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EFFECTS OF HARVEST MATURITY AND POSTHARVEST STORAGE DURATION ON THE NUTRITIONAL AND PHYTOCHEMICAL COMPOSITION OF *CITRULLUS LANATUS* CV. "WLÊWLÊ" SEEDS

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ABSTRACT

Food self-sufficiency depends on the availability of nutritious and safe food resources. In this context, the valorization of underutilized plant species rich in essential nutrients could contribute to improving food and nutritional security. This study aimed to evaluate the effects of harvest maturity and postharvest storage duration on the biochemical composition of *Citrullus lanatus* seeds (cv. "Wlêwlê"). The experiment was conducted at Nangui ABROGOUA University, where female flowers were tagged at flowering. Fruits were harvested at 30 (R30) and 35 (R35) days after fertilization, cut open, and stored for 0 (E0), 30 (E30), or 60 (E60) days before seed extraction. The extracted seeds were analyzed for their nutritional and phytochemical composition. Harvest maturity and storage duration significantly affected several biochemical parameters ($p < 0.05$), although the magnitude and direction of these changes depended on the parameter considered. Lipid content reached its highest value after 30 days of storage for both harvest maturities, with a maximum of 56.71% in R35 seeds. Protein content was generally higher in R30 seeds, reaching a maximum of 30.09% at E30. Ash content decreased slightly with storage duration and was generally higher in R35 seeds, whereas total phenolic content showed a maturity-dependent response, reaching its highest value in R35 seeds after 60 days of storage. These findings demonstrate that harvest maturity and postharvest storage duration jointly influence the

nutritional and phytochemical composition of *C. lanatus* seeds. A 30-day storage period may represent a suitable compromise for preserving several nutritional attributes, particularly protein and lipid contents.

Keywords: *Citrullus Lanatus,* Storage Duration, "Wlêwlê", Harvest Maturity, Biochemical Composition

1 INTRODUCTION

Food and nutritional security in sub-Saharan Africa depends largely on the availability and accessibility of safe and nutritious foods. In this context, the valorization of underutilized crops rich in essential nutrients represents a promising strategy for diversifying food resources and contributing to the prevention of protein-energy malnutrition. Among these plant resources, cucurbits are of particular interest because of their nutritional and socioeconomic importance. The Cucurbitaceae family, which belongs to the order Cucurbitales, comprises approximately 825 species distributed mainly in tropical and subtropical regions [1]. In West Africa, the seeds of several cucurbit species are commonly referred to as "pistachios", particularly *Citrullus lanatus* (Thunb.), *Lagenaria siceraria* (Molina), *Cucurbita moschata* (Duchesne), *Cucumeropsis mannii* (Naudin), and *Cucumis melo*. Among these species, *C. lanatus* is one of the most widely cultivated [2] and represents an important source of proteins and lipids [2,3]. *Citrullus lanatus* includes sweet-fleshed and oilseed types [4,5]. The oilseed type is an underutilized food crop mainly cultivated in sub-Saharan Africa, where its seeds are valued for their high nutritional content. They may contain more than 50% lipids and approximately 30% proteins [3,6]. Their richness in proteins and essential fatty acids confers considerable nutritional value [7]. The seeds of *C. lanatus* are processed into a paste similar to peanut paste, which is commonly used as a thickening ingredient in sauces or as a raw material for oil extraction [8]. In Côte d'Ivoire, dishes prepared from these seeds are particularly appreciated during traditional ceremonies among Akan communities, including yam festivals, births, and weddings [2]. In addition to their nutritional and cultural importance, these seeds may contribute to improving farmers' livelihoods because of their relatively high market value [9]. Despite these advantages, the postharvest management of oilseed *C. lanatus* fruits remains a major constraint. The seeds are embedded in the fruit pulp and are difficult to extract immediately after harvest. Traditionally, harvested fruits are therefore left on the field for a period of time to allow the pulp to soften or decompose, thereby facilitating seed extraction [10]. However, prolonged postharvest storage may induce physiological and biochemical changes in the seeds and consequently affect their nutritional quality [11]. The extent to which fruit maturity at harvest and subsequent storage duration influence the biochemical composition of "wlêwlê" seeds remains poorly documented.

Therefore, this study aimed to evaluate the effects of harvest maturity and postharvest storage duration on the biochemical composition of seeds from the "wlêwlê" cultivar of *C. lanatus*. Specifically, the study sought to characterize the biochemical composition of seeds obtained from fruits harvested at 30 (R30) and 35 (R35) days after fertilization and to assess the effects of fruit storage for 0 (E0), 30 (E30), and 60 (E60) days on the biochemical parameters of the seeds.

