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Evaluation of Drying Methods and Leaf Age on the Nutrient Composition of Orange-fleshed Sweetpotato (*Ipomoea batatas* L.) Leaves

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Abstract. **Sweetpotato leaves are considered highly nutritious, serving as an excellent source of minerals, vitamins, and other functional phytochemicals. Their tender, tasteful tips make them a versatile vegetable, suitable for daily consumption either fresh or dried. The nutritional composition of leafy vegetables varies significantly based on factors such as leaf age and drying methods, which can impact their overall health benefits. Therefore, this study aimed to determine the effects of leaf age and drying methods on the nutritional content of orange-fleshed sweetpotato leaves. The experiment followed a completely randomized design with a 4 × 3 factorial arrangement, replicated three times. Four levels of leaf age (upper, middle, lower, basal) and three drying methods (sun-, shade-, oven-drying) were applied as treatments. Significant interactions between leaf age and drying methods were observed for ash content, crude protein, fat, neutral detergent fiber (NDF), calcium, magnesium, potassium, phosphorus, zinc, manganese, and copper. Ash, calcium, and magnesium contents increased with leaf age, with the highest ash content recorded in basal leaves dried in the shade, whereas the lowest was found in shade-dried upper leaves. Conversely, crude protein content was higher in shade-dried upper leaves, sun-dried upper leaves, sun-dried middle leaves, and shade-dried middle leaves. The study indicates that the consumption of shade-dried middle and upper leaves can contribute to addressing food security and promoting the intake of nutritious vegetables due to their higher crude protein content and lower sodium levels.**

Sweetpotato (*Ipomoea batatas* L.), a dicotyledonous plant from the Convolvulaceae family, is an important tuberous root (and potentially leafy vegetable) crop cultivated mostly under mild temperate, tropical and subtropical conditions. It has high adaptability to different soil types and climatic conditions, exhibits drought tolerance, and achieves good productivity in short durations (Neela and Fanta 2019; Nguyen et al. 2021; Oloniyo et al. 2021). It is a multipurpose plant used as food for humans, serving as a secondary staple food or added to meals to enhance the nutritive value (Sapakhova et al. 2023).

Although sweetpotato plants are primarily valued for their tubers, they are also considered as leafy vegetables because their leaves are used as potherbs. The leaves have high contents of essential elements such as magnesium, phosphorus, calcium and potassium. They also contain high amount of vitamins such as B1, B2, B3, B5, B6, biotin, β-carotene, and vitamins C and E per unit of biomass, making them highly nutritious (Nguyen et al. 2021). Moreover, sweetpotato leaves are known to have significant amounts of various bioactive compounds, such as antioxidants, anticancer bioactivities, anti-mutagenic activities, immune modulators and hepato-protective properties (Ayeleso et al. 2016; Nguyen et al. 2021; Oloniyo et al. 2021).

Studies show that new biofortified orange-fleshed sweetpotato varieties (OFSP) have high yield potential and do well under suboptimal conditions. These cultivars are highly rich in carotene (provitamin A) and vitamin A (Van Jaarsveld et al. 2005). Therefore, the crop is being introduced to the Eastern Cape Province to address vitamin A deficiency (Laurie and Faber 2008).

To extend the availability of leafy vegetables, their preservation has been practiced for many years. The drying method has been the most effective method to extend their shelf life. Dried vegetables are considered a solution to the seasonality of leafy vegetables, ensuring a continuous supply of nutritious food to support a healthy lifestyle. Shade- and sun-drying are the two commonly used traditional methods for this purpose. The concentration of nutrients and other phytochemicals such as antioxidants can be affected by subjecting the leaves to the drying method (Garba and Oviosa 2019).

