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Nutritional evaluation of flour obtained from *Tacca leontopetaloides* used as an alternative food in Muanza-Mozambique

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Tubers from wild *Tacca leontopetaloides* plants are frequently used as a food commodity, but when consumed raw it has a bitter taste and can be toxic, thus threatening food security. This study aimed to evaluate the nutritional composition of flour from *T. leontopetaloides* subjected to distinct washing treatments, hoping to improve its suitability as a pivot food commodity in regions affected by poverty and food insecurity, such as Muanza (Sofala, Mozambique). To remove the bitter taste and potentially toxic compounds, flour from *T. leontopetaloides* was subjected to a single washing (SW) and to 13 sequential deep washing cycles (DW). Samples were analysed for several nutritional and mineral parameters, including carbohydrates, proteins, lipids, fibre, energy, phosphorous, potassium, calcium, magnesium, and sodium. Flours prepared with SW had (per 100 g): 5.25 mg proteins, 0.73 mg fats, 0.43 mg fibres, 935 mg phosphorous, 833.7 mg potassium, 120 mg calcium, 275.3 mg magnesium, and 333.6 mg sum. Deep washing significantly decreased protein (80%) and mineral contents (by at least 27%) and eliminated the presence of glycosides and quinones, but a rich nutritional profile was still preserved after this procedure. Overall, *T. leontopetaloides* flour has a balanced nutritional profile when adequately washed, thus serving as a promising food commodity.

Key words: Food processing, food safety, macronutrients, micronutrients, nutritional composition, mineral profiling, washing process.

INTRODUCTION

Muanza is one of the poorest districts in Sofala Province, where agriculture is the basis for the population's sustenance (Pacheco, 2009). However, the prevalence of drylands and cyclical droughts, which characterize this region, compromise subsistence agriculture, leading the population to resort to wild tubers that may be poisonous for food consumption (Ogbonna et al., 2017). This is the case of *Tacca leontopetaloides*, locally known as “pirinde”, which is commonly used as a flour for human consumption (Uachisso et al., 2019). *T. lentopetaloides* is a perennial herbaceous species with a tuberous rhizome, belonging to the Taccaceae family. Tubers of *T. leontopetaloides* are similar in appearance to potatoes, usually with 10 to 15 cm in diameter but reaching 30 cm in rich soils, average weight from 70 to 340 g, but up to 1 kg. They are rich in starch but are generally bitter and almost unpalatable when raw (Murai et al., 1958; Kay, 1987). Several studies have shown that this tuber has anti-nutritional compounds, including cyanogenic compounds such as taccalonolides, which can cause death when the flour is not processed properly (Jiang et al., 2014; Ogbonna et al., 2017; Agus et al., 2021). Processing by immersion in water at room temperature tends to minimize the concentration of these anti-nutritional factors, some of which have beneficial health effects if present in minimal amounts (Ogbonna et al., 2017), allowing to significantly increase its safety for human consumption. The flour from *T. leontopetaloides* is commonly used as a food source in the District of Muanza, in Mozambique, to make a traditional bread (locally known as “micate”) and porridge (“xima”), thus contributing to mitigating hunger arising from the unavailability of food, especially during the dry season. However, its agronomical exploitation is still limited because this tuber is not cultivated in Africa, having persisted in its wild state. Moreover, there is scarce accurate information about its nutritional properties. For many of the developing world's poorest farmers and food-insecure people, tubers, serve as a critical source of food, nutrition and cash income, and they have been particularly important in areas where local agri-food systems are under stress (Scott, 2021).

