Technological upgrading and performance comparison of artisanal, semi-industrial, and industrial cashew processing systems in Benin, West Africa.

Abstract

Despite growing interest in local value addition within the African cashew sector, comparative evidence on the performance of artisanal, semi-industrial, and industrial processing systems remains limited, particularly in West Africa where these systems coexist within the same value chain. This study evaluated and compared the technological characteristics, processing efficiency, productivity, and product quality of nine cashew-processing units in Benin, comprising three artisanal, three semi-industrial, and three industrial units. Data were collected through structured interviews, direct observations, production-record analysis, process mapping, and material-flow assessment.Technical, productivity, and quality indicators were calculated and compared using one-way analysis of variance (ANOVA).

Results showed a clear technological upgrading gradient from artisanal to industrial processing systems. Industrial processing showedsignificantly higher ($p < 0.05$) kernel recovery rates (33.1%), whole kernel rates (78.6%), shelling efficiency (80.2%), and peeling efficiency (96.4%) than artisanal processing, while recording the lowest processing losses (3.0%) and defective kernel rates (7.6%). Annual processing capacity increased from 34.6 t year^{-1} in artisanal units to 3,061.6 t year^{-1} in industrial units, whereas processing time decreased from 77.8 h t^{-1}to 9.4 h t^{-1}. Semi-industrial processors consistently exhibited intermediate performance, achieving substantial gains in efficiency and product quality relative to artisanal systems.These findings demonstrate that technological upgrading is strongly associated with improvements in resource-use efficiency, processing performance, and kernel quality in the cashew-processing sector. The study further suggests that semi-

industrial technologies may provide a practical and inclusive upgrading pathway for small and medium-scale processing by balancing performance improvements with more moderate investment requirements. The results provide evidence to support policies promoting technological modernization, workforce training, quality certification, and strengthening of processing enterprises to enhance domestic value addition and competitiveness in West African cashew value chains.

Keywords:*Anacardium occidentale*; cashew kernel processing; technological upgrading; kernel recovery rate; agro-industrial development; West Africa.

1. Introduction

The cashew tree (*Anacardium occidentale* L.) is one of the most important tropical cash crops, generating income for millions of smallholder farmers and contributing significantly to rural livelihoods in Africa, Asia, and Latin America(Juneja et al., 2026; Nkumbula et al., 2023; Yepié et al., 2026). Over the last two decades, global demand for cashew kernels has increased steadily owing to changing dietary preferences, rising consumer awareness of the nutritional benefits of tree nuts, and the expansion of international snack and food ingredient markets. Consequently, the cashew sector has evolved from a primarily commodity-based industry into a dynamic value chain in which processing efficiency, product quality, and market access have become major determinants of competitiveness(Sarath et al., 2025; UNCTAD, 2021; World Bank Group, 2025).

West Africa has become a major contributor to global raw cashew nut (RCN) production, with Côte d'Ivoire, Benin, Ghana, Guinea-Bissau, and Nigeria ranking among the world's leading suppliers of raw cashew nuts to international markets(Bojang & Gibba, 2021; Kinkpe et al., 2025; Olubode et al., 2018). However, despite growing production volumes, a large proportion of African cashew nuts are still exported in raw form, limiting opportunities for domestic value addition, employment creation, and industrial development(Bojang & Gibba, 2021). Recent initiatives aimed at strengthening local processing have highlighted the strategic importance of developing competitive processing industries capable of transforming raw cashew nuts into high-value kernel products(ACA, 2026; UNCTAD, 2021; World Bank Group, 2025).

Cashew processing plays a critical role in value creation because raw nuts cannot be consumed directly due to the presence of caustic compounds in the shell, notably cashew nutshell liquid (CNSL). Cashew processing comprises a series of interconnected operations, including drying, grading, thermal treatment, shelling, kernel drying, peeling, final grading, and packaging, each of which plays a critical role in determining kernel yield, product quality, food safety, and overall energyomic performance(ACA, 2026; Azam-Ali & Judge, 2001; Kinkpe et al., 2025).The primary objective of processing is to maximize the recovery of high-value whole kernels while minimizing breakage, defects, and material losses(Agriculture.Institute, 2025; World Bank Group, 2025).

The cashew processing sector is highly diverse in terms of technology adoption and organizational arrangements. Processing operations vary from small-scale artisanal units dependent on manual labour to semi-industrial enterprises that combine manual and mechanized processes, and large-scale industrial plants employing automation, process optimization, and quality assurance systems(Azam-Ali & Judge, 2001; Mgonja & Shausi, 2022). The level of technological sophistication adopted by processing enterprises is a major determinant of operational performance, influencing production efficiency, labour productivity, energy efficiency, product quality, and compliance with increasingly demanding domestic and international market standards. Accordingly, the literature consistently identifies technological upgrading as a fundamental driver of competitiveness in agro-industrial value chains, enabling firms to optimize production processes, improve product consistency and quality, and penetrate higher-value market segments(Kinkpe et al., 2025; UNCTAD, 2021).