Leaf dry matter and carbohydrates are some of the leaf metabolites that increase with leaf age and younger leaves have more active metabolism than older leaves. In addition, leaf age may determine nutrient compositions while they may be influenced by soil nutrient availability (Ji et al. 2021). The different mineral and metabolite contents in the leaves may differently respond to the drying methods. Drying methods including sun and shade drying have mostly been used to preserve the leaves for later use and to increase their shelf life. Modernization of these techniques has brought in the use of freeze drying, which preserves most of the biochemical composition of the samples such as vegetable leaves, and oven drying, which may affect the contents and forms of volatile compounds in the samples (Oni et al. 2015). Microwave-vacuum, hot-air, and vacuum freeze-drying methods have been studied for drying sweetpotato leaves; however, there are limited studies on the sun-, oven-, and shade-drying methods concerning the nutritive age of sweetpotatoes. Therefore, the current study aimed to determine the effect of leaf age and drying method on the nutritional content of OFSP. It is hypothesized that there is an age at which OFSP leaves are most nutritious and an optimal drying method that extends their shelf life leaves while maintaining their nutritional value.

Materials and Methods

Experimental site. The study was conducted in the summer seasons of 2018 and 2019 at the Research Farm of the University of Fort Hare, Alice, in the Eastern Cape Province of South Africa. The research area is situated at a latitude and longitude of 320°78′61″S and 260°84′46″E, respectively, and an elevation of 506 m above sea level. The study site receives an annual average rainfall of 535 mm and the average temperature of the area per year is 18.7 °C. Figure 1 shows the average monthly rainfall and temperature for the duration of the experiment.

Planting material and cultural practices. OFSP, cultivar Bophelo (tested and released by the South African Agricultural Research Council), was grown under standard conditions at the Research Farm of the University of Fort Hare. Stem cuttings were planted on ridges 30 cm by 1.5 m apart. During planting, 400 kg/ha of 2–3–4 (30) fertilizer was incorporated in the soil before planting the sweetpotato vines. Then 25 kg/ha N top dressing was applied 4 weeks after the first application and the second top dressing of 25 kg/ha N was applied four weeks after the first. The plants were irrigated with a sprinkler irrigation system as needed. Weeding was also done when needed using mechanical means, such as a walk-behind tractor, hand weeding, and garden hoeing. Eighty days after planting, when there was enough vegetative growth (the ground was covered), vines with a minimum of 12 healthy green leaves per vine were selected randomly from the field. The leaves were then taken to the laboratory to be separated according to different age groups as per the treatments allocated.

Experimental design and layout. The experiment was conducted as a 4 × 3 (four leaf

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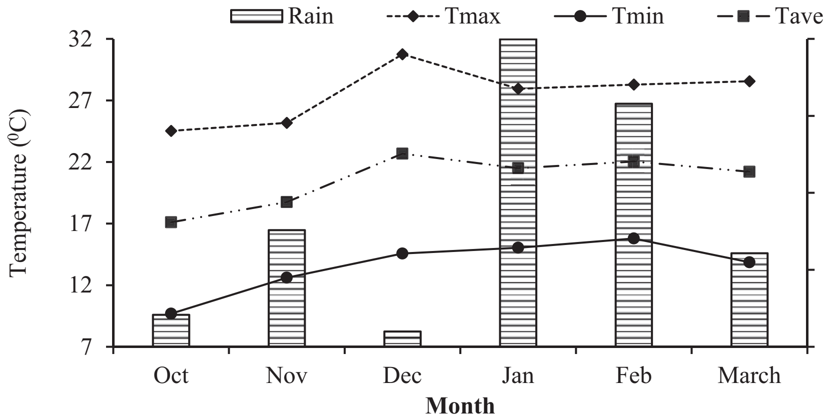

Fig. 1. Average monthly rainfall, minimum (Tmin), maximum (Tmax), and average (Tave) temperature readings over the study period of Oct 2018 to Mar 2019.

age group × three drying methods) factorial experiment and laid out in a complete randomized design (CRD) replicated three times. The leaves were separated according to age groups. Four leaves were selected per age group or position from a randomly selected vine. The age group used as treatments (based on their position on the vines) were the upper (distal/youngest), middle, lower (proximal/oldest), and basal leaves. The sampled leaves were immediately weighed to determine fresh leaf mass.