According to FAO, the number of people affected by hunger has been growing in the last three years, arising to similar values of a few decades ago. This problem is further exacerbated by climate changes, which contributed to the economic slowdown due to extreme climatic variations, negatively impacting food security and sustainable agriculture (FAO, 2018). Extreme climatic variability is the key factor behind the increase in hunger and the cause of serious food crises, hence, the need to invest in the consumption of foods that do not depend much on climatic variations, such as *T. leontopetaloides* that grows in the forest, and can be found even in the dry season. When properly processed before consumption, the flour from *T. leontopetaloides* has great potential as a food source, since it provides several minerals including calcium, iron, potassium, and other micronutrients necessary for the proper functioning of the human organism (Ogbonna et al., 2017). However, the methods used to prepare the flour vary from region to region, potentially resulting in different nutritional compositions (Murai et al., 1958; Roger et al., 2012; Omojola, 2013; Ogbonna et al., 2017). In Muanza region, flour can be obtained by two processes. The first consists of leaving the tubers immersed in the running water of the rivers for seven days, to be later peeled, air-dried and turned into flour. The second process consists of peeling and subsequent immersion and washing cycles (changing the water with each wash). For making traditional bread (micate), a portion of the flour is used still moist (sluge), while the remaining portion is air-dried fully for later use. Most of the population in the district of Muanza uses these techniques; however, there is a lack of knowledge of the effect of these handling procedures on the nutritional value of the flour obtained. As such, this study aimed to evaluate the nutritional composition of flour obtained from *T. leontopetaloides*, after the tubers were submitted to single and multiple washing procedures, in order to identify the nutritional values of the final product consumed by the population.

MATERIALS AND METHODS

Plant and sample preparation

Tubers (*ca*. 5-6) of *T. leontopetaloides* were harvested from 35 plants growing in wild conditions in the District of Muanza (Sofala, Mozambique, latitude 19° 16'43 "S, longitude 34° 53'60" E, altitude 109.7 m), with hot and humid tropical climate and poorly evolved alluvial soils. Samples, collected during the month of October after their physiological maturation (assessed through organoleptic evaluation), had an approximate diameter of 15 cm and 300 g of weight.

For flour preparation (summarized in Figure 1), tubers (with a starting weight of 11 kg) were washed with running water to remove soil residues, peeled and further washed and weighed again (10 kg). Thereafter they were grossly laminated with a cutter, and exposed to room conditions under the sun until drying.

Grinding was carried out in a shredder, and the flour obtained was subjected to immersion in water to separate the sediment from the supernatant, which was discarded. In each washing cycle, samples were submerged in 15 L of water (inside a fabric mesh), hand mixed, and left to rest for 6 min. After this procedure, they were strained using a plastic mosquito net (with a mesh diameter of 0.8 mm) and allowed to settle for 40 min. Sample SW corresponded to flours subjected to a single washing cycle (final weight *ca*. 4 kg), while samples DW were prepared through the same washing procedure repeated until the reddish colour disappeared from the supernatant (13 times, final weight 2.5 kg).

The sedimented portion of each sample, corresponding to the flour, was air-dried during 12 h at 28°C, mown using a sieve (mesh size of 0.6 mm), and stored in plastic jars with a screw cap at 4°C until analysis.

