Solar-Drying of Vegetables for Micronutrients Retention and Product Diversification

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ABSTRACT

Micronutrients retention of solar-dried vegetables were studied with an aim of increasing iron, zinc and β-carotene bioaccessibility as well as product diversification. Iron, zinc and β-carotene contents in fresh and dried *Moringa oleifera* leaves (ML), *Ipomoea batatas* leaves (IBL) and *Daucus carota* (DC) were evaluated. Iron and zinc were analyzed using Atomic Absorption Spectrophotometer (AAS) and β-carotene by High Performance Liquid Chromatography (HPLC). Moisture content for dried ML, IBL and DC was also determined. From results, final moisture values attained for dried ML, IBL and DC were 7.24, 7.46 and 10.51% respectively. Retention of specific micronutrients in dried vegetables was observed. A significant ($p < 0.05$) increase in iron (64.55 ± 0.39 mg/100 g) and zinc (2.73 ± 0.09 mg/100 g) contents were observed in dried ML. Zinc content in dried DC was 0.88 ± 0.05 mg/100 g. Iron content in dried IBL was 29.99 ± 0.42 mg/100 g which is 2.45 folds significant increase. On the other hand, dried IBL showed increased β-carotene content of 1.63 ± 0.25 mg/100 g, which is 9.59 folds significant increase, whereas insignificant ($p > 0.05$) increase was observed in ML. Furthermore, β-carotene loss from 6.72 ± 0.28 mg/100 g to 3.53 ± 0.41 mg/100 g (0.53 folds decrease) in dried DC. Solar drying of vegetables facilitates micronutrients retention and product diversification to enhance accessibility of nutrients for improved health through micronutrients supplementation.

Keywords: *Moringa oleifera* leaves, *Ipomoea batatas* leaves, *Daucus carota*, solar drying, micronutrient retention, product diversification

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INTRODUCTION

Vegetables are major sources of vitamins, minerals, fibre and other plant bioactive compounds like antioxidants important for human health and well-being. Vegetables are highly perishable due to high moisture content (some up to 95%) therefore requires appropriate preservation methods to keep them fresh. High moisture support enzymes activity and microbial growth causing crop deterioration or spoilage hence post-harvest losses. Post-harvest losses of vegetables account up to 30–50% in sub-Saharan Africa depending on crop, markets and region (Sagar and Kumar, 2010; Gustavsson et al., 2011; Ofor, 2011).

The level of vegetables processing and preservation in sub-Saharan Africa countries is still very low with sun drying being the most common method and to some areas practising fermentation for surplus crops (Ofor and Ibeawuchi, 2010; Ofor, 2011; Ukegbu and Okereke, 2013). Sun drying has been reported to affect micronutrients significantly due to direct sunlight exposure to the product, with a possibility of product contamination with dust, insects and animals and a great risk of microbial spoilage. Therefore, it is imperative to use solar drying technology for micronutrients, flavour and colour preservation and improve storage at low moisture content thereby improving shelf life as well as promoting food and nutrition security (Sagar and Kumar, 2010). Solar drying methods are reported to retain micronutrients in vegetables that can be used in the diet to supply micronutrients and reducing seasonal dependence on raw vegetables (Chege et al., 2014).

Solar energy comparing to other form of energy sources is clean, renewable and can be used free of environmental pollution. Technical, environmental and economic benefit of drying method takes into account on the selection of types on the wide range of solar drying method commercially available in operation today (Prakash and Kumar, 2013). Solar drying has broad applications in agriculture that include drying of vegetables, fruits, spice, medical plants, grains and other materials of biological origin (Panwar et al., 2012; Prakash and Kumar, 2013). Drying aims at reducing moisture to a level that allows proper storage with reduced enzymes and water activity. Example solar dried Moringa leaves powder is recommended as nutritional supplement in some African and Asian countries (Fuglie, 1999; Kasolo et al., 2010). *Ipomoea batatas* leaves are mainly used as vegetables in Tanzania and to some area practising sun drying (Mwanri et al., 2011). The leaves are rich in calcium, iron, zinc, protein, vitamin B, β-carotene, antioxidants and fibres (Islam, 2014). On the other hand, carrots are rich in β-carotene and can be consumed both fresh and processed due to health benefit it provides. Dried carrots retains considerable amount of β-carotene and dried powder or carrot extracts are used to fortify and improve sensory quality of food products (Madukwe and Eme, 2012; Alam et al., 2013). Therefore, this study aimed at determining the extent of iron, zinc and β-carotene retention with solar drying of ML, IBL and DC.

