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Preservation of *Mangifera indica Var Kent* mango grown in the Democratic Republic of Congo by oven-drying and freeze-drying methods

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ABSTRACT

Objective: The present investigation concerns the preservation by freeze-drying of mango of one of the Kent varieties grown in the Democratic Republic of the Congo.

Methodology and Results: The mangoes used were harvested from the same tree and picked at three degrees of ripeness. The mango pulp was cut into 5-8 mm slices and oven-dried at 50 °C for approximately 24 h before being ground and sieved to obtain a powder for analysis. The Kjeldahl method was used for protein determination, the fluorescence-X method (Spectrometer ED-XRF Xepos III) for elemental analysis, and Soxhlet extraction method with petroleum ether to extract lipids. Ash content was determined gravimetrically by calcining the sample at 600 °C for 4 h using a muffle furnace. Vitamins A and C were determined by spectrophotometry and titrimetric methods, respectively. The results obtained show that freeze-drying enables mango to be preserved for over six months without any noticeable variation in their physicochemical parameters.

Conclusion and application of results: Freeze-dried mango powder thus opens up the possibility of its valorisation as a food ingredient and additive for infant porridges and food for the elderly.

Key words: *Mangifera indica*, freeze-drying, chemical composition, preservation.

INTRODUCTION

There are around 1000 species of mango in the world. Global production of this fruit is estimated at around 17 million tons per year, with India, China and Thailand being the main producers. The Democratic Republic of Congo (DRC) is 23rd producer with around 260,000 tons per year and 7th producer in Africa (Jimmy Moran, 2024). Despite this production, the DRC is not one of Africa's leading mango exporters. This seasonal fruit produced in the DRC is consumed exclusively in its fresh state, and a very large part rots unnecessarily. This results in significant post-harvest losses (Ilboudo *et al.,* 2022). However, mango is an important source of dietary fibre, mineral elements (Ca, Mg, Fe, P, Zn, Mn, Se,) and vitamins (A, C, K, B1, B2, B3, B5, B6 and B12) (Maldonado-Celis *et al.,* 2019; Barbosa

et al., 2017). To preserve mango as well as other fruits and vegetables, cooling (Nunes and Delgado, 2020), freezing (Delgado and Sun, 2011), or even drying is one of the most commonly used thermal techniques (Zhang *et al.,* 2022).Throughout storage, processing or distribution, a number of physical, chemical or biological changes can take place within a food, resulting in the alteration of its physical appearance that affects both the colouring and the structure. During this alteration, certain undesirable reactions take place, causing deterioration of the food's aroma, lipids, proteins, carbohydrates, vitamins. (Pathare *et al.,* 2013). To prevent this spoilage, various methods are usually used, including drying, which is one of the most important methods of food preservation. Indeed, hot-air drying has been widely applied to dry a variety of fruits and vegetables and their derivatives (Zhang *et al.,* 2022; Fernandes *et al.,* 2014). During the drying process, heat is transferred by convection, conduction, radiation, or their combination, from the food to be dried to the surrounding environment (Wang *et al.,* 2021).
Drying is widely used in the food industry to ensure microbiological stability, reduce product deterioration due to chemical reactions, facilitate storage and reduce transport costs. Vegetables and fruit are very sensitive to heat; it is therefore necessary to find the right conditions for their drying (Wu *et al.,* 2022; Rahman & Perera, 2020). Two drying routes are commonly used: drying under a stream of hot air or in the open air, and freeze-drying. While air-drying produces dehydrated products with a longer shelf life, freeze-drying remains the best method of water removal, as it results in higher-quality end products (Zhang *et al.,* 2023; Fernandes & Rodrigues, 2021). Hot-air drying of mangoes has been the subject of numerous studies (Khan *et al.,* 2023; Islam *et al.,* 2021). Current mango drying practice requires at least 9 h, which leads to quality and vitamin losses, as well as colour changes (Hossain *et al.,* 2022). The paper investigates the drying of mangoes at different stages of maturation by steaming and freeze-drying; in order to determine the optimal duration after which mango composition remains unchanged. This study is the first to examine the impact of drying and freeze-drying on the quality of mangoes (*Mangifera indica* Var Kent) grown in the Democratic Republic of the Congo. The results of this study have important implications agri-food industry. Congolese **(**Oduro-Yeboah, *et al.,* 2022; Kouassi & Brou, 2021).

