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Research article

Effect of warehouse storage on the alteration, cooking and organoleptic characteristics of *Kponan* yam (*Dioscorea cayenensis-rotundata*) of Côte d'Ivoire

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ABSTRACT

Yam holds the top position in food crop production, and *Kponan* yam is highly prized by Ivorians. However, storage deterioration poses economic challenges for wholesalers and producers. This study assesses *Kponan* yam quality in warehouse storage, considering its geographical origin. To achieve this, yams from the Bondoukou, Bouna, and Kouassi-Kouassikro regions were kept at a warehouse in Abidjan, allowing an assessment of alterations, cooking properties, and organoleptic characteristics over a 3-month storage period. *Kponan* yam tubers were placed on boards at the warehouse's temperature (27.98 °C) and relative humidity (85.61 %). Temperature and humidity levels were recorded three times per week and four times daily at 08:00, 12:00, 16:00, and 20:00. Physical, cooking, and sensory characteristics were checked at harvest and during each month. The results showed that the main damage observed during storage at the warehouse was rotting and dehydration of the tubers. Rot rates were 47.53 % for yams grown in Bondoukou, 51.96 % for those grown in Bouna and 60.65 % for those grown in Kouassi-Kouassikro. Dehydrated tubers rates were 17.88 %, 25.04 % and 29.20 % for yams from Bondoukou, Bouna and Kouassi-Kouassikro, respectively. The browning indices of *Kponan* yams decrease ($P < 0.05$) during storage, with a much more marked effect for yams grown in Bouna (23.43-18.56) and Bondoukou (24.73-18.11), in contrast to those grown in Kouassi-Kouassikro (26.09–22.96). Hardness also dropped for *Kponan* yams grown in Bouna, Bondoukou and Kouassi-Kouassikro (38.94–25.19 N, 39.39–26.52 N and 35.59–26.66 N respectively). Sensory analysis showed that yams from Bouna stored for three months were rated highest in taste (score = 4). The storage quality of *Kponan* yams was influenced by the cultivation region. Organic production of *Kponan* yams benefits the environment and human health, while increasing shelf life.

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1. Introduction

In tropical regions, root and tuber plants serve as vital food sources. In 2017, the total production of these crops reached approximately 866 million tons, and their combined economic value far exceeds that of cereal crops as well as all other food crops in tropical Africa [1]. Yams, part of the Dioscorea genus, are cultivated globally as one of the key tuber crops. With approximately 600 species, about 90 are recognized as edible [2,3]. Yams serve as a staple food for more than 500 million people in tropical regions [4,5]. The yam tuber is rich in various nutrients and functional compounds, such as starch, fiber, protein, polysaccharides, sapogenins, dioscorin, allantoin, flavonoids, polyphenols, vitamins, and essential minerals [6,7]. These components offer significant health benefits, including supporting digestive health, boosting immunity, and slowing the aging process [8].

Yam cultivation is predominantly concentrated in West Africa, accounting for over 94 % of global production. It plays a critical role in the food security of at least 60 million people in the region [4,9–11]. Yams are grown both for household consumption and as a source of income [12], making them an important cash crop that supplies urban markets [13,14]. Nigeria stands as the world's leading yam producer, with over 50 million tons more than 67 % of global production, which was estimated at 75.14 million tons in 2021 [4]. In Côte d'Ivoire, yam production has been steadily increasing. From 1971 to 2021, it surged from 1.56 million tons to 7.85 million tons. Contributing over 10 % to global production, Côte d'Ivoire ranks third among yam producers, following Nigeria (67 %) and Ghana (11 %) [5,15]. Yams are the country's most important food crop [16], and Côte d'Ivoire has the highest per capita yam consumption among major producing countries, with an intake of 502 kcal per person per day [15,17]. Despite their substantial contribution to both nutrition and the economy, yam tubers are highly perishable and subject to seasonal availability. Losses are especially significant in early-harvested tubers [18,19]. Yam storage poses numerous challenges, often beyond the capabilities of the average farmer [20]. Without proper storage conditions, tubers undergo gradual physiological deterioration after harvest. These changes affect the tuber's internal composition, leading to the breakdown of edible matter often reaching 10 % after three months and as much as 25 % after five months of storage. However, a well-preserved yam represents valuable wealth, providing farmers with year-round income opportunities [21]. Unfortunately, the *Kponan* yam (*Dioscorea cayenensis rotundata*), highly prized by the population of Abidjan [22–24], is particularly vulnerable to rotting during storage and preservation [24]. As a result, these losses drastically diminish yields and, consequently, the availability of seed tubers [15]. However, above all, yam storage losses represent a serious financial challenge for Ivorian agriculture [25].

