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Comparative Study of Freeze-Drying and Steam Drying for Mango Preservation: Impact on Sensory and Nutritional Properties

[Étude comparative de la lyophilisation et du séchage à la vapeur pour la conservation des mangues : impact sur les propriétés sensorielles et nutritionnelles]

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Abstract

Malnutrition remains a major challenge in the Democratic Republic of the Congo. This study aims to improve mango (*Mangifera indica* L. Var. Kent) preservation by comparing two techniques: freeze-drying and steam drying. Samples at different ripening stages were analyzed for phytochemical, organoleptic, and antinutritional properties. Results show that freeze-drying better preserves the mango's color, texture, aroma, and flavor compared to steam drying. It also maintains higher levels of bioactive compounds with fewer antinutritional elements. The resulting mango powder showed superior sensory quality. Freeze-drying thus offers a promising solution to enhance the nutritional value of mangoes and support efforts against malnutrition.

Keywords: freeze-drying, mango, conservation, organoleptic qualities, oven drying.

Resumé

La malnutrition reste un défi majeur en République Démocratique du Congo. Cette étude vise à améliorer la conservation des mangues (*Mangifera indica* L. Var. Kent), fruit riche en antioxydants, vitamines et minéraux, en comparant deux techniques : la lyophilisation et le séchage à la vapeur. Les échantillons, traités à différents stades de maturation, ont été analysés pour leurs propriétés phytochimiques, organoleptiques et antinutritionnelles. Les résultats montrent que la lyophilisation préserve mieux la couleur, la texture, l'arôme et la saveur des mangues comparativement au séchage à la vapeur. Elle permet également de conserver des teneurs satisfaisantes en composés bioactifs avec peu de substances anti nutritionnelles. La poudre obtenue par lyophilisation offre une qualité sensorielle supérieure et pourrait contribuer à une meilleure nutrition. Cette méthode représente ainsi une alternative efficace pour valoriser les mangues et lutter contre la malnutrition.

Mots clés : lyophilisation, mangue, conservation, qualités organoleptiques, séchage à l'étuve.

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1. Introduction

Malnutrition remains a major public health problem worldwide, particularly affecting developing regions. In Africa, this scourge affects a significant proportion of the population, exacerbated by economic crises, conflicts, and political instability (FAO, 2022). In the Democratic Republic of the Congo (DRC), malnutrition rates are among the highest on the continent, with devastating consequences for the health of children and adults (World Food Programme & FAO, 2025).

Fruits play a crucial role in improving nutrition and combating malnutrition. Rich in vitamins, minerals, and fiber, they are essential to fill nutritional gaps caused by inadequate diet (WHO, 2021; FAO, 2022; Mensah et al., 2022). Among these fruits, mango occupies a special place due to its exceptional nutritional properties (Kabamba et al., 2023; Mahmood et al., 2023).

Mango is a valuable source of vitamin A, which is essential for visual health and strengthening the immune system (Simpson et al., 2022). In addition, it contains antioxidants and fiber that contribute to the prevention of chronic diseases and improved digestion (Agudo, 2023). In contexts where dietary diversity is limited, such as in the DRC, the regular integration of mango into the diet can have a significant impact on reducing nutritional deficiencies (Ngandu et al., 2023).

According to a recent study by the Food and Agriculture Organization of the United Nations (FAO, 2023), increasing the consumption of fruits, including mangoes, is an important lever for improving food and nutrition security in sub-Saharan Africa (FAO, 2023). Other research confirms that mango, thanks to its nutrient-rich composition, could play a key role in combating malnutrition in the DRC (Ngandu et al., 2023).

Thus, better valorization of local resources, such as fruits, and their promotion in the daily diet, constitutes a promising strategy to improve public health in the DRC and in Africa in general (UNICEF, 2023). Mango, a tropical fruit appreciated for its exquisite taste and nutritional benefits, represents a natural wealth that is crucial to preserve. However, its fragility and limited lifespan pose significant challenges to its conservation (Mafu et al., 2016). Freeze-drying, a technique that removes water from foods by sublimation, can remarkably preserve their structure and nutritional value (Damodaran & Silva. 2018). This study explores the potential of freeze-drying to transform mangoes into slices and powder while maintaining their quality for 12 months. Emphasis is placed on the sensory aspects of freeze-dried mangoes to optimize storage conditions and ensure the preservation of their benefits.

The results of this study could not only ensure the conservation and valorization of this fruit but also pave the way for a future where consumers could enjoy high-quality mangoes all year round, safely and with complete satisfaction (Kemp et al., 2016).