MATERIALS AND METHODS

Sample collection and preparations

Moringa oleifera leaves were purchased from Nduruma farmers in Arusha and *Ipomoea batatas* leaves were obtained from AVRDC farm plots Tengeru-Arusha. *Daucus carota* was purchased from Tengeru market, Arusha. *Moringa oleifera* leaves and IBL were sorted to remove inedible parts and cleaned using tap water to remove dust, debris and any foreign matters ready for blanching. On the other hand, carrots were sorted, cleaned, peeled and grated with kitchen grater (MLIE-KC-0676-Zhenjiang, China) into thin slices of 2 mm thickness and 2.5 cm long.

Blanching

Prepared vegetables were blanched in boiling water at 97 °C according to the method described by other researcher (Patras et al., 2011; Gamboa-Santos et al., 2013). *Moringa oleifera* leaves and IBL were blanched at 94 °C for 2 min. Grated carrots were blanched by dipping into hot water at 94 °C for 3 min. Blanching is aimed at inactivating enzymes to prevent enzymatic browning and nutrients oxidation, sterilising vegetables, structural softening to facilitate moisture removal during drying and evaporating herb like flavours (Chiewchan et al., 2010).

Drying of vegetables

Freshly prepared DC, ML and IBL approximately 400 g each were blanched and loaded on the tray by spreading to make thin layer for effective drying during morning hours at 0900 h. Drying was conducted from 0900 – 1700 h. Unloading of the dried vegetables from solar drier was done in the afternoon (1400–1600 h) when relative humidity was low to avoid moisture pickups. Constant moisture content was used to decide end of drying. Dried vegetables were packed in polyethylene bags ensuring no airspace and stored at room temperature in a dark dry place for further analysis.

Moisture content determination

Moisture content was determined based on oven drying method,where5 grams of the dried sample was placed in an oven at 105 °C for 24 h (Nielsen, 2010). Samples were cooled to room temperature in a desiccator before weighing again. Moisture content was expressed as percentage.

$$\text{Moisture content (\% MC)} = \frac{(W1 - W2)}{W1} \times 100$$

Where, W_1=Weight of vegetable before oven drying; W_2=Weight of dried vegetable after oven drying

Micronutrient determination

Mineral analysis

Dry ashing was performed in muffle furnace at 550 °C for 6 h using 2 g of dried vegetables on a clean porcelain crucible (AOAC, 1990). A starting temperature of 450°C was used and gradually increased to 550 °C at a rate of 50 °C/h. The obtained ash was digested in 10% HCl, filtered with an acid wash filter paper into 100 mL flask and made up to volume using deionised water. Iron and zinc were determined using Atomic Absorption Spectrophotometer (GBC 906AA–USA). Iron absorption wavelength was set at 392 nm and zinc at 307 nm.

Extraction and HPLC quantification of β-carotene

Beta-carotene solvent extraction was performed using 95% n-hexane (Sigma Aldrich –UK). Fresh raw and dried vegetable samples were grounded using mortar and pestle. Two grams of vegetable sample was weighed into 50 mL polytetrafluoroethylene (PTFE) (Sigma Aldrich–UK) centrifuge tube and 10 mL of 95% n-hexane was added and shaken for 1 min. Four grams of $MgSO_4$, NaCl (1 g), $C_6H_8O_7$(1 g), and $Na_3C_6H_5O_7$(0.5 g) were added in distilled water to make 40 mL and mixed vigorously for 1 min then centrifuged at 4000 rpm for 10 min (Hettich Rotofix 32A). The hexane supernatant layer was transferred into dispersive centrifuge tube containing 150 g of primary secondary amine (PSA) (Sigma Aldrich-UK) and 900 mg of $MgSO_4$ and then vortexed for 1 min, followed by centrifugation at 4000 rpm for 5 min to obtain a clear supernatant. The clear supernatant 10 µL was injected into the HPLC, (Shimadzu, Japan) connected to Hypersil BDS C18, 150x4.6, 5 µm (ThermoFisher Scientific, UK) column and detector (Shimadzu Prominence Diode Array)at 436 nm wavelength for β-carotene quantification. The mobile phase consisted of acetonitrile: methanol: ethyl acetate (88:10:2) at a flow rate of 1.5 mL/min (Tee and Lim, 1991, 1992; Szpylka et al., 2005).

Data analysis

All samples were analyzed in triplicates. Microsoft excel 2010 was used to organise data for descriptive statistics. The R software version 3.2.1 (Stats package) was used for statistical analysis. A paired two sample student's t-test was performed to compare micronutrient values between fresh and dried vegetables. The differences were considered statistically significant if $p < 0.05$.