According to several authors [14,26], the methods of cultivation, harvesting, and storage of *Kponan yams*, whether in fields or in the warehouses of city wholesalers, impact their shelf life. Consequently, our previous studies focused solely on the shelf life and damage sustained by *Kponan* yams during field storage [19,24,26]. However, the *Kponan* yams sold in the markets of Abidjan (the main commercialization and consumption area for *Kponan* yams) primarily come from Bondoukou, Bouna, and Kouassi-Kouassikro, which are the main production zones [23]. The aim of this study is to assess the influence of the cultivation area (Bondoukou, Bouna, and Kouassi-Kouassikro) and farming methods on the culinary and sensory characteristics, as well as the damage sustained by *Kponan* yams during warehouse storage.

Fig. 1. Location of the study area.

2. Materials and methods

2.1. Material

The plant material used in this study was *Kponan* yam (*Dioscorea cayenensis-rotundata*), which was cultivated in fields across Bondoukou, Bouna, and Kouassi-Kouassikro. In each locality, *Kponan* yams from the three regions were grown in a single field using local agricultural practices. The field layout featured a fully randomized, balanced design with three blocks subdivided into three plots, each representing one type of *Kponan* yam of each locality [15].

2.2. Methods

2.2.1. Geographic location of the site

The town of Bondoukou serves as the capital of both the Zanzan District and the Gontougo region, situated in northeastern Côte d'Ivoire, 420 km from Abidjan. Bouna, the capital of the Bounkani region, is also located in the northeast of the country, 610 km from Abidjan. The Gontougo and Bounkani regions form the Zanzan District (Fig. 1).

Kouassi-Kouassikro is a department in the N'zi region, located in the center-east of Côte d'Ivoire, 250 km from Abidjan.

Bouna, Bondoukou and Kouassi-Kouassikro are the primary regions for *Kponan* variety production in Côte d'Ivoire and the principal suppliers of this variety to wholesalers in Abidjan [23].

Abidjan, the economic hub of Côte d'Ivoire, with a population of over 5 million [27], stands as the central market and largest consumer base for *Kponan* yams [23].

2.2.2. Ecological characteristics of the study areas

The vegetation in Zanzan (Bondoukou and Bouna) is of the wooded savanna type, while that of Kouassi-Kouassikro is a pre-forest zone (Table 1). The soils in the departments of Bondoukou and Bouna are predominantly (around 90 %) composed of leached tropical ferruginous soils, with concretions and very variable and often heterogeneous agronomic characteristics [14]. These soils, although poor or deficient in nutrients such as phosphorus, potassium, and nitrogen, provide excellent growth conditions for plants. Compared to ferralitic soils, they have better chemical fertility [28].

The soils in the department of Kouassi-Kouassikro are primarily ferralitic, very rich but extremely fragile [29]. These soils are divided, on the one hand, into sandy-alluvial soils in the plains and, on the other hand, into alluvial and schistose soils along the rivers such as the N'zi and its tributaries. They are suitable for food crops as well as cash crops [30].

Rainfall data from the stations in Bondoukou and Bouna for the year 2021, during the period of setting up the experimental plots, show average annual rainfall of 1284.3 mm and 245.4 mm, respectively. The total rainfall from February (sowing month) to August (harvest month) was 718.1 mm in Bondoukou and 245.4 mm in Bouna. As for Kouassi-Kouassikro, rainfall data for 2021 indicate an average annual rainfall of 752.2 mm, with a total of 1193.1 mm of rain from February to August [26].

Regarding temperatures, the annual averages recorded at the Bondoukou station in 2021, according to data from SODEXAM (Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique de Côte d'Ivoire), indicate an average temperature of 26.8 °C in the departments of Bondoukou and Bouna, and 27.8 °C in the department of Kouassi-Kouassikro [26].

2.2.3. Farming practices adopted in each area

In each area, the cultivation techniques used were those of the selected producer, which represent the most common method in the region. The operations included land clearing (July–August 2020), mounding (in August 2020), and planting (February 2021 with cuttings weighing between 0.5 kg and 1 kg), staking, and weeding. The clearing of fields was done using herbicides (Glyphosate: 3 L/ha) in Bouna, Bondoukou, and Kouassi-Kouassikro.

Regarding staking, in Bouna and Kouassi-Kouassikro, the stakes were made from shrubs left in the field. In Bondoukou, in addition to the shrubs, maize stalks were also used as stakes. Field maintenance, which mainly consisted of weeding, was done manually using hoes in Bouna (two weedings: May and July) and in Bondoukou (four weedings: from May to August). In Kouassi-Kouassikro, the initial weeding was performed using herbicide (Atrazine: 4 L/ha**)** in May, followed by a second manual weeding with a hoe just before the first harvest.

Finally, the management of the cropping system was completed with intercropping with yam. Two types of polyculture were observed (intercropping with cash crops and intercropping with food crops and cash crops). In Bouna and Kouassi-Kouassikro, yam cultivation was intercropped exclusively with cashew cultivation. However, in Bondoukou, yam cultivation was intercropped with both cashew and maize.