Despite increasing interest in local cashew processing capacity across Africa, comparative assessments of artisanal, semi-industrial, and industrial cashew processing systems remain limited. Existing studies have largely focus on specific processing operations such as shelling, drying, grading, or individual technological innovations. Consequently, there is a lack of integrated empirical evidence comparing different processing systems using a common framework that simultaneously evaluates technological characteristics, material flows, processing efficiency, productivity, and product quality. This knowledge gap is particularly evident in West Africa, where different processing systems coexist and compete within the same value chain but remain insufficiently documented from a comparative technological perspective.

Benin provides an appropriate context for such an analysis because the country has experienced rapid growth in both cashew production and processing activities over the last decade. Artisanal, semi-industrial, and industrial processors currently operate alongside one another, offering a unique opportunity to examine how different levels of technological development influence processing performance and value creation. A better understanding of these differences can support evidence-based decisions by policymakers, investors, development agencies, and processing enterprises seeking to strengthen the competitiveness of the national cashew sector.

Therefore, the objective of this study was to compare artisanal, semi-industrial, and industrial cashew processing systems in Beninwith respect to their organizational characteristics, processing technologies, material flows, processing efficiency, productivity and product quality. By identifying the strengths and limitations observed in each processing category, the study contributes to the understanding of technological upgrading pathways and provides evidence to inform strategies for sustainable development of the cashew-processing industry in Benin and other West African producing countries.

2. Materials and Methods

2.1. Study area and selection of processing units

The study was conducted in major cashew processing zones of Benin, namely Tchaourou, Djougou and Parakou municipalities, where artisanal, semi-industrial, and industrial processing enterprises are actively engaged in cashew value addition. These locations were selected because they represent major processing hubs and collectively encompass the diversity of processing technologies operating within the Beninese cashew sector

A purposive sampling approach was used to select processing units. This approach was considered appropriate because the number of operational industrial processors remains limited and because access to production records and continuous processing activities were required for reliable comparisons. A total of nine processing units were surveyed, including three artisanal, three semi-industrial, and three industrial enterprises (Table 1). Selection criteria included: (i) operational status during the study period, (ii) willingness to participate, (iii) accessibility of production facilities, and (iv) availability of production and processing records.

2.2. Research design

A comparative cross-sectional research design was adopted to evaluate technological, technical, quality, and productivityacross the three processing categories. The studycomprised five stages: (1) characterisation of processing units, (2) field data collection through interviewsand direct observations (3) process mapping and material flows analysis, (4) evaluation of technical, quality, productivity indicators, and (5) statistical comparison amongprocessingcategories.

2.3.Data collection

Data were collected through structured interviews with factory managers, production supervisors, machine operators, and processing workers. Direct observations were performed during routine processing operations to document processing sequences, equipment configuration, labour allocation, processing duration, and operational practices. Wherever available, production records were consulted to validate information relating to processing capacity, production volumes, yield performance, and operational characteristics. Data collection focused on all major processing stages, including raw nut reception, storage, conditioning, cooking, shelling, drying, peeling, grading, packaging, and storage.

2.4.Process mapping and technological assessment

Process mapping was conducted to identify technological differences among artisanal, semi-industrial, and industrial processing systems. Each processing stage, including raw nut reception, conditioning, cooking, shelling, drying, peeling, grading, packaging, and storage, was documented. The level of mechanization, quality-control measures, food-safety practices, and by-product recovery activities were assessed and compared across processing categories.

2.5.Material flow analysis

Material flow analysis (MFA) was used to quantify the distribution of raw materials, intermediate products, final products, by-products, and losses throughout the processing chain.

The analysis was standardized using 1,000 kg of raw cashew nuts (RCN) as the reference input for comparison among processing systems. The following fractions were quantified: whole kernels, broken kernels, defective kernels, shells and testa, processing losses.

The masse balance equation applied was:

$$M_{in} = M_{products} + M_{byproducts} + M_{losses}$$

Where :

M_{in}: raw cashew nuts input (kg)

$M_{products}$: marketable kernels (kg)

$M_{byproducts}$: shells, testa and CNSL (kg)

M_{losses}: processing losses (kg)

2.6.Determination of performance indicators

Performance evaluation was based on technical, quality, productivity indicators.

Kernel recovery rate (KRR)

Kernel recovery rate is the percentage of consumable cashew extracted from raw cashew nuts.

