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POTENTIAL OF ENERGY SAVING BY MICROWAVE DRYING FOR WASTE *Cucumis metuliferus* SEEDS AS ALTERNATIVE TO FREEZE DRYING

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Abstract

In this study, the influences of microwave and freeze-drying methods on chemical composition, sensory, textural and antioxidative properties of the seeds of Kiwano and the potential of microwave drying as an alternative to freeze drying were investigated. For this aim, the Kiwano seeds were dried with freeze-dryer and microwave dryer. The protein, ash, fat, fiber, vitamin C, β-carotene, total phenolic content, antioxidant, textural and sensory properties of dried seeds were compared. Kiwano seeds dried at 180 W and freeze-dried seeds took the highest scores by the panelists ($p>0.05$). Microwave drying increased the total phenolic content of Kiwano seeds up to 35.54 ± 0.09 mg/g. As a practical and energy-saving method, microwave drying reduced the drying times. The results of present study revealed that microwave drying have a potential to be a promising innovative alternative for the rapid production of freeze-dried fruit materials while maintaining product quality.

Key words: drying, food, freeze-drying, Kiwano fruit, microwave

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1. Introduction

Food drying is one of the practical techniques for preserving food matters for later use (Kanlayanarat, 2013). This method is also known to be used in ancient times (Hirun et al., 2014). The technique of drying process entails lowering moisture content, needed by bacteria, mold, and yeast to grow, to allow safe storage for a prolonged time (Amit et al., 2017; Khodja et al., 2020). Moreover, while dried fruits are consumed as healthy snack foods, dried vegetables can be used in stews, soups, and casseroles. Dried foods do not required energy when they store. Furthermore, little storage space is required for them (Saifullah et al., 2019). Serving as important healthful snacks all over the world, dried foods supply a concentrated form of fresh foods (Chang et al., 2016). Dried foods are nutritious, easy-to-prepare, tasty, lightweight, and easy-to-store. In order to increase fibre intake, dried fruits could be employed as easy snacks (Sadler, 2017). It is important to note that these products contain more oxidants and fiber compared to fresh fruit per unit mass of dry product (Vinson et al., 2005). Their advantages consist in the protective effect against heart disease, some types of cancer, obesity, and their adding together with dried fruits in the diet is highly recommended by nutritionists even for their satiety (Carughi et al., 2015; Kwork et al., 2013; Mossine et al., 2020; Patel et al., 2013).

In the course of drying, foods undergo a series of physico-chemical transformations and also the modification of their textural, nutritional, sensorial, functional properties (An et al., 2016; Li et al., 2020). These are largely influenced by drying temperatures, the type of dryer, as well as a series of drying parameters, as humidity and air flow rate, the presence of pre-treatment agents, which can ensure a successful and efficient drying process (Monton et al., 2019). Drying time depends on the materials to be dried, their moisture content and characteristics of air used as a drying agent (Tunde-Akintunde and Ogunlakin, 2011). In the drying process, one of the main points is to remove moisture from the food as rapid as possible, at a temperature that does not cause a change in the color, texture, and flavor. Too low temperature at the beginning of the drying may causes the growth of microorganisms, so affects adversely the product quality. However, high drying temperatures combined with low food humidity can destroy their surface, hindering deep drying, and producing degradation of nutritional, phytochemical, heat-sensitive components (Duan et al., 2010; Nadi, 2017; Nguyen et al. , 2018). That is why it is essential to select the most suitable drying technique and drying conditions for the type of food.

Adequately drying methods including sun drying, hot air drying, freeze drying, microwave drying, fluidized bed drying, vacuum drying, and spray drying have been developed for the food industry. The oldest technique used since ancient time in food drying, is the sun drying. Principally, it depends on the sun power, supported by natural airflow (Monton et al., 2019a). It is a mild technique encompassing a simple reaction between the sun light and the food (Jain et al., 2003). This drying method is cheaper than others since it is not necessary costly energy from gas or electricity. This is why sun drying is a popular cooking method in the world today, even in the most modern kitchens. However, since the heat of the sun cannot be controlled, the food may not be dried quickly, and the mold may grow on the surface of the food materials.