2 MATERIALS

2.1 Plant Material

The plant material consisted of seeds of the "wlêwlê" cultivar of *Citrullus lanatus* (Figure 1). The seeds were obtained from fruits grown on experimental plots at Nangui ABROGOUA University. Fruits were harvested at two maturity stages, corresponding to 30 (R30) and 35 (R35) days after fertilization. After harvest, the fruits were stored for 0 (E0), 30 (E30), or 60 (E60) days before seed extraction.

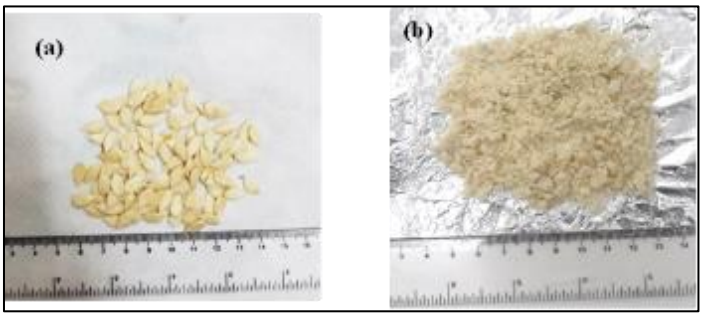


Figure 1: Peeled seeds (a) and seed kernel powder (b) of *Citrullus lanatus* cv. "wlêwlê

3 METHODS

3.1 Sample Preparation

The *Citrullus lanatus* fruits were obtained from experimental plots at Nangui ABROGOUA University. Fruits were harvested at two maturity stages, corresponding to 30 (R30) and 35 (R35) days after fertilization. After harvest, the fruits were cut open using a machete, wrapped in plastic film, and stored for 0 (E0), 30 (E30), or 60 (E60) days to allow the pulp to soften and facilitate seed extraction. At the end of each storage period, the seeds were manually extracted from the fruit pulp, thoroughly washed to remove adhering pulp and other residues, and dried. Seeds obtained from each combination of harvest maturity and storage duration constituted a separate experimental sample.

3.2 Preparation of Seed Kernel Powder

The *Citrullus lanatus* seed samples were sorted to remove foreign materials, particularly sand and other impurities. The seeds were then manually shelled to separate the kernels from the seed coats. Kernels obtained from each combination of harvest maturity (R30 and R35) and storage duration (E0, E30, and E60) were ground into powder using a Moulinex-type blender (Normandy, France). The resulting powders were transferred into hermetically sealed glass jars, appropriately labeled, and stored until biochemical analysis. The different steps involved in sample preparation are summarized in the flow diagram presented in Figure 2.

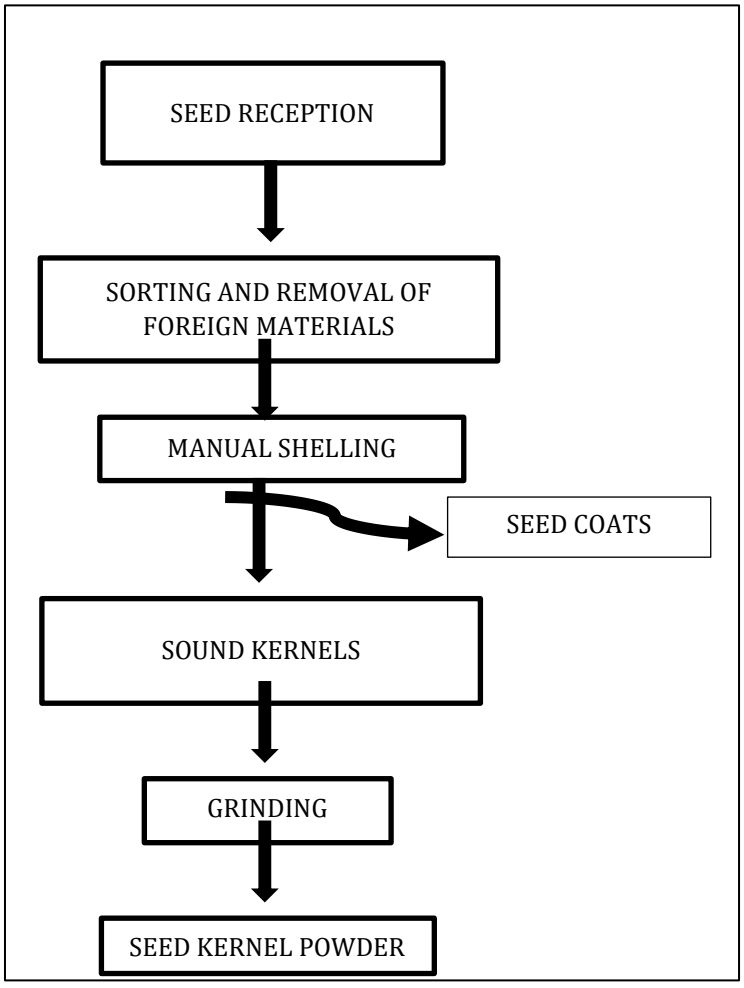


Figure 2: Flow diagram for the preparation of *Citrullus lanatus* cv. "wlêwlê" seed kernel powder.