Kernel recovery rate was calculated as:

$$KRR(\%) = \frac{W_k}{W_r} \times 100$$

Where:

W_k: weight of total kernels obtained (kg)

W_r: weight of raw nuts processed (kg)

Shelling Efficiency

$$SE(\%) = \frac{N_{undamaged}}{N_{total}} \times 100$$

Where

$N_{undamaged}$: number of kernels recovered without damage

N_{total} : total number of kernels processed

Peeling efficiency

$$PE(\%) = \frac{K_{peeled}}{K_{total}} \times 100$$

Where:

K_{peeled} : successfully peeled kernels

K_{total} : total kernels entering the peeling stage

Labour productivity

$$LP = \frac{Q_p}{N_w}$$

Where

LP: labour productivity (kg worker^{-1} day^{-1})

Q_p: quantity processed per day (kg)

N_w: number of workers involved

Moisture content

Kernel moisture content (MC) was determined using the oven-drying method at 105°C until constant weight.

$$MC(\%) = \frac{W_i - W_f}{W_i} \times 100$$

Where:

W_i: initial sample weight

W_f: final dried weight

Additional indicators included processing capacity, processing time, defective kernel rate, andprocessing losses,

2.7.Statistical analysis

Data collected were analysed using descriptive statistics and one-way analysis of variance (ANOVA) to assess differences among artisanal, semi-industrial, and industrial processing systems. Prior to ANOVA, data normality and homogeneity of variance were assessed using the Shapiro-Wilk and Levene tests, respectively.When significant differences were detected, means were separated using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p < 0.05$. Results are presented as mean ± standard error. Statistical analyses were performed using Statistica version 7.1

3. Results and discussion

3.1. Structural and organizational characteristics of the surveyed cashew processing systems

Table 2 presents the structural, organizational, and operational differences among artisanal, semi-industrial, and industrial cashew processing systems. Industrial units (16.6 ± 0.8 years) were significantly older($p < 0.05$) than semi-industrial (13.0 ± 1.0 years) and artisanal units (8.8 ± 0.8 years). The greater age of industrial plants may reflect greater business continuity, and long-term investment capacity(ACA, 2024, 2026; Agyemang et al., 2022; Kanji, 2004; World Bank Group, 2025), whereas the relatively younger artisanal units suggest more recent entry into processing activities(Kinkpe et al., 2025; UNCTAD, 2021; World Bank Group, 2025).

Employment levels also varied markedly among processing categories. Industrial units employed significantly($p < 0.05$) more permanent workers (10.4 ±0.8 persons) than artisanal (2.0 ± 0.8 persons) and semi-industrial units (4.0 ± 1.0 persons), which did not differ significantly ($p > 0.05$) from each other. A similar result was observed for seasonal employment, where industrial processors engaged an average of 181.8 ± 21.6 workers, substantially exceeding artisanal (7.4 ± 21.5 workers) and semi- industrial enterprises (33.7 ±

27.8 workers). These findings demonstrate the important role of industrial processing units to employment creation in cashew producing areas(ACA, 2024, 2026; World Bank Group, 2025).

Although women represented a lower proportion of the workforce in industrial units (55.0%) than in artisanal (97.2%) and semi-industrial units (92.9%), the absolute number of women employed was considerably higher because of the much larger workforce involved(ACA, 2024; Kanji, 2004). Women remained highly engaged in activities such as shelling, peeling, sorting and grading, which are critical for kernel quality.

Processing capacity showed the greatest differentiation among the three categories. Annual raw cashew nut (RCN) processing capacity increased from 34.6 tyears^{-1} in artisanal units to 773.3 t years^{-1}in semi-industrial enterprises and 3,061.6 t years^{-1}in industrial enterprises. Likewise, daily processing capacity rose from 96.1 kg day^{-1} to 2,1481 kg day^{-1} and 8,504.5 kg day^{-1}, respectively. The superior capacities observed in industrial unitscan be attributed to greater mechanization, improved infrastructure; stronger raw material supply systems and more extensive market linkages(Gereffi et al., 2005; Humphrey & Schmitz, 2002).

Interestingly, batch size did not differ significantly ($p > 0.05$) among processing systems, despite considerable differences in total processing capacity. This result suggests that productivity gains in larger facilities are achieved mainly through increased processing frequency, parallel processing lines, and greater operational efficiency rather than through larger individual batches.

Artisanal processing generally operated for shorter periods (4-6 months per year), whereas industrial units-maintained operations for up to 8-12 months annually, probably because of better storage facilities and greater access to working capital.

The duration of the processing season also increased with processing scale. Artisanal units operated for only 4 - 6 months per year, whereas semi-industrial units processed nuts for 7 –

10 months and industrial units for 8 - 12 months annually. The longer operating periods of industrial processors likely result from improved storage facilities, stronger supply chain networks, and greater working capital, enabling year-round or near year-round processing activities.

3.2.Main processing operations across cashew nut processing systems

Figure 1 presentstheflow sheet of cashew nut production process systems from artisanal through semi-industrial to industrial operations.