Table 1
Yam cultivation conditions in 2021 by area.

Area	Vegetation	Soil	Average rainfall	Average temperature
Bondoukou	Tree savannah vegetation	Ferruginous soil	1284.3 mm	26.80 °C
Bouna	Tree savannah vegetation	Ferruginous soil	245.4 mm (January–Jun)	26.80 °C
Kouassi-Kouassikro	Pre-forest area	Ferralitic soil	1193.1 mm	27.80 °C

2.2.4. Harvesting practices adopted by producers

The first harvest of *Kponan* yam tubers was carried out at physiological maturity, six months after planting, in August 2021, distinctly by sub-blocks within the same block. In practice, the mound was opened, and the upper part of the tuber was cut either with a machete (in Bouna and Bondoukou) or with a hoe (in Kouassi-Kouassikro), and the mound was then closed again over the vine roots for the second harvest. The tubers from the first harvest were used in this study.

The yams are transported from the field to the village by various means: by motorcycle in Kouassi-Kouassikro, by tricycle in Bouna, and by pickup truck in Bondoukou. They are then transported to Abidjan by bus.

2.2.5. Storage conditions for Kponan yams in the warehouse

The healthy yam tubers, free from blemishes and injuries, were carefully stored in a warehouse at the Université Nangui ABRO-GOUA in Abidjan. The yams were placed on boards and classified by production zone and according to the geographic origin of the yams. Storage conditions were similar to those in the wholesale market warehouses, with a relative humidity and average temperature at the start of storage of 85.61 % and 27.98 °C respectively. Temperature and humidity readings were taken four times daily (at 08:00, 12:00, 16:00, and 20:00) and three times per week [21]. A digital thermo-hygrometer (EXTECH, SD700, Taipei, Taiwan) was used to monitor these conditions.

2.2.6. Determination of tuber damage during storage in the warehouse

Each month, yams are checked for rot. The damage rate was determined by calculating the proportion of affected tubers relative to all stored tubers using the mathematical formula 1 [15,26].

$$\text{Rot}\ (\%) = \frac{\sum \text{Rotted tubers}}{\text{Total yams in storage}} \times 100 \tag{1}$$

The dehydrated tubers rate was assessed monthly. The rate of desiccated or Withered tubers was computed using the formula outlined in equation 2:

$$\text{Dehydrated tubers}\ (\%) = \frac{\sum \text{Withered, dried out and dehydrated tubers}}{\text{Total yams in storage}} \times 100 \tag{2}$$

The identification of the cracking rate was carried out each month by visually inspecting the interior of the damaged yams. The internal cracking rate was determined using the mathematical formula 3.

$$\text{Cracks}\ (\%) = \frac{\sum \text{Damaged tubers with internal cracks}}{\text{Total yams in storage}} \times 100 \tag{3}$$

2.2.7. Determination of hardness of yam slices

At harvest and every month of storage, healthy tubers are sampled for hardness analysis. Before any analysis, the length of each yam tuber is measured and a tenth (1/10) of both the distal and proximal ends is sectioned and removed. The central part was rinsed and then peeled in water. Yam slices, measuring 2 cm in thickness and 5 cm in length, were boiled over medium heat for 10 min [31]. The hardness of the cooked slices was assessed by measuring the Newtonian penetration force using a penetrometer (FORCE GAUGE, FR-5120, New Delhi, India) with a shaft diameter of 20 mm [32].

2.2.8. Determination of browning index of yam slices

At harvest and every month of storage, healthy tubers are sampled to determine the browning index of boiled yams. The color cooked yam tubers was measured using a portable colorimeter (3nh, NH310; Beijing, China) based on the L* a* b* color system, which defines luminance (L*), red-green balance (a*), and yellow-blue balance (b*) according to the standards of the Commission Internationale de l'Eclairage (CIE). The device's sensor was placed on the surface of the boiled yam slices from each sample was used to record the CIE L*a*b* values. Additionally, the L* coordinate, along with color parameters derived from chroma (C*) and hue angle (H*), were measured. The browning index (BI) was then calculated using equation (4), as described by Pathare [33].

$$\text{BI} = 100 \times \frac{X - 0,31}{0,17} \tag{4}$$

The term X in equation (4) is a constant, and its value is provided by equation (5):

$$\text{X} = \frac{(a + 1,75L)}{(5,645L + a - 3,012b)} \tag{5}$$

2.2.9. Organoleptic analysis of Kponan yams stored in the warehouse

At harvest and every month of storage, healthy tubers are sampled to determine the organoleptic characteristics of boiled yams. The organoleptic evaluation of boiled yam slices was conducted by a panel of 60 regular tasters. The assessed attributes included color, taste, firmness, chewiness, and overall appreciation. A bipolar rating scale ranging from 1 to 5 was used, with the following definitions: 1: I don't like it; 2: I like it a little; 3: I like it; 4: I like it a lot; and 5: I like it very much. Mineral water was provided to the panelists for mouth rinsing after each sample, which was presented to them in a randomized and coded manner [15].

