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Effect of drying methods on the nutritional and anti-nutritional quality of African nightshade (*Solanum* sp.)

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Abstract

African nightshade (ANS) is a luminary food plant, considered a cheap and potential dietary source for micronutrients and bioactive compounds. This study evaluated the effects of drying techniques on nutritional (minerals & vitamin C) and anti-nutritional (oxalates & phytate) contents of *Solanum scabrum* (SS) and *S. villosum* (SV). The study employed three methods of drying; indirect solar drying (ISD), mixed solar drying (MSD), and open sun drying (OSD). Furthermore, blanching (85 °C, 2 min) with and without 3% NaCl were used as pre-treatments. Results showed that the ISD method retained more vitamin C in a range of 14.76% - 19.2% in both SS and SV leaves. The ISD was the most effective method in Ca (92.90%, 96.57%), Fe (77.88%, 71.54%), and Zn (86.94%, 90.09%) retention for both SS and SV leaves, respectively. On the other hand, all drying methods significantly reduced the oxalate and phytate content. The effect of pre-treatment methods on nutrient retention and anti-nutrients remaoval was also recorded. Results showed that ISD to be the best method for vitamin C and minerals retention and anti-nutrient reduction. Therefore, ISD can be a suitable method for preserving ANS while retaining nutrients and reducing anti-nutrients.

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Introduction

African nightshade (ANS) is among the African indigenous vegetables, substantially contributing to nutritional and pharmacological benefits (Traoré *et al.*, 2017; Kamga *et al.*, 2013). Like other indigenous vegetables, ANS can grow naturally or be cultivated in gardens/farms (Gockowski *et al.*, 2003; Ojiewo *et al.*, 2013). *Solanum villosum* (SV) and *Solanum scabrum* (SC) are among the commonly available ANS species in Tanzania. Other than being used as a food source, ANS is considered a cash crop, contributing to income generation to the local communities.

Fresh ANS contains higher moisture contents, accelerating microbial growth and senescence, leading to postharvest losses (Constant *et al.*, 2016). The postharvest losses of leafy vegetables range from 30% to 50% in sub-Saharan Africa (Gustavsson *et al.*, 2011; Sagar *et al.*, 2010; Tumwet *et al.*, 2014). Nevertheless, small-scale farmers face quantitative and qualitative losses in the value chain. Due to the high perishability of ANS, proper postharvest handling is highly required to extend the shelf-life (Patricia *et al.*, 2014). Cooking of ANS leaves, and tender shoots is common to improve the organoleptic properties and reduce anti-nutrients. The preferable cooking methods include frying, steaming, or boiling (Ojiewo *et al.*, 2013; Yuan *et al.*, 2018). In Tanzania and Kenya, the main dishes accompanied by ANS are cereal staples such as Ugali (Ekesa *et al.*, 2009; Ochieng *et al.*, 2018; Oluoch *et al.*, 2012).

Besides, processing and preservation of ANS is still a challenge in sub-Saharan Africa, whereas direct sun drying is the standard preservation method, with fermentation being less common (Ofor and Ibeawuchi, 2010; Ukegbu and Okereke, 2013).

The sun-drying method causes deterioration of micronutrients since the product is exposed to direct sunlight with higher chances of contamination (Constant *et al.*, 2016; James and Matemu, 2016). However, drying technology improves storage at low moisture content, organoleptic quality, and extends shelf life. It also aids micronutrient retention, reduces food bulkiness, transportation costs, and promotes food and nutrition security (Hasan *et al.*, 2019; Sagar *et al.*, 2010). Solar drying has been shown to retain micronutrients and decrease seasonality on raw vegetables (Chege *et al.*, 2014). Direct, indirect, and mixed solar driers are the typical modern drying techniques (Pardhi *et al.*, 2013). Nevertheless, their effect on nutrient retention and anti-nutrients removal in ANS is not well known. Therefore, this study aimed to evaluate the impact of the open sun, indirect solar, and mixed solar drying methods in retaining vitamin C, minerals (Ca, Fe,mg, and Zn) and reduction of anti-nutrients (oxalates and phytate) in *S. villosum* and *S. scabrum,* respectively.

Methods and materials

Sample collection

Fresh *S. scabrum* (SS) and *S. villosum* (SV) leaves were obtained from Arusha Urban and Meru districts, Arusha region. ANS was harvested at their maturity stage during the fourth to fifth weeks after planting. The harvesting was conducted in the morning from 06:30 am to 08:00 am EAT. The harvested ANS leaves were packaged in the perforated plastic crates and immediately transported to thenm-AIST food processing unit for sorting, washing, and de-stalking.

Pre-treatments of Solanum sp.

Before drying, SS and SV leaves were pre-treated by blanching with (WBS) or without 3% NaCl (WB). Briefly, about 500 g of the fresh leaves were blanched at 85 °C for 2 min with or without salt separately, followed by immediate cooling in ice water for both treatments (Xiao *et al.*, 2017). Water was drained, and the pre-treated leaves were ready for drying. For control, no pre-treatment was done on fresh SS, and SV leaves, i.e., un-blanching (UnB).

Drying of Solanum sp. leaves

The pre-treated (UnB, WB, and WBS) SS and SV leaves were dried using either an open sun (OSD), or mixed solar (MSD), or indirect solar driers (ISD) separately. The drying started at 09:30 am to 5:30 pm EAT with an average drying rate of 28.43 g/h and 24.44 g/h-SS, and SV for OSD; 56.19 g/h-SS, 60.01 g/h-SV for MSD, and 23.83 g/h-SS and 24.31 g/h-SV for ISD respectively.

Frequently turning of the samples was done to allow an even heat distribution and equal drying time. The temperature and relative humidity were recorded using a temperature and relative humidity data logger (PCE HT 71N, China). For ODS, samples were removed from the driers at night to avoid moisture pick-up as the relative humidity increases. The dried SS and SV samples were collected after reaching the set limit for moisture contents measured using the Oven drying method (AOAC, 1990). The dried samples were stored in a dark, cool place for further analyses.