Artisanal processing involved a relatively short production chain comprising roasting, manual shelling, manual peeling, sorting and packaging. The system relied heavily on manual labour and traditional equipment, with limited process monitoring or quality-control measures. In contrast, semi-industrial processors incorporated steam treatment, sizing operations, semi-mechanical shelling, waste recovery practices and additional safety measures. Industrial processors implemented the most complex process configuration, including controlled steam cooking, mechanized shelling, moisture monitoring, controlled drying, metal detection and certified food-safety management systems.

These technological differences were reflected in drying conditions (Figure *2*). Drying temperature increased from approximately 30°C in artisanal units to 53.3°C in semi-industrial units and 76.4°C in industrial plants, while drying time decreased from 17.4 h to 8.3 h and 4.2 h, respectively. The results indicate that controlled drying systems allow processors to reduce processing time while achieving more standardized moisture reduction.

Overall, the three categories represent distinct processing models adapted to different production scales and market orientations. Artisanal processors mainly target local markets, semi-industrial enterprises serve national and regional markets, while industrial processors are primarily export oriented.

3.3. Material flow and processing efficiency

Material-flow analysis revealed significant differences in resource utilization efficiency among processing categories (Table 4). For a standardized input of 1,000 kg of raw cashew nuts, industrial processing produced the highest quantity of whole kernels (248.0 ± 12.4 kg), compared with 230.0 ± 16.1 kg in semi-industrial units and 178.0 ± 12.5 kg in artisanal processing. Conversely, defective kernel production decreased markedly from 85.4 kg in artisanal systems to 27.2 kg in industrial facilities. Material losses followed a similar pattern, declining from 126.0 kg to only 30.0 kg per tonne of raw nuts processed

The improved material-flow performance observed in industrial facilities is likely associated with better control of critical operations such as steaming, shelling, drying and grading. Reduced losses indicate more efficient utilization of raw materials and a greater proportion of valuable outputs. In addition, higher shell and testa recovery in industrial systems suggests improved separation and by-product management practices.

Kernel recovery rate increased significantly ($p < 0.05$) from 24.0% in artisanal processors to 30.5% and 33.1% in semi-industrial and industrial systems, respectively. Similarly, shelling efficiency improved from 20.8% in artisanal units to 80.2% in industrial facilities, while peeling efficiency increased from 69.0% to 96.4%. These results demonstrate that processing performance is strongly associated with the level of process control and equipment used during shelling and peeling operations(Eang & Tippayawong, 2018; Ogunsina & Bamgboye, 2012). Because kernel recovery directly determines the quantity of marketable product obtained from raw nuts, these differences have important economic implications(Ogunsina & Bamgboye, 2012; Olubode et al., 2018).

3.4. Productivity performance

Marked differences were also observed in productivity indicators. Processing capacity increased from 13.6 ± 10.5 kg h^{-1} in artisanal units to 183.7 ± 13.6 kg h^{-1} in semi-industrial enterprises and 941.4 ± 10.5 kg h^{-1} in industrial plants. Processing time simultaneously decreased from 77.8 h t^{-1} to only 9.4 h t^{-1}. These results indicate that mechanized equipment and improved workflow organization substantially enhance throughput and operational efficiency(Veena Devi et al., 2026).

Labour productivity increased from 12.4 ± 4.7 kg $worker^{-1}$ day^{-1}in artisanal units to 56.2 ± 6.0 and 48.3 ± 4.6 kg $worker^{-1}day^{-1}$in semi-industrial and industrial systems, respectively. The absence of significant differences between semi-industrial and industrial processing suggests that industrial plants continue to require substantial human intervention for inspection, sorting, grading, packaging and quality-control activities.Consequently, mechanization appears to complement labour rather than fully replace it(Jekayinfa & Bamgboye, 2006; Olubode et al., 2018; Shinyclimensa & Parthiban, 2025).

3.5. Product quality performance

Kernel quality improved significantly across processing categories. The defective-kernel rate declined from 26.4 ± 1.3% in artisanal units to 13.2 ± 1.6% in semi-industrial processing and 7.6 ± 1.2% in industrial plants. Similarly, kernel moisture content decreased from 6.3 ± 0.6% to 3.6 ± 0.6%. These improvements are likely associated with the use of controlled drying systems, standardized thermal treatments and more rigorous quality-control procedures.

In contrast, the broken-kernel rate remained relatively stable at approximately 25% across all processing categories, suggesting that factors beyond processing technology, such as raw-nut quality and varietal characteristics, may also influence kernel breakage.

Lower moisture contents and reduced defect levels are particularly important for product stability, shelf life and market acceptance. Furthermore, industrial processing were the only units implementing HACCP and ISO 22000 certification systems, reflecting their orientation toward export markets that impose stricter quality and food-safety requirements.