Sample preparation. The plants were harvested 80 d after planting. Leaves were cut from the main branches and separated according to the different treatments as described in the previous section. A minimum of three leaves were selected per treatment. Leaves were washed thoroughly three times with tap water to remove all dust particles. After washing, the leaves were allowed to air dry the water on their surface by spreading them on a paper towel on a tabletop.

All leaf samples were dried to a constant weight through the various drying methods, including shade drying for 10 d, sun drying for 4 d, and oven drying for 1 h at 65 °C. In all three drying methods, the leaves were considered completely dry when they were brittle, crisp, and easy to crush. The dried samples were milled into powder with a Retsch Cross Beater Mill SK 100 [Monitoring and Control Laboratories (Pty) Ltd, Parkhurst, South Africa] and sifted with a 1-mm sieve. The powder was stored in zipper polythene plastic pockets until nutrient analysis (Mbah et al. 2012).

Data collection. Moisture, ash, and fat contents were determined using the standard procedures based on the recommendations by the Association of Official Chemists of 1975 (Baur and Ensminger 1977). Thus, the determination of ash involved the burning of samples in a muffle furnace at 550 °C for 24 h. Crude fat was determined using exhaustive Soxhlet extraction of a known weight of a sample with petroleum ether (boiling point 40 to 60 °C) and methanol mixed in a 1:1 ratio. The crude fiber was determined by boiling a fat and moisture-free sample (of ∼1 g) with 200 mL of a 1.25% sulphuric acid for 30 min and then with a 30-min boiling in 200 mL with a 1.25% sodium hydroxide solution. The residue was then filtered and dried, and the loss in weight on ignition was calculated as the crude fiber content of the material sampled (Eq. [1]):

$$\%fibre = \frac{loss\ of\ weight\ on\ ignition}{weight\ of\ sample\ used} * 100 \qquad [1]$$

Crude protein was analyzed using macro-Kjeldahl nitrogen method, where the crude protein was determined by multiplying the value of nitrogen by 6.25 to give the percentage of crude protein (Eq. [2]):

$$\%\ crude\ protein = \frac{(blank - titre\ value\ (ml)) * 1.401 * 6.25 * 20 * Normality\ of\ NaOH}{sample\ weight\ (g)} * 100 \qquad [2]$$

Carbohydrate content was determined by subtracting the total crude protein, crude fiber, ash, and fat from the total dry matter. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed by the methods described by Goering and Van Soest (1970). Micro- and macro-elements were determined after digesting the leaf samples using aqua regia [3:1 v/v hydrochloric acid (37%): nitric acid (55%)] in a MARS 5 microwave digester (CEM Corporation, Matthews, NC, USA). Minerals were thereafter determined using the inductively coupled plasma optical emission spectroscopy method (Varian Inc., Middelburg, The Netherlands).

Statistical analysis. Data collected were subjected to analysis of variance using RStudio Version 4.0.1. Where a significant difference was detected, the variables mean were separated using Fisher's protected least significant difference ($P < 0.05$).

Results

Evaluation of proximate analysis on the OFSP samples. This study determined the proximate analysis of the plant samples (Fig. 2), which included moisture content, ash, fat, ADF, NDF, and crude protein. The results of the moisture content analysis indicate insignificant differences among the means of the treatment methods. The highest moisture content was noted in the basal-shade dried treatment (8.98%), followed by the lower-shade dried treatment at 8.34%. Conversely, the lower-oven-dried treatment 6.06% showed a significantly lower moisture content.

The results in Fig. 2 also show that ash content in shade-dried basal leaves was significantly higher at 18.26% compared with other drying methods and leaf age groups. In contrast, the ash content in shade- and sun-dried upper leaves measuring 11.84 and 10.16%. Oven-dried leaves showed relatively higher levels of fat content across the different age groups. Inversely, sun-dried leaves had the lowest fat content across all age groups, with the lowest levels recorded in the lower leaves. The highest fat content was observed in the oven-dried lower-leaves treatment combination, followed by the basal-oven dried and upper-oven dried leaves, although no significant differences ($P > 0.05$) were found among these treatment combinations.