MATERIALS AND METHODS

Materials: Samples of mangoes (*Mangifera indica Var Kent*) were selected and picked at different stages of ripening, with an approximate density greater than 1.00 kg L^{-1}, during April 2023 in Kinshasa, at the Gombele neighbourhood (S 4°23'56.48388", E 15°19'13.39212',; 378 m altitude). The mangoes with diseases or visible physical defects were rejected. Fresh weight per fruit ranged from 185 g to 420 g.

Methods

Fruit processing: Quantities of 3 kg to 5 kg of mangoes at three different ripening stages (Early Ripe DM, Intermediate Ripe MI and Very Ripe MT) were washed, peeled manually and cut into slices of up to 8 mm. A first part of each of the three prepared samples was immediately analysed for water, mineral content, lipids, total protein, fibre, sugars, vitamin C, vitamin A, mineral elements and pH. A second part was dried with hot air, and a third was subjected to freeze-drying.

Oven drying and freeze-drying: Mangoes intended for hot-air drying were cut into thinner slices of 1 mm to 1.5 mm before being placed in a conventional oven (OSK) at 60 °C for 24 h (Mert *et al.,* 2021). Dried mango slices were stored in hermetically sealed sterile glass bottles. After one-month storage, mango slices were sampled for grinding and analysis. For freeze-drying, the foodstuff to be processed was cooled to freeze all materials. The frozen water was then removed by sublimation (Xu Duan *et al.*, 2016). Freeze-dried mango slices were also stored in hermetically sealed sterile glass vials. Each month, one vial is opened to collect a sample for analysis.

Chemical composition analysis: The chemical composition (moisture, crude protein, crude fat and ash, fibre, titratable acidity, sugars, vitamins A and C, mineral elements) of fresh, dried or freeze-dried mangoes was determined using conventional AOAC methods (*Association of Official Analytical Chemists*, 2016). Moisture content was measured by drying the samples at 105 °C for 24 h in an oven (OSK) (Zhang *et al.,* 2020; AOAC International, 2019). Crude protein content was determined by the Kjeldahl procedure with successive stages of digestion, distillation and titration. Crude fat content was determined by the Soxhlet extraction method using petroleum ether as the extraction solvent, between 40 ºC – 60 °C. All analyses were carried out three times to obtain mean values for the parameters under examination. Ash content was determined gravimetrically by calcining the sample at 600 °C for 4 h in a muffle furnace (NABER THERM, Germany), which involves reacting approximately 1 g of sample successively with 150 mL H_2SO_4 1.25 % and 150 mL KOH 1.25 % (AOAC International, 2019). The residue is washed, dried and calcined. The fibre content is obtained by the equation:

$$\%\, Fibres = \frac{W_1 - W_2}{W_1}\, x\, 100 \quad (1)$$

with W_1 the mass of the sample and W_2 the mass of the fibres and ash (AOAC International, 2019). Vitamin C was measured by the method described by AOAC International (2019), based on the reduction of 2,6-dichlorophenol-indophenol.

Ten (10) g of ground sample was dispersed in 40 mL of H_3PO_4-CH_3COOH solvent (2 %; w/v). The mixture was centrifuged at 3000 rpm^{-1} for 20 min. The supernatant was transferred to a 50 mL volumetric flask and the volume adjusted with hot distilled water, and then cooled in atmospheric temperature. Ten (10) mL of this solution was titrated with 2.6 DCPIP 0.5 g L^{-1} until the colour turns to persistent pink. The vitamin C content of the sample is given as a percentage by the following expression and converted into mg g^{-1}:

$$VitC\,(\%) = \frac{\left(0.5\, x\, V\, x\, 10^{-3}\, x\, 5\right)}{me}\, x\, 100 \quad (2)$$

where V = volume (mL) of 2.6 DCPIP poured at equivalence; me: mass (g) of sample. Multiplying by 10 gives the Vit C content (mg g^{-1}). Vitamin A was measured using the slightly modified procedure described by AOAC International (2019).

