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EFFECT OF DRYING METHOD ON THE NUTRITIONAL AND ANTIOXIDANT PROPERTIES OF MANGO, AVOCADO, AND TOMATO

Short communication

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ABSTRACT

The present study aims to evaluate nutrient retention in mango, avocado, and tomato dried using freezing, refractance windows, and oven methods. The quality parameters of the dried products were assessed, such as color, water activity, and antioxidant content. Greater color retention was observed for freeze-dried products than for products dried using other methods. All products showed low water activity (>0.4), which prevented microbial growth. Freeze-dried products had the highest content of lycopene and carotenoids. Instead, more flavonoids and phenolics were detected in the refractance window method and then in the oven-dried products. Although freeze-dried products are preferred, the refractance windows method could be a promising drying technology because of its energy savings, easy operations, and low cost.

Key words: carotenoids, flavonoids, phenolics, refractance window drying technology

INTRODUCTION

Fruits and vegetables are excellent sources of nutrients and play an important role in human health (Kaparapu et al. 2020). Their consumption is linked to several health benefits owing to their high nutritional value and medicinal properties. It contributes to reducing diseases such as cardiovascular, neurological, and carcinogenic illnesses (Rondini et al. 2012). Among the risk factors for global mortality is low fruit and vegetable consumption (Demissie et al. 2009). Therefore, increased consumption of fruits and vegetables is required to maintain good health (Lim et al. 2007).

Fruits and vegetables are highly perishable crops because of enzymatic and non-enzymatic reactions during maturation and storage, altering nutritional, sensory, and physiochemical properties (Guiamba 2016). Fruit decay is a common issue primarily due to its high free water content. However, the main culprits are improper pre- and postharvest treatments and a need to understand food preservation methods, significantly contributing to fruit perishability (Arah et al. 2016). Urge et al. (2014) report that postharvest losses in horticultural crops in Ethiopia are 15–70%, of which 40–50% are fruits (Hailu & Derbew 2015).

Drying, one of the best food processing mechanisms, is widely used to preserve highly perishable horticultural crops (Kumar et al. 2022). This area of research has led to the creation of dried food products that are valued for their compactness and reduced packaging, transportation, and storage costs. They also show better resistance to microbial spoilage and longer storage life compared to other preservation methods (Jangam et al. 2011). However, drying fruits and vegetables is a challenge to overcome because it affects several parameters of fresh

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fruits (Akther et al. 2023). This requires producing a dried product with the best nutrient retention using cost-effective, easy-to-use, and available drying technology. However, the benefits of these dried food products are undeniable, making the challenge well worth the effort.

Some drying methods require high energy consumption owing to the high drying time and temperature. Most horticultural crops are sensitive to heat, causing an increase in shrinkage and hardness, a decrease in rehydration, and a loss of sensory and nutritional properties. For instance, high-drying techniques degrade the nutritional quality of mangoes (Arah et al. 2016). In this regard, a refractance window can be used to overcome such limitations due to its performance in a short period at high temperatures; moreover, it is inexpensive and has excellent thermal efficiency (Zomorodi & Hedayat 2023), energy consumption is 50% lower than that of freeze-drying methods. The working principles are based on the heat transmittance from boiling water to the surface using a polyethylene film, a thin infrared transparent material until the machine is equivalent to the surrounding temperature (Rostami et al. 2018). On the other hand, compared to hot air drying, freeze-drying preserves the form, aroma, color, flavor compounds, cellular structure of the fruit (Marques et al. 2006) and prevents the growth of microorganisms. However, freeze-drying is not cost-effective (Castañeda-Saucedo et al. 2014). Moreover, high freezing rates have been reported. Therefore, the necessity for advanced drying methods in the context of horticultural crops must be balanced. These methods are crucial for achieving rapid and efficient thermal processing without compromising the quality of the crops (Askari et al. 2009). With this in mind, our study is dedicated to evaluating the effects of various drying technologies on different fruit quality parameters. Our ultimate goal is to pinpoint the most effective drying technology for individual fruit drying, a finding that could significantly advance food science, horticulture, and agricultural engineering.

MATERIALS AND METHODS

Sample preparation

Fully mature avocado, mango, and tomato samples of local genotypes were collected from the Melkassa Agricultural Research Center of the Horticultural Research Program and transported to the Food Science and Nutrition Research Laboratory. For each mango and avocado sample, over 20 kilograms were collected from different mango and avocado trees, whereas 14 kg of fully matured tomato samples were harvested and then kept at room temperature to ripe for consumption. Then, uniformly ripe samples of avocado, mango, and tomato were cleaned, washed, and prepared for drying via slicing across the fruit with a knife (mango: 5–6 mm, avocado: 4–5 mm, tomato: 6–7 mm). Each sliced sample was dried in triplicate using each method. Three drying methods were evaluated. Drying in the infrared oven at 60 °C lasted 11 h for mango, 12 h for avocado, and 9:30 h for tomato. Freeze drying for mango lasted 36 h, avocado 48 h, and tomato 30 h. Drying in a refractance window at 80 °C [(locally adopted drying technology (Minuye et al. 2021)] lasted 2 h for mango, 2:30 h for avocado, and 1:30 h for tomato. After drying, the samples were ground into flour using a cyclo-miller, stored in polyethylene bags, and analyzed in triplicate. The initial pH, total soluble solids, and moisture values of fresh experimental samples are presented in Table 1.