2.2.10. Data analysis

Analyses of variance (ANOVA) were conducted using Stastica 7.1 software to compare means within the same production zone throughout the storage period. Differences were identified using Tukey's test at a significance level of 5 %.

3. Results

3.1. Fluctuations in temperature and relative humidity during yam storage in the warehouse

The storage conditions were marked by an increase in relative humidity, influenced by the storage temperature. During the first month, the average recorded temperature was 27.97 °C, accompanied by an average relative humidity of 85.6 %. Both of these parameters continued to rise until the third month, where the temperature reached 28.87 °C and the relative humidity climbed to 90.15 % (Fig. 2).

3.2. Effect of storage time on damage of Kponan tubers

Damage rates to yam tubers during warehouse storage are shown in Table 2. Rot was the most common deterioration during storage. At one month of storage, yams cultivated in Kouassi-Kouassikro had higher rot rates (22.45 %) than those grown in Bondoukou (11.35 %) and Bouna (12.03 %). Rot rates increased at three months of storage, reaching 60.65 % for yams from Kouassi-Kouassikro, 51.96 % for those grown in Bouna and 47.53 % for those grown in Bondoukou.

At one month of storage, the rate of dehydrated tubers was greater for yams from Kouassi-Kouassikro (13.45 %) than for those from Bouna (3.03 %) and Bondoukou (3.09 %). This trend remained unchanged at three months of storage, with yams grown in Kouassi-Kouassikro losing 29.20 % of their weight due to dehydration, compared with yams grown in Bouna (25.04 %) and Bondoukou (17.88 %).

At three months of storage, yams from Kouassi-Kouassikro had the highest rates of internal cracks in tubers (10.15 %), followed by those from Bondoukou (8.97 %) and Bouna (4.99 %).

For all damages, yams from Bondoukou had a loss rate of 73.85 %, followed by yams from Bouna at 81.99 %, while yams from Kouassi-Kouassikro were entirely damaged (100 %) at three months of storage.

3.3. Effect of cultivation area and cutting geographical origin on damage of Kponan tubers

The impact of the geographical origin of the cuttings on rot varies significantly ($P < 0.05$) depending on the cultivation site (Table 3). Yams from Kouassi-Kouassikro and cultivated in the same location (Kouassi-Kouassikro*Kouassi-Kouassikro) showed the highest rot rate (70.00 %), followed by those from Bouna and Bondoukou, also cultivated in Kouassi-Kouassikro (Kouassi-Kouassikro*Bouna and Kouassi-Kouassikro*Bondoukou), with respective rates of 58.62 % and 53.33 %. Conversely, yams originating from Bondoukou and those from Kouassi-Kouassikro, both cultivated in Bondoukou (Bondoukou*Bondoukou and Bondoukou*Kouassi-Kouassikro), recorded the lowest rot rates, with 47.05 % and 48.49 %, respectively. Regarding dehydrated tubers, the lowest rate (15.15 %) was observed in yams from Bouna and cultivated in Bondoukou, while yams from Bondoukou cultivated in Kouassi-Kouassikro (Kouassi-Kouassikro*Bondoukou) showed the highest drying rate (36.67 %). As for internal cracks, the rates ranged from 3.03 % (Bouna*Kouassi-Kouassikro) to 15.15 % (Bondoukou*Bouna).

3.4. Effect of storage time on the cooking characteristics of yams

3.4.1. Effect on yam hardness

The hardness of boiled yam slices from Bouna significantly decreased ($P < 0.05$) from 38.94 N at the start of storage (0 months) to 25.19 N at three months in the warehouse (Table 4). Similarly, the hardness of Bondoukou yam slices declined ($P < 0.05$) from 39.39 N

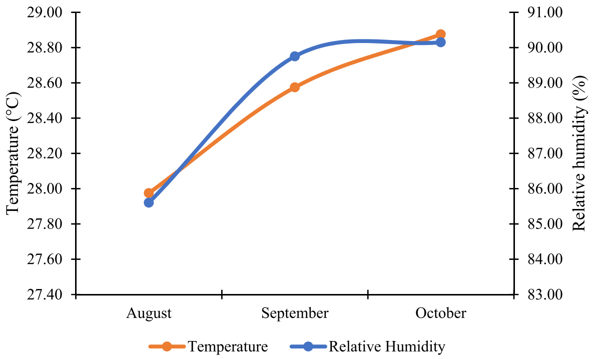

Fig. 2. Evolution of storage conditions in the warehouse.

Table 2
Progression of *Kponan* tubers deterioration during storage in the warehouse.