3.3 Analytical Methods

The biochemical composition of *Citrullus lanatus* cv. "Wlêwlê" seed kernel powder was assessed by determining moisture, ash, crude protein, lipid, crude fiber, total phenolic, flavonoid, tannin, and vitamin C contents. Moisture, ash, crude fiber, lipid, and crude protein contents were determined according to [12] methods. Lipids were extracted using a Soxhlet apparatus with hexane, while crude protein was determined by the Kjeldahl method using a nitrogen-to-protein conversion factor of 6.25 [13]. Phenolic compounds were extracted with 80% acetone according to [14]. Total phenolic, flavonoid, and tannin contents were determined according to [15,16] and [17], respectively, and expressed as

mg GAE, QE, and TAE/100 g DM. Vitamin C was determined by DCPIP titration according to [18]. All biochemical analyses were performed in five determinations for each experimental sample.

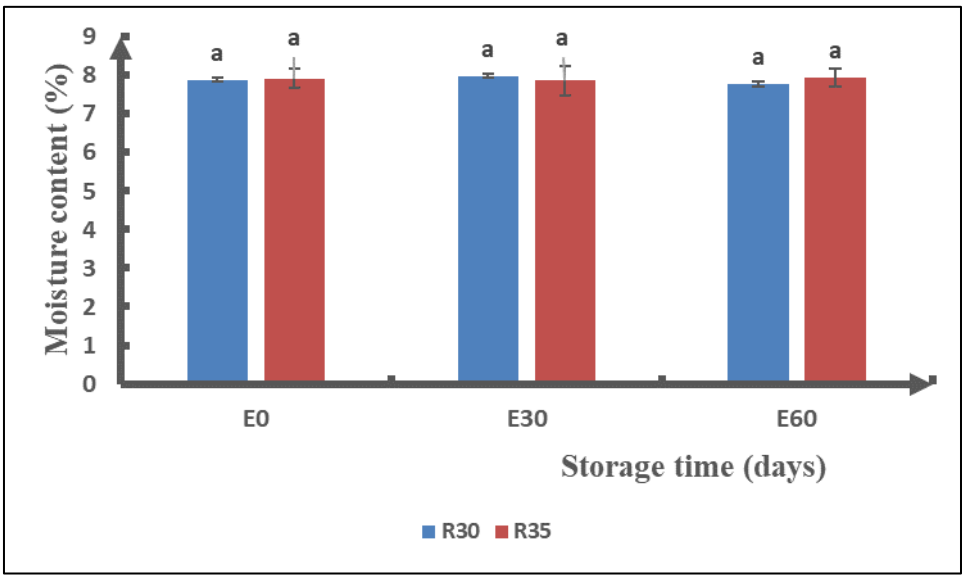
3.4 Statistical Analysis

Data were expressed as mean ± standard deviation (n=5). A two-way analysis of variance (ANOVA) was performed using STATISTICA 7 and XLSTAT-Pro 7.5.2 to evaluate the effects of harvest maturity (R30 and R35), storage duration (E0, E30, and E60), and their interaction on the biochemical parameters. Means were compared using Duncan's multiple range test at a significance level of 5%.

4 RESULTS

4.1 Moisture content of *C. lanatus* seeds as a function of storage duration

The moisture content of *C. lanatus* seed powders ranged from 7.780% (E60) to 7.985% (E30) for R30 and from 7.857% (E30) to 7.923% (E0) for R35 (Figure 3). Analysis of variance showed that these variations were not significant at the 5% level ($p > 0.05$), regardless of harvest maturity. Therefore, no significant differences were observed among the moisture contents of the different samples.

