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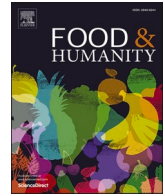
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Aluminium accumulation in loengo (*Anisophyllea boehmii* Engl.), a fruit from the Miombo ecoregion consumed in Angola

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ABSTRACT

The fruit of *Anisophyllea boehmii*, known as loengo in Angola, is a wild fruit typically harvested in the Miombo forest. It is widely consumed locally and appreciated for its organoleptic qualities. It also has proven nutritional interests. However, analysis of the mineral profile of the fruit pulp using inductively coupled plasma with mass spectrometry (ICP-MS) on 7 samples collected in 3 geographical areas over 3 consecutive years revealed an uncommon aluminium content of around 8 g·kg⁻¹ of dry matter. Indeed, the concentrations measured in the leaves confirmed that the plant is an aluminium hyperaccumulator. No correlation was found between the aluminium content of the pulp and that in soil. This particularly high value led to the recommendation to limit consumption of the fruit to protect local populations from excessive and repeated exposure to aluminium.

1. Introduction

The Miombo forest is an ecological zone characteristic of southern Africa that spans seven countries (Deweese et al., 2010). It is very rich in bioresources and is home to many plant species that produce edible fruits. These wild fruits are traditionally part of the local population's diet but are poorly understood and characterized in terms of composition. Among these forest resources, the fruit of *Anisophyllea boehmii* Engl. is particularly appreciated for its pleasant flavor.

A recent study conducted in Angola, including a field survey and an in-depth compositional work, showed that this fruit is widely consumed throughout most of the year in the form of fresh fruits or processed products like beverages, and that it has interesting nutritional and sensorial potentials (da Costa et al., 2025). The fruit is quite energy-dense. It is rich in sugars, fibers, minerals, polyphenols especially anthocyanins, and carotenoids. It has a distinctive flavor linked to a complex aromatic profile consisting mainly of esters. The composition of the mineral profile in the edible part of the fruit has been addressed. From a nutritional point of view, the pulp of the fruit contains particularly interesting contents of Mg, Mn, Fe, Zn and Cu. Nevertheless, during these first investigations, an abnormally high aluminum content was found in fruits sampled in Angola in 2021. This result was very surprising because aluminium is an element that generally does not

accumulate in plants as it is toxic at the cellular scale (Chauhan et al., 2021; Ofoe et al., 2023).

Given that this element has proven subchronic toxicity to humans, and due to the total lack of data on the subject, the objective of this short communication is to investigate the aluminium content of *A. boehmii* fruit by comparing several samples from various sites in Angola, collected over three consecutive years. The ultimate goal is to make recommendations regarding the consumption of this fruit.

2. Materials and methods

2.1. Samples

Fruits of unspecified origin were collected from local markets in September 2021. Between July and August 2022, 3 new fruit samples (3 kg·area⁻¹) were collected in different areas of Angola (Fig. 1): Malanje (Guiné-Malanje), Huambo (Luvili) and Huíla (Tchimbungo-Caconda). Fruit samples were prepared as described by da Costa et al. (2025). They were depulped (Auriol PH3 refiner, Marmande, France), freeze-dried at -18°C, and then freeze-dried (Cryonext Benchtop freeze dryer, Montpellier, France) before being analyzed. In November 2023, in the same areas, fruits (3 kg·area⁻¹), leaves, roots (0.5 kg·area⁻¹), and soils (1 kg·area⁻¹) were collected. The leaves and roots were washed

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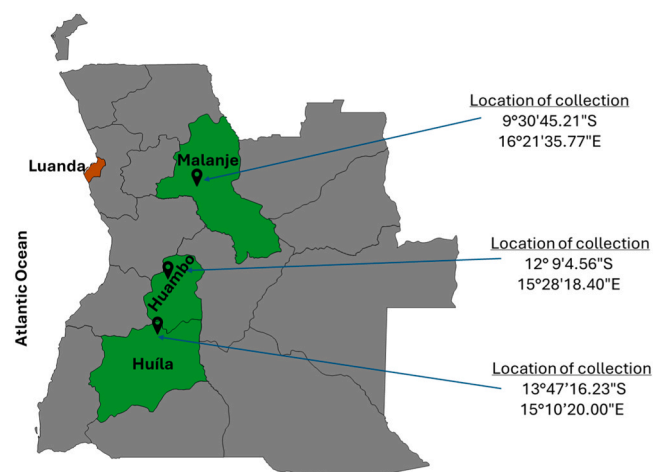


Fig. 1. Locations where samples of fruits, leaves, roots and soils were collected.

with tap water, dried at room temperature, and packaged in polyethylene bags. The soils were removed from the rhizosphere at approximately 40 cm depth, dried at room temperature, and also packaged in polyethylene bags without pretreatment. All samples were transported to the Institute of Agro-Food Technology in Malanje (Angola) and then to the CIRAD analysis center (France), with intervals between collection and analysis of 1 – 4 months.