Moisture Content Determination

The Oven drying method determined the moisture content of fresh and dried SS and SV leaves (AOAC, 2000). A 5 g of fresh and dried samples were placed on dry and labeled moisture dishes. The samples were heated in Oven (DIN EN60529-IP 20, Germany) at 105 °C for 24 h. The samples were removed and cooled in a desiccator before being re-weighed. The moisture content was calculated as per the below formula;

$$\text{Moisture contents} = \frac{W_I - W_2}{W_1} \times 100$$

Where W_1= Weight of SS or SV before oven drying

W_2 = Weight of SS or SV after oven drying.

Vitamin C determination

The vitamin C from the fresh and dried SS and SV was evaluated as total ascorbic acid (Kapur *et al.*, 2012). Five grams of fresh or dried samples were homogenized with 25mL of 3% Meta-phosphoric acid-8% acetic acid solution (Loba Chemie Pvt. Ltd, India). The mixture was centrifuged at 4000 rpm for 15 min (Eppendorf. AG, Germany) and filtered with Whatman paper no. 1 (Johnson Test Papers Ltd, UK). Four milliliters of extract were added in 0.23mL of 3% bromine water (Bio-Chem Laboratory, USA), followed by 0.13mL of 10% Thiourea (Loba Chemie Pvt. Ltd, India). After that, 1mL of 2,4-Dinitrophenylhydrazine solution (BDH Lab. Chem. Group, England) was added. The mixture was heated at 37 °C for 3 h in a water bath (Constant thermostat water tank, XMTE-205, China), cooled in an ice bath (Icemaker S/N14728341, China) for 30 min. Then 5mL of chilled 85% Sulphuric acid solution (Loba Chemie Pvt. Ltd, India) was added to a cooled mixture. The resulting red solution's absorbance was measured at 521nm (UNICO Spectrophotometer, USA). The total ascorbic acid content was calculated from the calibration curve of the Ascorbic acid standard (Merck Chemicals, USA) and expressed asmg/100g (dry basis).

$$\text{Vitamin C} = \frac{Co*Df}{Ws*10}$$

Where Co = Concentration from the graph; Df = Dilution factor; Ws = Weight of sample

Minerals Determination

Dry ashing at 600°C was performed in a Muffle furnace (Thermal Scientific, Germany) for 5 h using 5g of fresh and dried SS and SV leaves on a clean porcelain crucible (AOAC, 1990). The starting temperature was 550°C and gradually increased to 600°C at a rate of 50°C/h. The ash obtained was digested with 10% Hydrochloric acid (Loba Chemie Pvt. Ltd, India) and filtered with Whatman filter paper no. 41 (Fisher Scientific, UK) into a 25mL flask, and the volume made to the mark using distilled water. The mineral (Ca, Fe,mg, and Zn) content was determined using Atomic Absorption Spectrophotometer (Thermo Scientific iCE 3300, UK). The absorption wavelength for Ca, Fe,mg, and Zn were set at 422.6nm, 248.1nm, 285.1nm, and 213.6nm, respectively. The mineral in each sample was calculated by the formula below;

$$\text{Mineral conc.} \frac{\text{mg}}{100\text{g}} = \frac{(\text{Graph conc x dilution Factor})}{(\text{Weight of samplex10})}$$

Anti-nutrients Determination

Oxalate content

The oxalate content was evaluated according to the Kandonga *et al.* (2019) method with some modification. Briefly, 1g of fresh or dried leaves was mixed with 75mL of 3M Sulphuric acid solution (Loba Chemie Pvt. Ltd, India) and stirred (MR Hel-Standard, Germany) for 1h. The mixture was centrifuged at 4000 rpm for 15 min (Eppendorf. AG, Germany) and filtered using Whatman filter paper no. 1 (Fisher Scientific, UK). Twenty-five milliliters of the filtrate was titrated against 0.05 M of Potassium permanganate (Dentex Industry Ltd, Kenya), while

hot (90°C) until pale pink color appeared and persisted for at least 30 secs. The oxalate in the samples was calculated and expressed inmg/100g (dry basis) by considering 1mL of 0.05M Potassium permanganate equivalent to 2.2mg of oxalate (Agbaire and Management, 2011; Jonathan and Funmilola, 2014).

Phytate content

The phytate quantification in fresh or dried SS and SV was done according to Mwanri *et al.* (2018), with slight modifications. Concisely, 0.5 g of grounded leaves was added in 12.5mL 3% Tri-chloroacetic acid (Loba Chemie Pvt. Ltd, India), stirred by orbital shaker (Thermo Scientific, USA) for 45 min, and centrifuged at 4000 rpm for 15 min (Eppendorf AG, Germany). To a 10mL of the supernatant, 4mL of ferrous chloride solution (Loba Chemie Pvt. Ltd, India) was added by lowering rapidly from the pipette. The content was then heated in a boiling water bath (WBH-200, Germany) for 45 min, cooled, and centrifuged at 2000 rpm for 15 min (Eppendorf AG, Germany). The precipitate was washed twice by dispensing well in 12.5mL of 3% Tri-chloroacetic acid solution, heated in boiling water bath for 10 min, centrifuged, and washed with water repeatedly. The precipitate was dispersed in 5mL of water and 3mL of 1.5 N Sodium hydroxide (Loba Chemie Pvt. Ltd, India) with mixing. The volume was brought to approximately 30mL with distilled water and then heated in a boiling water bath (WBH-200, Germany) for 30 min. The precipitate was filtered through a moderately retentive Whatman filter paper no. 2 (Fisher Scientific, UK). The residue was washed with 70mL hot water, and filtrate discarded; dissolved the precipitate from the paper with 40mL hot 3.2 N Nitric acids (Loba Chemie Pvt. Ltd, India). The filter paper was washed with several portions of distilled water and collected in the same flask taking care not to exceed 100mL. The flask was cooled at ambient temperature and diluted to volume with water. An aliquot of 5mL was diluted to 100mL mark and withdrawing 0.5mL of the diluted sample, added with 7.5mL distilled water and 2mL of 1.5 M Potassium thiocyanate (Loba Chemie Pvt. Ltd, India). The absorbance was taken at 470nm within 1 min; phytate content calculated using the formula below;

$$\text{Phytate content in}\frac{\text{mg}}{100\text{g}} = \frac{(\text{C} \times \text{E} * \text{DF} * 100)}{(\text{S} \times \text{Av})}$$