Food can start to spoil before it is sufficiently dried in the sun. In addition, involving a lot of people in the process, the sun drying technique is a labor-intensive method. The drawbacks of the sun drying led to the development of improved drying techniques. One of the methods developed as an alternative to sun drying is hot air drying. While hot air drying has many advantages over sun drying, it causes loss of many aromatic and nutritional food component during drying (Maskan, 2001). Moreover, the hot air adversely affects the quality of dried food materials (Mayor and Sereno, 2004). Conventional drying techniques including conductive and convective modes of heat transfer can cause a final product with poor quality thus, probability of product contamination can be augmented (Moses et al., 2014). Moreover, fruit drying at high temperatures may causes Maillard reaction products because of non-enzymatic browning reactions, which are potentially genotoxic (Rawson et al., 2011). Drying at low temperatures can ensure the improvement of the quality of dried products, their stability over time, which is why it is necessary to design the drying process in optimal conditions, and its simulation (Di Scala and Crapiste, 2008).

In this context, lyophilization is one of the most appropriate techniques, which can eliminate the disadvantages of hot air drying and ensure the maintenance of food quality, and the chemical composition of dried products. Freeze-drying provides dried foods with better quality compared to other drying techniques (Assegehegn et al., 2019). Freeze-drying causes less damage to the dried food materials than other drying techniques using higher temperatures. Freeze-drying preserves nutritional value of dried food materials better than other drying methods. This technique also retains the color and shape of the foods, reassuring consumers they are actually getting real fruits and vegetables in their diets. The aroma and flavor freeze-dried food materials also closely resembles the profile of the raw material. Compared to processes involving heat treatment for drying, heat sensitive nutrients are less lost in the freeze-drying process.

Nowadays, since the market for organic products has increased, freeze drying of fruits and vegetables is gaining ground (Hsu et al., 2003). However, freeze drying is a costly and time-consuming process, which limits the use of this technique in all types of food. The technique is generally used only for heat sensitive foods due to the high cost. In recent years, research on innovative drying methods has intensified. Some research has shown that microwave drying requires short drying times and can be applied to heat sensitive foods (Gagare et al., 2015). This technique can increase the quality of dry materials, their texture and color. It also preserves some components such as vitamins, lipids and antioxidants (Sommano et al., 2013; Pham et al., 2018; Polovka and Suhaj, 2010). During microwave drying, energy is transferred to wet matter with greater efficiency, and moisture is removed more quickly (Bolek and Ozdemir, 2017). This makes that the drying process takes less time and energy. Microwave method may be considered as an alternative to freeze drying method.

Kiwano, *Cucumis metuliferus*, is the fruit of a climbing plant annual of the Cucurbitaceae family species that, similar to rest of its genus, is native to Africa (in particular, Nigeria). The *C. metuliferus* has only lately been put into the Spanish market by just two commercial producers. Part of the production is exported to France and elsewhere, while no constant consumption data are accessible. Kiwano is a rich source of a majority of vitamins and minerals including vitamin C, vitamin A, zinc, and lutein, many of which play a role in its ability to positively impact health. Besides, it is also a good source of energy with low caloric power (Ferrara, 2018). Different parts of *C. metuliferus* are used for different culinary and medicinal purposes (Usman et al, 2015). The seeds of *C. metuliferus* is a rich source of nutrient and have the potential to be used for therapeutic purposes. (Ezekaibeya et al., 2020). After drying, the seeds of fruits are eaten raw as food supplement. On the other hand, large amounts of the Kiwano seeds are discarded as waste.