2.2. Aluminium analysis

Aluminium content was analyzed by inductively coupled plasma with mass spectrometry (ICP-MS). Around 50 mg of the sample was digested with a $\text{HNO}_3\text{:H}_2\text{O}_2$ solution (65:35, v/v) using a MARS Xpress microwave system (CEM Corporation, Mathews, France). The digestion conditions were as follows: up to 120°C in 15 min and then constant for 10 min, up to 160°C in 20 min and constant for 15 min, final cooling to 22°C for 30 min and diluted with deionized ultrapure water. The ICP-MS device used was a Thermo Elemental, X-Series (Germany). The uncertainty of the measurement was around 10 % and the limit of detection was evaluated at 0.2 $\text{mg}\cdot\text{kg}^{-1}$.

2.3. Statistical evaluation

Statistical data treatment was realized using XLSTAT 2025 software (Addinsoft, Paris, France). For the analysis done in triplicate, comparison between average values were carried out using the Tukey HSD test ($p < 0.05$). Correlations were evaluated through the linear regression coefficient R^2 .

3. Results and discussions

3.1. Aluminium contents

Table 1 summarizes the results of aluminium measurements carried out during this exploratory work.

The average aluminium content of the fruit pulp, calculated from all samples collected ($n = 18$), was $8188 \pm 1321 \text{ mg}\cdot\text{kg}^{-1}$ dry basis (DB). Considering the pulp fruit moisture varies from 72 and 80 % with an average value of 78.4 % (da Costa et al., 2025), this corresponded to a content of approximately $1769 \text{ mg}\cdot\text{kg}^{-1}$ fresh basis (FB). A comparison of the contents obtained in pulp samples collected in 2021 and 2022 revealed significant differences depending on the origin of the samples.

With regard to leaves, the average aluminium content obtained from the Malanje, Huambo and Huíla samples was $12906 \pm 5179 \text{ mg}\cdot\text{kg}^{-1}$ DB. This content is particularly elevated but corresponds to those measured in the leaves of a number of aluminium hyperaccumulating

Table 1

Total aluminium content of fruit pulps, leaves, roots of *A. boehmii* and of soils by region and year of collection, expressed in dry basis (DB).

Samples	Origin	Sampling year	Total Al content ($\text{mg}\cdot\text{kg}^{-1}$ DB)
Fruit pulp	Angola, blend	2021	9175 ± 384^{ab}
		2022	7738 ± 21^{bc}
		2023	$7370 \pm 41^{**}$
	Huambo	2022	8304 ± 292^{bc}
		2023	$6297 \pm 40^{**}$
	Huíla	2022	10280 ± 136^a
Leaves	Malanje	2023	$6783 \pm 126^{**}$
			16660
			6997
Roots	Huambo		15060
			423
			1429
			10533
Soil	Malanje		10611
			15675
			51019

Mean and standard deviation ($n = 3^*$ or $n = 2^{**}$). Same letters in the last column indicate no significant difference at $p < 0.05$ (only for the samples analyzed in triplicate).

plants found in tropical areas as *Eumachia* or *Miconia* species (Metali et al., 2012; Timpone et al., 2025; Turner et al., 2021). However, it was 1.6 times higher than that measured by Baumgärtel et al. (2022) in the leaves of a closely related species (*Anisophyllea quangensis* Engl. ex Henriq.) collected in a nearby region of Angola ($7884 \text{ mg}\cdot\text{kg}^{-1}$ DB).

The results obtained for root samples ranged from 400 to over $10000 \text{ mg}\cdot\text{kg}^{-1}$ DB. Finally, for soils, the measured levels were high but corresponded to results already obtained for certain soils of the same type in tropical areas (Timpone et al., 2025).