Where; C = Phytate concentration from standard graph (mg/mL); E = Total extraction volume (12.5mL); D.F = Dilution factor (0.05); S = Analytical sample taken (g); and Av = Analytical volume (10mL).

Data Analysis

The results of fresh and dried samples were organized by Microsoft excel 2010 for descriptive statistics. The data were analyzed using the R statistical package (R Development Core Team, Version 3.0.6, Vienna, Austria) for two-way analysis of variance (ANOVA) to determine the differences and interactions between the processing methods with various parameters. Means were separated by post hoc pair-wise test (Turkeys Honest Significant Difference) at $p<0.05$. The differences were considered statistically significant at $p < 0.05$.

Results and discussion

Effect of drying methods on the moisture content

Drying of vegetables removes the moisture to extend shelf life hence the preservation effect. Table 1 presents the moisture content of both fresh (FO) and dried SS and SV leaves. Fresh SS and SV leaves had the highest moisture content of 87.03% ± 0.17 and 84.06% ± 0.4, respectively. This amount agreed to the study done by Nnamani *et al.*, 2009 and Traoré *et al.*, 2017 on *S. scabrum* Mill, which reported the moisture contents to be 87.13 ± 1.39%. A significant moisture content reduction was recorded in both dried SS and SV leaves. Conversely, all drying methods substantially reduced moisture content with ISD recording a range of 8.58% to 11.96% for SS and 8.61% to 10.69% for SV, respectively. Further, for MSD, the moisture content ranged between 7.64% to 10.13% for SS and 6.37% to 9.16% for SV, respectively. Also, for OSD, the moisture content was between 7.96% - 8.98% in SS and 8.38% - 9.96% in SV. Generally, all dried samples, regardless of pre-treatment and drying methods, attained recommended moisture content for leafy vegetables.

Similarly, Traoré *et al.* (2017) reported a reduction in moisture content of black nightshade to 11.82 ± 3.5% under shade drying, 6.47 ± 1.24% under cabin drying (60 °C), and 7.38 ± 3.84 under cabin drying (50 °C), which agrees to the findings from this study.

Table 1. Effect of drying methods on the moisture content of SS and SV leaves.

African nightshade	Drying methods	Pre-treatment methods	Moisture (%)
S. scabrum (SS)	ISD	FO	87.03 ± 0.17
		UnB	8.58 ± 0.00
		WB	9.52 ± 0.00
		WBS	11.96 ± 0.00
	MSD	UnB	7.64 ± 0.00
		WB	9.74 ± 0.11
		WBS	10.13 ± 0.11
	OSD	UnB	7.96 ± 0.00
		WB	8.63 ± 0.00
		WBS	8.98 ± 0.01
S. villosum (SV)	ISD	FO	84.06 ± 0.40
		UnB	8.61 ± 0.00
		WB	9.82 ± 0.00
		WBS	10.69 ± 0.00
	MSD	UnB	6.70 ± 0.00
		WB	9.16 ± 0.01
		WBS	6.37 ± 0.00
	OSD	UnB	8.38 ± 0.10
		WB	9.96 ± 0.00
		WBS	8.98 ± 0.01

Means ±SD (n=3). UnB: Unblanched sample; WB: Water blanched; WBS: Water blanched with NaCl.

A study by Yakubu *et al.* (2012) reported higher moisture content of *Vernonia amygdalina* blanched with salt. Nevertheless, variation in moisture content might have been contributed by differences in leaf size, with large and broader leaves in *S. scabrum* with thin and small size, leaves in *S. villosum*. Furthermore, farming location and fertilizers use and abuse within the varieties may contribute to the differences. According to Uusiku *et al.* (2010), agronomic reasons, including differences in the vegetables' harvesting time and maturity stages, may result in moisture content variations. The moisture content of all dried SS and SV leaves was < 13%, recommended for safe storage of dried vegetables for six months and above without deteriorating at ambient temperature (Sahar *et al.*, 2015; Seidu *et al.*, 2012).

Effect of drying methods on vitamin C retention

Table 2 shows the vitamin C content of both fresh and dried SS and SV leaves. The vitamin C content of fresh SS and SV leaves was 118.36 ± 2.97mg/100 g and 92.58 ± 2.49mg/100g, respectively. Fresh SS leaves contained significantly higher levels of vitamin C than fresh SV leaves. Both pre-treatment and drying methods had a significant effect on vitamin C reduction. A marked decrease in vitamin C was observed in both untreated (UnB) and pre-treated (WB and WBS) dried SS and SV leaves in contrast to fresh leaves.

Table 2. Effect of drying methods on vitamin C content of SS and SV.