X-ray fluorescence analysis of mineral elements was carried out using the ED-XRF Xepos III spectrometer with four secondary targets: molybdenum (39.76 kV voltage and 0.88 mA current), aluminum oxide (49.15 kV voltage and 0.7 mA current), cobalt (35.79 kV current and 1mA current) and finally HOPG Bragg Crystal (17.4 kV voltage and 1.99 mA current) of the palladium anode. A 5 g test sample was mixed with 1 g Fluxana as binder and homogenized, then placed in a mold before being pelletized with a hydraulic press *(*1000 kg *Specac).* The $K_{\alpha 1}$ peak (3,313 keV) of the K shell was used for calculation, the HOPG Bragg Crystal target (17.4 kV voltage and 1.99 mA current) gave the areas which were normalized to the coherent and incoherent scattering peak (Sarker & Rashid, 2021; Noli & Tsamos, 2016).

RESULTS AND DISCUSSION

Humidity evolution during storage: Drying method reduces the water content of foodstuffs, thus preventing or considerably delaying the growth of micro-organisms. Foods dried in this way may nevertheless be contaminated by micro-organisms during drying under uncontrolled conditions. In addition, if drying is not sufficiently thorough, some pathogens can continue to develop during storage, leading to deterioration in food quality (Alp and Bulantekin, 2021). Figures 1 and 2 show the evolution of moisture content in parboiled and freeze-dried mangoes as a function of the number of months.

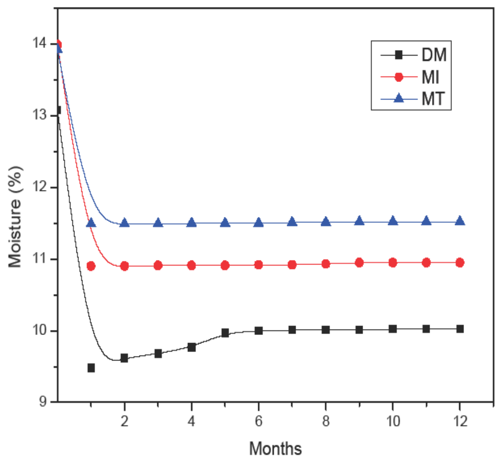

Figure 1: Evolution of oven-dried mangoes moisture

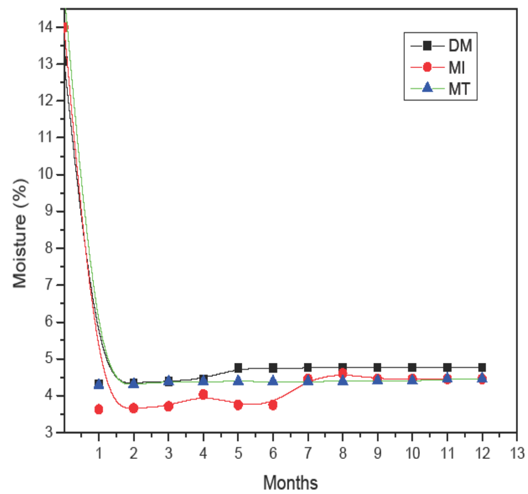

Figure 2: Evolution of freeze-dried mangoes moisture

It can be seen from these figures that very ripe mangoes contain more water than others do. Therefore, after the fourth month, there is a steady increase in humidity, indicating a lack of airtightness in the packaging. This increase in humidity is more pronounced in steamed mangoes than in freeze-dried ones. Rehydrating dried food during storage exposes it to the development of microorganisms. The results of this study show that freeze-drying significantly reduces the water content of foods, thereby extending their shelf life. It was also found that the intermediate ripeness mango (MI) had a better shelf life in terms of moisture than the other two (MI, TM).

pH evolution: Figures 3 and 4 show the pH progress of mangoes dried by parboiling and freeze-drying.