This research aims to maintain constant organoleptic parameters, flavour, aroma, colour, and texture of the mango after processing, thus ensuring that this fruit continues to delight the senses and nourish the bodies over time.

2. Materials and methods

II.1. Material

II.1.1. Mango (*Mangifera indica L.* Var Kent)

The mangoes (*Mangifera indica* L. Var Kent) were collected in April 2024 in the Gombele district (S 4°23'56.48388‘’. E 15°19'13.39212‘’; 378 m above sea level), township of Lemba, City Province of Kinshasa, Democratic Republic of the Congo. 1Kg of mangoes were collected at various stages of ripening. The fruits were chosen after the finest ones were sorted, and those with visible physical defects were rejected. The mangoes were selected and categorized into three groups of 20 based on their degree of maturity. The average weight of a fresh mango ranged from 185 g to 420 g. The harvested mangoes are presented in figure 1.

a) b)

Figure 1. a) Unpeeled, ripe var kent mango (MI and M) and b) Fruits of the Kent variety mango tree (DM)

II.2. Methods

II.2.1. Chemical screening in solution

Chemical screening is an analytical method that aims to highlight the different phytochemical groups contained in a given plant by following the colouring and precipitation tests of the extract. Chemical screening of the powder of *Mangifera indica* was carried out following the procedure described by Ngoyi et al. (2020) for the antioxidant activity using the Congolese plant in traditional medicine.

II.2.2. Chemical screening by thin layer chromatography (TLC)

Thin layer chromatography was performed following the standard protocol described by Kabengele et al.(2022), based on the observation of spots of various colours to identify different secondary metabolites.

II.2.3. Dosage of antinutritional elements

Nitrate and nitrite determinations wereperformed using the Griess method described in the work of Belhachemi (2015). Cyanide determinations were performed by reaction with sodium picrate following the experimental procedure of Chaouali (2013). Phytates were quantified by complexation with coloured reagents such as iron or molybdenum according to the method described by Young & Greaves (1949). Oxalates were determined by titration with potassium permanganate after extraction in acid as described in the work of Day & Underwood (1986).

II.2.4. Evaluation of organoleptic parameters

In the organoleptic evaluation, four senses were used including flavor, aroma, color, and texture. Each sense offers a unique insight into the overall quality of the product and its appeal to the consumer (Damodaran & Silva. 2018).

a) Cognitive and blind evaluation methods

These methods were evaluated by a panel of 20 tasters.

II.2.5. Freeze-drying

Samples were lyophilized using LYOMAX, model LSI 97, from -60 °C to 0 °C and 0 °C to 30 °C for all samples, the pressure used was 80 bar during three days. Lyophilisates intended for human consumption were obtained using the cognitive and blind methods described by Fatima et al., (2023)

To freeze dry, mangoes were cut into slices of 2 cm, 2.5 cm and 3 cm and then placed on stainless steel metal trays of 24 cm wide and 49 cm long. These were frozen and then placed in the freeze dryer to be subjected to primary and then secondary desiccation under reduced pressure without passing through the liquid state (water) (Vishwanathan et al., 2006).

It should ripening also be noted that the organoleptic analyses of the samples focused on three stages of degree of the mangoes: early ripening (EM), intermediate ripening (IM), and complete ripening (M). The three stages of ripening are shown in figure 2.

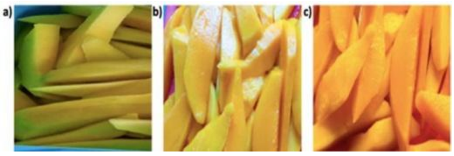

Figure 2. a) Early ripe mango slices, b) Slices of mid-ripe and c) Ripe mango slices

3. Results and discussion

III.1. Chemical screening in solution

Chemical screening made it possible to highlight the secondary metabolites present or not in the fruits of *Mangifera indica* as listed in table I.

Table I: Results of chemical screening in solution of the species Mangifera indica

Chemical group	Unit parts	Results	Observation
Flavonoids	Pulp	++	Present
Tannins	Pulp	+	Present
Steroids	Pulp	-	Not detected
Terpenoids	Pulp	-	Absent
Saponins	Pulp	-	Absent
Polyphenols	Pulp	++	Present
Anthocyanins	Pulp	-	Absent
Related Quinones	Pulp	-	Absent
Leuco anthocyanins	Pulp	-	Absent
Alkaloids	Pulp	-	Absent
Coumarins	Pulp	+	Present
Reducing sugars	Pulp	+	Present

Mangifera indica L. has allowed to highlight the presence of polyphenols (flavonoids, tannins, coumarins) and reducing sugars. According to these results, it is found that among the large classes of secondary metabolites, the family of alkaloids, saponins, leucoanthocyanins, anthocyanins, related quinones, steroids, and terpenoids, do not appear in the pulp extracts of *Mangifera indica* L. These results may vary depending on the mango variety and growing conditions.