African nightshade	Drying methods	Pre-treatment Methods	Vitamin C (mg/100g (db))
S. scabrum (SC)	ISD	FO	118.36 ± 2.97^{a}
		UnB	17.47 ± 1.04^{b}
		WB	11.67 ± 0.39^{d}
		WBS	10.77 ± 0.58^{de}
	MSD	UnB	15.31 ± 1.04^{c}
		WB	9.57 ± 0.06^{e}
		WBS	7.14 ± 0.86^{f}
	OSD	UnB	14.30 ± 0.59^{c}
		WB	9.34 ± 0.29^{e}
		WBS	6.48 ± 0.40^{f}
S. villosum (SV)	ISD	FO	92.58 ± 2.49^{a}
		UnB	17.79 ± 0.20^{b}
		WB	17.26 ± 0.23^{bc}
		WBS	12.35 ± 0.20^{de}
	MSD	UnB	16.47 ± 0.82^{bc}
		WB	12.79 ± 0.03^{de}
		WBS	10.65 ± 0.57^{e}
	OSD	UnB	14.53 ± 0.66^{cd}
		WB	12.65 ± 0.79^{e}
		WBS	10.65 ± 0.61^{e}

Means ± SD (n=3). The means in columns with different superscript letters are significantly other ($p<0.05$); ISD: Indirect solar drier, MSD: Mixed solar drier; OSD: Open solar drier; UnB: Un-blanched; WB: Water blanched; WBS: Water blanched with NaCl. db : dry weight basis

The vitamin C retention in SS dried was between 9.10% – 14.76% in ISD, 6.03% – 12.94% in MSD, and 5.47 – 12.08% in OSD, respectively. For dried SV, vitamin C retention was between 13.33%– 19.23% in ISD, 11.5% – 17.79% in MSD and 11.5%– 15.69% in OSD, respectively. Generally, the average loss in vitamin C during drying ranged between 81.36% to 94.53%.

Likewise, Kandoga *et al.* (2019) reported a 99.51% loss in vitamin C in blanched and dried false sesame and common bean leaves. Ndawula *et al.* (2004) reported 84.54% loss in vitamin C when fruits and cowpeas leaves were open sun-dried. Furthermore, Babalola *et al.* (2010) reported a significant loss of vitamin C in blanched and sun-dried samples, whereas open sun had a tremendous impact compared to other drying methods.

The vitamin C losses were significantly affected by blanching. Blanching with salt (WBS) negatively affected vitamin C retention regardless of the drying methods. Comparably, slightly higher vitamin C was retained in untreated (UnB) than pre-treated (WB and WBS). Further losses occurred in WBS, suggesting that salt negatively affected vitamin C levels. Therefore, pre-treatment with WB and WBS was not practical in retaining vitamin C in dried SS and SV (Table 2). As a whole, vitamin C retention was more significant in dried SV than SS.

Noteworthy, all drying methods had a tremendous decrease in vitamin C. The vitamin C loss trend was in the order of ISD < MSD < OSD. The indirect exposure to sunlight might have contributed to the variation in levels of vitamin C in MSD or ISD. Hence, less oxidation, mainly in the open sun, accelerated vitamin C losses due to oxidation, oxygen, and ultraviolet rays (Constant *et al.*, 2016).

According to Constant *et al.* (2016), the loss of vitamin C by sun-drying in different five-leafy vegetables was 85.12% to 96.42%. Besides, the drying temperature in ISD (39.9 °C) and MSD (47.2 °C) may also affect the drying rate and vitamin C levels.

Conversely, less vitamin C retention resulted from the drying process and the pre-treatments. Blanching causes leaching as vitamin C is water-soluble and is sensitive to heat and light (Lee *et al.*, 2000). This is consistent with Kandonga *et al.* (2019) findings of 70.62% to 91.24% vitamin C losses due to blanching and sun-drying of false sesame and common bean leaves. Negi *et al.* (2000) and Ndawula *et al.* (2004) reported 7.5% retention of vitamin C in blanched solar-dried cowpeas leaves. Hence, drying un-blanched SS and SV leaves with ISD can be an alternative method to avoid more vitamin C losses regardless of the *Solanum* sp.

Effect of drying methods on mineral content

Table 3 presents mineral content (Ca, Fe, mg, and Zn) retained in the fresh and dried SS and SV leaves. Fresh SS and SV leaves displayed significantly higher mineral values than dried ones. Therefore, different drying methods significantly lowered the mineral content of SS and SV leaves. Notably, much higher mineral levels were retained in untreated (UnB) than pre-treated (WB and WBS) dried leaves. Nonetheless, pre-treatment with WBS resulted in a further reduction in mineral content (Table 3). According to Saltzman *et al.* (2014), mostly Fe and Zn are minerals of public health concerns needed in small quantities despite their importance for disease prevention, development, and human well-being. The amount obtained from the dried samples is enough to supply the body with the required amount per daily recommended allowances.

For Ca, fresh (FO), SS, and SV leaves recorded 1392.02 ± 18.00mg/100 g and 1243.95 ± 22.35mg/100 g, respectively (Table 3). All drying methods reduced Ca levels in SS leaves by 7.4% – 20.53% in ISD, 16.88% – 29.41% in MSD, and 15.24% – 22.68% in OSD, respectively. In SV Ca losses ranged from 3.14% – 10.17% (ISD), 8.71% – 11.63% (MSD), and 6.46% – 10.78% (OSD). Nonetheless, a much higher Ca levels was retained in UnB than WB and WBS respectively. Kamga *et al.* (2013) reported Ca reduction in *S. scabrum* and *Corchorus olitorius* (Jute mallow), respectively.

Generally, Ca reduction in this study was significantly higher with a range between 3.14% to 22.68%, irrespective of the drying method. Regardless of the reduced levels, the reported amount is still within the recommended dietary allowance, ranging from 1000 to 3000mg/100g. Oni *et al.* (2015) reported a significant decrease in Ca concentration in sun-dried edible botanicals ranging from 1.23 ± 0.42% to 1.62 ± 1.70%. Also, blanching resulted in further Ca reduction, especially when blanched with salt. Therefore, the trend for Ca retention considering both pre-treatment and drying methods was ISD > OSD > MSD.

Table 3. Effect of drying methods on minerals retention in dried SS and SV leaves (mg/100g dry basis).