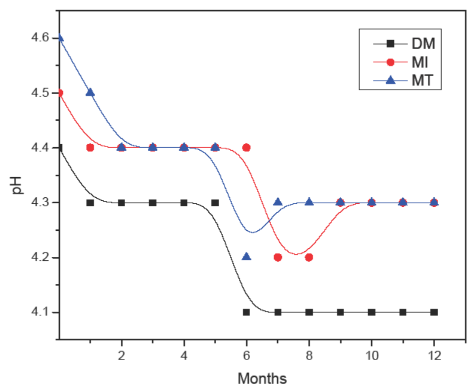

Figure 3: Changes in oven-dried mangoes

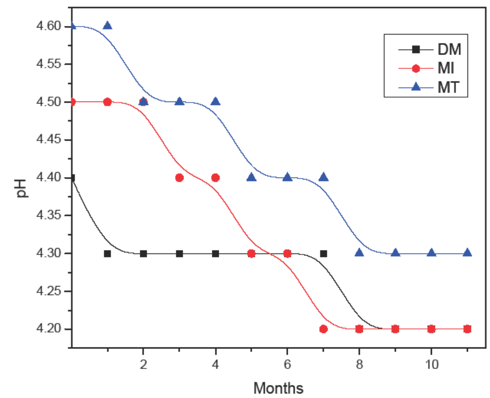

Figure 4: Changes in freeze-dried mangoes

pH reflects the acidity of a food, and in the case of mango it is closely linked to ascorbic and citric acid content. Several authors report that the pH of mango increases with the degree of ripening of the fruit (Pleguezuelo *et al.,* 2012; Akhtar *et al.,* 2010; Shawkat *et al.,* 2023). The same observation is reflected in the results of this study. In addition, mango acidification was observed, resulting in a slight drop in pH after the fourth month of storage, with the exception of the very ripe freeze-dried mango, whose pH remained constant for over seven months. The acidification of the mangoes during storage could be attributed to a microbial process triggered by the rehydration of the mango after four months of storage.

Vitamin C evolution: Figures 5 and 6 show the variation in vitamin C content of dried mangoes throughout the storage period. A decrease in vitamin C content is observed with the degree of ripening of the mango.

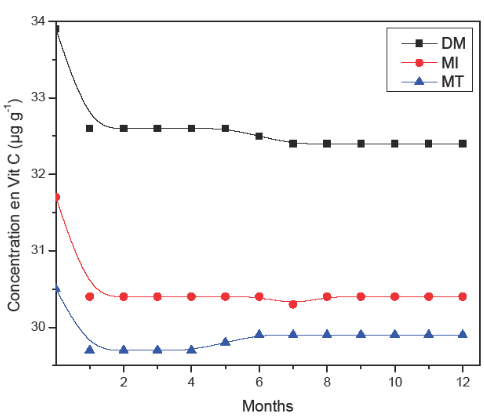

Figure 5: Evolution of Vit C in oven-dried mangoes

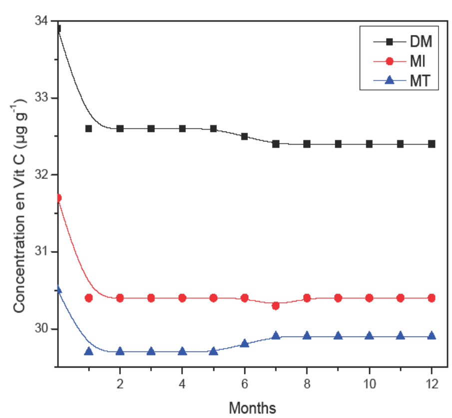

Figure 6: Evolution of Vit C in freeze-dried mangoes

This drop is easily attributable to the extensive non-enzymatic browning of mangoes at advanced maturity, and to the fact that Vitamin C is a substrate of the Maillard reaction (Rozis, 1995), and a highly unstable compound (Kameni *et al.*, 2002; Wang & Zhang, 2013). For mangoes dried by parboiling, the drop in vitamin C content recorded is around 15 %, whereas it is 17 % for mangoes undergoing freeze-drying. In all cases, the very ripe mango, despite its lower vitamin C content than the others, suffers a smaller drop in vitamin C during preservation. Shawkat *et al.* (2023) reported in their study on the influence of ripening stages of different mango varieties on chemical composition, that vitamin C decreased with storage time. The vitamin content fall from 70.32 mg 100 g^{-1} to 57.58 mg 100 g^{-1} after 12 months.