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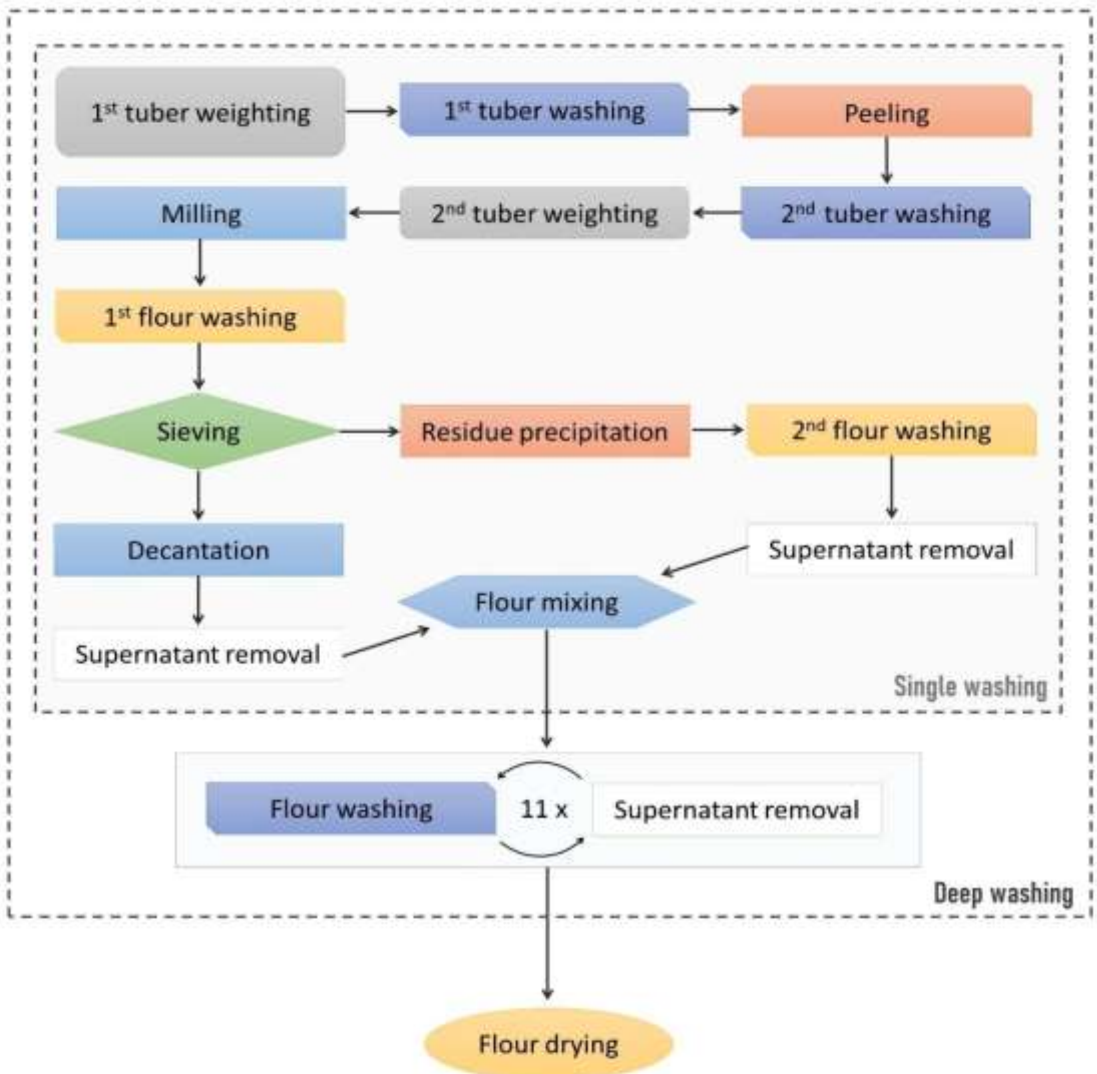

Figure 1. Schematic overview of the procedure used for the preparation of flour from *T. leontopetaloides*.
Source: Authors.

This methodology was implemented to mimic, as much as possible, the procedure most commonly applied by the local population. Samples were subjected to bromatological analysis for the determination of humidity, dry matter, ash, crude fibre and fat, nitrogen (N, for protein calculation), sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), and phosphorus (P) (at the Institute of Agricultural Research of Mozambique). Phytochemicals qualitative analysis was performed at the Faculty of Natural Sciences and Mathematics of the Pedagogical University of Maputo (Mozambique).

Bromatological analysis

For the determination of humidity and total ash, 5 g of each flour sample was placed in a preheated oven at 105°C for 2 h, followed by cooling in the desiccator. Sample moisture percentage was determined by the weight difference before and after drying. Total ash was obtained by sample calcination at 600°C for 24 h (AACC, 1995). Fibre determination was based on the destruction of the non-cellulosic organic matter and part of the mineral matter in two successive digestions (acid digestion, followed by basic digestion), as described by Campos et al. (2004). Fat content was determined by the Soxhlet method for 6 h in an extractor, using n-hexane as a solvent (AOAC, 1980). Total proteins were determined by the Kjeldahl method based on the determination of total nitrogen and using the conversion factor 6.25 for conversion to crude protein (AOAC, 1980). Carbohydrates were obtained by difference between 100 and the sum of the percentages of other nutrients (Quadros et al., 2009).