African nightshade	Drying Method	Pre-treatment	Ca	Fe	Mg	Zn
S. scabrum (SC)	ISD	FO	1392.02±18.60^{a}	152.01 ± 4.96^{a}	253.56 ±3.08^{a}	6.05±0.20^{a}
		UnB	1289.01 ± 5.29^{b}	118.39 ± 0.47^{b}	191.08 ± 7.78^{b}	5.26±0.36^{b}
		WB	1157.06 ± 1.94^{cd}	79.22 ± 0.63^{d}	188.11 ± 0.69^{b}	4.56±0.10^{c}
		WBS	1106.24 ± 6.67e	78.20 ± 0.30^{d}	175.90 ±0.92^{de}	3.15±0.06^{d}
	MSD	UnB	1157.03 ± 7.54^{cd}	79.49 ± 10.96^{d}	185.29 ±1.26^{bc}	3.56± 0.19^{d}
		WB	1115.29 ± 10.92^{e}	62.00 ± 0.36^{e}	171.84 ±1.39^{de}	3.17±0.11^{d}
		WBS	982.59 ± 1.85^{g}	60.27 ± 0.42^{e}	159.54±14.98^{f}	2.41±0.08^{e}
	OSD	UnB	1179.88 ± 5.72^{c}	90.16 ± 1.14^{c}	178.63±4.78^{cd}	2.64±0.21^{e}
		WB	1141.87 ± 3.91^{d}	78.39 ± 0.19^{d}	167.01±0.15^{ef}	2.39±0.10^{e}
		WBS	1076.35 ± 8.29^{f}	62.03 ± 2.99^{e}	148.42±0.83^{g}	2.30±0.03^{e}
S. villosum (SV)	ISD	FO	1243.95± 22.35^{a}	158.23±1.74^{a}	223.16±4.13^{a}	4.24±0.00^{a}
		UnB	1201.38± 24.98^{a}	113.48 ± 0.19^{b}	180.45±0.62^{b}	3.82±0.31^{b}
		WB	1146.18 ± 4.75^{a}	71.71 ± 0.49^{de}	163.22±0.66^{f}	3.42±0.12^{cd}
		WBS	1117.38 ± 17.67^{a}	71.63 ± 5.35^{de}	147.81±0.97^{de}	3.27±0.02^{d}
	MSD	UnB	1135.60 ± 10.26^{a}	80.60 ± 0.26^{c}	156.57±9.06^{c}	3.66±0.01^{bc}
		WB	1115.45 ± 22.50^{a}	69.65 ± 1.33^{e}	155.62±0.50^{cd}	3.31±0.11^{d}
		WBS	1099.34 ± 5.60^{a}	68.97 ± 0.33^{e}	135.35±1.12^{f}	2.89±0.04^{ef}
	OSD	UnB	1163.59 ± 12.88^{a}	78.75 ± 0.02^{cd}	157.69±0.29^{c}	3.16±0.10^{de}
		WB	1125.40 ± 3.81^{a}	69.67 ± 5.41^{e}	141.58±1.59^{ef}	2.87±0.03^{ef}
		WBS	1109.87 ± 1.52^{a}	55.32 ± 4.93^{f}	115.47±0.58^{g}	2.79±0.01^{f}

Means ± SD (n=3). The means in columns and rows with different superscript letters are significantly different ($p<0.05$); ISD: Indirect solar drier, MSD: Mixed solar drier; OSD: Open solar drier; UnB: Un-blanched; WB: Water blanched; WBS: Water blanched with the addition of NaCl.

Generally, a similar trend in Fe, mg, and Zn retention was observed (Table 3). The Fe content in fresh SS was 152.01 ± 4.96mg/100g and 158.23 ± 1.74mg/100 g in SV respectively. The pre-treatment and drying methods employed had less retention effect on Fe in both SS and SV leaves. The UnB samples retained a higher Fe level, with WB and WBS significantly reducing Fe levels. Furthermore, WBS treated dried leaves presented the lowest Fe values.

For dried SS leaves, Fe retention was between 51.44 – 77.77%, 39.65% – 52.29%, and 40.81% – 59.31% for ISD, MSD, and OSD, respectively. On the other hand, Fe retention in dried SV leaves was in the range of 45.26% – 71.72% in ISD, 43.59% – 50.94% in MSD, and 34.96% – 49.77% in OSD, respectively. Generally, Fe losses were in a range of 22.23% – 60.35% for SS and 28.28% – 65.04% for SV regardless of the drying methods. Considering the drying, both MSD and OSD had the lowest Fe values ($p < 0.05$) compared to ISD. Therefore, Fe retention was in the order of ISD> MSD> OSD. Kamga *et al.* (2013) reported Fe contents in *S. scabrum* to be 14.74 ± 1.69mg/100g and 38.74 ± 13.61mg/100g, lower than values from this study.

Table 3 showsmg concentrations in both fresh and dried SS and SV leaves. Like in Ca and Fe,mg concentration was higher in UnB than WB and WBS. Magnesium retention in dried SS was in a range of 69.37% – 75.34%, 62.92% – 73.06%, and 58.53% – 70.49% in ISD, MSD, and OSD, respectively. While, for dried SV, it was 66.15% – 80.76% in ISD, MSD (60.57% – 70.67%), and OSD (51.67% – 70.57%) correspondingly. To sum up, both drying methods influenced themg retention levels, with WB and WBS causing further losses. The decline might be due to the effects of water-soluble minerals that reduce their contents; moreover, the effect increases as the blanching time increases (Babalola and Alabi, 2015; Bamidele *et al.*, 2017; Yakubu *et al.*, 2012). The effect of drying methods on mg retention was in a trend of ISD > ISD > OSD. This study's findings show that the ISD method was the best in mg retention under both treatments.