Evolution of vitamin A: Figures 7 and 8 show how vitamin A levels change during storage of dried mangoes.

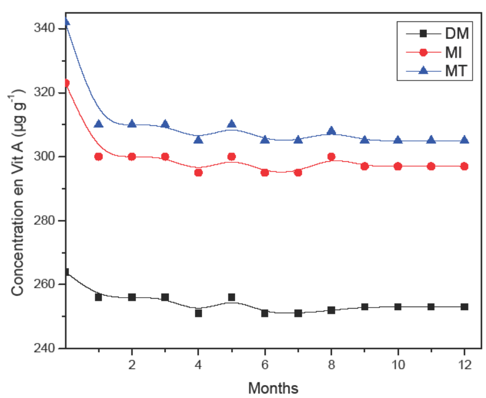

Figure 7: Evolution of Vit A in oven-dried mangoes

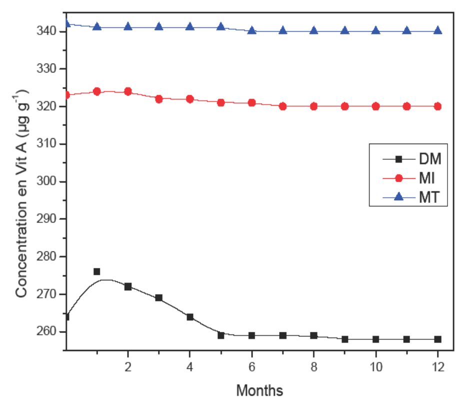

Figure 8: Evolution of Vit A freeze-dried mangoes

Fruits are known to be subject to microbial spoilage characterized by fermentation or putrefaction, enzymatic spoilage caused by endocellular enzymes in plant tissue, and physicochemical spoilage or non-enzymatic browning (Mudgil & Barak, 2023). Although fermentation and putrefaction were not detected during the storage of dried mango, other types of spoilage may explain the observed drop in vitamin A content. This drop is less pronounced for ripe mango.

Fibre evolution: Dietary fibres do not break down during digestion and help to form stools and reduce the risk of constipation. Mangoes are a good source of those fibres (Maldonado-Celis *et al.*, 2019; Barbosa *et al.*, 2017). As they are not subject to degradation, the results of this study show that their contents vary little during storage of dried mango.

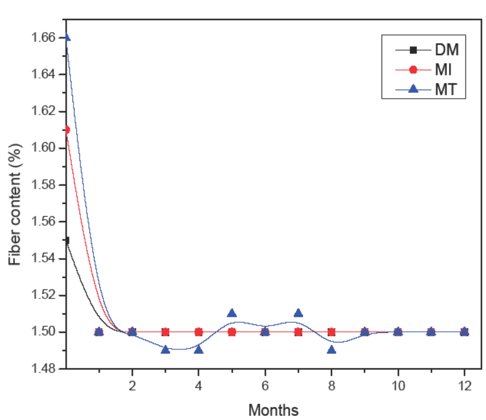

Figure 9: Fibre trends in oven-dried mangoes

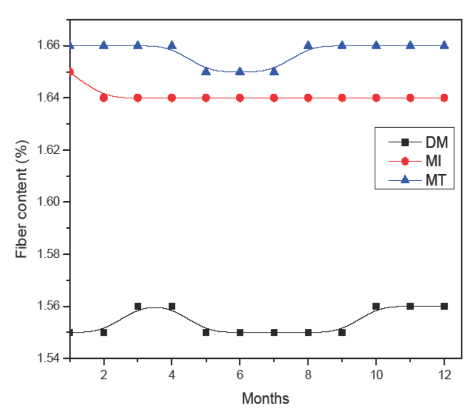

Figure 10: Fibre trends in free-dried mangoes

Protein evolution: In mangoes, proteins are in small quantities and remain relatively constant during storage. Protein content varies from 0.5 % to 0.7 % in fresh mangoes, around 1.2 % in oven-dried mango and an average of 2 % in freeze-dried mango. (FAO/SIDA., 1982). Some FAO reports indicate protein contents of 0.7 % in green mango and 0.6 % in ripe mango.