3.6.Overall comparison of processing categories

The comparative assessment revealed distinct strengths and limitations among the three processing categories. Industrial processors achieved the highest technical performance, product quality and operational efficiency. Artisanal processors exhibited the lowest productivity and highest losses but maintained strong participation of local entrepreneurs and women workers. Semi-industrial processors consistently occupied an intermediate position, achieving substantial improvements over artisanal systems while operating at lower investment levels than fully industrialized facilities.

The coexistence of artisanal, semi-industrial and industrial systems highlights the diversity of processing models within the Beninese cashew sector. Rather than representing stages of a linear evolution, these categories constitute distinct production systems characterized by different technological configurations, resource requirements, market orientations and performance outcomes(World Bank Group, 2025).

3.Conclusion

This study demonstrated that technological upgrading is strongly associated with improved technical, operational, and economic performance in cashew processing systems in Benin. Industrial processors achieved the highest kernel recovery rates, whole-kernel yields, shelling and peeling efficiencies, while recording the lowest processing losses, defective-kernel rates, and unit processing costs. These advantages were largely attributable to greater mechanization, process standardization, quality-control integration, and improved resource management. Semi-industrial processors occupied an intermediate position, significantly outperforming artisanal units while requiring lower investments than fully industrialized facilities, highlighting their potential as a practical upgrading pathway for small and medium-scale processors.

The findings emphasize the importance of investments in processing technologies, quality certification, workforce training, infrastructure, and cooperative strengthening to enhance domestic value addition and competitiveness in the cashew sector. A phased upgrading strategy centred on semi-industrial technologies could provide an effective and inclusive pathway for accelerating industrial development, employment creation, and sustainable growth of the cashew value chain in Benin and other West African producing countries.

However, the results should be interpreted with caution because the study was based on a relatively small sample of processing units and a purposive sampling approach that may not fully represent the diversity of processors operating in Benin. In addition, the analysis was limited to selected production zones and relied on cross-sectional observations, which may not capture seasonal or long-term variations in processing performance. Future studies should incorporate larger and more representative samples, longitudinal assessments, and comprehensive profitability and environmental analyses to further strengthen evidence on technological upgrading pathways in the cashew-processing sector.

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Conflicts of Interest Statement

The authors declare no conflict of interest.

References

ACA. (2024). *Special Feature: Investing In Africa's Grey Gold – Empowering Women And Youth For A Resilient Cashew Value Chain | African Cashew Alliance*. https://www.africancashewalliance.com/fr/node/4698

ACA. (2026). *Benin's cashew industry drives economic shift | African Cashew Alliance*. https://www.africancashewalliance.com/en/news-and-info/cashew-news/benins-cashew-industry-drives-economic-shift

Agriculture.Institute. (2025). *Cashew Nut Processing: From Raw Nut to Edible Kernel - Agriculture Notes by Agriculture.Institute*. https://agriculture.institute/post-harvest-mgt-value-addition/cashew-nut-processing-edible-kernel/

Agyemang, M., Kusi-Sarpong, S., Agyemang, J., Jia, F., & Adzanyo, M. (2022). Determining and evaluating socially sustainable supply chain criteria in agri-sector of developing countries: insights from West Africa cashew industry. *Production Planning & Control*, *33*(11), 1115–1133. https://doi.org/10.1080/09537287.2020.1852479

Azam-Ali, S. H., & Judge, E. C. (2001). *Small-scale cashew nut processing*. https://openknowledge.fao.org/items/9748f25d-532a-4b67-b304-505a2e068476

Bojang, B., & Gibba, A. (2021). The global competitiveness of West African cashew exporters . *Bulgarian Journal of Agricultural Science*, *27*(6), 1084–1092.

Eang, R., & Tippayawong, N. (2018). Optimization of process variables for drying of cashew nuts by superheated steam. *Cogent Engineering*, *5*(1), 1–13. https://doi.org/10.1080/23311916.2018.1531457

Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). The governance of global value chains. *Review of International Political Economy*, *12*(1), 78–104. https://doi.org/10.1080/09692290500049805

Humphrey, J., & Schmitz, H. (2002). How does insertion in global value chains affect upgrading in industrial clusters? *Regional Studies*, *36*(9), 1017–1027. https://doi.org/10.1080/0034340022000022198

Jekayinfa, S. O., & Bamgboye, A. I. (2006). Estimating energy requirement in cashew (Anacardium occidentale L.) nut processing operations. *Energy*, *31*(8–9), 1305–1320. https://doi.org/10.1016/J.ENERGY.2005.07.001

Juneja, R., Johny, T. E., Gulati, A., & Goel, K. (2026). *Strategies to boost India's cashew exports*. Indian Council for Research on International Economic Relations (ICRIER).