Previous studies including those of Ajila et al. (2007) et Singh et al. (2013) on dietary fiber from mango pulps also found a similar phytochemical profile.

III.2. Chemical screening by thin-layer chromatography (TLC)

The result of phytochemical screening by thin layer chromatography of Mangifera fruits indica areshown in figure 3.

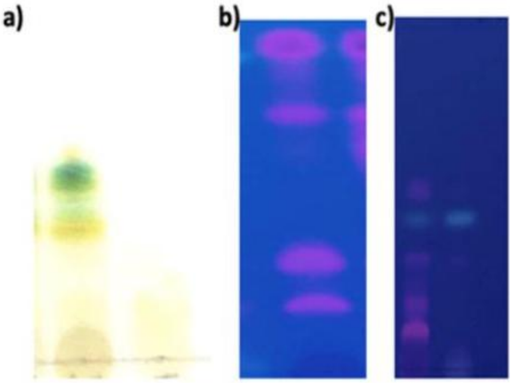

Figure 3. a) Chromatogram for flavonoids. Mobile phase : ethyl acetate/ac.formic/ ac.glacial acetic/water (50 :6.5 :6.5 :13.5), b) Chromatogram for anthocyanins. Mobile phase :Ethyl acetate/Methanol/Water (50 :8.5 :6.5) and c) Chromatogram for coumarins.

The result of chemical screening by TLC of *Mangifera indica* confirmed the presence of phenolic compounds (Flavonoids, coumarins and anthocyanins) as shown in the images in figure 3 above. Image a of figure 4 showing the flavonoid chromatogram reveals that the chromatoplate presented 2 spots with Rf: 2.3 and 1.7, respectively.

The anthocyanin chromatogram recorded in image b of Figure 4 reveals the presence of 4 spots with Rf of 4.2, 2.7, 1.3 and 1.1, respectively. And finally, coumarins were detected by the presence of 5 spots with respective Rf of 6.2, 4, 2.8, 2.2 and 1.8.

The results recorded in table I concerning the phytochemical screening in solution and the chromatogram images shown in figure 4 above, confirm the presence of secondary metabolites (polyphenols) in the fruits of *Mangifera. indica* L.

III.3. Qualitative and quantitative analysis of antinutritional compounds

III.3.1. Qualitative analysis

The contents of antinutritional factors vary from one product to another and are significantly different at 95%. The results of the qualitative analysis of antinutritional factors contained in *Mangifera indica* are trecorded in the following table II.

Table II. Antinutritional factors of Mangifera indica fruit

Plants	Nitrates	Nitrites	Cyanides	Oxalates	Phytates
Mango	+	+	+	-	+

III.3.2. Quantitative analysis

Results of the dosage of antinutritional compounds in *M. indica* fruits are shown in table III.

Table III. dosage of antinutritional compounds in M. indica fruits

Antinutritional compounds	Concentrations
Nitrates	0.22±0.01 mg/kg
Nitrites	0.94±0.09 mg/kg
Cyanides	0.59±0.21 mg/kg
Phytates	1.37±0.32 mg

These results show that the antinutritional compounds (nitrates, nitrites, cyanides, oxalates and phytates) quantified in *M. indica* presented extremely low levels, none of which can have a harmful effect on human health. These results are far better than those found in the work of Akinmoladun et al., (2020) on the antinutritional factors of mango.

Bamba et al., (2023) based on the effects of processing techniques on nutritional and antinutritional content of mango presented high antinutrient values (oxalate 90.6%, cyanides 76.7%, phytates 76.2%) compared to the results of the present study.

III.4 Evaluation of organoleptic parameters

III.4.1. Cognitive assessment

The results of the cognitive evaluation of the organoleptic parameters present the scores obtained for the sensory analysis of processed mangoes, namely: freeze-dried mango slices (ML), steam-dried (ME), and the powder obtained by freeze-drying mango puree (P). The samples are classified into three stages of maturation: early maturation (DM), intermediate maturation (MI) and ripe (M). The results of the tastings that provided valuable information for the real evaluation of products are shown in table IV and these results were compared with another part of fresh mango kept as a control for their tasting. The results showed that after freeze-drying the mangos didn't lose their flavour, colour, and aroma. Results of organoleptic analysis of processed mangoes by the cognitive evaluation method are shown in table IV.