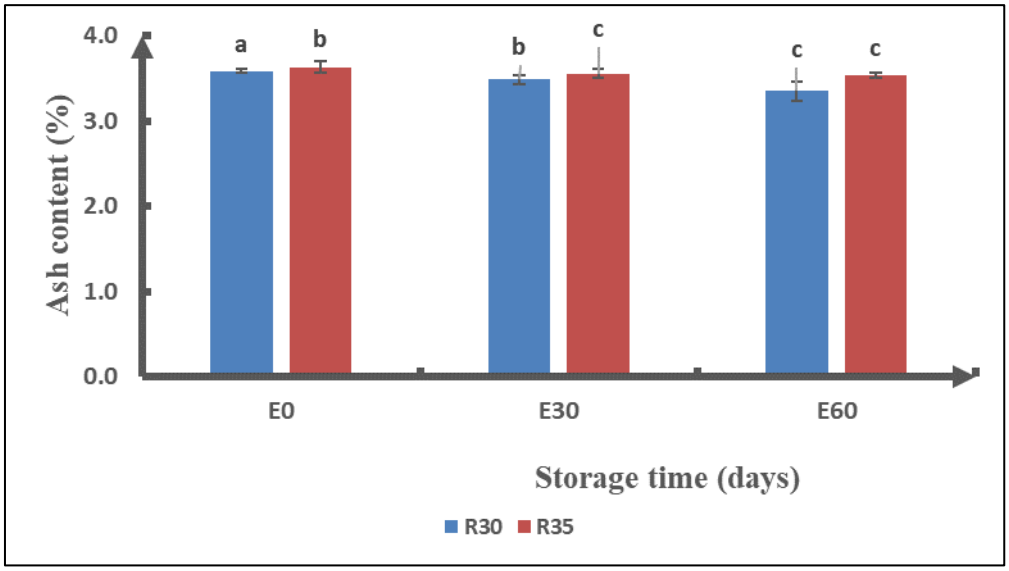


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 3: Moisture content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration.

4.2 Ash content of *C. lanatus* seeds as a function of storage duration

The ash content of *C. lanatus* seed powders decreased slightly with increasing storage duration for both harvest maturities (Figure 4). For R30, ash content decreased from 3.587% at E0 to 3.483% at E30 and 3.353% at E60. Similarly, for R35, it decreased from 3.633% at E0 to 3.557% at E30 and 3.537% at E60. **Analysis of variance indicated a significant effect on ash content at the 5% significance level ($p < 0.05$). Duncan's multiple range test revealed significant differences among the mean ash contents of the different samples ($p < 0.05$).**

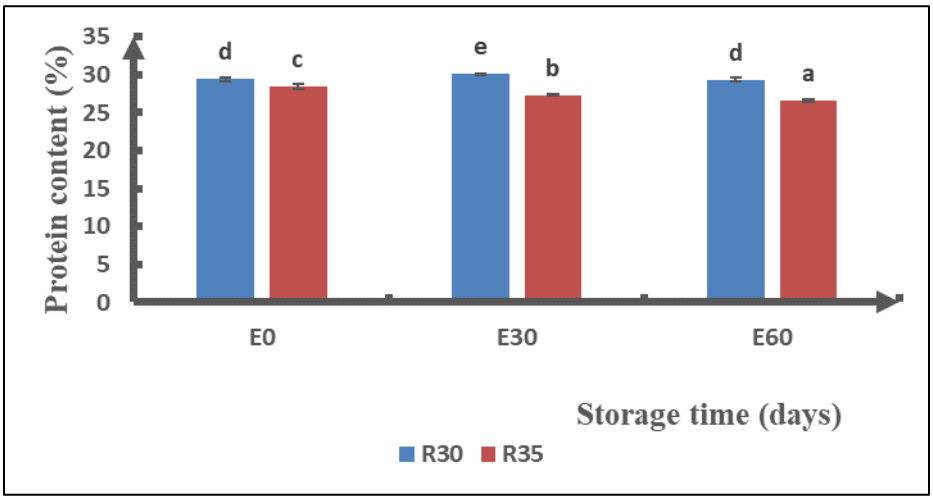


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 4: Ash content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration.

4.3 Protein content of *C. lanatus* seeds as a function of storage duration

The protein content of *C. lanatus* seed powders varied with storage duration, whatever the harvest date (Figure 5). It ranged from 29.337% to 30.093% for R30 and from 26.597% to 28.437% for R35. Analysis of variance showed a significant effect on protein content at the 5% significance level ($p < 0.05$). Thus, significant differences appeared among the mean protein contents of the different samples ($p < 0.05$).