Zinc content in fresh SS and SV leaves was 6.05 ± 0.20mg/100g and 4.24mg/100g, respectively (Table 3). Zinc is a micronutrient essential for proper human immune functioning and required body growth (Black, 2003).

Hotz and Brown (2004) reported an estimated 20% of the world population to be at risk of inadequate intake of Zn. The standard RDA for Zn is between 4 to 40mg/100g. The pre-treatment and drying methods reduced the amount of Zn in both SS and SV leaves. Zinc retention in dried SS was (50.07% – 86.94%), (39.83% – 58.84%) and (38.02% – 43.64%) for ISD, MSD, and OSD respectively.

On the other hand, the amount of Zn retained in dried SV ranges from 77.12% – 90.09%, 68.16% – 86.32%, and 65.80% – 74.53% for ISD, MSD, and OSD, respectively. Like in other minerals, both pre-treatment and drying methods negatively affected Zn content in SS and SV. Specifically, WB caused a further decrease in Zn content from UnB, with the least retention in WBS. This indicates that the drying methods caused more destruction of these minerals, especially OSD. Despite the decrease, ISD was the best method for Zn retention in the dried SS. Therefore, the effect of the drying method on Zn retention was in trend of ISD > MSD > OSD.

Kamga *et al.* (2015) reported that the quantity of Zn in S. *scabrum* ranges from 3.890 + 3.07mg/100g to 4.18 ± 1.56mg/100g, which was a little bit lower than fresh SS but similar to fresh SV leaves. Iron and Zn as trace elements are significantly reduced in vegetables dried by the open sun (Abiodun *et al.* 2010). Nevertheless, the decrease in minerals concentration in the blanched samples is due to disruption of cell walls as minerals are also found in plant cell walls; hence blanching results in the leaching of minerals (Babalola and Alabi, 2015; Bamidele *et al.*, 2017; Yakubu *et al.,* 2012).

Generally, Ca and mg work together to reduce hypertension and blood pressure in the human body. Still, also they are the potential for good healthy teeth, strong bones, and provide healthy muscles (Oni *et al.*, 2015; Wardlaw *et al.,* 2004). Iron produces hemoglobin, and its deficiency can result in anemia in children and women (Kumar *et al.*, 2020). The shortage of Zn results in malfunctioning of the immune system and gastrointestinal tract (Welch, 1993).

Effect of drying methods on oxalate and phytate removal

Anti-nutritional factors in foods reduce the bioavailability of nutrients by impairing the body to utilize nutrients absorbed from the diet (Danso *et al.*, 2019). Fig. 1A&B presented percentage oxalate and phytate reduction dried leaves of SS and SV. A significant decrease ($p < 0.05$) in oxalate and phytate levels was observed in both pre-treatment and drying methods (Fig. 1A&B). Similarly, pre-treatment with WB and WBS positively impacted oxalate removal, comparable UnB in a sequence of WBS > WB > UnB. These findings suggest that WB significantly reduced more oxalate; besides, the highest oxalate removal was attained in WBS (Fig. 1A).

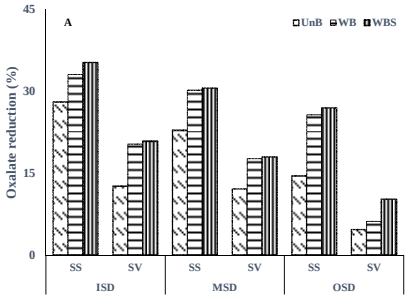

Fig. 1A. Effect of drying methods on oxalate reduction in *Solanum scabrum* (SS) and *Solanum villosum* (SV). ISD: Indirect solar drier, MSD: Mixed solar drier; OSD: Open solar drier; UnB: Un-blanched; WB: Water blanched; WBS: Water blanched with the addition of 3% NaCl.

From the drying methods, oxalate reduction ranged from 14.48 – 26.92% in OSD, 22.78% – 30.55% in MSD, and 27.98% – 35.24% in ISD for dried SS, respectively. For dried SV, oxalate removal ranged from 4.66% – 10.21% in OSD; 12.07% – 17.94% in MSD and 12.61% – 20.79% in ISD, respectively. The oxalate removal followed a trend of ISD > MSD > OSD. Generally, the ISD method with WBS pre-treatment was the best in oxalate reduction.

Likewise, Mwanri *et al.* (2018) reported similar oxalate values in *S. villosum*, although some were higher due to differences in the maturity stage. Various studies also reported oxalate reduction in

different vegetables during drying (Abiodun *et al.* 2010; Kandonga *et al.*, 2019; Matazu and Haroun 2004, and Oni *et al.* 2015). Similarly, other processing methods, including pressure cooking, open pan cooking, blanching, boiling, and drying, have shown a tremendous effect in oxalate reduction in vegetables (Babalola and Alabi, 2015; Essack *et al.*, 2017; Mosha *et al.*, 1995; Mwanri *et al.*, 2011; Virginia *et al.*, 2012).

For phytate, both fresh SS and SV recorded 0.90 ± 0.06mg/100g and 0.94 ± 0.02mg/100g, respectively (Fig. 1B). The amount of phytate in fresh ANS was higher than that recorded by Mwanri *et al.* (2018) for the ANS, spider plant, and amaranths, respectively.

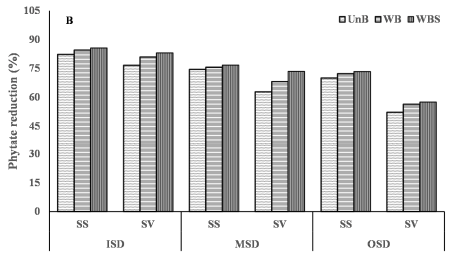

Fig. 1B. Effect of drying methods on phytate reduction in *Solanum scabrum* (SS) and *Solanum villosum* (SV). ISD: Indirect solar drier, MSD: Mixed solar drier; OSD: Open solar drier; UnB: Un-blanched; WB: Water blanched; WBS: Water blanched with the addition of 3% NaCl.