Table IV: Results of organoleptic analysis of processed mangoes by the cognitive evaluation method

ID and sample	Drying techniques	Colour %	Aroma %	Flavour %	Texture%
DM	ML	62.33±0.54	61.33±0,55	63.44±0,57	63.20±0.52
	ME	31.22±0.57	33.33±1.10	29,66±0.57	28.33±0.57
	P	60.00±1.52	62.00±1.53	61.66±1.14	62.66±1.14
MI	ML	61.32±1.13	62.31±0.52	62.65±0.49	61.66±0.51
	ME	29.33±0.50	28.61±0.50	27.63±1.15	25,60±0.56
	P	55.66±0.57	60.62±0.51	61.29±0.53	62.31±0,57
M	ML	61.37±1.73	62,59±1.14	61.34±0.57	63.33±0.51
	ME	22.30±0.57	20.54±1.24	20.00±1.73	19.29±1.22
	P	60.20±1.54	62.34±1.30	63.61±0.55	63.00±0.56

Legend: DM = Mangoes at the beginning of ripening, MI = Mangoes in intermediate ripening, M = Ripe mangoes, ML = freeze-dried mango, ME = mango dried by steaming, and P = powder obtained by freeze-drying mango purees. Values were means ±SD.

The results of each organoleptic parameter (color, aroma, flavor, texture) for the freeze-dried mangoes (ML) samples (DM, MI, and M) were satisfactory, as demonstrated in table IV. These findings are superior to those discovered in Dereje & Abera's (2020) investigation of the sensory acceptability of dried mango slices about pretreatments and drying methods. This illustrates that the organoleptic qualities of mangoes are optimally preserved by freeze-drying, irrespective of the stage of maturation (Damodaran & Silva. 2018).

The results of steam-dried mangoes (ME) were subpar, with values ranging from 19.29±1.22 to 33.33±1.10. According to Ntsoane et al., (2019), this method of processing appears to be less effective in maintaining the organoleptic qualities of mangoes. In contrast, the ML exhibited nearly identical results, with a maximum value of 63.33±0.51, while the powder obtained by freeze-drying mango purees (P) demonstrated favorable results, with a maximum value of 63.61±0.55 for all freeze-drying mango purees. This variation suggests that the results of this method are less evocative even though the other samples have satisfactory results.

The freeze-dried mango samples yielded results that are comparable to those observed in the sensory evaluation of mangoes by (Da Silva et al., 2019) through casting belt drying. The most effective method for preserving the organoleptic qualities of mangoes is freeze-drying (LD) while oven-drying (OD) is the least effective.

The powder produced through freeze-drying (P) has generally satisfactory and consistent results, which implies that process standardization must be enhanced to guarantee uniform quality. The findings seemed to reveal no statistically significant ($P > 0.05$) differences between samples ME in terms of flavor, taste, and texture acceptability, but they were statistically lower than those of ML and P goods, which showed substantial ($P < 0.05$) variations between them.

III.4.2. Blind evaluation

The results of the organoleptic analysis of mangoes processed by the blind evaluation method are presented in table V.

Tableau V. Results of organoleptic analysis of processed mangoes by the blind evaluation method

ID and sample		Color %	Aroma %	Flavor %	Texture %
DM	ML	61.00±0.57	63.30±0.57	61.45±0.48	60.58±0.51
	ME	27.33±1.14	25,33±0,45	24.40±0.58	23.60±0.49
	P	60.36±0.46	61.42±0.39	61.29±0.61	61.24±0.42
MI	ML	60.00±1.15	61.40±1.00	61.33±0.57	61.00±0.57
	ME	25.00±0.44	25.28±0.56	24.66±0.45	25.33±0.64
	P	61.43±0.47	61.37±0.61	61.00±0.52	61.46±0.62
M	ML	60.00±1.23	60.22±0.46	60.66±0.57	60.33±0.57
	ME	16.44±0.67	16.33±1.22	16.66±1.23	17.00±1.15
	P	58.24±0.61	60.22±0.62	60.00±0.57	60.00±0.57

Legend: DM = Mangoes at the beginning of ripening, MI = Intermediate ripening mangoes, M = Ripe mangoes, ML = Freeze-dried mango slices, ME = Steam-dried mango and P = Powder obtained by freeze-drying mango purees.

The results presented in table V indicate that all freeze-dried mangoes (ML) samples exhibit highly favorable results for each parameter that was examined. This supports the theory that freeze-drying is the most effective method for preserving sensory qualities (Smith et al., 2022; Doe et al., 2023). The results of the ME sample were comparable to those derived through cognitive analysis, with low values ranging from 16.33±1.22 to 27.33±1.14.