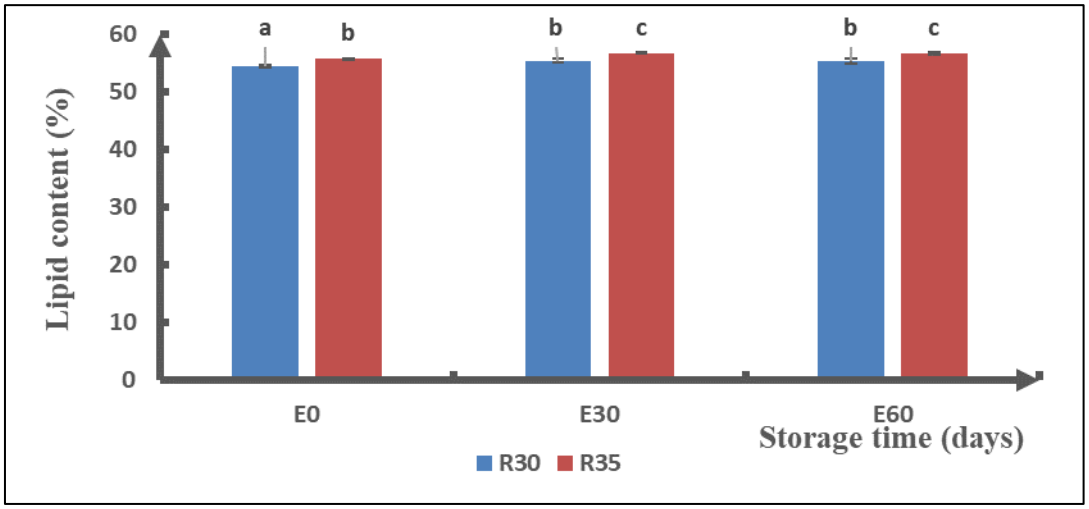


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 5: Protein content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration.

4.4 Lipid content of *C. lanatus* seeds as a function of storage duration

The lipid content of *C. lanatus* seed powders varied with storage duration for both harvest maturities (Figure 6). For R30, lipid content increased from 54.370% at E0 to 55.383% at E30, before decreasing slightly to 55.253% at E60. A similar trend was observed for R35, with lipid content increasing from 55.637% at E0 to 56.713% at E30 and then decreasing slightly to 56.537% at E60. The highest lipid content was therefore recorded at E30 for both harvest maturities. Analysis of variance showed a significant effect on lipid content at the 5% significance level ($p < 0.05$). Therefore, significant differences were observed among the mean lipid contents of the different samples ($p < 0.05$).

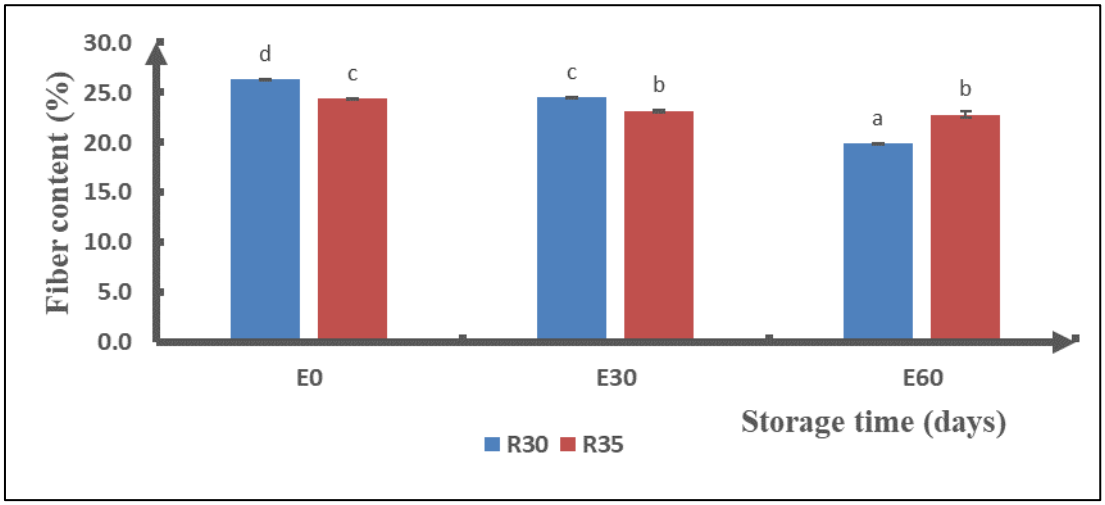


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 6: Lipid content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration.

4.5 Fiber content of *C. lanatus* seeds as a function of storage duration

The fiber content of *C. lanatus* seed powders decreased with storage duration, regardless of harvest maturity (Figure 7). It decreased from 26.270% (E0) to 19.900% (E60) for R30 and from 24.357% (E0) to 22.780% (E60) for R35. Analysis of variance showed a significant effect on fiber content at the 5% significance level ($p < 0.05$). Thus, significant differences ($p < 0.05$)were observed among the mean fiber contents of the different samples.