RESULTS AND DISCUSSION

Effect of solar drying on moisture content

The moisture values were reduced from 79.09 ± 0.29–7.24 ± 0.34% (ML), 79.92 ± 0.41–7.46 ± 0.19% (IBL) and 91.42 ±0.21–10.51 ± 0.31% (DC) following solar drying of vegetables (Table 1). All values obtained were below 12% moisture content which is recommended for safe storage of dried vegetables for more than six months (Rahman et al., 2010; Seidu et al., 2012; Sahar et al., 2015). The values for moisture content, showed fresh DC having the highest value (91.42 ± 0.21%) indicating that DC is more prone to deterioration since foods with higher moisture content are also highly perishable. Moisture content of fresh DC reported in other studies were

85.51, 86.77, 87.77 and 88.12% (Sun and Temelli, 2006; Rahman et al., 2010; Al-Amin et al., 2015). A final moisture content of 7.42 ± 2.89% in dried ML was reported by Witt 2013, which is similar to the value observed in this study (Witt, 2013). Besides, lower moisture values in a range of 3.06 ±1.38 – 3.34 ± 1.36% in ML powder has been also reported (Valdez-Solana et al., 2015). Carrots represented highest weight loss at 93.35% reflecting its high initial moisture content of 91.42% as compared to ML and IBL (Table 1).

Moisture contents of both fresh ML (79.09 ± 0.29%) and IBL (79.92 ± 0.41%) in this study were similar to 76.53 ± 0.02% (ML) or in a range of 80.16 ± 0.08 to 88.20 ± 0.09% (IBL) (Oduro et al., 2008). Other studies have reported moisture content of 75.0, 76.1 and 79.28% in fresh ML (Kwenin et al., 2011; Satwase, 2012; Singh and Prasad, 2013) which is similar to value observed in this study.

Table 1: **Moisture content (%) of the dried vegetables and weight loss (%)**

	Moisture content (%)		
Vegetable	**Fresh**	**Dried**	**Weight loss (%)**
ML	79.09 ± 0.29	7.24 ± 0.34	81.20 ± 0.39
IBL	79.92 ± 0.41	7.46 ± 0.19	82.28 ± 0.52
DC	91.42 ±0.21	10.51 ± 0.31	93.35 ± 0.21

Percentage weight loss is represented as difference in weight loss in dried and fresh vegetables. Means±SE, (*n=12*).

Furthermore, IBL moisture value observed in this study was relatively lower compared to 84.09 – 88.92% reported by (Sun et al., 2014). The observed variation in moisture content in vegetables might be due to soil type, climate conditions, vegetable level of maturity and genetic variations between and within species (Hanif et al., 2006; Msuya et al., 2009). Dried vegetables can keep β-carotene and other micronutrients for a longer period of time as most undesirable enzymatic reaction, like browning are stopped and subsequent microbial spoilage are arrested keeping other storage conditions right (Lavelli et al., 2007). Therefore, solar drying has been shown to reduce amount of water from the vegetables thus to extend shelf-life and product diversification.

Effect of solar drying on vegetable micronutrients

The effect of solar drying on the micronutrients (zinc and iron) and β-carotene of dried vegetables were evaluated. Iron, zinc and β-carotene contents of fresh and dried vegetables are as shown in Table 2. Iron contents in dried ML and IBL were 64.55 ± 0.39 and 29.99 ± 0.42 mg/100 g respectively, indicating a significant increase ($p < 0.05$). Iron content in DC was 5.03 ± 0.22 mg/100 g indicating an insignificant increase ($p > 0.05$) (Table 2). Zinc contents in dried DC and ML were 0.88 ± 0.05 and 2.73 ± 0.09 mg/100 g respectively, indicating a significant increase ($p < 0.05$). Conversely, an insignificant increase in zinc was observed in dried IBL. From this study, a 1.55 and 2.15 folds increase in zinc was observed in ML and DC whereas 2.29, and 2.45 folds increase in iron was observed in ML and IBL respectively (Table 2). According to Moyo et al. (2013), iron (490.0 ± 49.65 mg/kg) and zinc (31.03 ± 3.41 mg/kg) contents in dried ML powder has been reported in South Africa. Also, dried ML iron (7.07 ± 0.4 – 19.37 ± 6.6 mg/100 g) and zinc (1.0 ± 0.7 – 1.6 ± 0.6 mg/100 g) reported in Mexico (Valdez-Solana et al., 2015). Similarly, an increase in micronutrients content in dried Moringa has been reported (Mensah et al., 2012; Madukwe et al., 2013; Moyo et al., 2013).