Table 1. Properties of initial mango, avocado and tomato samples

Crop	**pH**	**TSS** (°Brix)	**Moisture** (%)
Mango	3.93±0.17	18.28±0.38	83.77±1.0
Avocado	5.36±0.4	6.20±0.49	77.0 ±1.35
Tomato	4.07±0.12	4.46±01	86.34±1.09

Physicochemical analysis

pH

The pH of the fresh juice samples was determined by a pH meter (Sartorius, USA) after calibrating with buffer solutions of pH 4 and 7 (AOAC 2006).

Total soluble solids (TSS)

It was analyzed using a digital optical prism refractometer (ATAGO, Model-1990, Japan), and the results were expressed in degrees Brix (°Brix).

Color

The color of dried avocado, tomato, and mango samples was measured using Hunter Lab (Aeros, Dual-beam Non-contact Reflectance Spectrophotometer, USA), as described previously (Pagani et al. 2014). The equipment was calibrated before use with a standard white tile and black box for 100 and 0% reflectance, respectively. The result was reported in terms of 3-dimensional color values of the following rating scale CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness).

Moisture content

It was determined by the oven-dry method (AOAC 2006) at a temperature of 105 °C and expressed as a percentage.

Water activity

The water activity of the dried avocado, tomato, and mango powder was measured using a water activity measurement device (Wert Messer, Germany, ± 0.001 sensitivity at 25 °C) by direct reading (Minuye et al. 2021).

Lycopene

Lycopene content was determined using a UV-Vis spectrophotometer (Thermo Electron Scientific Instruments LLC, USA) at 503 nm, according to Barrett and Anthon (2001) and expressed in µg per g of sample.

Total carotenoids

Total carotenoid analysis was performed as described by Rodriguez-Amaya and Kimura (2004) using spectrophotometer (Shimadzu UV800, Japan) at 452 nm and expressed in µg per g of sample.

Bioactive compounds

Sample extraction was performed as previously described (Zuhair et al. 2013). Two grams of dried avocado, mango, and tomato samples were dissolved in 30 mL of 80% acidic methanol (with 1% HCl) and extracted for 2 h at 35 °C using an electrical shaker. The extracted sample was then centrifuged at 2236×g, and the supernatant was collected for further analysis.

Total phenolics

The total phenolic compounds of the extracts was determined by the Folin–Ciocalteu method (Singleton et al. 1999) using a UV-Vis spectrophotometer (Genesys-10 UV, USA) and expressed in mg per g of sample as gallic acid equivalent.

Total flavonoids

Total flavonoid concentration was determined spectrophotometrically as mentioned by Quettier-Deleu et al. (2000) using a UV-Vis spectrophotometer (Genesys-10UV, USA) and expressed in mg per g of sample as quercetin equivalent.

Statistical analysis

Results were analyzed by ANOVA using SPSS version 23.0 (SPSS Inc. Illinois, USA), and mean comparisons were analyzed using Tukey's multiple range post hoc test with a probability of $P < 0.05$. All measurements were performed in triplicate, and the results were recorded as the mean ± standard deviation (SD).

RESULTS AND DISCUSSION

Product color is one of the decisive quality traits in the food industry that can influence consumer preferences. It is governed by genotype, chemical, biochemical, microbial, and physical changes during growth, maturation, postharvest handling, and processing. The color, moisture, and water activity of dried fruit are the main indicators of the condition of the dried product in terms of shelf life or safety of consumption. In our study, the color parameters of dried mango, avocado, and tomato showed a statistically significant variation between drying technologies. The color of horticultural products changes due to browning reactions during heat-inducing, mainly linked to the Maillard reaction (Baini & Langrish 2009). A higher L* value was characteristic for the freeze-dryer products, followed by the refractance window, whereas the lowest value was observed in the oven drying in all dried products. Hence, the freeze dryer is less exposed to enzymatic reactions. The research output is consistent with the findings of Zomorodi and Hedayat (2023), who reported refractance window drying retained the color of tomato powder better

than other drying techniques. In horticultural dried products, higher L* and a* values indicate lower browning due to the inactivation of enzymes (Shi et al. 1999). However, this may only sometimes be true for a* value in different fruits. Avocado pulp dried by the freeze-drying method had a bright light green color compared to other drying methods because of lower and enzymatic non-enzymatic browning. Such processing techniques contribute to preserving the color of sliced avocado pulp (Castañeda-Saucedo et al. 2014). Even though there is a higher variability of tomato color based on genotype, environment, and ripening stage, the present study's output for freeze-dried tomatoes is in harmony with Farooq et al. (2020), who found that freeze-dried tomato color values were 58.44, 18.03, and 32.33, respectively, while in oven-dried sample color values were 32.87, 16.33, and 24.13 for L*, a*, and b* respectively.