Growing area	Rots (%)				Dehydrated tubers (%)				Cracks (%)				Total losses (%)
	Storage period (month)												
	1 month	2 months	3 months	Total	1 month	2 months	3 months	Total	1 month	2 months	3 months	Total	
Bouna	12.03^{b}	16.96^{b}	22.96	**51.96^{b}**	3.03^{b}	10.01^{b}	12.00	**25.04^{a}**	1.99^{a}	0.98^{a}	2.02	**4.99^{a}**	**81.99^{b}**
Bondoukou	11.35^{b}	14.83^{b}	20.82	**47.53^{ab}**	3.09^{b}	5.94^{c}	8.85	**17.88^{a}**	3.98^{a}	1.99^{a}	3.00	**8.97^{a}**	**74.38^{c}**
Kouassi-Kouassikro	22.45^{a}	38.20^{a}	–	**60.65^{a}**	13.45^{a}	15.75^{a}	–	**29.20^{a}**	6.75^{a}	3.41^{a}	–	**10.15^{a}**	**100^{a}**

Mean ± standard deviation. Mean values of the same column with different letters are significantly different at the 5 % level based on Tukey's ANOVA test.

Table 3
Effects of cultivation zone and geographical origin of cuttings on *Kponan* deterioration.

	Rots (%)	Dehydrated tubers (%)	Craks (%)
Bouna*Bouna	51.48^{cd}	27.27^{b}	6.06^{de}
Bouna*Kouassi-Kouassikro	51.45^{cd}	27.27^{b}	3.03^{f}
Bouna*Bondoukou	52.94^{c}	20.58^{cd}	5.88^{e}
Bondoukou*Bouna	47.05^{e}	15.15^{e}	15.15^{a}
Bondoukou*Bondoukou	47.05^{e}	20.58^{cd}	5.88^{e}
Bondoukou*Kouassi-Kouassikro	48.49^{de}	17.92^{de}	5.88^{e}
Kouassi-Kouassikro*Bouna	58.62^{b}	27.59^{b}	13.79^{b}
Kouassi-Kouassikro*Bondoukou	53.33^{c}	36.67^{a}	10.00^{c}
Kouassi-Kouassikro*Kouassi-Kouassikro	70.00^{a}	23.33^{c}	6.67^{d}

Mean ± standard deviation. Mean values of the same column with different letters are significantly different at the 5 % level based on Tukey's ANOVA test.
Kouassi-Kouassikro*Kouassi-Kouassikro: *Kponan* yam originating from Kouassi-Kouassikro and grown in Kouassi-Kouassikro; Kouassi-Kouassikro*Bondoukou: *Kponan* yam originating from Bondoukou and grown in Kouassi-Kouassikro; Kouassi-Kouassikro*Bouna: *Kponan* yam originating from Bouna and grown in Kouassi-Kouassikro; Bouna*Bouna: *Kponan* yam originating from Bouna and grown in Bouna; Bouna*Bondoukou: *Kponan* yam originating from Bondoukou and grown in Bouna; Bouna*Kouassi-Kouassikro: *Kponan* yam originating from Kouassi-Kouassikro and grown in Bouna; Kouassi-Kouassikro*Bouna: *Kponan* yam originating from Bouna and grown in Kouassi-Kouassikro; Kouassi-Kouassikro*Bondoukou: *Kponan* yam originating from Bondoukou and grown in Kouassi-Kouassikro; Kouassi-Kouassikro*Kouassi-Kouassikro: *Kponan* yam originating from Kouassi-Kouassikro and grown in Kouassi-Kouassikro.

(0 months) to 26.52 N at three months of storage. In contrast, the yams from Kouassi-Kouassikro had a shorter storage duration of less than two months, with hardness values decreasing from 35.59 N (0 months) to 26.66 N (after one month).

3.4.2. Effect on yam browning index

The browning index (BI) of boiled yams during warehouse (Table 5) showed that yams grown in Kouassi-Kouassikro had a BI of 26.09 (0 month), which decrease ($P < 0.05$) to 22.96 0 after one month of storage in the warehouse. Yams cultivated in Bondoukou showed a notable decrease ($P < 0.05$) in BI, from 24.73 at the beginning (0 month) to 18.11 at three months in the warehouse. For yams grown in Bouna, the BI was 23.43 before storage in the warehouse, before dropping ($P < 0.05$) to 20.86 and 18.56 respectively after one and three months in the warehouse.

3.5. Effect of storage on the organoleptic characteristics of yams

The organoleptic analysis data (Table 6) revealed a decrease in the appreciation of the color of yams from Bondoukou, which dropped from 4.03 (I like very much) prior storage (Bondoukou_M0) to 3.08 (I like) after three months in the warehouse (Bondoukou_M3). Similarly, color preference for yams from Bouna decreased from 3.96 (I like very much) before storage (Bouna_M0) to 3.07 (I like) after three months in storage (Bouna_M3).