The efficient fruit waste management ensures the sustainable development uses wastes in maximum level and improves the fruit processing technology (Serban and Nicu, 2004). However, to date no study investigated the impacts of the drying method on the chemical composition of the seeds of *C. metuliferus*. Therefore, the present research work aimed to perform a comparative study on the effects of the microwave drying and freeze-drying methods on sensory, textural, chemical, and antioxidative properties of the seeds of Kiwano and the potential of microwave drying as an alternative to freeze-drying in drying process of Kiwano seeds.

2. Material and methods

2.1. Material

Non-bitter *C. metuliferus* fruits were obtained from a local farm in August 2019 in Alanya, Turkey. The whole plant and fruits were identified and authenticated by the farmer who has botanical certification. The samples were transported to the laboratory in polyethylene bags and they were stored -18 °C until further analysis. The fruits were cut open, the pulp scooped out and the seeds were separated from the pulp.

2.2. Drying experiments

The microwave drying process was conducted by a microwave dryer (Siemens, HF12G540 with the cavity dimensions of 290 x 461 x 351 mm. Experiments were conducted at 180 W, 360 W, 600 W with 1-min intervals and 2450 MHz frequency. The drying process was continued until the moisture value of the samples reached 10 % (dry basis). Drying tests were performed in three replications for each experimental condition.

Freeze drying process was conducted by a freeze-dryer (Buchi L-200 Flawil, Switzerland) for about 24 h with the condenser temperature and chamber vacuum at −50 °C and 125 mbar respectively. The fresh Kiwano seeds were previously frozen at −80 °C before the freeze-drying process.

2.3. Proximate composition analysis

The moisture content (AACC Method, 44-01.01, 2000), ash content (AACC Method, 08-01.01, 2000), protein content (AOAC Method, 950.36, 2000), fat content (AOAC Method 30-25,01,2000), fiber content (AACC Method, 32-07.01, 2000) of Kiwano seeds were determined.

2.4. Vitamin analysis

Vitamin C of Kiwano seeds were determined according to the AOAC (2005) by titrimetric method by titration of filtrate against 2,6-dichlorophenol indophenol.

β-carotene content of Kiwano seeds were determined by The De Ritter and Purcell (1981) procedures. The seeds were extracted using hexane. One g of seed was weighted in a mortar. 15 ml of hexane was then added and quickly transferred to an amber bottle. Then the bottle was left to stand. The extract was then filtered into a 50 ml volumetric flask by Whatman filter paper no: 1. The residue was treated with 15 ml of fresh hexane and the prescript was repeated to extract the remaining β-carotene. The entire extract was treated with up to 50 ml more hexane and stored under refrigerator conditions in an amber plastic bottle until absorbance was measured in a spectrophotometer.

2.5. Antioxidant activity

The free radical scavenging activities of the seeds were determined using 2,2-diphenyl-1-picryl-1-hydrazil (DPPH) method (Brand-Williams et al., 1995). DPPH solution in methanol was added to 0.5 mL of samples in various concentrations. After 20 min, the absorbance was determined at 517 nm against a blank solution. The DPPH radical scavenging activity was determined by using the Eq. 1.

$$DPPH\ Scavenging\ Activity = \frac{A_C - A_t}{A_C} x100 \quad (1)$$

where A_c was the absorbance of the control and A_t the absorbance of the sample solution.

2.6. Total phenolic content analysis

Total phenolic contents of seeds were determined according to the method proposed by Kumazawa et al. (2002) by Folin-Ciocalteu reagent. One mL Folin-Ciocalteu reagent (diluted 10 times with water) mixed with 0.1 mL extract in test tubes. Then, 1.0 mL sodium carbonate (10%, w/v) was added. Tubes were vortexed and incubated for 60 min at room temperature. Absorption was measured at 760 nm. Total phenolic content of the Kiwano seeds are reported as gallic acid equivalents (mg/g dry basis).

2.7. Textural properties

Texture profile analysis of Kiwano seeds was performed by a TA/XT texture analyzer (Stable Microsystems, England) by 5 kg load cell. The seeds were compressed to 75% using a probe (P/75). The test speed was 1 mm/s. The hardness and fracturability were determined. Thirty replications were performed on each sample.