On the other hand, phytate removal in dried SS was 82.22% – 85.55% (ISD), 74.44% – 76.66% (MSD) and 70% – 73.33% (OSD). While in dried SV, phytate removed ranged from 76.6% – 82.99% in ISD, 62.77% – 73.4% (MSD) and 52.12% – 57.45% (OSD) respectively. Further, both pre-treatment and drying methods had a significant effect on phytate reduction. In addition, pre-treatment with WBS and WB resulted in more phytate removal than UnB. A substantial reduction of phytates was observed in all drying methods (Fig. 1B); nonetheless, the highest removal was recorded in ISD (82.22% – 85.55%). Generally, the ISD was the most efficient method in reducing phytates. Therefore, the trend for phytate removal was ISD > MSD > OSD.

Thus, the ISD can be recommended as the best method for removing phytates in ANS. Blanching, sun, and solar drying were also reported to reduce phytates in green leafy vegetables (Elisha *et al.*, 2016; Ilelaboye *et al.*, 2013; Natesh *et al.*, 2017; Yakubu *et al.*, 2012).

Conclusion

The nutritional quality of *Solanum* sp. is essential for health benefits and well-being of the human. All drying methods affected the vitamin C, minerals, oxalate, and phytate levels in *Solanum* sp. A substantial loss of vitamin C was evident, with a reduction in mineral content. Interestingly, oxalate and phytate as anti-nutrients were reduced by all drying methods. Nonetheless, pre-drying treatments employed had a considerable impact on the quality of the final dried products compared to untreated. Among the drying methods used, ISD was the most effective method for nutrient retention; and oxalates and phytates reduction in *Solanum* sp. Therefore can be recommended as an effective method for *Solanum* sp. Drying.

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References

Abiodun AR, Aletor O, Aladesanwa RD. 2012. The influence of freeze and sun-drying on the nutrient and the anti-nutrient constituents of scent and basil leaves. Internl J Chem **22(3),** 197-205.

Agbaire PO, Emoyan OO. 2011. Nutritional and anti-nutritional levels of some local vegetables from Delta State, Nigeria **15(4),** 625-628. https://doi.org/10.5897/AJFS11.175

AOAC. 1990 Official Methods of Analysis of the Association of Analytical Chemists (K. Helrich Ed. 15 Ed. Vol. 1). Arlington VA, USA: Association of Official Analytical Chemists, Inc.

Babalola JO, Alabi O. 2015. Effect of processing methods on nutritional composition, phytochemicals, and antinutrient properties of chaya leaf (*Cnidoscolus aconitifolius*) **9(12),** 560-565. https://doi.org/10.5897/AJFS2015.1330

Bamidele OP, Fasogbon MB, Adebowale OJ, Adeyanju A, Technology. 2017. Effect of blanching time on total phenolic, antioxidant activities and mineral content of selected green leafy vegetables. https://doi.org/10.9734/CJAST/2017/34808

Chege P, Kuria E, Kimiywe J, Nyambaka H, Research. 2014. Changes in nutrient content for β-carotene, iron and Zinc in solar dried and stored Amaranthus cruentus vegetables **3(3),** 880-882.

Constant A, Lessoy Z, Niamkey A, Niamke S. 2016. Effect of sun-drying on nutritive and antioxidant properties of five leafy vegetables consumed in southern CÔTE D'ivoire **14(3).**

Danso J, Alemawor F, Boateng R, Barimah J, Kumah D. 2019. Effect of drying on the nutrient and antinutrient composition of Bombax buonopozense sepals **13(1),** 21-29. https://doi.org/10..5897/AJFS2018.1765

Ekesa B, Walingo MK, Onyango M. 2009. Accessibility to and consumption of indigenous vegetables and fruits by rural households in Matungu division, western Kenya. Agriculture, Nutrition, & Development **9(8).** https://doi.org/10..4314/ajfand.v9i8.48410

Elisha GO, Arnold OM, Christian U, Huyskens-Keil SJ. 2016. Postharvest treatments of African leafy vegetables for food security in Kenya: a review *9*.

Erdman J. 1979. Oilseed phytates: nutritional implications **56(8),** 736-741. https://doi.org/10.1007/BF02663052

Essack H, Odhav B, Mellem J, Technology. 2017. Screening of traditional South African leafy vegetables for specific anti-nutritional factors before and after processing **37(3),** 462-471. https://doi.org/10.1590/1678-457X.20416

Garba ZN, Oviosa S. 2019. The effect of different drying methods on the elemental and nutritional composition of Vernonia amygdalina (bitter leaf) **13(1),** 396-401. https://doi.org/10.1080/16583655.2019.1582148

Gockowski J, Mbazo'o J, Mbah G, Moulende T. 2003. African traditional leafy vegetables and the urban and peri-urban poor **28(3),** 221-235. https://doi.org/10.1016/S0306-9192(03)00029-0

Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R, Meybeck A. 2011. Global food losses and food waste: FAO Rome.

Hasan MU, Malik AU, Ali S, Imtiaz A, Munir A, Amjad W. 2019. Modern drying techniques in fruits and vegetables to overcome postharvest losses: A review **43(12),** e14280 https://doi.org/10.1111/jfpp.14280

Ilelaboye N, Amoo I, Pikuda O. 2013. Effect of cooking methods on mineral and anti nutrient composition of some green leafy vegetables **5(3),** 254-260.

James A, Matemu A. 2016. Solar-drying of vegetables for micronutrients retention and product diversification **4(8),** 1-13. http://dspace.nm-aist.ac.tz/handle/123456789/204

Jonathan AA, Funmilola AS. 2014. Nutritional and anti-nutritional composition of Bridelia ferruginea Benth (Euphorbiaceae) stem bark sample **2(2),** 92. http://dx.doi.org/10.12983/ijsrk-2014-p0092-0104

Kumar D, Kumar S, Shekhar C. 2020. Nutritional components in green leafy vegetables: A review **9(5),** 2498-2502.