The moisture content of dried mango had the lowest value (7.87%) in freeze drying and the highest (10.6%) in the refractance window-drying product (Table 2). Concerning avocado, the lowest moisture (2.71%) was obtained in refractance window-dried products, while in freeze- and oven-drying 4.31–4.41%. In tomatoes, the lowest moisture presented products from oven drying (8.38%), while in freeze- and refractance window-drying 10.72% and 10.41% were obtained. A lower value for mango, avocado, and tomato was found in the freeze, refractance window, and oven drying, respectively. The moisture content of dried avocados agrees with the findings of Alkaltham et al. (2021), providing further validation to our research. Similarly, the dried tomato moisture content of this finding agrees with Ladi et al. (2017) and Alkaltham et al. (2021), reinforcing the reliability of our results.

The other critical parameter for the shelf-life is water activity, defined as the amount of free water in the sample responsible for microbial growth. For dried products to guarantee microbial stability, the water activity value should be lower than 0.6 (Samoticha et al. 2016). In this study, water activity was below 0.34 in all fruits. The values were insignificant regardless of the drying method (Table 2). With such low water activity levels, the products were protected from pathogenic and spoilage microorganisms (Shafiur Rahman et al. 2007).

Antioxidants

All three fruits retained the highest lycopene and carotenoid contents in freeze-dried products, followed by refractance window, and oven-dried products (Table 3). In mango, the lycopene content varied from 36.59 $\mu g \cdot g^{-1}$ (freeze-dried) to 156.33 $\mu g \cdot g^{-1}$ (oven-dried), whereas in avocado from 16.12 $\mu g \cdot g^{-1}$ (freeze-dried) to 7.87 $\mu g \cdot g^{-1}$ (oven-dried) and in tomatoes from 420.56 $\mu g \cdot g^{-1}$ (freeze-dried) to 192.72 $\mu g \cdot g^{-1}$ (oven-dried). The carotenoid content in mango varied from 298.15 $\mu g \cdot g^{-1}$ (freeze-dried) to 211.46 $\mu g \cdot g^{-1}$ (oven-dried). In avocado, these values ranged from 219.9 $\mu g \cdot g^{-1}$ (freeze-dried) to 131.96 $\mu g \cdot g^{-1}$ (oven-dried), and in tomato from 654.54 $\mu g \cdot g^{-1}$ (freeze-dried) to 355.47 $\mu g \cdot g^{-1}$ (oven-dried). These results are consistent with tomato studies by Zomorodi and Hedayat (2023) and Farooq et al. (2020).

As stated by Goula et al. (2006), the degradation of lycopene in tomatoes depends on the moisture content of the product, and when the moisture content is in the range of 55–95% (high), faster chemical reactions occur. This could be due to the greater solubility and mobility of the catalytic substance in the reaction. Moreover, it can be attributed to the breakdown of cell membranes and cell walls and the breakage of the lycopene–protein complex by high drying temperatures (Dewanto et al. 2002). The most flavonoids and phenolics were found in mango and tomato dried using a refractance window, while in avocado the flavonoid content did not differ depending on the drying method. The highest phenolic content in avocado was in products dried using a refractance window (Table 3).

Studies have generally confirmed (Minuye et al. 2021) that freeze-dried products retain more nutrients than other dried products. However, some nutrients such as flavonoids and phenolic compounds have been found to have higher values in refractance windows and oven dryers. This is because the heat associated with far infrared drying has the ability to break down covalent bonds and thus enable the release of bioactive compounds such as flavonoids and phenolics from repeating polymers (Loh et al. 2016). Furthermore, Leong and Oey (2012) found that heating increases the chemical extractability of phytochemicals, leading to their release from chromoplasts and the growth of a highly unsaturated structure.