The results indicate that the concentrations of oven-dried crude protein were consistent across different leaf ages. However, sun- and shade-dried leaves exhibited similar concentrations within each age group, with the highest levels observed in the upper leaves, recording 27.02% and 27.75%, respectively. These concentrations decreased as the plants aged. Furthermore, the study revealed no significant differences in the concentrations of both ADF and NDF across the various treatments.

Nutrient composition response to drying methods and leaf age. This study investigated the effects of drying methods and leaf age on calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), phosphorus (P), zinc (Zn), copper (Cu), and manganese (Mn) elements, as presented in Figs. 3 and 4. Sun-drying produced relatively similar K concentration across all age groups. The highest K concentration was observed in the upper leaves, with oven- and shade-dried upper leaves had 5.53 mg/kg and 4.58 mg/kg, respectively. Na, Mg, and Ca concentrations increased progressively with leaf age across all drying methods. The potassium-to-calcium and magnesium (K/Ca+Mg) ratio was significantly higher in

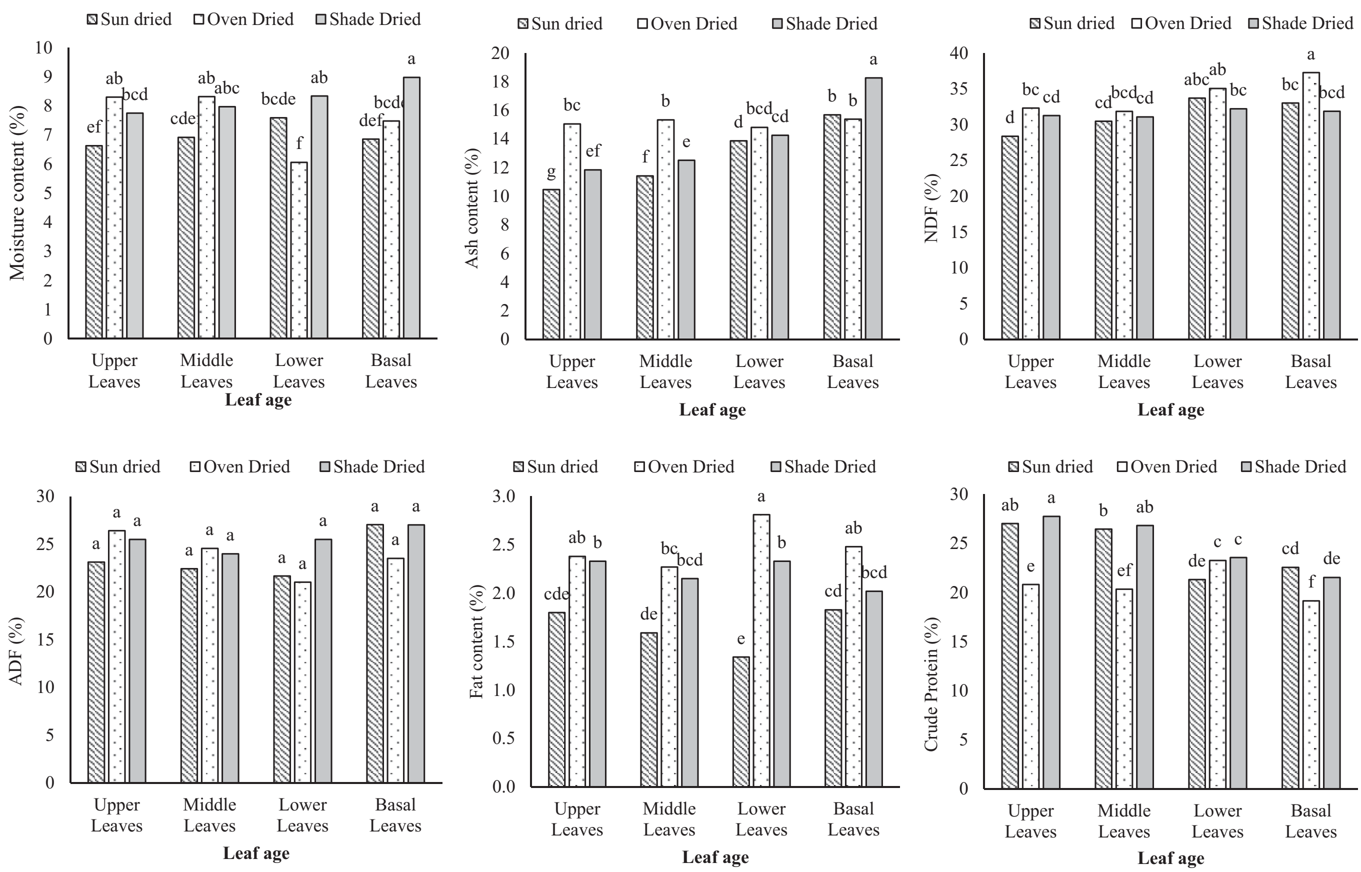

Fig. 2. Approximate analysis of orange-fleshed sweetpotatoes.

the upper leaves for all drying treatments. A similar trend was observed for phosphorus content, with the sun-dried upper leaves containing 0.39 mg/kg compared with 0.22 mg/kg in the basal leaves.

Zn levels as shown in Fig. 4, were the highest in the upper sun-dried leaves at 21.65 mg/kg and decreased with leaf age to 15.5 mg/kg in the basal leaves. There was no significant difference in Cu content among the treatments for both leaf age and drying method. However, the upper and middle oven-dried leaves measured the lowest Cu concentration of 4.5 and 4.8 mg/kg, respectively, compared with 7.58 mg/kg of the upper shade-dried leaves. Mn concentration followed a similar pattern, being lowest in younger leaves and peaking in basal leaves, indicating Mn's immobility in plants as it accumulates in older tissues. The lower sun-dried leaves recorded 277.1 mg/kg Fe content, which was the highest concentration among the treatments, whereas upper oven-dried leaves had the lowest concentration at 115 mg/kg.

Discussion

This study explored effects of leaf age and drying methods on the nutritional composition of OFSP leaves. Proximate analysis (Fig. 2) showed that oven drying significantly reduced moisture content, particularly in older leaves, due to controlled temperature and drying duration. The reduced moisture in older leaves suggests fewer metabolic reactions and readiness for senescence. The low moisture content in the older leaves is an important signal for a longer preservation period for the leaves (Okunlola et al. 2019).