The determination of sodium (Na) and potassium (K) was done by flame photometry (Model DM-ESPEC1, Digimed, São Paulo, Brazil), phosphorus (P), magnesium (Mg) and calcium (Ca) by complexometric titration, as described by Campos et al. (2004).

Phytochemical analysis

Tannins were determined according to Matos (1997), by heating sample extracts in a water bath at 60°C, after which they

Table 1. Nutritional composition of the flours obtained from *T. leontopetaloides* tubers, collected in the wild in Mozambique, after single washing (SW), and after 13 sequential deep washing cycles (DW) (n = 3).

Parameter (%)	Single washing (SW)	Deep washing (DW)	*p*-value
Humidity	12.47 ± 0.14	15.82 ± 0.01	< 0.0001
Dry matter	87.46 ± 0.28	84.13 ± 0.01	< 0.0001
Carbohydrates	78.80 ± 0.12	75.36 ± 0.04	< 0.0001
Proteins	5.23 ± 0.01	0.88 ± 0.01	< 0.0001
Lipids	0.73 ± 0.01	0.75 ± 0.01	> 0.9999
Fibre	0.42 ± 0.01	0.13 ± 0.01	0.9956
Ash	2.35 ± 0.03	7.06 ± 0.01	< 0.0001
Energy	342.67 ± 0.53	312.02 ± 0.41	< 0.0001

Significant *p*-values are highlighted in bold case.
Source: Authors.

were filtered, and 5% ferric chloride was added. The presence of tannins was evaluated by the intensity of the dark green colour resulting from the reaction. Saponins were determined by the foam-agitation test, involving the addition of 5 mL of distilled water to a portion of the sample extract, followed by strong agitation and the addition of a few drops of oil. The formation of permanent foam indicated the presence of saponins (Matos, 1997). Steroids were determined using 2 mL of sample extract, 2 mL of chloroform, followed by 2 mL of concentrated sulfuric acid. The appearance of a reddish-brown ring indicated the presence of steroids (Zucula, 2011).

The presence of flavonoids was determined by the Shinoda test, through reaction with concentrated hydrochloric acid and fragments of magnesium oxide. The appearance of a pink colour indicated the presence of flavonoids. Glycosides were evaluated by the Liebermann test, using 2 mL extract to which 2 mL of chloroform and 2 mL of acetic acid were added. The presence of glycosides was indicated by the appearance of violet to blue to green colouration. The Salkowski test was used for alkaloids quantification, using 2 mL of extract, to which a few drops of Hager's reagent were added. The appearance of a yellow precipitate indicated the presence of alkaloids.

Terpenoids were assessed using a mixture of 5 mL of sample extract with 2 mL of chloroform and 3 mL of H_2SO_4. The appearance of a reddish-brown colour in the interface layer indicated a positive result. The identification of quinones was evaluated by adding 1 mL of an alcoholic extract of each sample to 0.5 mL of 10% NaOH. After gentle stirring for 2 min, the appearance of pink, red or violet colour indicated the presence of quinones. The aforementioned determinations were based on the method of Matos (1997), adapted by Yadav et al. (2014) and Soni and Sosa (2013).

Statistical analysis

Differences between treatments were tested through analysis of variance (ANOVA) and mean separation was done using Student's T-test ($p < 0.05$) in GraphPad Prism v7.0 (GraphPad Software, Inc., California, USA).

RESULTS

The washing procedure affected the yield of flour obtained from *T. leontopetaloides* tubers as the single washing procedure yielded 36% of flour, whereas the deep washing procedure resulted in a yield of 23%. The analysis of the proximal composition of the flours before and after a prolonged wash is as shown in Table 1. Flours subjected to a single wash (SW) had (per 100 g): 78.80 mg carbohydrates, 5.23 mg proteins, 0.73 mg fats, and 0.42 mg fibre, providing 342.67 kcal. Significant differences between samples from SW and DW were observed in terms of humidity, dry matter, carbohydrates, protein, ash and energy, whereas fat and fibre were not affected by the washing procedure. Protein content was the most affected by the washing procedures, with the flour subjected to deep washing (DW) having only 0.88 mg protein per 100 g of flour (that is, 83.1% less than SW). After deep washing, dry matter and carbohydrates also decreased (by 3.8 and 4.4%, respectively), but flour humidity and ash content significantly increased (by 26.9 and 200%, respectively).