2.8. Sensory analysis

Sensory analysis was conducted by 62 (35 female, 27 male) untrained panelists. 5-point hedonic scale was used to compare the sensory properties of freeze-dried and microwave dried Kiwano seeds. Four samples were tested by each panelist. The samples were presented to the panelists with odorless, disposable, white ceramic plates labeled with randomly-coded three-digit numbers. The sensory analysis was conducted in a well-lightened test room.

2.9. Statistical analysis

Data of the experiments stated as mean ± SE. Statistical analysis was conducted by SPSS software (version 20.0) for the analysis of variance (ANOVA). Duncan's multiple range test was used to compare the means at the level of $p<0.05$.

3. Results and discussions

3.1. Proximate analysis

Proximate analysis of Kiwano seeds is given in Table 1. Microwave drying and freeze-drying affected non-significantly the total protein, ash, and fat content of Kiwano seeds ($p<0.05$). As the power of the microwave drying increased, the total protein content of the seeds decreased non-significantly ($p>0.05$). As the microwave power increased, the crude fiber contents of Kiwano seeds decreased significantly ($p<0.05$). El Anany (2015) roasted the guava seeds and found similar results for fiber content.

However, crude fiber contents of freeze-dried Kiwano seeds and microwave dried at 180 W Kiwano seeds are not different significantly ($p>0.05$). As the microwave power increased, the ash content of Kiwano seeds decreased slightly ($p>0.05$). This may be due to the destroying some minerals in the seeds. The microwave power affected the fat content of the Kiwano seeds non-significantly ($p>0.05$).

3.2. Effects of drying methods on vitamin C and β-carotene content

The effects of drying methods on vitamin C and β-carotene content are given in Table 2. Drying methods affected the vitamin C and β-carotene content of Kiwano seeds significantly ($p<0.05$).

As a consequence of the fact that β-carotene and vitamin C are especially prone to oxidative destruction in the presence of heat, in the experimental tests performed at a microwave power of 600 W, in dried seeds, it was found the greatest loss of vitamin C and β-carotene content, while the lowest was at 180W microwave power and lyophilized samples.

Suvarnakuta et al. (2005) investigated the β-carotene degradation in carrot undergoing different drying processes. In the results of their study it was found that β-Carotene degradation depended on the carrot temperature.

3.3. Influences of drying methods on antioxidant activity and total phenolic contents

Table 3 shows the effects of drying methods on antioxidant activity and total phenolic contents. It was found that drying method and microwave power affected the antioxidant activity and total phenolic contents of Kiwano seeds significantly ($p<0.05$). Kiwano seeds drying using microwave had higher antioxidant activity and total phenolic content than freeze-dried Kiwano seeds.

Furthermore, as the microwave power increased, the antioxidant activity and total phenolic content of Kiwano seeds increased significantly ($p<0.05$). Though, there was a slight decline in the antioxidant activity after a drying power of 360 W. Changes in antioxidative activity of Kiwano seeds could be attributed to novel antioxidant substances formed during the roasting process such as Maillard reaction products (Priftis et al., 2015).

Table 1. Proximate analysis of Kiwano seeds

Treatments	*Total Protein (g/100g)*	*Crude Fiber (g/100g)*	*Ash (g/100g)*	*Fat (g/100g)*
Fresh seeds	2.61 ± 0.04^a	19.16 ± 0.12^a	5.12 ± 0.11^a	14.99 ± 0.16^a
Microwave_{180}	2.52 ± 0.15^a	18.20 ± 0.03^b	5.10 ± 0.02^a	15.02 ± 0.02^a
Microwave_{360}	2.48 ± 0.11^a	16.03 ± 0.11^c	5.08 ± 0.03^a	15.08 ± 0.01^a
Microwave_{600}	2.44 ± 0.18^a	15.22 ± 0.09^d	5.06 ± 0.05^a	15.14 ± 0.01^a
Freeze-drying	2.49 ± 0.15^a	18.22 ± 0.14^b	5.08 ± 0.07^a	15.10 ± 0.02^a

Mean of thee determination ± standard error. Means have same letters in the same line do not differ at $p<0.05$.