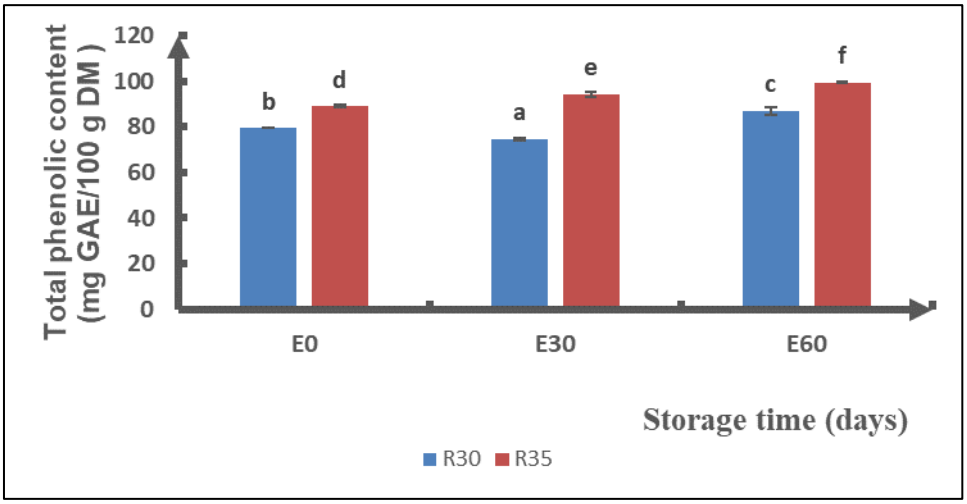


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 7: Fiber content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration.

4.6 Total phenolic content of *C. lanatus* seeds as a function of storage duration

The total phenolic content (TPC) of *C. lanatus* seed powders varied with storage duration depending on harvest maturity (Figure 8). For R30, TPC decreased from 79.365 mg GAE/100 g DM at E0 to 74.717 mg GAE/100 g DM at E30, before increasing to 86.971 mg GAE/100 g DM at E60. In contrast, for R35, TPC increased progressively from 88.955 mg GAE/100 g DM at E0 to 94.246 mg GAE/100 g DM at E30 and 99.394 mg GAE/100 g DM at E60. Analysis of variance indicated a significant effect on total phenolic content at the 5% significance level ($p < 0.05$). Thus, there are significant differences ($p < 0.05$) among the mean total phenolic contents of the different samples.

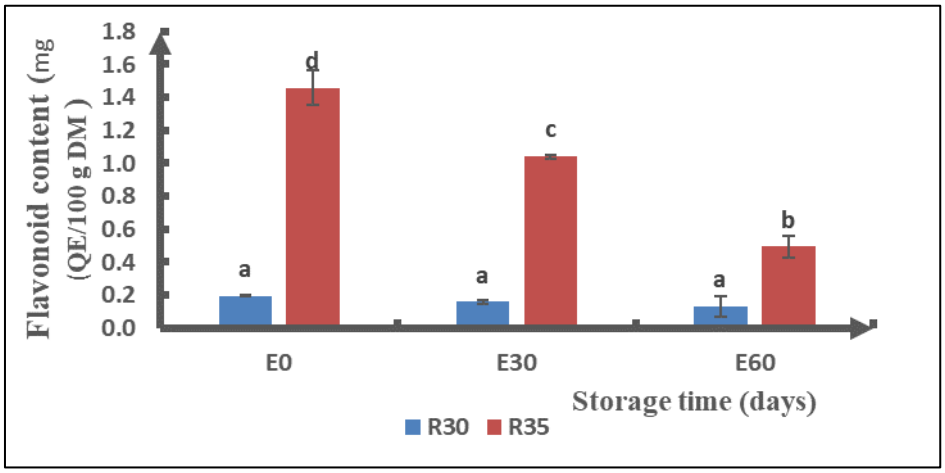


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 8: Polyphenol content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration

4.7 Flavonoid content of *C. lanatus* seeds as a function of storage duration

The flavonoid content of *C. lanatus* seed powders decreased with storage duration, particularly for R35 (Figure 9). For R35, flavonoid content decreased from 1.456 mg QE/100 g DM at E0 to 1.041 mg QE/100 g DM at E30 and 0.493 mg QE/100 g DM at E60. For R30, flavonoid content remained comparatively low and decreased slightly from 0.195 mg QE/100 g DM at E0 to 0.158 mg QE/100 g DM at E30 and 0.129 mg QE/100 g DM at E60. Analysis of variance showed a significant effect on flavonoid content at the 5% significance level ($p < 0.05$). Therefore, significant differences ($p < 0.05$) were observed among the mean flavonoid contents of the R35 samples.