Mineral analysis (Table 2) revealed a significant reduction in phosphorus (89.7%), potassium (98.8%), calcium (50.0%), magnesium (27.3%) and sodium (91.4%) after deep washing. Nevertheless, the mineral composition of these flours (DW) remained high, with 96.3 mg of phosphorus, 9.7 mg of potassium, 60.0 mg of calcium, 200.2 mg of magnesium and 28.7 mg of sodium.

Qualitative analysis of phytochemical compounds revealed the presence of alkaloids, glycosides, quinones and saponins in flour samples subjected to just one washing procedure (Table 3). After deep washing, only alkaloids and saponins were detected, that is glycosides and quinones were successfully removed from the *T. leontopetaloides* flour. Steroids, flavonoids, tannins and terpenoids were not detected in none of the flour types (Table 3).

DISCUSSION

In Mozambique, the wild production of *T. leontopetaloides*, locally known as "pirinde", constitutes an important food source from which flour can be

Table 2. Mineral composition of the flours obtained from *T. leontopetaloides* after a single washing (SW), and after 13 sequential washings (deep washing, DW) (n = 3).

Minerals (mg/100 g)	Single washing (SW)	Deep washing (DW)	*p*-value
Phosphorous	937.43 ± 1.48	96.27 ± 0.01	<0.0001
Potassium	833.37 ± 0.24	9.73 ± 0.01	<0.0001
Calcium	120.00 ± 0.12	60.0 ± 0.12	<0.0001
Magnesium	275.30 ± 0.17	200.20 ± 0.12	<0.0001
Sodium	333.57 ± 0.12	28.67 ± 0.09	<0.0001

Significant *p*-values are highlighted in bold case.
Source: Authors

Table 3. Qualitative phytochemical composition of the flours obtained from *T. leontopetaloides* after a single washing (SW), and after 13 sequential washings (deep washing, DW).

Phytochemical compound	Analytical procedure	Result	
		Single washing (SW)	Deep washing (DW)
Alcaloids	Hager test	Present	Present
Steroids	Salkowski test	Absent	Absent
Flavonoids	Shinoda test	Absent	Absent
Glycosides	Liebermann test	Present	Absent
Quinones	Bortraenger test	Present	Absent
Saponins	Foam test	Present	Present
Tannins	Braymer test	Absent	Absent
Terpenoids	Salkowski test	Absent	Absent

Source: Authors

extracted and used to make traditional bread and porridge.

Here, different washing procedures resulted in distinct flour yields, with multiple washing cycles resulting in the lowest yield (23%), likely due to biomass loss during supernatant removal after soaking. Nevertheless, this value is still higher than the yield of flour recovery from *T. leontopetaloides* tubers estimated in previous reports (18 to 20%) (Vu et al., 2017). Previous works by other authors have demonstrated a great heterogeneity in the proximal nutritional and mineral composition of this tuber (Table 4), most likely related to the distinct procedures used to obtain the final product destined for consumption, or to the specific climatic edaphic conditions of each region and time of harvest that can influence its composition (Borokini, 2012; Binh and Dao, 2020).

In the present work, although the 13 subsequent washes of the flour allowed to remove its naturally bitter taste (based on the experience and familiarity with the product from members of this research team and colleagues, which performed a sensorial evaluation), this procedure significantly increased the humidity (Table 1). Therefore, the drying time of the final product should be increased to more than 12 h (which was the drying period used in this work) to improve its shelf life. Due to the washing procedure, a significant reduction in protein content was observed (Table 1). Nevertheless, deep-washed flours from this study had similar or higher protein contents when compared with previous works by other authors, in which no washing or saltwater washing were employed (Murai et al., 1958; Roger et al., 2012; Omoloja, 2013) (Table 4). This evidence supports the use of the deep washing procedure employed in the present work to improve the consumption of flours from *T. leontopetaloides*.