Similar increase of iron (3.5 mg/100 g fresh to 7.2 mg/100 g dried DC) and zinc (0.9 mg/100 g to 10.5 mg/100 g dried DC) were also reported in study previously conducted in Tanzania (Strøm, 2011). Increases in iron (7 – 28.2 mg/100 g) and zinc (0.16 – 3.29 mg/100 g) contents in dried ML has also been reported (Fuglie, 1999; Hiawatha, 2010). Furthermore, similar iron content in a range of 9.62 ± 0.047 to 28.29 ±0.047 mg/100 g in dried IBL has been reported in Kenya (Oduro et al., 2008). Also, in a study conducted in Morogoro Tanzania, dried IBL was reported to have slightly higher iron content of 19.15 ± 0.19 mg/100 g from 17.43 ± 0.31 mg/100 g fresh IBL (Mwanri et al., 2011). In addition, iron was concentrated from 10.89 to 19.6 mg/100 g and zinc 6.12 to 8.79 mg/100 g in shade dried IBL in a study conducted in Ivory Cost (Zoro et al., 2016).

Table 2: Iron, Zinc and β-carotene content of dried vegetables (mg/100g)

	ML		IBL		DC	
Nutrients	**Fresh**	**Dried**	**Fresh**	**Dried**	**Fresh**	**Dried**
β-carotene	3.73 ± 0.18	4.96 ± 0.71*	0.17 ± 0.01	1.63 ± 0.25	6.72 ± 0.28	3.53 ± 0.41
Iron	28.24 ± 0.17	64.55 ± 0.39	12.25 ± 0.17	29.99 ± 0.42	3.91 ± 0.37	5.03±0.22*
Zinc	1.76 ± 0.17	2.73 ± 0.09	1.28 ± 0.19	1.39 ± 0.07*	0.41 ± 0.05	0.88 ± 0.05

Mean ± SE, β-carotene (*n=3*), zinc and iron (*n=3*). *Means in the same row with asterisk represents insignificant changes in micronutrients in solar dried vegetables ($p > 0.05$).

On the other hand, β-carotene in dried IBL was 1.63 ± 0.25 mg/100 g, which is 9.59 folds significant increase as opposed to insignificant increase ($p > 0.05$) in dried ML (Table 2). Likewise, higher β-carotene content of 743.5 ± 35 µg/g dw in IBL has been reported in Sri-Lanka (Chandrika et al., 2010). β-carotene content of 6.8 – 18.9 mg/100g has been reported in dried ML (Fuglie, 1999; Hiawatha, 2010). Conversely, a significant 0.53 folds decreased in β-carotene was observed in dried DC (Table 2). A similar decrease in β-carotene content, from 71.70 to 60.13 ppm following solar drying of carrots has been reported in the study conducted in Ethiopia (Tadesse et al., 2015). In addition, other studies reported 40 – 43.92 and 48.9 – 67.5% β-carotene losses in solar dehydration and/or hot air drying of carrots (Sharma et al., 2012; Zhao et al., 2014). The decrease might be due to β-carotene degradation caused by high initial moisture content and prolonged exposure to solar energy that may cause oxidation and other chemical changes during processing (Sagar and Kumar, 2010).

Furthermore, micronutrients values reported in this study were found to vary with what has been reported in other studies. The variations might be attributed with climate condition, soil nutrients and types, genetic variation within or between vegetable species and level of maturity (Hanif et al., 2006; Msuya et al., 2009). For dried vegetables, better micronutrients retention was observed. Therefore, dried vegetables can provide easy way of utilization as might be processed into powder, which is easy to use and/or mix in soup or porridge to enhanced micronutrients utilization to needy women at reproductive age and children below age of five years (Chege et al., 2014). Solar dried ML, IBL and DC retained sufficient micronutrients that can help to supplement diet when incorporated in a meal.

CONCLUSION

Drying of vegetables assists to concentrate micronutrients and product diversification. Greater micronutrients retention were observed in dried ML, IBL and DC. Iron and zinc were substantially concentrated in dried vegetables, with an exception of β-carotene in DC. Lower moisture values attained in all dried vegetables signify improved shelf-life, product diversification, offseason availability and year round micronutrient supply for daily micronutrients intake. Reduction of weight of dried vegetables facilitates easy transportation, storage and distribution for micronutrients accessibility throughout the year. Availability of dried vegetables can ensure improved health through micronutrient supplementation and dietary diversification. Also, solar drying of vegetables contributes to post-harvest losses management.

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