a
Tech. 1		9	99.6 ± 0.5a	-	-	3.1 ± 1.5b	0.1 ± 0.1a	-	-	0.1 ± 0.1a	14 ± 4.9b	0.9 ± 0.0a

Technologie	Step	N	TMS	Lipid (%BS)	aw	Acid Index	Acidity (% Acid oleic)	Force (N)	Length (mm)	Brun Index	Peroxide value	Density volumique
Tech. 2	HF	9	99.6 ± 0.4a	-	-	-	-	-	-	-	17.4 ± 14.3a	0.9 ± 0.0a
Tech. 3		9	99.7 ± 0.3a	-	-	-	-	-	-	-	18.1 ± 6.5a	0.9 ± 0.0a
Tech. 1		9	99.5 ± 0.5a	-	-	-	-	-	-	-	16.9 ± 8.5a	0.9 ± 0.0a

Legend: Abs: raw peanut; Ato: Roasted peanut; PAT: peanut paste; PDA: Partially defatted peanut; Pato: stick-shaped peanut paste before frying; KKT: Stick kluiklui; HAB: Freshly pressed peanut oil; HF: Frying oil; Lipide (%BS): percentage of lipid content on dry basis, aw: water activity, Acid Index, Acidity (% Acid oleic), Force (N); Texture fracture, Length (mm): texture distance to break kluiklui, Brun Index: non enzymatic browning values of peanut oil, Peroxide value, Density volumetric

TMS: total dry matter; BS: dry basis; aw: water activity. Different superscripts within a column denote significant differences ($p < 0.05$); NS = not significant.

Table 3 b. Stepwise physicochemical properties — Roasted peanut chain

Technology	Step	N	TMS (%)	Lipide (%BS)	aw
White clay	Abs	3	93.6 ± 1.1a	44.7 ± 3a	-
No heat carrier		3	93.9 ± 1.0a	45.8 ± 0.9a	-
Dried Maize bran		3	92.8 ± 1.7a	46.6 ± 3.4a	-
White clay	Abp	9	80.8 ± 5.2a	-	-
No heat carrier		9	82.4 ± 4.4a	-	-
Dried Maize bran		9	79.7 ± 3.9a	-	-
White clay	AGT	9	97.3 ± 1.0a	43.1 ± 2.8a	0.3 ± 0.0a
No heat carrier		9	97.2 ± 0.5a	39.3 ± 4.5a (8)	0.3 ± 0.0a
Dried Maize bran		9	97.8 ± 1.0a	40.8 ± 4.4a	± 0.0a 0.3

Legend: Abs: raw peanut; Abp: Soaked/precooked and dried peanut; AGT: Roasted peanut snack TMS: total dry matter; BS: dry basis; aw: water activity. Different superscripts within a row denote significant differences ($p < 0.05$); NS = not significant.

Conclusion:-

This study assessed the extent to which traditional processing variants for kluiklui/oil and roasted peanuts influence processing conditions, intermediate product characteristics, and the quality attributes of the resulting products, thereby providing a basis for targeted process improvement. The results revealed significant differences across operational parameters and intermediate matrices among processing variants. These variations were particularly observable in kneading, pressing, and frying durations, thermal profiles, oil extraction, and the compositional characteristics of defatted peanut paste. Collectively, these findings highlight the importance of specific processing

steps and intermediate product transformations in explaining the variability associated with traditional peanut processing.

However, these process-oriented differences were largely weakened at latter processing stages for showing no overall difference between process variants. Consistently, several physicochemical characteristics of the finished products also showed substantial convergence. Nevertheless, some attributes remained sensitive to processing configuration, particularly kluiklui texture and the acid and peroxide values of crude peanut oil.

Overall, the findings indicate that traditional processing variants may partially offset differences occurring at earlier processing stages, ultimately yielding finished products with broadly comparable quality characteristics despite distinct processing trajectories. Accordingly, process improvement should not necessarily aim to standardize all processing operations, but rather focus on identifying and controlling the specific process parameters that contribute most to the observed quality differences. Such an approach would facilitate the identification of critical processing steps and the establishment of optimized processing conditions, thereby improve process efficiency while maintain the desirable quality attributes of traditional peanut products.

Conflict of interests:-

The authors declare that there is no conflict of interest in the study.