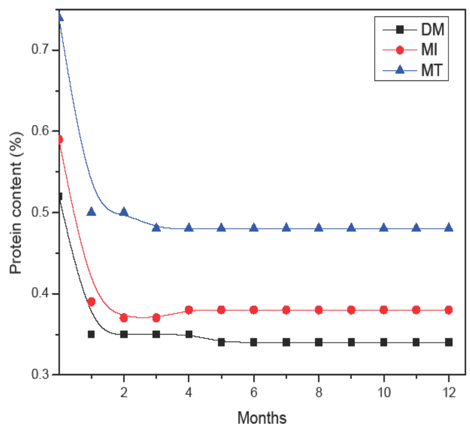

Figure 11: Protein trends in oven-dried mangoes

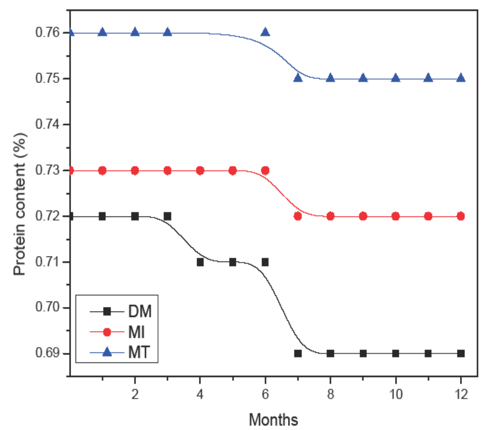

Figure 12: Protein trends freeze-dried mangoes

Lipids content: These constituents, in small quantities, remain proportionally constant during fruit development and storage. Lipids content in mango is negligible, ranging from 0.9 % to 2.3 %. On the other hand, Pathak and Sarada report lipid levels of 0.80 % and 1.36 %, respectively, for the Malgoa and Benishan varieties from India.

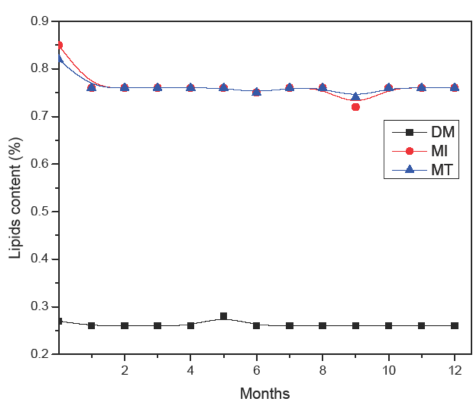

Figure 13: Evolution of lipids in oven-dried mangoes

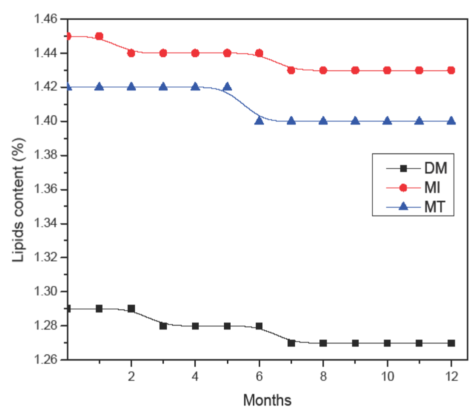

Figure 14: Evolution of lipids in freeze-dried mangoes

Mineral composition: The analyses carried out on 4 samples yielded the results shown in Table 1. It can been seen that the highest concentrations of minerals are as follows:

- Phosphorus (P): the percentage for the parboiled sample varies from 681.59 mg g^{-1} for the early ripening mango (DM), 311.82 mg g^{-1} for the intermediate ripening mango (MI), 628.32 mg g^{-1} for the very ripe mango (TM), and 572.30 mg g^{-1} for the freeze-dried sample (MI);