Regarding taste, a significant difference ($P < 0.05$) was found in the scores for boiled yams, with ranged from 3.09 (Kouassi-Kouassikro_M0) to 4.00 (Bouna_M3).

Overall appreciation for boiled yam slices also showed a significant difference ($P < 0.05$), with scores varying from 3 (I like) to 4 (I like very much) before and after three months of storage. The yams from Bouna stored for three months received the highest overall rating (4.00), while the lowest score (3.09) was recorded for yams from Kouassi-Kouassikro before storage.

Regarding the firmness and chewability of boiled yams, the statistical analysis showed no notable differences ($P > 0.05$) between freshly harvested and stored yams.

4. Discussion

The loss is defined as a measurable reduction in the quality of food products, which can be both quantitative and qualitative. In this study, rot (47.53 %–60.65 %) was identified as the main quantitative loss measured during warehouse storage, followed by dehydrated tubers (17.88 %–29.20 %). Damage limits the use of the product, while loss renders it unusable. These findings align with those of

Table 4
Variation in the hardness of boiled *Kponan* yams during warehouse storage.

Growing area	Hardness (N)			
	0 month	1 month	2 months	3 months
Bouna	38.94 ± 2.83^{a}	31.90 ± 1.14^{b}	26.99 ± 2.58^{bc}	25.19 ± 2.36^{c}
Bondoukou	39.39 ± 4.32^{a}	32.44 ± 1.87^{ab}	29.37 ± 3.27^{b}	26.52 ± 1.56^{b}
Kouassi-Kouassikro	35.59 ± 2.29	26.66 ± 0.88		

Mean ± standard deviation. Mean values of the same row that have different letters are significantly different at the 5 % level based on Tukey's ANOVA test.

Table 5
Evolution of the browning index of *Kponan* yams during warehouse storage.

Growing area	Browning index			
	0 month	1 month	2 months	3 months
Bouna	23.43 ± 0.37[a]	20.86 ± 1.08[b]	19.72 ± 0.59[bc]	18.56 ± 0.58[c]
Bondoukou	24.73 ± 0.60[a]	21.86 ± 1.40[b]	20.350 ± 1.14[bc]	18.11 ± 0.12[c]
Kouassi-Kouassikro	26.09 ± 0.92	22.96 ± 0.40		

Mean ± standard deviation. Mean values of the same row that have different letters are significantly different at the 5 % level based on Tukey's ANOVA test.

Table 6
Changes in sensory attributes of *Kponan* yams during warehouse storage.

	Color	Taste	Firmess	Chewability	Overall appreciation
Bouna_M0	3.96 ± 0.02[b]	3.04 ± 0.04[h]	4,00 ± 0,01[a]	4,00 ± 0.01[a]	3.26 ± 0.01[f]
Bouna_M1	3.26 ± 0.00[c]	3,19 ± 0.01[f]	4.00 ± 0.00[a]	4.00 ± 0.00[a]	3.41 ± 0.00[c]
Bouna_M2	3.18 ± 0.01[d]	3.67 ± 0.01[b]	4.00 ± 0.00[a]	4.00 ± 0.00[a]	3.20 ± 0.01[g]
Bouna_M3	3.07 ± 0.02[e]	4.00 ± 0.00[a]	4.00 ± 0.02[a]	4.00 ± 0.02[a]	4.00 ± 0.00[a]
Bondoukou_M0	4.03 ± 0.06[a]	3.19 ± 0.01[f]	4.00 ± 0.01[a]	4.00 ± 0.01[a]	3.38 ± 0.1[d]
Bondoukou_M1	3.11 ± 0.00[e]	3.27 ± 0.00[e]	4.00 ± 0.01[a]	4.00 ± 0.01[a]	3.32 ± 0.02[e]
Bondoukou_M2	3.18 ± 0.01[d]	3.44 ± 0.00[c]	4.00 ± 0.00[a]	4.00 ± 0.00[a]	3.48 ± 0.01[b]
Bondoukou_M3	3.08 ± 0.00[e]	4.01 ± 0.01[a]	4.00 ± 0.00[a]	4.00 ± 0.00[a]	3.47 ± 0.02[b]
Kouassi-Kouassikro_M0	3.11 ± 0.01[e]	3.07 ± 0.00[g]	4.00 ± 0.01[a]	4.00 ± 0.01[a]	3.09 ± 0.01[i]
Kouassi-Kouassikro_M1	3.09 ± 0.00[e]	3.32 ± 0.02[d]	4.00 ± 0.10[a]	4.00 ± 0.10[a]	3.12 ± 0.02[h]

Mean ± standard deviation. Mean values of the same column with different letters are significantly different at the 5 % level based on Tukey's ANOVA test.
Note: Bondoukou_M0: Yam grown in Bondoukou before storage; Bondoukou_M1: Yam from Bondoukou stored for 1 month; Bondoukou_M2: Yam from Bondoukou stored for 2 months; Bondoukou_M3: Yam from Bondoukou stored for 3 months. Bouna_M0: Yam grown in Bouna before storage; Bouna_M1: Yam from Bouna stored for 1 month; Bouna_M2: Yam from Bouna stored for 2 months; Bouna_M3: Yam from Bouna stored for 3 months. Kouassikro_M0: Yam grown in Kouassi-Kouassikro before storage; Kouassikro_M1: Yam from Kouassi-Kouassikro stored for 1 month.