Correlation analysis, based on samples collected in 2023 (Table 2), revealed a potential association between aluminium content in leaves and fruit pulp ($R^2 = 0.832$). A strong correlation was obtained between root and soil aluminium contents ($R^2 \geq 0.999$). However, there was no clear correlation between aluminium content in pulp and that in soil or roots. Of course, these first results need to be confirmed by supplementing the data with further measurements in more samples.

3.2. Comparison with other fruits

Common edible fruits contain low aluminium amount with most fruits between 3 and $20 \text{ mg}\cdot\text{kg}^{-1}$ DB (Table 3). Fruits that are usually grown for large-scale human consumption do not concentrate aluminium. These plant dispersal organs therefore do not accumulate this element, even when the soil contains significant amounts of it. Citrus hydroponic studies showed Al is immobilized primarily in roots and root cell walls by pectin-binding with comparatively low translocation to shoots, indicating limited movement toward aerial tissues under many conditions (Zhang et al., 2022). Experimental studies in other species likewise find the highest Al in roots and root-associated fractions (de Abreu et al., 2021). These plant-level findings support the general expectation that fruit pulp often contains less Al than root tissues.

For a given fruit, Al content can vary according to soil chemistry, agronomic practices (irrigation sources, liming, etc.), genotype and local

Table 2

Correlation table (R^2) between aluminium contents in fruit pulp, leave, root and soil samples taken in 2023.

	Fruit pulp	Leaves	Roots	Soil
Fruit pulp	1	0.832	0.021	0.029
Leaves		1	0.075	0.063
Roots			1	0.999
Soil				1

Table 3

Aluminium content in several cultivated edible fruits, expressed in dry basis (ANSES, 2025a; Bobuş Alkaya et al., 2022; Liang et al., 2019).

Fruits	Al content (mg·kg ⁻¹ DB)
Stone fruits: peach, apricot, cherry, plum	5.0–21.3
Citrus: orange, lime, lemon, grapefruit	9.5 – 18.4
Berries: strawberry, blueberry, raspberry	5.6 – 13.4
Grape	3.4 – 4.5
Tropical fruits: banana, papaya, pineapple, mango	2.5 – 8.0
Pome fruits: apple, pear	3.6 – 5.1
Watermelon	3.3

contamination. Low soil pH (acidic soils) increases Al solubility and so bioavailable Al. Raising soil pH by liming reduces exchangeable/toxic Al and shifts Al into less bioavailable forms. Tomato experiments in tropical soils showed liming lowered exchangeable Al and reduced plant uptake, and genotype responses differed accordingly (Nogueirol et al., 2015). Plant genotype and root-cell-wall chemistry strongly influence retention versus translocation. For example, in Citrus, pectin in the root cell wall preferentially binds Al and limits Al translocation to shoots; species/genotype differences in root-cell wall affinity control how much Al moves upward (Zhang et al., 2022). Other experimental works emphasize that species, cultivar/rootstock and developmental stage alter accumulation and tolerance. Some rootstocks/cultivars tolerate and sequester more Al in roots without translocating to shoots (de Abreu et al., 2021; Ofoe et al., 2023). Aluminium can also be in competition with calcium and other cations. High calcium content in roots was for instance associated with reduced Al uptake (Frankowski, 2016). Finally, comparisons between polluted and protected sites showed substantially higher plant tissue Al where soils or local emissions due to anthropogenic activities increased available Al, supporting geographic/environmental hotspots for elevated plant Al.

Nevertheless, the aluminium contents measured in loengo pulp were therefore unusual and could not be compared to well-known and well-characterized fruits. Indeed, the aluminium content of loengo pulp is at least 300 times higher in dry basis than that of standard edible fruits. However, there is very little literature available on the detailed mineral profile of endemic African wild fruits. It is therefore difficult to say whether the loengo is an exception, and it would be useful to analyze the mineral composition of other fruits collected in the same ecosystems.

3.3. Elements of toxicology and recommendations

After ingestion of foods, acidity in the stomach tends to solubilize the aluminium compounds mainly as Al³⁺. However, the pH increases in the intestine progressively that results in the formation of aluminium insoluble complexes or salts as hydroxides, which cannot be absorbed and so are eliminated in feces. This phenomenon contributes to the weak bioavailability of aluminium that is evaluated between 0.1 % and 0.3 % (ANSES, 2025b). Nevertheless, Al bioavailability does not depend only on water solubility. It can also be modulated by other compounds that are simultaneously present in the bolus and that can increase (organic acids for example) or decrease it (polyphenols for example).