Ash content, reflecting mineral content in the plant, showed increased composition with leaf age (Fig. 2), consistent with studies on nutrient composition of plants (Atalay et al. 2017; Falade 2016; Oduntan et al. 2012; Ramsumair et al. 2014). Oven-dried samples retained more fat than the sun- or shade-dried samples, likely because of controlled conditions. Shade drying yielded better results than sun drying. Less fat content can be advantageous when consuming sweetpotato leaves because they have the potential to contribute to cardiovascular diseases (Okunlola et al. 2019). The study also showed that oven-dried and older leaves had lower crude protein levels than other drying methods (Ramsumair et al. 2014). Nitrogen and amino acids are typically found in higher concentrations in younger and developing leaves because they are also mobile. A similar study on tomatoes found that crude protein concentrations were high in the upper leaves during their development stage but started to decrease during maturity (Yu et al. 2023). These findings are consistent with the findings of the current study.

Calcium and magnesium concentrations were significantly higher in mature (basal) leaves compared with younger leaves (Fig. 3). This indicates a correlation between leaf maturity and increased Ca and Mg accumulation. Because both nutrients are not redistributed after being deposited into leaf vacuoles, they continue to accumulate over time, resulting in higher concentrations in mature leaves compared with younger leaves (Gilliham et al. 2011). Because of the mobility of K within plants, K levels were higher in younger leaves and decreased with age (Alakali et al. 2015). This trend was consistent across most treatments, although some showed no significant differences, likely because K is translocated to areas of higher demand during plant growth. Na content, although not essential for most plants, can be beneficial in potassium-deficient conditions (Maathuis 2014). Sodium content was found highest in basal sun-dried samples, and the lowest was in upper-oven dried leaves. This reduced Na concentration in younger leaves could have been influenced by environmental effects such as water distribution during the growth of the plants as it is also a mobile element (Adediran et al. 2015; Musa et al. 2011). This study also revealed significantly high P content in upper shade-dried and sun-dried leaves compared with basal leaves; P is another essential nutrient that is redistributed to young actively growing tissues (Ahmad et al. 2012).