Kouadio et al. [26], who identified rot and weight loss as the main degradations encountered during *Kponan* yam storage. However, the storage experiment conducted by Maalekuu et al. [20] revealed that sprouting of the *Pona* and *Tela* cultivars (*Dioscorea rotundata*) during storage is the main cause of loss, reaching 93 % [20]. These damages are also linked to factors such as insects, rats, and chemicals [15,19,24,26].

The high rate of rot observed in yams from Kouassi-Kouassikro may be attributed to herbicide application during land clearing and weeding. This observation is corroborated Kouadio et al. [26], who demonstrated that excessive herbicides and pesticides use in yam cultivation in Kouassi-Kouassikro significantly contributes to rot. N'goran et al. [34] also noted that fertilization could amplify losses during prolonged storage, negatively affecting physiological losses, especially for the *Dioscorea cayenensis-rotundata* species.

Considering the geographic origin and cultivation zone of the yams, there is a significant difference between these two factors. Yams from Kouassi-Kouassikro show a higher rate of rot (70 %) when grown in the same region, while yams from Kouassi-Kouassikro but grown in Bondoukou show a lower rate of rot (48.49 %). However, after two months of warehouse storage, all yams grown in Kouassi-Kouassikro showed signs of damage, regardless of their specific area of origin. This suggests that the origin of the cutting does not influence the shelf life or the rot rate of *Kponan* yams. Thus, agricultural practices, especially the use of herbicides, may play a key role in yam preservation. These results confirm the research of Kouakou and Anoh [14], which established a correlation between the application of chemical fertilizers and pesticides and the reduced shelf life of yams.

According to Ngue et al. [35], an adequate application of phosphorus or potassium doses higher than nitrogen helps improve tuber preservation and reduce sprouting. Consequently, understanding the soil's chemical composition is crucial before applying mineral fertilizers, as yams require balanced nutrient levels for optimal growth and storage. Moreover, excessive herbicide use, combined with poor ventilation in warehouses, could lead to heat and moisture accumulation around the tubers, creating a favorable environment for the proliferation of fungi and bacteria responsible for rot. Assiri et al. [36,37] also showed that rot is often triggered by fungal agents that infiltrate tubers damaged by insects, nematodes, or mechanical injuries occurring during and after harvest.

The soils of Kouassi-Kouassikro, mainly ferralitic and very rich, are conducive to both food and cash crops [29,30]. The rainfall recorded from February to August 2021 (1193.1 mm) favored optimal ripening of yams cultivated in Kouassi-Kouassikro compared to those grown in Bondoukou and Bouna [26]. However, larger tubers, due to their high-water content (80–85 %), are poorly preserved and more fragile than smaller ones [35]. Diby et al. [38] concluded that the fertilizers response of *Dioscorea alata* and *Dioscorea cayenensis-rotundata* is influenced by soil characteristics. Additionally, Diby et al. [39] found that soils low in organic matter do not show increased yields with the application of mineral fertilizers. These results suggest that forest soils, often too rich, and savanna soils, often too poor, react differently to chemical fertilizers.

It is important to note that fertilizers and herbicides are not directly responsible for tuber rot. However, their excessive or inappropriate use, combined with other unsuitable agricultural practices, can create favorable conditions for tuber deterioration [26].

Some components of fertilizers and herbicides, such as nitrogen, can influence the quality of the tubers. An excess of nitrogen, for example, can alter the chemical composition of the tubers, making them more susceptible to diseases and rot. Thus, balanced fertilization is crucial [35].

Environmental conditions such as temperature (27.97–28.87 °C) and relative humidity (85.6–90.15 %) in storage warehouses can also accelerate rot. High humidity promotes the proliferation of fungi and the degradation of tubers. According to Osunde and Orhevba [21], tubers stored under ventilated conditions had a lower rot rate (1.85 %) compared to those stored without ventilation (12.03 %).

Regarding dehydrated tubers, it is mainly caused by tuber respiration and transpiration. Temperature and relative humidity also influence these processes. At low temperatures, respiration is reduced, which slows down sprouting and prolongs shelf life [40]. However, excessive moisture loss leads to weight reduction and tuber shriveling. Under optimal storage conditions, with a temperature of 26–28 °C and a relative humidity of 70–80 %, a balance can be achieved, preserving the quality of the tubers, including their color, smell, taste, and chemical composition.