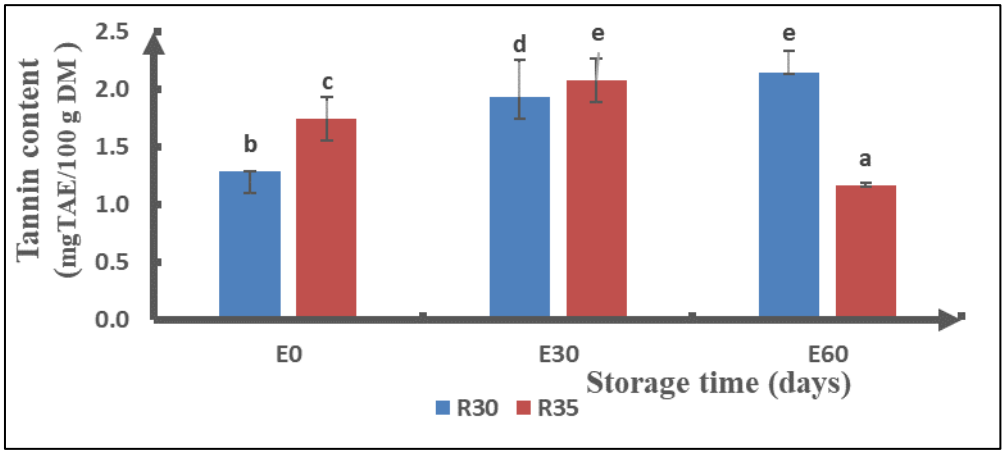


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 9: Flavonoid content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration

4.8 Tannin content of *C. lanatus* seeds as a function of storage duration

The tannin content of *C. lanatus* seed powders varied according to storage duration and harvest maturity (Figure 10). For R30, tannin content increased progressively from 1.286 mg TAE/100 g DM at E0 to 1.929 mg TAE/100 g DM at E30 and 2.144 mg TAE/100 g DM at E60. For R35, tannin content increased from 1.744 mg TAE/100 g DM at E0 to 2.077 mg TAE/100 g DM at E30, before decreasing to 1.171 mg TAE/100 g DM at E60. Analysis of variance indicated significant differences ($p < 0.05$) in tannin content among the treatments.

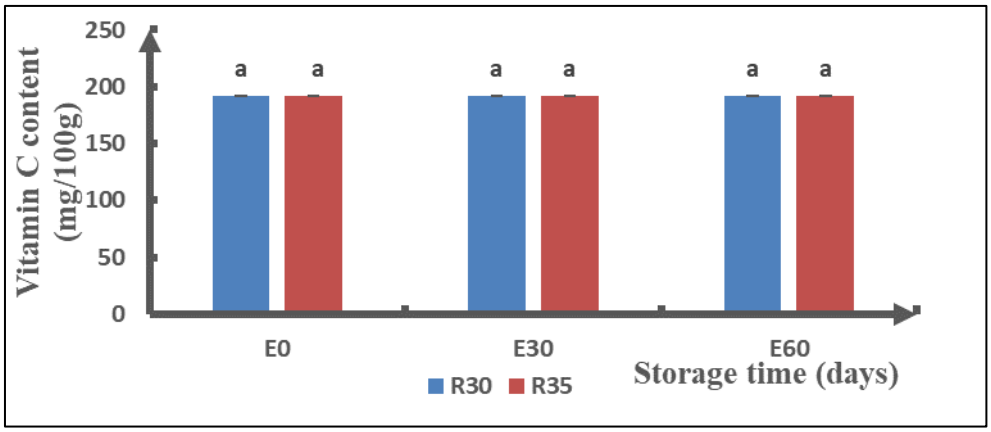


Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 10: Tannin content of *Citrullus lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration

4.9 Vitamin C content of *Citrullus lanatus* seeds as a function of storage duration

Vitamin C content did not vary significantly among the different treatment combinations (Figure 11). A mean value of 191.667 mg/100 g was recorded for E0, E30, and E60 at both harvest maturities. Analysis of variance showed no significant differences among treatments ($p > 0.05$).



Bars bearing different letters are significantly different according to Duncan's multiple range test ($p < 0.05$).