Lee SK, Kader AA. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops **20(3),** 207-220. https://doi.org/10.1016/S0925-5214(00)00133-2

Morris A, Barnett A, Burrows O. 2004. Effect of processing on nutrient content of foods **37(3),** 160-164.

Mosha T, Gaga H, Pace R, Laswai H, Mtebe K. 1995. Effect of blanching on the content of anti-nutritional factors in selected vegetables **47(4),** 361-367.

Mwanri AW, Kogi-Makau W, Laswai HS. 2011. Nutrients and antinutrients composition of raw, cooked and sun-dried sweet potato leaves **11(5),** 5142-5156.

Natesh H, Abbey L, Asiedu S. 2017. An overview of nutritional and anti-nutritional factors in green leafy vegetables **1(2),** 00011.

Nnamani C, Oselebe H, Agbatutu A. 2009. Assessment of nutritional values of three underutilized indigenous leafy vegetables of Ebonyi State, Nigeria ***8*(10).**

Ochieng J, Afari-Sefa V, Karanja D, Kessy R, Rajendran S, Samali S, Systems F. 2018. How promoting consumption of traditional African vegetables affects household nutrition security in Tanzania **33(2),** 105-115. https://doi.org/10.1017/S1742170516000508

Ofor M, Ibeawuchi I. 2010. Sun-drying a low cost technology for reducing postharvest losses **2(1),** 56-59.

Ojiewo CO, Mwai GN, Abukutsa-Onyango MO, Agong SG, Nono-Womdim R. 2013. Exploiting the genetic diversity of vegetable African nightshades ***7*(1),** 6-13. http://oar.icrisat.org/id/eprint/6365

Oluoch MO, Habwe FO, Ngegba JB, Koskei KR, Yang R. 2012. Food preparation and processing methods on nutrient retention and accessibility in selected indigenous vegetables from East Africa **15,** 233-241.

Oni MO, Ogungbite OC, Akindele A. 2015. The effect of different drying methods on some common Nigerian edible botanicals **1,** 15-22.

Pardhi CB, Bhagoria J. 2013. Development and performance evaluation of mixed-mode solar dryer with forced convection **4(1),** 23.

Patricia O, Zoue L, Megnanou RM, Doue R, Niamke S. 2014. Proximate composition and nutritive value of leafy vegetables consumed in Northern Côte d'Ivoire **10(6).**

Sagar VR, Suresh Kumar P. 2010. Recent advances in drying and dehydration of fruits and vegetables: A review. J Food Sci Technol **47,**15-26. DOI: 10.1007/s13197-010-0010-8 https://doi.org/10.1007/s13197-010-0010-8

Sahar N, Arif S, Iqbal S, Afzal QUA, Aman S, Ara J. 2015. Moisture content and its impact on aflatoxin levels in ready-to-use red chillies **8(1),** 67-72. https://doi.org/10.1080/19393210.2014.978395

Saltzman A, Birol E, Wiesman D, Prasai N, Yohannes Y, Menon P, Thompson J. 2014. 2014 global hunger index: The challenge of hidden hunger. Intl Food Policy Res Inst.

Seidu J, Bobobee E, Kwenin W, Frimpong R, Kubge S, Tevor W, Mahama AJJABS. 2012. preservation of indigenous vegetables by solar drying **7(6),** 47-415.

Traoré K, Parkouda C, Savadogo A, Ba/Hama F, Kamga R, Traoré Y. 2017. Effect of processing methods on the nutritional content of three traditional vegetables leaves: Amaranth, black nightshade and jute mallow **5(6),** 1139-1144. https://doi.org/10.1002/fsn3.504

Tumwet T, Kang'ethe E, Kogi-Makau W, Mwangi A. 2014. Diversity and immune boosting claims of some African indigenous leafy vegetables in western Kenya. Agriculture, Nutrition, & Development **14(1),** 8529-8544. https://doi.org/10..18697/ajfand.61.12945

Ukegbu P, Okereke C. 2013. Effect of solar and sun drying methods on the nutrient composition and microbial load in selected vegetables, African spinach (*Amaranthus hybridus*), fluted pumpkin (*Telferia occidentalis*), and okra (*Hibiscus esculentus*) **2(5),** 35-40.

Uusiku NP, Oelofse A, Duodu KG, Bester M J, Faber M. 2010. Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *23*(6), 499-509. https://doi.org/10.1016/j.jfca.2010.05.002

Virginia P, Swati V, Ajit PJ. 2012. Effect of cooking and processing methods on oxalate content of green leafy vegetables and pulses **5(4),** 311-314.

Welch RM. 1993. Zinc concentrations and forms in plants for humans and animals Zinc in soils and plants (pp. 183-195): Springer. https://doi.org/10..1007/978-94-011-0878-2_13

Xiao HW, Pan Z, Deng L Z, El-Mashad HM, Yang XH, Mujumdar AS, Zhang Q. 2017. Recent developments and trends in thermal blanching–A comprehensive review **4(2),** 101-127. https://doi.org/10.1016/j.inpa.2017.02.001

Yakubu N, Amuzat A, Hamza R. 2012. Effect of processing methods on the nutritional contents of bitter leaf (*Vernonia amygdalina*) **2(1),** 26-30. http://repository.futminna.edu.ng:8080/jspui/handle/123456789/7410

Yuan B, Byrnes D, Giurleo D, Villani T, Simon JE, Wu Q. 2018. Rapid screening of toxic glycoalkaloids and micronutrients in edible nightshades (*Solanum* spp.) **26(2),** 751-760. https://doi.org/10.1016/j.jfda.2017.10.005