References:-

1. Abdul-Majeed, I. (2017). Peanuts and aflatoxin contamination in northern Ghana: Women's local knowledge and practices. Tropical Resources Institute, 36.
2. Adjénia, M. J., Sogbossi Gbétokpanou, C., Mehinto, O. A., Kpossilande, C. E., Iko Afè, O. H., Anihouvi, D. G., Poncellet, M., Mongbo, R., Douny, C., Bragard, C., Scippo, M.-L., Mahillon, J., Azokpota, P., Hounhouigan, D. J., Sindic, M., & Madodé, Y. E. (2026). Diversity and physicochemical characteristics of major peanut-based products marketed in Benin, West Africa. *Food Science & Nutrition*, 1-53.
3. Ali, M. A., & Muhammad, I. W. (2014). Design of a Mechanical Oil Kneader Based on Ergonomic Studies of the Traditional Kneading Process. *Applied Mechanics and Materials*, 528, 264-271. doi:<https://doi.org/10.4028/www.scientific.net/AMM.528.264>
4. Allan, E., Ndiaye, A., Song, M., Raber, E., & Kuo, W. (2023). Developing a culturally acceptable peanut nutrition bar with smallholder women farmers in Kaffrine, Senegal using response surface methodology. *Journal of Food Science*, 88(2), 608-624. doi:10.1111/1750-3841.16412
5. Assogba, M. F., Ahouansou, R. H., Kpoclou, Y. E., Djohi, N. O. R., Douny, C., Mahillon, J., Scippo, M.-L., Hounhouigan, D. J., & Anihouvi, V. B. (2020). Development of improved equipments reducing levels of PAHs in grilled pork and smoked fish products. *Meat Science*, 40p.
6. Bagheri, H., Kashaninejad, M., Ziaifar, A. M., & Aalami, M. (2016). Novel hybridized infrared-hot air method for roasting of peanut kernels. *Innovative Food Science & Emerging Technologies*, 37, 106-114. doi:<http://dx.doi.org/10.1016/j.ifset.2016.08.014>
7. Bonuedi, I., Owusu-Addo, E., Wadei, B., Tetteh, R. O., & Antoh, E. F. (2025). The effect of groundnut processing infrastructure on access to nutritious diets in northern Ghana. *Scientific African*, 30, 1-14. doi:<https://doi.org/10.1016/j.sciaf.2025.e03028>
8. Bouchon, P., Aguilera, J.M. and Pyle, D.L. (2003). Structure oil-absorption relationships during deep-fat frying. *Journal of Food Science*, 68(9), 2711-2716.
9. Casulli, K. E., Calhoun, S., & Schaffner, D. W. (2019). Modeling the Risk of Salmonellosis from Consumption of Peanuts in the United States. *Journal of Food Protection*, 82(4), 579-588. doi:<https://doi.org/10.4315/0362-028X.JFP-18-314>
10. Chen, P., Chen, N., Zhu, W., Wang, D., Jiang, M., Qu, C., Li, Y., & Zou, Z. (2023). A Heat and Mass Transfer Model of Peanut Convective Drying Based on a Two-Component Structure. *Foods*, 12(9), 1823. Retrieved from doi:10.3390/foods12091823
11. Chiou, R. Y., Chang, Y. S., Tsai, T. T., & Ho, S. (1991). Variation of flavor-related characteristics of peanuts during roasting as affected by initial moisture contents. *Journal of Agricultural and Food Chemistry*, 39(6), 1155-1158.
12. Chiou, R. Y. Y. (1990). Effects of heat treatments on peanut arachin and conarachin. *Journal of Food Biochemistry*, 14(3), 219-232. doi:<https://doi.org/10.1111/j.1745-4514.1990.tb00835.x>
13. CXS 210. (1999). Standard for named vegetable oils (CXS 210-1999, revised 2019). Retrieved from Rome:

14. Gao, F., Zhang, Y., Zhao, Y., & Wang, Q. (2017). Effects of roasting on the physical properties, chemical composition, and volatile compounds of peanut oils. *LWT - Food Science and Technology*, 84, 782–788.
15. Gao, L., Luo, D., Hu, X., & Wu, J. (2017). Se in Se-enriched peanut, and losses during peanut protein preparation. *International Journal of Food Science and Technology*, 52(3), 843-850. doi:10.1111/ijfs.13347
16. Honfo, F. G., Akissoé, N., Linnemann, A. R., Soumanou, M., & Van Boekel, M. A. J. S. (2011). Nutritional composition of shea products and chemical properties of shea butter: a review. *Critical Reviews in Food Science and Nutrition*, 54(5), 673–686.
17. Honfo, F. G., Hell, K., Akissoe, N., Dossa, R., & Hounhouigan, J. D. (2010). Diversity and nutritional value of foods consumed by children in two agro-ecological zones of Benin. *African Journal of Food Science*, 4(4), 184-191.
18. Ijarotimi, O. S., Ogunmola, T. G., & Oluwajuyitan, T. D. (2022). Effect of some traditional processing operations on the chemical, functional, antioxidant, glycaemic index and glycaemic load of groundnut (*Arachis hypogaea* L.) seed flour. *Journal of Food Measurement and Characterization*, 16(3), 2024-2040. doi:10.1007/s11694-022-01320-6
19. Ingenbleek, L., Veyrand, B., Adegbeye, A. O., Marchand, P., & Le Bizec, B. J. (2019). Polycyclic aromatic hydrocarbons in foods from the first regional total diet study in Sub-Saharan Africa: contamination profile and occurrence data. *Food Control*, 103, 133-144. doi:10.1016/j.foodcont.2019.04.006
20. Islam, S., Li, Z., Wang, X., Tasci, C., Ozturk, S., Erdoğan, F., Zhang, Q., & Liu, S. (2026). Quality deterioration kinetics of roasted peanut matrices under fixed-time and estimated-lethality at various water activities. *Food Research International*, 245, 120838. doi:https://doi.org/10.1016/j.foodres.2026.120838
21. ISO1442. (1997). Viande et produits à base de viande -Détermination de l'humidité (Méthode de référence). Retrieved from Geneva: <https://cdn.standards.iteh.ai/samples/6037/d5ff6f512a8946f2993b1b09ab5cee2c/ISO-1442-1997.pdf>
22. ISO11085. (2015). Céréales, produits céréaliers et aliments des animaux -Détermination de la teneur en matières grasses brutes et en matières grasses totales par la méthode d'extraction de Randall à base de viande - Détermination de l'humidité (Méthode de référence). Retrieved from Geneva: <https://cdn.standards.iteh.ai/samples/63542/a1b5b669477147a5b6fc64564f584e5b/ISO-11085-2015.pdf>
23. ISO21807. (2004). Microbiologie des aliments -Détermination de l'activité de l'eau. Retrieved from Geneva: <https://cdn.standards.iteh.ai/samples/34728/90e81ea89db44329a5998b9879f4becb/ISO-21807-2004.pdf>
24. Karimuna, L., Halim, Ansi, A., Marfi, W., Asyik, N., & Hasanuddin, L. (2021). Effects of maize flour substitution on the organoleptic characteristics and nutritional values of fried peanut products (*Arachis hypogaea* L.) applied by bokashi plus fertilizer in improved agroforestry system in Napabalan District, Muna Regency. Paper presented at the IOP Conference Series: Earth and Environmental Science.
25. Kortei, N. K., Osei, S., Addae, A. A., Akonor, P. T., Manaphraim, N. Y. B., & Annan, T. (2024). Impact of some Ghanaian local roasting methods on aflatoxin reduction in groundnuts (*Arachis hypogaea* L.). *Scientific African*, 23(e02022), 1-11. doi:https://doi.org/10.1016/j.sciaf.2023.e02022
26. Lee, C. M., & Resurreccion, A. V. A. (2006). Predicting sensory attribute intensities and consumer acceptance of stored roasted peanuts using instrumental measurements. *Journal of Food Quality*, 29(4), 319-338. doi:https://doi.org/10.1111/j.1745-4557.2006.00076.x
27. Loko, Y. L. E., Montcho, D., Zandjanakou-Tachin, M., Orobiyi, A., Toffa, J., Hounmakou, E., Gavodo, D., & Dansi, A. (2020). Farmers' management of peanut (*Arachis hypogaea* L.) diversity, their varietal preference traits and uses in Southern and Central Benin. *Journal of Crop Science and Biotechnology*, 23(3), 259-272. doi:https://doi.org/10.1007/s12892-020-00034-9
28. Lykomitros, D., Den Boer, L., Hamoen, R., Fogliano, V., & Capuano, E. (2018). A comprehensive look at the effect of processing on peanut (*Arachis* spp.) texture. *Journal of the Science of Food and Agriculture*, 98(10), 3962-3972. doi:https://doi.org/10.1002/jsfa.8920
29. Lykomitros, D., Fogliano, V., & Capuano, E. (2016). Flavor of roasted peanuts (*Arachis hypogaea*) - Part I: Effect of raw material and processing technology on flavor, color and fatty acid composition of peanuts. *Food Research International*, 89, 860-869. doi:https://doi.org/10.1016/j.foodres.2016.09.024
30. Martínez-Navarrete, N., & Chiralt, A. (1996). Influence of roasting on the water sorption isotherms of nuts / Influencia del tueste sobre las isotermas de sorción de agua de diferentes frutos secos. *Food Science and Technology International*, 2(6), 399-404. doi:10.1177/108201329600200606
31. Martinez-Yusta, A., Ruiz-Aracama, A., & Alberdi-Cedeño, J. (2025). Vacuum frying as an alternative technique to increase the oxidative stability of sunflower oil. A comprehensive 1H NMR and SPME-GC/MS study focused on oxygenated compounds. *LWT*, 218, 117507. doi:https://doi.org/10.1016/j.lwt.2025.117507
32. Meng, S., Li, J., Chang, S., & Maleki, S. J. (2019). Quantitative and kinetic analyses of peanut allergens as affected by food processing. *Food Chemistry: X*, 1, 1-11. doi:https://doi.org/10.1016/j.fochx.2019.100004