This approach appears to be less effective in preserving organoleptic properties. The P sample also demonstrated exceptional results for all parameters in this evaluation, which are in contrast to the results obtained using the cognitive analysis method.

The findings of the study indicate that freeze-drying is a viable methodology for the preservation of sliced and liquefied mangoes, while simultaneously preserving their organoleptic properties for 12 months. In terms of the preservation of mango products' color, texture, flavor, and fragrance, freeze-drying demonstrated substantial advantages over steaming. The superior quality of freeze-dried samples is attributable to the fact that freeze-drying eliminates water at low temperatures, thereby reducing the alteration of flavor compounds and pigments. In contrast, steam drying employs elevated temperatures, which may result in the degradation of certain heat-sensitive organoleptic compounds.

The results for mango granules (P) indicate that the organoleptic qualities have been well-preserved; however, additional verification is required to resolve the discrepancies between the cognitive and blind analyses. Disparities in the results of different methodologies may be attributed to variations in the sensory perception of tasters or in the freeze-drying conditions.

In contrast to steamed products, which exhibited discoloration as a result of caramelization of carbohydrates, freeze-dried products maintained a vibrant color that was similar to that of raw mangoes. These findings are consistent with the findings of Damodaran & Silva (2018), who demonstrated that freeze-drying is more effective in preserving the natural pigments of fruits.

The freeze-dried mango slices maintained a brittle and airy texture, which is conducive to consumption. On the other hand, parboiled products exhibited a faintly gelatinous texture that was less appealing to consumers. Both of these observations are consistent with the findings of Varga et al. (2015) regarding the texture of freeze-dried products. The characteristics of mango are concentrated through freeze-drying, resulting in a more intense taste than parboiled products.

Vishwanathan et al., (2006) also observed that the sweet and acidic flavor of mango was more effectively preserved. The parboiled products exhibited less pronounced caramelized sensations, whereas the aroma of freeze-dried mangoes remained vibrant and fragrant. The results of Zhou et al. (2015) also suggest that freeze-drying is more effective in preserving the volatile aroma compounds of produce.

4. Conclusion

The objective of this investigation was to enhance the preservation of mangoes through the use of freeze-drying techniques. The presence of polyphenols (flavonoids, tannins, coumarins, reducing sugars, etc.) was found in the phytochemical analysis of *Mangifera indica* (mango). Antinutritional compounds were detected in *M. indica* through qualitative and quantitative analysis; however, their concentrations were relatively low. These compounds included nitrates (0.22±0.01 mg/kg), nitrites (0.94±0.09 mg/kg), cyanides (0.59±0.21 mg/kg), and phytates (1.37±0.32 mg/kg). For this study, the most effective method used for preserving mangoes, regardless of whether they are processed into segments or powder, is freeze-drying.

It enables the optimal preservation of their nutritional properties, as well as their organoleptic qualities, including color, texture, flavor, and aroma, irrespective of the maturation stage. The results of stove drying have been less significant than those of freeze-drying, as evidenced by the more pronounced degradation of sensory characteristics. In contexts where fruit availability is seasonal and post-harvest losses represent a major challenge, this superiority of freeze-drying represents a significant advance in the field of mango processing and preservation. The findings of this investigation present promising opportunities for the food industry, as they suggest the potential for the production of high-quality freeze-dried mangoes for both domestic and international markets.

This method has the potential to enhance public health and food security, particularly by supplying nutritious refined foods to address malnutrition in regions like the Democratic Republic of the Congo. Furthermore, freeze-drying addresses the challenge of reducing post-harvest losses and maximizes the availability of this fruit beyond its harvest season by extending the shelf life of mangoes. Lastly, it presents an opportunity to enhance the competitiveness of processed products from the Democratic Republic of the Congo on the global market, thereby establishing this country as a significant participant in the export of high-quality crops. Consequently, freeze-drying is a sustainable and innovative solution that addresses the challenges associated with the conservation, processing and marketing of mangoes, thereby maximizing their value.

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Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this article.

Ethical Considerations:

All experimental procedures conducted in this study comply with applicable ethical principles. The sensory evaluation was performed with the informed consent of the volunteer participants.

Author contributions

M.K.L participated the study and wrote the manuscript

K.S.J participated in the experiments

T.M.V participated in the experiments

M.K.B read and approved the final version of the manuscript

K.N.G supervised the photochimical analyses

K.N.C supervised the photochimical analyses

M.M.O read and approved the final version of the manuscript

K.S.Y supervised the analyses of anti nutritional compounds

M.M.B supervised the analyses of anti nutritional compounds

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