After intestinal absorption, aluminium is mainly carried in blood by transferrin, a metal binding plasmatic protein (Aguilar et al., 2008). Despite being mainly eliminated through urine excretion (> 80 %), a small but significant amount of this circulating metal is able to accumulate in various tissues, especially bones, as shown by various studies on animal models. Clinically demonstrated in cases of high chronic exposure, the toxic effects of aluminium mainly affect the central nervous system (encephalopathies, psychomotor disorders) and bone tissues. However, no study has yet clearly demonstrated such effects in a standard human population exposed to aluminum solely through their regular diet (Aguilar et al., 2008).

Based on various toxicity studies and population exposure (Aguilar et al., 2008; ANSES, 2025b), EFSA set a Provisional Tolerable Weekly

Intake (PTWI) of 1 mg·kg⁻¹ body weight per week in 2008 (a sevenfold reduction from the previous PTWI established in 1990 by FAO-WHO). In 2011, JECFA revised the value established in 2008 upwards, setting the PTWI at 2 mg·kg⁻¹ body weight per week (ANSES, 2025b). This PTWI includes all chemical species of aluminium potentially present in food.

Without considering other potential sources of aluminium in the diet, calculations made for an adult weighing 60–80 kg, assuming that the average weight of a fruit is 14 g and that the mass fraction of pulp in a fruit is 55 %, show that it is not advisable to consume more than 10 loengo fruits per week. This number drops to 5 for a 10-year-old child (30 kg). These results deserve special attention when considering the data on fruit consumption provided by da Costa et al. (2025).

4. Conclusion

Based on the analysis of seven different fruit samples collected from three distinct areas over three consecutive years, this study clearly showed that *A. boehmii* is a species that hyperaccumulates aluminium. While high aluminium levels have already been described in the leaves of various tropical plant species, to our knowledge, such accumulation in edible fruit has never been reported.

As the amount of aluminium present in the edible part of the fruit is very elevated, chronic toxicity problems can be expected for regular consumers of the fruit. For populations accustomed to consuming it, special attention is required, particularly for children. In any case, it is advisable not to consume this fruit in large quantities.

Of course, in order to complete this exploratory work and to be clearer for the fruit consumption recommendation, it would be necessary to conduct further studies by increasing the number of samples and carrying out cross-checks between different laboratories. A better understanding of how the plant accumulates aluminium in its fruits would also be of great interest.

CRedit authorship contribution statement

Manuel Dornier: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft. **Betencourt Munanga:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. **Famoro João da Costa:** Data curation, Investigation, Software, Validation, Visualization, Writing – review & editing. **Adrien Servent:** Data curation, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of Competing Interest

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

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References

- Aguilar, F., Autrup, H., Barlow, S., Castle, L., Crebelli, R., Dekant, W., Engel, K. H., Gontard, N., Gott, D., Grilli, S., Gürtler, R., Larsen, J. C., Leclercq, C., Leblanc, C., Malcata, F. X., Mennes, W., Milana, M. R., Pratt, I., Rietjens, I., & Toldrá, F. (2008). Safety of aluminium from dietary intake: Scientific Opinion of the Panel on Food Additives, Flavours, Processing Aids and Food Contact Materials (AFC). *EFSA Journal*, 754, 1–34. <https://doi.org/10.2903/j.efsa.2008.754>