Kanji, N. (2004). Corporate responsibility and women's employment: The case of cashew nuts. *Gender & Development*, *12*(2), 82–87. https://doi.org/10.1080/13552070412331332240

Kinkpe, A. T., Grethe, H., & Luckmann, J. (2025). The potential of cashew by-product processing for a more sustainable agri-food system. *Discover Sustainability 2025 6:1*, *6*(1), 1155-. https://doi.org/10.1007/S43621-025-02138-0

Mgonja, N. S., & Shausi, G. L. (2022). Challenges Facing Small-scale Cashew Nut Processors in Ruangwa district, Tanzania: An Implication for Policy Change. *European Journal of Agriculture and Food Sciences*, *4*(3), 1–8. https://doi.org/10.24018/ejfood.2022.4.3.492

Nkumbula, L. E., Mng'ong'o, M., Masawe, P. A., Mukela, I., Mneney, E. E., & Venkataramana, P. B. (2023). Cashew improvement approaches and technologies across countries, and their implication to the Zambian cashew industry. *South African Journal of Botany*, *162*, 220–229. https://doi.org/10.1016/J.SAJB.2023.08.074

Ogunsina, B. S., & Bamgboye, A. I. (2012). Effect of Moisture Content, Nut Size and Hot-Oil Roasting Time on the Whole Kernel "Out-Turn" of Cashew Nuts (Anacardium occidentale) During Shelling. *Nigerian Food Journal*, *30*(2), 57–65. https://doi.org/10.1016/S0189-7241(15)30036-9

Olubode, O. O., Joseph-Adekunle, T. T., Hammed, L. A., & Olaiya, A. O. (2018). Evaluation of production practices and yield enhancing techniques on productivity of cashew (Anacardium occidentale L.). *Fruits*, *73*(2), 75–100. https://doi.org/10.17660/th2018/73.2.1

Sarath, C. M., Rao Sahib, P., Achuthan, K., & Chandran, R. (2025). From farm to table: India's transition towards cashew production and sustainable livelihood of smallholder farmers. *International Journal of Agricultural Sustainability*, *23*(1). https://doi.org/10.1080/14735903.2025.2557083

Shinyclimensa, C., & Parthiban, A. (2025). Forecasting cashew production in India using a hybrid machine learning framework with STL decomposition, ensemble methods, and global trade network analysis. *Scientific Reports 2025 16:1*, *16*(1), 191-. https://doi.org/10.1038/s41598-025-29254-1

UNCTAD. (2021). *Commodities at a Glance, Special issue on cashew nuts*. https://unctad.org/system/files/official-document/ditccom2020d1_en.pdf

Veena Devi, S. V., Sowmya Nag, K., Ravikant, Nayak, S., Kiran, H. R., Manoj Kumar, B. V., & Yogeesh, A. S. (2026). Classification of cashew kernel using deep learning. *International Journal of Food Properties*, *29*(1). https://doi.org/10.1080/10942912.2026.2699529

World Bank Group. (2025). *In a Nutshell: Agri-processing adds value in Cote d'Ivoire's cashew industry*. https://www.worldbank.org/en/results/2025/04/15/agri-processing-adds-value-in-cote-d-ivoire-s-cashew-industry

Yepié, O. F., Koffi, K. K., Akaffou, S. D., & Zoro, B. I. A. (2026). Participatory Identification of Cashew (Anacardium occidentale L.) Promising Genetic Resources in Ivory Coast. *Plant Breeding*, *145*(2), 219–243. https://doi.org/10.1111/PBR.70028;REQUESTEDJOURNAL:JOURNAL:14390523;PAGE:STRING:ARTICLE/CHAPTER