Although all leaf ages offer essential nutrients, the findings suggest that older leaves may provide higher nutritional value and that their lower moisture content could enhance preservation, extending the shelf life of the leaves. Drying methods have been found to significantly impact the nutritional composition of food sources. For instance, crude protein content is affected by heat-based drying methods. In contrast, shade drying in place of

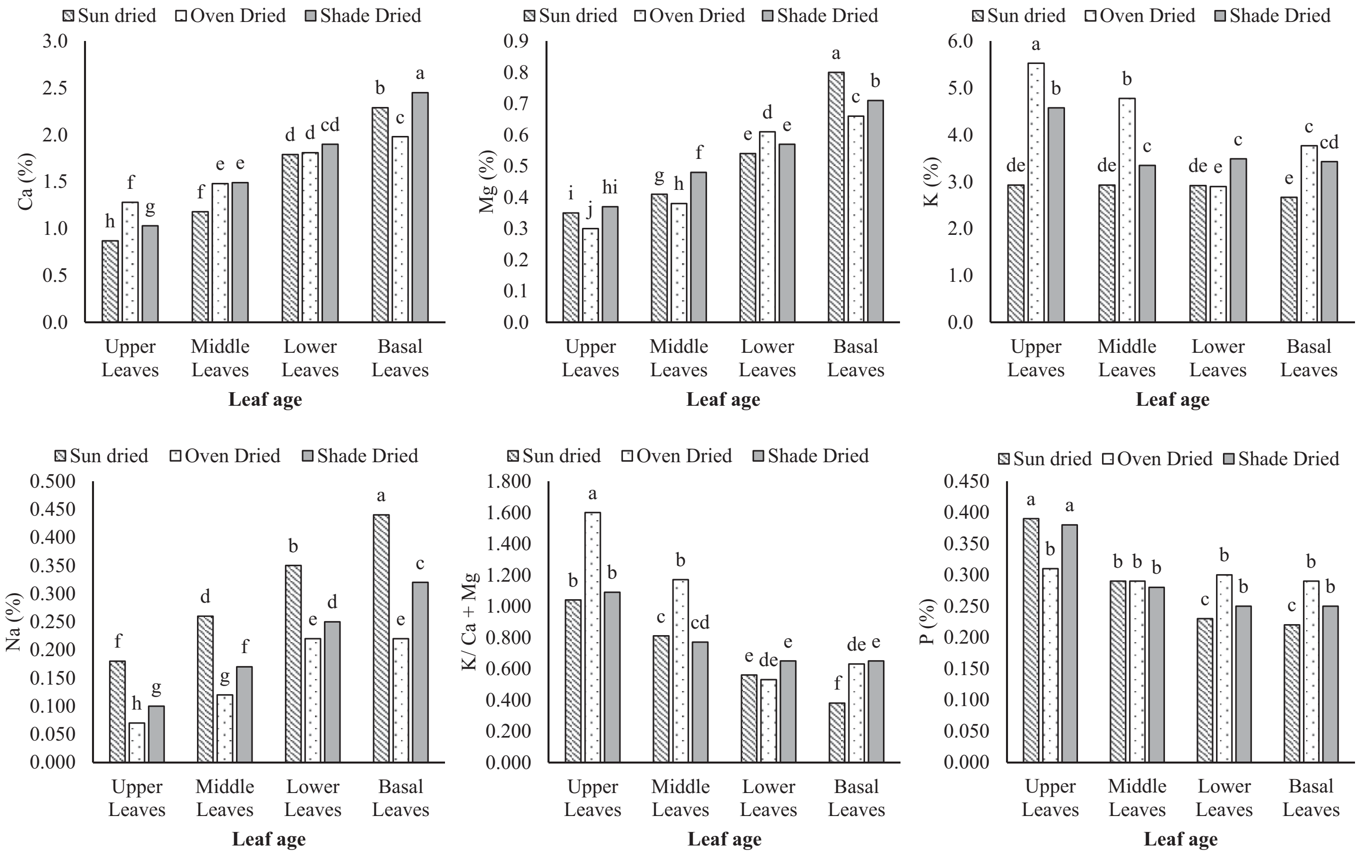

Fig. 3. Orange-fleshed sweetpotatoes Ca, Mg, K, Na, K/ca+Mg, and P composition as affected by leaf age and drying methods.

freeze drying can be recommended as a necessary approach to preserve a higher nutrient content during the drying process (Wang et al. 2024). These results align with findings from other studies, further highlighting the invaluable benefits of OFSP as a rich source of essential nutrients and vitamin A (Laurie et al. 2018). This study demonstrates that OFSP leaves can be promoted as a valuable vegetable