- ANSES (2025a). Table de composition nutritionnelle des aliments Ciqua. Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail, Maisons-Alfort (France). (www.ciqua.anses.fr).
- ANSES (2025b). *Aluminium et ses composés inorganiques. Valeurs toxicologiques de référence*, Rapport d'expertise collective, saisine 2023-MPEX-0137. Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail, Maisons-Alfort (France).
- Baumgärtel, C., Lautenschläger, T., Panzo, M. H. G., Afonso, F., Neinhuis, C., & Feger, K.-H. (2022). Metal Accumulation Properties of Eight Traditionally Utilized Nutritional Plants and Their Potential as Suitable Crops for Cultivation on Acidic Soils of the Northern Province Uíge, Angola. *Applied Sciences*, 12(2), 792. <https://doi.org/10.3390/app12020792>
- Bobuş Alkaya, G., Demirci, Ç., & Şevik, H. (2022). Aluminum in food and potential role on Alzheimer's disease of aluminum. *Turkish Journal of Engineering*, 6(2), 118–127. <https://doi.org/10.31127/tuje.846455>
- Chauhan, D. K., Yadav, V., Vaculík, M., Gassmann, W., Pike, S., Arif, N., Singh, V. P., Deshmukh, R., Sahi, S., & Tripathi, D. K. (2021). Aluminum toxicity and aluminum stress-induced physiological tolerance responses in higher plants. *Critical Reviews in Biotechnology*, 41(5), 715–730. <https://doi.org/10.1080/07388551.2021.1874282>
- da Costa, F. J., Mertz, C., Servent, A., Achir, N., Munanga, B., & Dornier, M. (2025). Physicochemical and Compositional Characterization of a Wild Fruit from the Angolan Miombo: *Anisophyllea boehmii* Engl. *Agriculture*, 15(11), 1175. <https://doi.org/10.3390/agriculture15111175>
- de Abreu, C. B., de O. Ribeiro, M., Pinho, C. S., Carneiro, C. N., de Azevedo Neto, A. D., de Souza, M. O., & de S. Dias, F. (2021). Exploratory analysis in the evaluation of stress due to aluminum presence in *Physalis angulata* L. and multielement determination by microwave-induced plasma optical emission spectrometry (MIP OES). *Environmental Science and Pollution Research*, 28(5), 5598–5608. <https://doi.org/10.1007/s11356-020-10871-4>
- Deweës, P. A., Campbell, B. M., Katerere, Y., Siteo, A., Cunningham, A. B., Angelsen, A., & Wunder, S. (2010). Managing the Miombo Woodlands of Southern Africa: Policies, Incentives and Options for the Rural Poor. *Journal of Natural Resources Policy Research*, 2, 57–73.
- Frankowski, M. (2016). Aluminum uptake and migration from the soil compartment into *Betula pendula* for two different environments: A polluted and environmentally protected area of Poland. *Environmental Science and Pollution Research*, 23(2), 1398–1407. <https://doi.org/10.1007/s11356-015-5367-9>
- Liang, J., Liang, X., Cao, P., Wang, X., Gao, P., Ma, N., Li, N., & Xu, H. (2019). A Preliminary Investigation of Naturally Occurring Aluminum in Grains, Vegetables, and Fruits from Some Areas of China and Dietary Intake Assessment. *Journal of Food Science*, 84(3), 701–710. <https://doi.org/10.1111/1750-3841.14459>
- Metali, F., Salim, K. A., & Burslem, D. F. R. P. (2012). Evidence of foliar aluminium accumulation in local, regional and global datasets of wild plants. *New Phytologist*, 193(3), 637–649. <https://doi.org/10.1111/j.1469-8137.2011.03965.x>
- Nogueirol, R. C., Monteiro, F. A., & Azevedo, R. A. (2015). Tropical soils cultivated with tomato: Fractionation and speciation of Al. *Environmental Monitoring and Assessment*, 187(4), 160. <https://doi.org/10.1007/s10661-015-4366-0>
- Ofoe, R., Thomas, R. H., Asiedu, S. K., Wang-Pruski, G., Fofana, B., & Abbey, Lord (2023). Aluminum in plant: Benefits, toxicity and tolerance mechanisms. *Frontiers in Plant Science*, 13, Article 1085998. <https://doi.org/10.3389/fpls.2022.1085998>
- Timpone, L. T., Bacci, L. F., Goldenberg, R., & Habermann, G. (2025). Aluminum accumulation in *Miconia* species of the Atlantic rainforest: Phylogenetic insights and soil interactions. *Trees*, 39(3), 1–17. <https://doi.org/10.1007/s00468-025-02623-z>
- Turner, I. M., Brearley, F. Q., Trethowan, L. A., & Utteridge, T. M. A. (2021). A survey of aluminium accumulation in *Eumachia* (Rubiaceae). *Edinburgh Journal of Botany*, 78, 1–10. <https://doi.org/10.24823/EJB.2021.335>
- Zhang, H., Li, X., Lin, M., Hu, P., Lai, N., Huang, Z., & Chen, L. (2022). The aluminum distribution and translocation in two citrus species differing in aluminum tolerance. *BMC Plant Biology*, 22(1), 93. <https://doi.org/10.1186/s12870-022-03472-5>