33. Muego, K., Koehler, P., & Resurreccion, A. (1990). Effect of temperature, time and number of water extractions on the physicochemical and flavor characteristics of peanuts. *Journal of Food Science*, 55(3), 790-792. doi:<https://doi.org/10.1111/j.1365-2621.1990.tb05232.x>
34. Nelkon, M., & Parker, P. (1995). *Advanced level physics*: Heinemann Publishers (Oxford)
35. Oguntoyinbo, F. A. (2014). Safety Challenges Associated with Traditional Foods of West Africa. *Food Reviews International*, 30(4), 338-358. doi:10.1080/87559129.2014.940086
36. Okere, E. E., Arendse, E., Nieuwoudt, H., Perold, W. J., & Opara, U. L. (2022). Non-destructive evaluation of the quality characteristics of pomegranate kernel oil by fourier transform near-infrared and mid-infrared spectroscopy. *Frontiers in Plant Science*, 13, 867555.
37. Olaimat, A. N., Osaili, T. M., Al-Holy, M. A., Al-Nabulsi, A. A., Obaid, R. S., Alaboudi, A. R., Ayyash, M., & Holley, R. (2020). Microbial safety of oily, low water activity food products: A review. *Food Microbiology*, 92, 103571.
38. Owade, J. O., Abong', G. O., Okoth, M. W., & Mwang'ombe, A. W. (2022). Comparative characterization of trends and patterns of physical and chemical attributes of fried peanut snacks in Kenya. *Journal of Food Quality*, 2022, 7482315.
39. Rivera, Á. E. R., Ulloa, J. A., Silvas, J. E. U., Ramírez, J. C. R., & Vazquez, J. A. R. (2025). Physicochemical, techno-functional, biochemical and structural characterization of a protein isolate from groundnut (*Arachis hypogaea* L.) paste treated with high-intensity ultrasound. *Food Chemistry*, 464, 141848. doi:<https://doi.org/10.1016/j.foodchem.2024.141848>
40. Sacca, C., Adinsi, L., Anihouvi, V., Akissoé, N., Dalodé, G., Mestres, C., Jacobs, A., Dlamini, N., Pallet, D. and Hounhouigan, D.J. (2012). Consumers appreciation and quality attributes of akpan, a fermented cereal-based beverage from Benin. *Journal of Science of Food and Agriculture*, 92(15), 2977–2984.
41. Sanders, T. H. (2002). Groundnut (peanut) oil. *Vegetable oils in food technology: composition, properties and uses*. CRC, Boca Raton, 231-243.
42. Shi, A., Wang, Q., Liu, H., Wang, L., Zhang, J., Du, Y., & Chen, X. (2016). Chapter 2 - Peanut Processing Quality Evaluation Technology. In Q. Wang (Ed.), *Peanuts: Processing Technology and Product Development* (pp. 23-61): Academic Press 23-61.
43. Shi, X., Dean, L. O., Davis, J. P., Sandeep, K. P., & Sanders, T. H. (2018). The effects of different dry roast parameters on peanut quality using an industrial belt-type roaster simulator. *Food Chemistry*, 240, 974-979. doi:<https://doi.org/10.1016/j.foodchem.2017.07.130>
44. Sithole, T. R., Ma, Y.-X., Qin, Z., Liu, H.-M., & Wang, X.-D. (2022). Technical aspects of peanut butter production processes: Roasting and grinding processes review. *Journal of Food Processing and Preservation*, 46(4), e16430. doi:<https://doi.org/10.1111/jfpp.16430>
45. Sogbossi Gbétokpanou, C., Iko Afé, H., Ogouyôm, Szternfeld, P., Scholl, G., Boutaleb, S., Miriam, P., Laure, J., Azokpota, P., Eppe, G., & Sindic, M. (2025). Health risk assessment related to heat-induced contaminants in peanut-based foods consumed in Southern Benin. *Journal of Food Composition and Analysis*, 148. doi:<https://doi.org/10.1016/j.jfca.2025.108525>
46. Sogbossi Gbétokpanou, C., Jonard, C., Mehinto, O. A., Gofflot, S., Adjénia, M. J., Iko Afe, O. H., Anihouvi, D. G., Boutaleb, S., Bragard, C., Azokpota, P., Mahillon, J., Sindic, M., Scippo, M.-L., Madodé, Y. E., & Douny, C. (2025). Peanut and Peanut-Based Foods Contamination by Toxigenic Fungi and Mycotoxins: Potential Risks for Beninese Consumers. *Toxins*, 17(11), 1-28. Retrieved from doi:<https://doi.org/10.3390/toxins17110532>
47. Tahmasbian, I., Wallace, H. M., Gama, T., & Hosseini Bai, S. (2021). An automated non-destructive prediction of peroxide value and free fatty acid level in mixed nut samples. *LWT*, 143, 110893. doi:<https://doi.org/10.1016/j.lwt.2021.110893>
48. Tian, K., & Dasgupta, P. K. (1999). Automated Measurement of Lipid Hydroperoxides in Oil and Fat Samples by Flow Injection Photometry. *Analytical Chemistry*, 71(10), 2053-2058. doi:10.1021/ac9813181
49. Videgla, E. A. G., Hounhouigan, M. H., Agassounon, D. T. M., Alamu, E. O., & Bationo, B. A. (2016). Traditional knowledge and consumer preferences of kluiklui, an artisanal peanut cake produced in Benin. *International Journal of Gastronomy and Food Science*, 6, 18–24.
50. Videgla, E. G., Floquet, A., Mongbo, R., Garba, K., Tossou, H. S., & Toukourou, F. (2016). Liens à l'origine et qualité spécifique d'un produit de l'artisanat agroalimentaire du Bénin – le kluiklui d'Agonlin. *Cahiers Agricultures*, 25, 1-8. doi:<https://doi.org/10.1051/cagri/2016016>
51. Wang, Q., Liu, H., Hu, H., Mzimhiri, R., Yang, Y., & Chen, Y. (2016). Chapter 3 - Peanut Oil Processing Technology. In Q. Wang (Ed.), *Peanuts: Processing Technology and Product Development* (pp. 63-81). London: Academic Press 63-81.
52. Wang, Q., WANG, H., & Huang. (2018). *Peanut processing characteristics and quality evaluation*: Springer