In fact, *T. leontopetaloides* could be a good source of protein to mitigate its nutritional deficit in children, pregnant women and adults who are subject to a great deal of physical effort during their activities in the agricultural fields. Carbohydrates and energy were also slightly decreased with the deep-washing procedure, but their contents remained high, with carbohydrates being inclusively higher in this work than in previous ones by other authors (Murai et al., 1958; Roger et al., 2012; Omoloja, 2013) (Tables 1 and 4).

Nonetheless, as potential losses of protein, carbohydrates or energy in this food commodity are of upmost relevance for the local population (Uachisso et al., 2019), additional efforts in the agronomical and processing handling of *T. leontopetaloides* should be dully pursued to improve its nutritional profile. Lipids and fibre contents were not affected by the washing

Table 4. Description of the traditional processes used in the preparation of flours from *T. leontopetaloides*, and its nutrient and mineral composition. Abbreviations: NA = not analysed.

Reference	Ogbonna et al. (2017)	Omojola (2013)	Roger et al. (2012)	Murai et al. (1958)
Study site and year	Nigeria (Shendam), 2017	Nigeria (Abuja), 2013	Cameroons, 2012	Marshall Islands, 1958
Grinding procedure	Milling device	Grate	Adapted pottery facility	Sharp stone
Washing procedure	No washing	No washing	No washing	Repeated immersion in salt water (inside a cloth)
Filtration procedure	Sari fabric	No filtration	Adapted pottery facility	Cloth
Sedimentation	Phase present	Phase present	Phase absent	Phase present
Humidity (%)	8.66 ± 0.01	9.15 ± 0.02	85 ± 10	12.10
Ash (%)	0.41 ± 0.04	0.20 ± 0.04	1.1 ± 0.0	1.89
Fibre (%)	5.44 ± 0.03	2.10 ± 0.06	2.5 ± 0.7	NA
Lipids (%)	0.51 ± 0.04	0.09 ± 0.01	0.1 ± 0.0	NA
Proteins (%)	6.79 ± 0.02	1.5 ± 0.02	0.99 ± 0.00	0.18
Carbohydrates (%)	78.2 ± 0.05	88.1 ± 0.00	10.31 ± 5.30	85.74
Energy (Kcal)	340	354	46	346
Phosphorous (mg/100 g)	0.06 ± 0.02	NA	NA	7.2
Potassium (mg/100 g)	40.2 ± 0.12	NA	NA	NA
Calcium (mg/100 g)	0.25 ± 0.13	NA	2.6 ± 0.2	58.0
Magnesium (mg/100 g)	1.40 ± 0.01	NA	0.2 ± 0.0	NA
Sodium (mg/100 g)	34.7 ± 0.55	NA	NA	NA
Copper (mg/100 g)	0.68 ± 0.04	NA	1.2 ± 0.0	NA
Iron (mg/100 g)	1.37 ± 0.15	NA	3.7 ± 0.8	0.55
Zinc (mg/100 g)	NA	NA	8.2 ± 1.7	NA
Manganese (mg/100 g)	0.72 ± 0.26	NA	7.3 ± 1.2	NA

Source: Authors

procedure and, while the flours of the present work had higher lipid content than the ones from previous works, fibre content was lower (Tables 1 and 4). It is clear that the handling procedures used to obtain the final product play a major role in the final composition of the flour, but it is noticeable that even after thirteen washes *T. leontopetaloides* flour still has a high nutritional value and can serve as a food amenity for the local community, particularly during critical drought periods where the food crisis is aggravated.