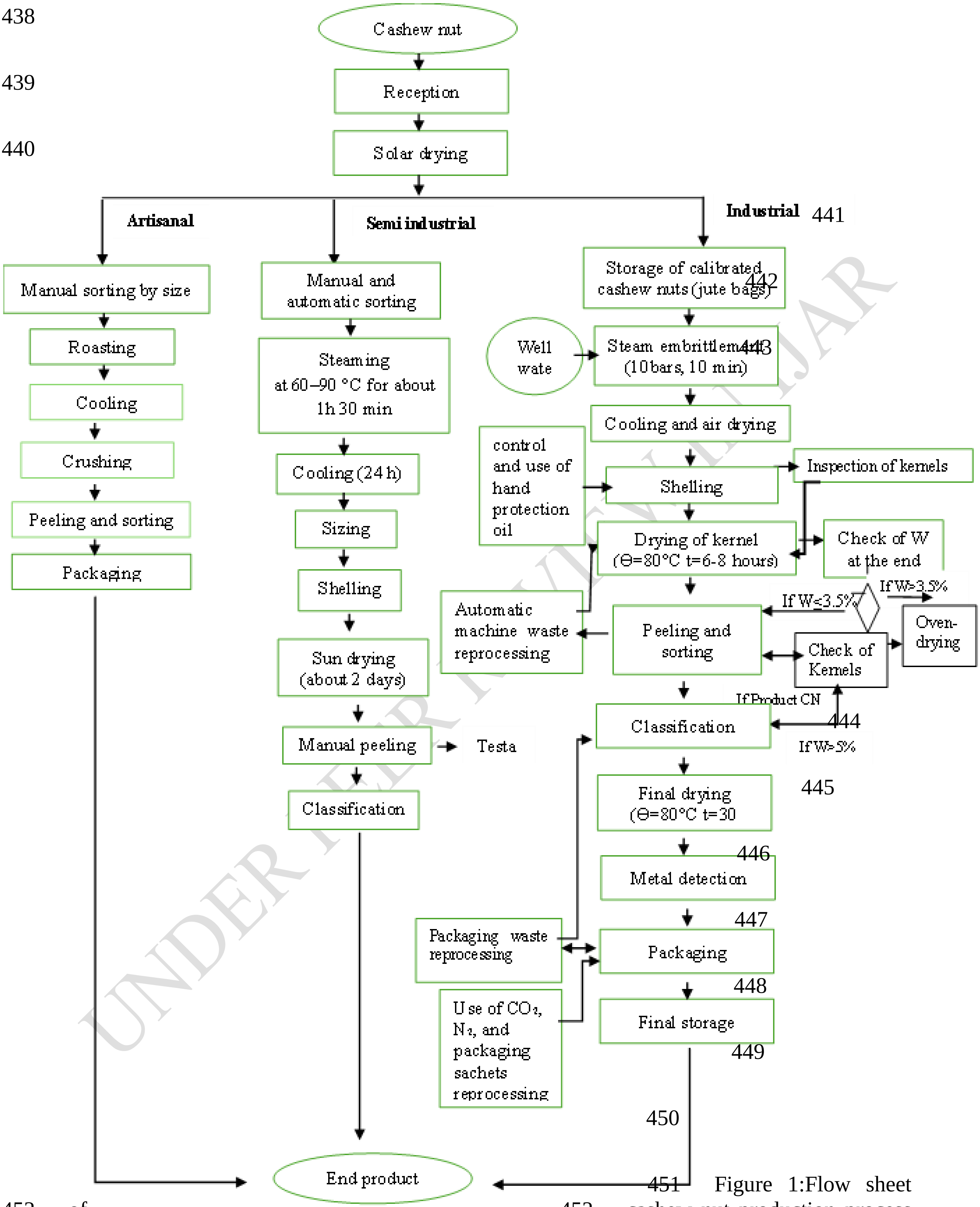

Figure 1:Flow sheet of cashew nut production process system

W: Water content; CN: cashew nut;

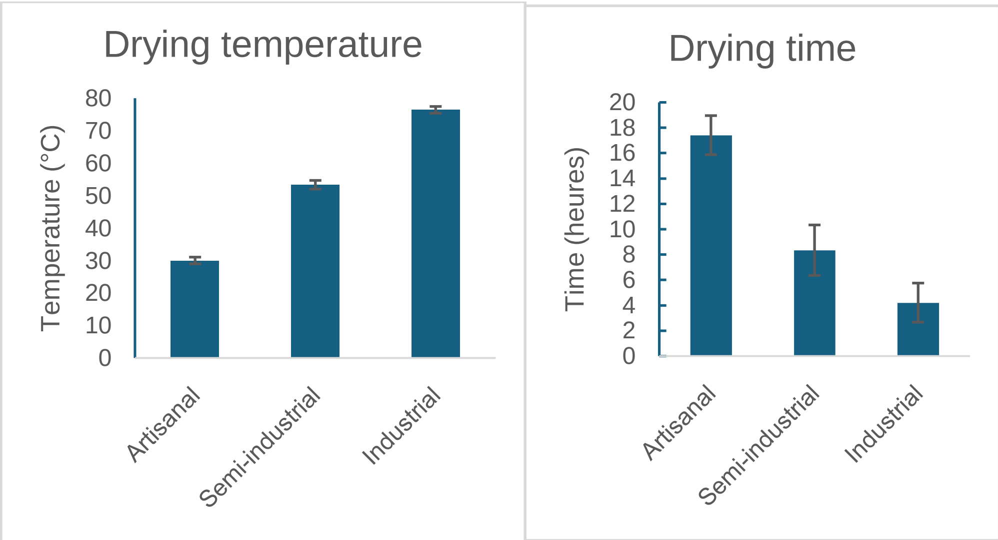

Figure 2. Temperature and time used in the surveyed cashew nut processing systems

Table 1 :Number of surveyed cashew nut processing unitsper locality and categories of processing units in the survey zones

Study area	Number of surveyed units			Total number of surveyed units
	Artisanal	Semi-industrial	Industrial	
Tchaourou	1	2	1	4
Parakou	2	1	1	4
Djougou	0	0	1	1
Total	3	3	3	9

Table 2.Structural, organizational, and operational characteristics of artisanal, semi-industrial, and industrial cashew processing systems.