- Magnesium (Mg): 442.09 mg g^{-1} (DM), 368.09 mg g^{-1} (MI), 446.86 mg g^{-1} (TM), and 438.90 mg g^{-1} (MI Lyo);
- Calcium (Ca): 347.02 mg g^{-1} (DM), 392.18 mg g^{-1} (MI), 370.04 mg g^{-1} (TM), and 208.38 mg g^{-1} (MI Lyo);
- Sodium (Na): 44.29 mg g^{-1} (DM), 61.22 mg g^{-1} (MI), 52.46 mg g^{-1} (TM), and 48.06 mg g^{-1} (MI LYo);
- Iron (Fe): 31.55 mg g^{-1} (DM), 19.19 mg g^{-1} (MI), 19.49 mg g^{-1} (TM), and 21.08 mg g^{-1} (MI Lyo);
- Potassium (K): 10.72 mg g^{-1} (DM), 7.51 mg g^{-1} (MI), 12.30 mg g^{-1} (TM), and 8.81 mg g^{-1} (MI Lyo);
- Manganese (Mn): 8.59 mg g^{-1} (DM), 6.67 mg g^{-1} (MI), 7.97 mg g^{-1} (TM), 8.86 mg g^{-1} (MI Lyo);
- Zinc (Zn): 5.74 mg g^{-1} (DM), 6.18 mg g^{-1} (MI), 5.47 mg g^{-1} (TM), 5.61 mg g^{-1} (MI Lyo);
- Copper (Cu): 4.57 mg g^{-1} (DM), 6.65 mg g^{-1} (MI), 6.14 mg g^{-1} (TM), 4.29 mg g^{-1} (MI Lyo);
- Other elements exist in trace amounts, such as selenium (Se): 2.1 mg g^{-1}.

Table 1: Mineral elements content in mango (mg g^{-1})

Chemical element	**DM**	**MI**	**TM**	**MI Lyo**
	Mean value (mg g^{-1})			
Na	44,29	61,28	52,46	48,06
K	10,72	7,51	12,30	8,81
P	681,59	311,82	628,32	572,30
Ca	347,02	392,18	370,04	208,38
Mg	442,09	368,09	446,86	438,90
Mn	8,54	6,67	7,97	8,86
Fe	31,55	19,19	19,49	21,08
Ni	0,82	0,77	0,75	0,68
Cu	4,57	6,65	6,13	4,29
Zn	5,74	6,18	5,47	5,61

For all samples, the phosphorus, potassium, iron and magnesium contents varied considerably. The stage of ripening of the fruit (mango) on the sample tree and the two different drying techniques (oven drying and freeze-drying) used for the same variety are some of the factors explaining this variability as compared to the values reported by other authors (Srivostave, 1967 and Pathak S.R; Saradar, 1974). For some mineral elements, there are less significant differences, notably for Zinc, Copper, Nickel, Sodium and Potassium. This discrepancy could be explained by the difference in maturation stage and drying technique. It has also been reported that mango ash is particularly rich in potassium (K), calcium (Ca), phosphorus (P) and iron (Fe) (Mahale *et al.*, 2020; Ornelas-Paz *et al.*, 2022). Fruits are also reported to be particularly rich in potassium, with an estimated potassium content of around 50 % of ash weight (Mahale *et al.*, 2020). In human body, these minerals play important functional roles of a metabolic and physicochemical nature, and are involved in the formation of compounds of particular physiological significance. The presence of these minerals in mangoes makes them particularly important for their richness in K, P, Ca, Mg and Fe (Lobo & Yahia, 2017; Liu *et al.*, 2023). Mango is of genuine nutritional interest, and can be indicated as a necessary fruit for so-called vulnerable consumers: children, pregnant and breast-feeding women, and the elderly (Akinwale & Adeoye, 2021).

CONCLUSION AND APPLICATION OF RESULTS

The observation of mango rotting after the harvest season prompted the need of carrying out research into how to process mangoes to make it permanently available on the market in the Democratic Republic of the Congo and elsewhere. To achieve this goal, drying and freeze-drying procedures were used to preserve the mango's nutritional value, and to determine how long the processed mango would retain its physicochemical characteristics. Experimental results showed that freeze-drying preserved the mango for over 7 months without any noticeable variation in its physicochemical parameters. It was also noticed that steaming enables mangoes to be preserved for 3 months without any loss of quality. This easy-to-use technique is ideal for making mangoes available out of season. Freeze-dried mango powder opens the way to a number of added-value applications.

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