At this stage of data analysis, it is evident that rot development and the shelf life of *Kponan* yams are largely impacted by the interplay of storage conditions (temperature and humidity), soil and climate characteristics, and the excessive use of herbicides during land preparation and weeding.

Furthermore, analysis of the cooking and organoleptic qualities of *Kponan* yam revealed that both hardness and BI decrease over storage time, with more pronounced variations for Kouassi-Kouassikro-grown yams. Similarly, Coulibaly et al. [41] noted a reduction in BI during freezer storage of *Kponan* yams. This decrease is probably of enzymatic origin and could be linked to the phenolic compounds present in yam tubers. According to Ortiz et al. [42], the rate of enzymatic browning is influenced by various factors, including polyphenol oxidase concentration and activity, along with the type and quantity of phenolic compounds. The data revealed that yams from Kouassi-Kouassikro had the highest BI during warehouse storage, likely associated with the extensive use of herbicides during field preparation and weeding. These findings align with Etejere et al. [43], who showed that *D. rotundata* tubers treated with 30 kg/ha of NPK fertilizer during growth had a greater tendency to brown compared to unfertilized tubers.

The decrease in yam hardness during storage is a phenomenon common to all stored yams, with a more pronounced drop for *Kponan* yams from Kouassi-Kouassikro. This significant drop in the hardness of *Kponan* yams cultivated in Kouassi-Kouassikro is likely due to the rotting process that develops as a result of storage conditions. Indeed, a strong negative correlation ($r = -0.89$) was observed between hardness and rotting rate. Thus, the more prone the yam is to rot, the less it retains its hardness when cooked as a porridge. Alzamora et al. [44] suggest that the onset of rot is typically linked to microbial enzymes that break down the cell walls of yam tubers. As storage time progresses, tubers become more vulnerable to the impact of microorganisms that cause deterioration, partly because their production of antifungal compounds decreases, and partly due to cell wall degradation. According to Hemati et al. [45], yam cell wall degradation during storage can be caused by factors such as humidity, heat or chemical reactions that modify cell wall structure.

Yam hardness is also affected by various factors, such as the variety, stage of maturity, and growing conditions. Young yams tend to be firmer than older ones. Yams grown in well-drained, nutrient-rich soils also tend to be firmer than those grown in nutrient-poor soils.

This reduction in BI also contributed to a decline in yam color quality during storage. It is important to note that the specific relationship between the decrease in browning index and the decrease in yellow color may vary according to the specific characteristics of the tubers and storage conditions, such as temperature and humidity. Inappropriate conditions can accelerate enzymatic degradation and alter tuber coloration. According to Ndangui [46], color is a key organoleptic characteristic by which consumers assess food quality. As the most important aspect of a food's appearance, color significantly influences consumer acceptance of the product [47]. This aspect probably explains the low overall acceptance of Kouassi-Kouassikro yams during storage in the warehouse.

Hedonic tests have shown an increase in taste ratings for boiled yams during storage, with a noticeable rise in sweetness over time for *Dioscorea rotundata* [48]. This enhanced sweetness positively impacted the overall evaluation of boiled yams. As Fakorede et al. [49] observed, key yam characteristics that affect consumer acceptance include overall tuber appearance, flesh color, taste and texture. The distinct sweetness and suitability for cooking contribute to the preference for *Kponan* yams among consumers.

5. Conclusion

This study reveals that prior to storage, *Kponan* yams exhibit favorable physical, culinary, and sensory attributes. However, these qualities decrease during storage in the warehouse, particularly in the case of *Kponan* yams cultivated in Kouassi-Kouassikro, attributed to the excessive use of pesticides and herbicides during cultivation. The organic production of *Kponan* yams, characterized by reduced dependence on herbicides, not only benefits the environment but also promotes human health. Additionally, it contributes to an extended shelf life of the yams.

CRediT authorship contribution statement

Yapo Hypolithe Kouadio: Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation, Conceptualization. **Kouakou Nestor Kouassi:** Writing – original draft, Visualization, Validation, Supervision, Project administration, Formal analysis, Conceptualization. **Kouadio Benal Kouassi:** Visualization, Formal analysis, Data curation. **Gbè Aya Jacqueline Konan:** Visualization, Formal analysis, Conceptualization. **Kouame Aristide Kouakou:** Visualization, Formal analysis. **Kouassi Dogni Dappah:** Visualization, Formal analysis. **Yao Denis N'dri:** Visualization, Supervision. **N'Guessan Georges Amani:** Visualization, Supervision.

Data availability

The data used in this study is confidential.

Additional information

No further information is available for this paper.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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