The flour from *T. leontopetaloides* of the present work was very rich in ash, compared with previous works by other authors (Tables 1 and 4), providing an indication of its richness in minerals. As macrominerals make up more than 0.005% of the human body and we require more than 100 mg of macrominerals per day including calcium, magnesium, phosphorus, potassium, sodium and sulphur (Hark, 2005), the flour from *T. leontopetaloides* has potential to meet this dietary requirement, making it a good resource as food and feed (Bosha et al., 2015). Nevertheless, we observed that the method used to obtain the flour plays a major role not only in its ash content, but also in its mineral composition (Table 2). Although deep washing significantly decreased phosphorous, potassium, calcium, magnesium and sodium (from 27.3 to 98.8%), compared with flours resulting from a single washing, phosphorous, calcium, magnesium remained elevated, being inclusively higher than the values reported by other authors (Tables 1 and 4). The daily intake of phosphorous, required for several metabolic processes of the muscular and nervous systems and an integral part of many enzymatic systems, should be around 700 mg/day, while calcium, the main mineral present in bones and teeth and involved in the blood clotting process and neuromuscular functions, has a daily intake value of 600 to 1000 mg/day. A fraction of these levels could be met by a provision of *T. leontopetaloides*-derived food products, after safety components have been assured. Phosphorous and calcium deficiency can remain hidden for several years, causing e.g., anaemia, bone and muscle weakness and stunted growth (Hark, 2005). Thus, to suppress their dietary needs, the daily intake of deep-washed flours from *T*. *leontopetaloides* should be at least 700 g, reason why its consumption should be complemented with other food amenities to guarantee the minimum daily intake of these minerals. In contrast, 175 g of deep-washed flours from *T*. *leontopetaloides* are sufficient to ensure the minimum daily intake of magnesium (350 mg/day). This mineral plays a vital role in the formation of bones and teeth, and together with other minerals it is involved in the transmission of nervous signals and muscle contraction, also contributing to the synthesis of proteins (Hark, 2005). Therefore, *T*. *leontopetaloides* is a good source of magnesium, particularly for the population of the district of Muanza that have access to a limited variability in their food options (Uachisso et al., 2019).

It has been demonstrated that the preparation process negatively affects the content of the several anti-nutrient compounds in flours from *T*. *leontopetaloides*. Repeated immersion of the tuber for 36 h led to a 90% reduction in these compounds (Ndouyang et al., 2015). Variations in the presence of alkaloids and glycosides were observed in leaves and tubers of *T*. *leontopetaloides*, with environmental factors having a small effect on the phytochemical content of plants from different locations (Borokini et al., 2012).

Qualitative analysis of the phytochemical composition of the flours from *T*. *leontopetaloides* (Table 3) revealed the presence of alkaloids and saponins. Similar results were observed by Borokini et al. (2012) in flours of this tuber, raising questions on food security due to their toxicity and anti-nutritional character. Nevertheless, this limitation can be overcome with heat treatment during the cooking procedures, improving the beneficial role of these metabolites in promoting human health when consumed in lower concentrations (Benevides et al., 2011).

Borokini et al. (2012) also reported the presence of tannins, anthraquinones and glycosides, which were not detected or were lost with the deep-washing procedure. Contrastingly, increased concentrations of antinutrients, such as oxalates, phenolics, tannins and cyanides, were reported after tuber soaking for 72 h (Ndouyang and Schinzoumka, 2022). These differences in the phytochemical composition of flours from *T*. *leontopetaloides* likely result from intraspecific differences among distinct geographical areas and, most importantly, from the preparation procedure employed. As such, the consumption of this flour would benefit from a standardized preparation method to minimize the toxic effects and enhance the nutritional properties of this wild plant (Omojola, 2013). Therefore, it will be relevant for governmental entities to make recommendations both in agricultural production, concerning the cultivation of this tuber, and in the technology applied to obtain this food amenity.

Conclusion

Results showed that *T*. *leontopetaloides* flour has a relevant nutritional value to serve as an alternative source of food for the population of the district of Muanza, where food shortages and "hidden hunger" are a reality. It is also concluded that the studied deep washing procedure (13 times) leads to relevant losses in terms of nutrients and bioactive compounds (glycosides and quinones). Therefore, further studies are needed to evaluate the impact of less intensive washing procedures, to minimize the loss of beneficial minerals and nutrients, but still ensuring food safety. The implementation of standardized procedures by official entities concerning the production of flours from *T*. *leontopetaloides* could increase its nutritional value and consumption, thus contributing to mitigating the dietary challenges endured by local populations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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