supplement, contributing to the United Nations Sustainable Development Goal to "end hunger, achieve food security, improve nutrition, and promote sustainable agriculture," due to their rich nutritional composition.

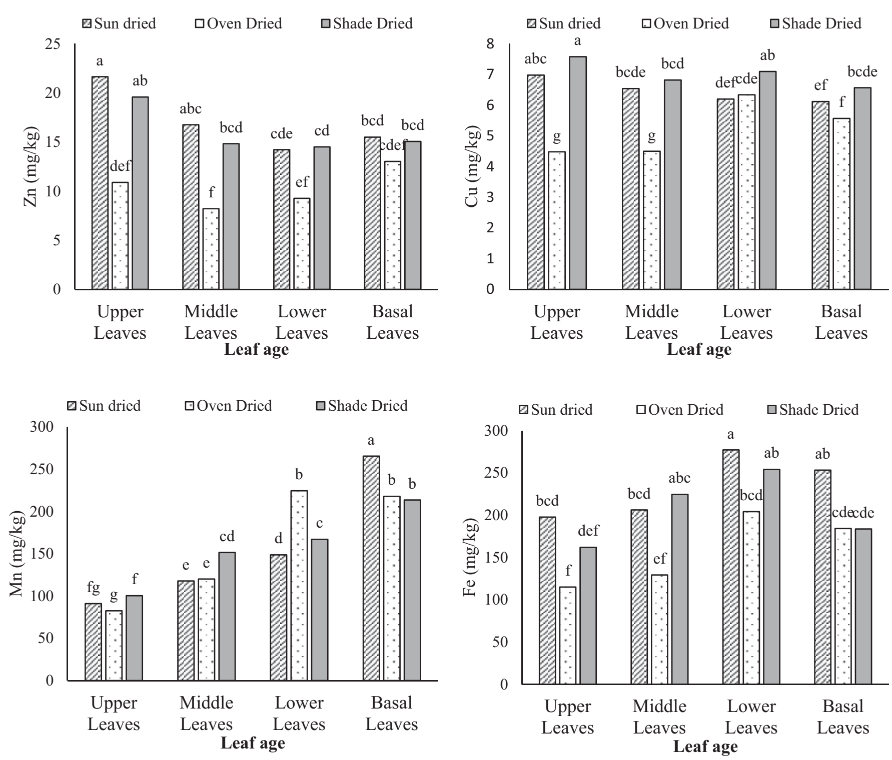

Fig. 4. Zn, Cu, Mn, and Fe concentration on orange-fleshed sweetpotatoes leaves.

Conclusions

In conclusion, this study demonstrates significant relationships among leaf age, drying methods, and the nutrient composition of OFSP leaves. Younger leaves were richer in crude protein and Zn, whereas older leaves contained higher levels of ash, Ca, and Mn. Shade drying preserved more Cu, sun drying resulted in higher Na and Fe levels, and oven drying was most effective for reducing moisture content while retaining K and Mg. These findings show the important role of leaf maturity and drying methods in maximizing available nutrients in OFSP leaves, with important implications for agricultural practices and human nutrition.

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