However, it was found that freeze-drying causes the most significant losses (65%), probably due to the disruption of fruit cells by ice crystals and the associated decompartmentalization of enzymes, substrates, and activators. Increased enzyme activity after thawing could lead to greater degradation of some biocompounds (Shofian et al. 2011). Freeze-drying involves drying food materials under vacuum and at very low temperatures. This process prevents deterioration and microbiological reactions, resulting in higher quality of final products (Ratti 2001). Hot-air drying, which is preferred for short drying times, can lead to greater losses of nutrients such as antioxidants due to the high temperature used. Refractance window drying, a fourth-generation dryer, offers improved features compared to previous drying technologies (Bernaert et al. 2019). It works through thermal energy in which circulating water transfers heat through the tin layer to food materials through radiation and conduction (Singh et al. 2018). Refractance window dried food products have higher energy saving, ease of operation, and lower cost than other drying technologies, and are more energy efficient (Moses et al. 2014), which is three times higher than oven drying and forty times higher than freeze-drying (Bernaert et al. 2019).

Table 2. The influence of the drying method on the color, moisture, and water activity of mango, avocado, and tomato

Crop	Drying method	Color value			Moisture (%)	Water activity
		L	**a**	**b**		
Mango	freeze	77.35±1.67^{a}	5.54±0.22^{c}	29.76±0.71^{c}	7.87±0.91^{b}	0.31±0.02^{a}
	refractance window	71.03±0.66^{b}	18.03±0.42^{a}	57.77±0.7^{a}	10.60±0.95^{a}	0.32±7.07^{a}
	oven	64.07±1.37^{c}	10.68±0.11^{b}	36.14±0.57^{b}	9.57±0.62^{ab}	0.33±0.00^{a}
Avocado	freeze	60.77±0.74^{a}	-2.61±0.02^{c}	58.05±0.70^{a}	4.31±0.63^{a}	0.34±0.01^{a}
	refractance window	41.56±1.04^{b}	10.99±0.25^{a}	37.86±0.75^{c}	2.71±0.25^{b}	0.33±0.00^{a}
	oven	39.97±0.93^{b}	9.42±0.19b	40.89±0.77^{b}	4.41±0.42^{a}	0.32±0.01^{a}
Tomato	freeze	60.47±1.96^{a}	25.88±2.30^{a}	28.00±1.63^{c}	10.72±0.68^{a}	0.29±0.00^{a}
	refractance window	47.35±0.10^{b}	20.41±0.31^{b}	33.54±0.39^{b}	10.41±1.37^{ab}	0.32±0.02^{a}
	oven	40.45±0.60^{c}	18.41±0.12^{b}	36.21±0.24^{a}	8.38±0.12^{b}	0.32±0.00^{a}

Note: Statistical analyses were conducted separately for individual crop; Means indicated by the same letter do not differ significantly according to Tukey test at p = 0.05

Table 3. Antioxidant properties in fruits depended on drying method

Crop	Drying method	Lycopene (μg·g^{-1})	Carotenoids (μg·g^{-1})	Flavonoids (mg·100 g^{-1})	Phenolics (mg·100 g^{-1})
Mango	freeze	36.59±1.8^{a}	298.15±5.4^{a}	0.52±0.03^{b}	76.89±3.37^{b}
	refractance window	28.67±3.61^{a}	258.66±4.04^{b}	0.81±0.04^{a}	141.78±7.11^{a}
	oven	15.33±0.48^{b}	211.46±2.49^{c}	0.58±0.04^{b}	92.44±3.20^{b}
Avocado	freeze	16.12±1.32^{a}	219.90±4.34^{a}	0.70±0.12^{a}	103.00±3.34^{c}
	refractance window	9.99±1.2^{b}	189.81±1.82^{b}	0.66±0.03^{a}	177.20±2.9^{a}
	oven	7.87±0.79^{b}	131.96±2.07^{c}	0.58±0.04^{a}	133.94±1.56^{b}
Tomato	freeze	420.56±5.02^{a}	654.54±4.21^{a}	0.65±0.02^{b}	117.73±5.32^{b}
	refractance window	284.11±3.63^{b}	610.43±3.65^{a}	0.95±0.04^{a}	288.32±2.42^{a}
	oven	192.72±3.31^{c}	355.47±0.79^{b}	0.96±0.01^{a}	155.30±3.42^{b}

Note: Statistical analyses were conducted separately for individual crop; Means indicated by the same letter do not differ significantly according to Tukey test at p = 0.05

CONCLUSION

The presented research findings have practical implications because they reveal statistically significant differences in the studied parameters of dried mango, avocado, and tomato, with the exception of water activity caused by drying techniques. The highest color, lycopene, and carotenoid retention parameters for all dried products were observed after freeze-drying and then in the refractance window. Higher values of phenolics and flavonoids content were recorded in the case of the refractance window method followed by oven drying. In conclusion, the potential of refractance window drying technology is underscored by its easy operation, lower energy consumption, and excellent nutrient retention, making it a promising drying technology with practical applications in the food industry.

Conflict of interest

There is no conflict of interest among the authors.

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