53. Xiang, F., Xiao, T., Zheng, Y., Ma, X., Ding, C., Xu, X., Hu, H., Shi, A., & Wang, Q. (2025). Changes in Quality during Peanut Roasting Process Based on Temporal Multiscale Structure. *Journal of Chinese Institute of Food Science and Technology*, 25(11), 13-27. doi:<https://doi.org/10.16429/j.1009-7848.2025.11.002>
54. Yaacoub, R., Saliba, R., Nsouli, B., Khalaf, G., & Birlouez-Aragon, I. s. (2008). Formation of Lipid Oxidation and Isomerization Products during Processing of Nuts and Sesame Seeds. *Journal of Agricultural and Food Chemistry*, 56(16), 7082-7090. doi:10.1021/jf800808d
55. Yu, J. (2023). 2.19 - Stability of Peanuts. In P. Ferranti (Ed.), *Sustainable Food Science - A Comprehensive Approach* (pp. 266-288). Oxford: Elsevier266-288.
56. Zhang, D., Li, X., Zhang, Z., Zhang, J., Sun, Q., Duan, X., Sun, H., & Cao, Y. (2022). Influence of roasting on the physicochemical properties, chemical composition and antioxidant activities of peanut oil. *LWT*, 154, 112613. doi:<https://doi.org/10.1016/j.lwt.2021.112613>
57. Zhang, T., Wang, Y., Chen, P., Jiang, M., & Zhu, W. (2026). Research progress on post-harvest drying, storage, and processing of peanuts: A review. *Food Reviews International*, 42(2), 487-513. doi:<https://doi.org/10.1080/87559129.2025.2487898>
58. Zhao, X., Wu, S., Gong, G., Li, G., & Zhuang, L. (2017). TBHQ and peanut skin inhibit accumulation of PAHs and oxygenated PAHs in peanuts during frying. *Food Control*, 75, 99-107.
59. Zio, S., Somda, N. S., Hama-Ba, F., Sawadogo, A., Tapsoba, F., Traoré, Y., & Savadogo, A. (2020). Cottonseeds and Crude Peanuts Oils Production Technology and the Edible Oils Sale Conditions in Ouagadougou and Bobo Dioulasso Markets. *Journal of Nutrition and Food Security*, 5(3), 236-247.