Parameters	**Artisanal (n=3)**	**Semi-industrial (n=3)**	**Industrial (n=3)**
Ownership type	Individual/Cooperative	SME/Cooperative	Private company
Number of surveyed units	3	3	3
Average age of processing unit (years)	8.8±0.8a	13.0±1.0b	16.6±0.8c
Permanent workers (persons)	2.0±0.8a	4±1.0a	10.4±0.8b
Seasonal workers (persons)	7.4±21.5a	33.7±27.84a	181.8±21.6b
Women participation (%)	97.2±5.4a	92.9±6.9a	55.0± 5.3b
Annual processing capacity (t RCN.year^{-1})	34.6±2.7a	773.3±133.4a	3061.62±242.7b
Daily processing capacity (kg RCN.day^{-1})	96.1±6.2a	2148.1±370.4a	8504.5±1046.5b
Batch size (kg)	3.46±0.9a	41.2±1.9a	60.1±46.7a
Processing season (months/year)	4-6	7-10	8-12

Means in the same row with different superscript letters (a, b, c) are significantly different $(p < 0.05)$ according to post-hoc multiple comparison tests. Values represent Mean $\pm$ Standard error. RCN=Raw cashew nut

Table 3. Technological and operational features of artisanal, semi-industrial, and industrial cashew processing systems

Variables	**Artisanal (n=3)**	**Semi-industrial (n=3)**	**Industrial (n=3)**
Raw nut reception	Manual inspection	Visual inspection and sampling	Standardized quality control and sampling
Raw nut storage	Jute bags in ventilated room	Warehouse storage	Controlled warehouse with humidity monitoring
Conditioning	Not practiced or limited	Moistening before steaming	Automated conditioning system
Main cooking technology	Drum roasting over firewood	Steam cooking (batch system)	Continuous steam cooking system
Shelling technology	Manual cutting with knives	Semi-mechanical shelling	Manual and automatic shelling machines,
Drying technology	Sun drying	Solar-mechanical drying	Controlled hot-air dryer
Peeling technology	Manual	Manual-assisted	Automatic peeling-manual
Grading technology	Visual sorting	Visual sorting, Mechanical grading table	Mechanical grading table
Electricity availability	Limited	Moderate	Continuous
Main energy source	Firewood	Firewood + Electricity	Steam + Electricity
Quality certification	none	National standards	HACCP, ISO 22000, National standard
Primary market destination	Local market	National and regional markets	Export market

Table 4.Material flow, processing efficiency, productivity, and quality of surveyed cashew processing systems.

Categories	Indicators	Unit	Artisanal (n=3)	Semi-industrial (n=3)	Industrial (n=3)
Material flow	Raw cashew nuts input	kg	1000	1000	1000
	whole Kernel	kg	178.0±12.5a	230.0±16.1ab	248.0±12.4b
	Broken kernel	kg	62.0±6.8a	75.3±8.8a	82.6±6.7a
	Defective	kg	85.4±3.1a	46.7±4.0b	27.2±3.1c
	Shells + Testa	kg	548.6±13.2a	562.0±17.06ab	612.2±13.2b
	Material loss	kg	126.0±5.5a	86.0±7.1b	30.0±5.5c
Processing efficiency					
	Kernel recovery rate (KRR)	%	24.0±1.1a	30.5±1.4b	33.1±1.0b
	Whole kernel rate (WKR)	%	62.3±2.2a	68.6±2.8a	78.6±2.2b
	Shelling efficiency (SE)	%	20.8±1.5a	73.0±1.9b	80.2±1.4c
	Peeling efficiency (PE)	%	69.0±1.2a	87.0±1.5b	96.4±1.1c
	Processing losses (PL)	%	12.6±0.6a	8.6±0.7b	3.0±0.6c
Productivity					
	Processing capacity	$Kg.\ h^{-1}$	13.6±10.5a	183.7±13.6b	941.4±10.5c
	Labour productivity	$Kg.worker^{-1}.day^{-1}$	12.4±4.7a	56.2±6.0b	48.3±4.6b
	Processing time	$h.ton^{-1}$ RCN	77.8±1.4a	23.3±1.8b	9.4±1.4c
Quality					
	Broken kernel rate	%	25.6±2.4a	25.01±3.1a	25.1±2.1a
	Defective kernel rate	%	26.4±1.3a	13.2±1.6b	7.6±1.2c
	Moisture content	%	6.3±0.6a	5.1±0.7ab	3.6±0.6b

Means in the same row with different superscript letters (a, b, c) are significantly different $(p < 0.05)$ according to post-hoc multiple comparison tests. Values represent Mean $\pm$ Standard erreur.