Figure 11: Vitamin C content of *C. lanatus* cv. "wlêwlê" seed kernel powders as affected by harvest maturity and storage duration

5 DISCUSSION

The biochemical composition of *C. lanatus* cv. "Wlêwlê" seeds was affected to different extents by harvest maturity and postharvest storage duration. The response to storage was parameter-dependent and, for several constituents, varied according to fruit maturity at harvest. Moisture content remained low and statistically stable across treatments. The determination of moisture content is important in food analysis because of its technological, analytical, commercial, and regulatory implications [19]. Low moisture levels are generally favorable for the preservation of dried food products because limited water availability may restrict microbial growth and slow several deterioration reactions. The stability observed in the present study suggests that the postharvest treatments did not substantially affect the moisture content subsequently measured in the seed powders. A relatively stable moisture content during storage has also been reported for *Moringa oleifera* leaf powder [20]. Ash content differed among treatments and was generally higher in seeds obtained from fruits harvested 35 days after fertilization. Since ash represents the inorganic residue remaining after incineration, these differences may reflect variations in the relative contribution of mineral matter to seed dry matter during maturation. Differences in the chemical composition of plant foods can occur according to maturity stage and growing conditions [21]. In addition, the variation in ash contents could be explained by environmental variants, the effect of maturation stages, and the effect of the storage time of cut fruits after harvest. Protein content responded differently according to harvest maturity. In R30 seeds, the highest value was recorded after 30 days of storage, whereas R35 seeds showed a progressive decline during storage. Nevertheless, the relatively high protein contents observed

confirm the nutritional potential of *C. lanatus* seeds. Indeed, the variation in protein contents is one of the results of metabolic modification during stress [22]. Fiber content generally decreased with increasing storage duration, particularly in R30 seeds. This pattern may reflect changes in the relative contribution of structural components during prolonged postharvest holding. Previous studies have shown that fiber-related characteristics of plant materials may vary according to maturity and physiological stage [23]. Total phenolic content exhibited a maturity-dependent response to storage. In R35 seeds, total phenolic content increased progressively during storage, whereas R30 seeds showed an initial decrease at E30 followed by an increase at E60. The effect of storage on phenolic compounds therefore cannot be described as a uniform increase or decrease. The accumulation and stability of phenolic compounds in plant materials may depend on maturity stage and storage conditions [24,25]. In addition, the quantity of phenolic compounds in the studied powders also depends on their origin [26], as well as the variety, growing season, harvesting season, climatic and environmental conditions (light, precipitation, topography, and soil type), geographical location, various diseases that can affect the plant, plant maturity [27]. Flavonoid content also varied markedly according to harvest maturity. R35 seeds contained substantially higher flavonoid levels than R30 seeds at E0, but their content decreased progressively with increasing storage duration. However, the decrease would be due to the difference in the degree of maturity of *C. lanatus* seeds [24]. It would also be attributable to the effect of storage time. Tannin content showed another contrasting pattern. It increased progressively in R30 seeds, whereas in R35 seeds it increased up to E30 and then decreased at E60. Such contrasting responses reinforce the importance of considering harvest maturity and storage duration jointly when interpreting phytochemical changes. Indeed, tannins could protect the consumer against free radicals and they also possess antioxidant activity [28,29]. However, this difference in the contents of these phytochemical constituents varies from one region to another due to environmental and climatic conditions [30]. The study revealed that harvest maturity significantly influenced ($p < 0.05$) the lipid content of *C. lanatus* seeds. According to [21], the chemical composition of plant foods may vary within the same species according to growing conditions and maturity stage. Thus, differences in maturity at harvest could partly explain the variations observed in lipid content. Vitamin C content did not differ significantly among the six treatment combinations under the analytical conditions used. This result suggests that the measured vitamin C content was relatively insensitive to the harvest maturities and storage durations investigated. Although vitamin C is generally sensitive to oxidation, no significant variation was detected under the experimental and analytical conditions of the present study. The vitamin C contents were lower than those previously reported for some vitamin-C-rich wild fruits, such as *Dialium guineense* [31]. These differences could be attributed to variations in tissue type, maturity stage, environmental conditions, and analytical methods used.

6 CONCLUSION

The study showed that the nutritional and phytochemical composition of *C. lanatus* cv. "Wlêwlê" seeds was influenced by harvest maturity and postharvest storage duration. Moisture and vitamin C contents remained relatively stable, whereas ash, fiber, and flavonoid contents generally decreased during storage. Protein content varied according to harvest maturity, while lipid content reached its highest values after 30 days of storage. Total phenolic and tannin contents showed contrasting responses depending on harvest maturity and storage duration. Overall, a 30-day storage period may represent a suitable compromise for maintaining several nutritional attributes of the seeds.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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