Table 2. Influence of drying methods on vitamin C and β-carotene content

Treatments	*Vitamin C (mg/g)*	*β-carotene (mg/g)*
Fresh seeds	1.71 ± 0.02^a	1.46 ± 0.03^a
Microwave_{180}	1.51 ± 0.15^b	1.02 ± 0.03^b
Microwave_{360}	1.05 ± 0.11^c	0.83 ± 0.11^c
Microwave_{600}	0.54 ± 0.18^d	0.54 ± 0.09^d
Freeze-drying	1.40 ± 0.15^b	0.88 ± 0.14^b

Mean of three determination ± standard error. Means have same letters in the same line do not differ at $p<0.05$

Table 3. Influences of drying methods on antioxidant activity and total phenolic contents

Treatments	***Inhibition (%)***	***Gallic acid (mg/g)***
Fresh seeds	36.25 ± 0.42^c	30.38 ± 0.03^c
Microwave$_{180}$	38.42 ± 0.34^b	32.22 ± 0.03^b
Microwave$_{360}$	40.05 ± 0.21^a	34.83 ± 0.11^a
Microwave$_{600}$	39.22 ± 0.24^a	35.54 ± 0.09^a
Freeze-drying	37.12 ± 0.17^c	30.91± 0.14^c

Mean of three determination ± standard error. Means have same letters in the same line do not differ at p<0.05

3.4. Influences of drying methods on textural properties

Structural collapse in food materials because of moisture removal from the food product causes important changes in food texture (Omolola et al., 2017; Khan et al., 2020). Effects of drying method on hardness and fracturability values are given in Table 4. Drying process and drying technique affected the textural properties of Kiwano seeds significantly ($p<0.05$).

The hardness and fracturability values of Kiwano seeds increased significantly ($p<0.05$), as the microwave power increased. However, hardness and fracturability values of freeze-dried Kiwano seeds and microwave dried at 180 W Kiwano seeds are not different from each other significantly ($p>0.05$). This results also supported by Deng and Zhao (2008) who stated that freeze-dried apples have softer texture than hot air-dried apples.

3.5. Influences of drying methods on sensory attributes

Influences of drying method on sensory properties of are given in Table 5. Kiwano seeds dried at 360 W took the highest sensory scores by the sensory panel. However, Kiwano seeds dried at 180 W and freeze-dried seeds took the highest scores by the panelists ($p>0.05$).

The microwave dried samples at 360 W took the highest scores in terms of flavor. This score could be attributed to the maillard and caramelization reactions giving the foods aroma compounds (Michalska et al., 2016). However, the Kiwano seeds dried at 600 W took the lowest scores by the panelists ($p<0.05$). The results of sensory analysis revealed that lower microwave power causes similar dried products to freeze-dryer.

4. Conclusions

Freeze drying and microwave drying affected the chemical, textural and sensory characteristics of Kiwano seeds significantly ($p<0.05$). In general, the properties of dried Kiwano seeds at 360 W and freeze-dried Kiwano seeds were not different significantly ($p<0.05$). However, higher microwave power caused a decrease in sensory scores of Kiwano seeds. On the other hand, microwave drying at high power caused an increase the antioxidant activity of Kiwano seeds significantly due to the Maillard reactions. Freeze drying and microwave drying of Kiwano seeds caused only minor changes in protein, fat and ash content. As a practical and energy-saving method, microwave drying reduced the drying times. Besides, the microwave dried samples at 180 W and 360 W were not different significantly from the freeze-dried samples in terms of sensory properties ($p>0.05$).

Table 4. Effects of drying methods on hardness and fracturability

Treatments	***Hardness (N)***	***Fracturability (N)***
Fresh seeds	30.25 ± 0.58^d	21.38 ± 0.55^d
Microwave$_{180}$	32.42 ± 0.78^c	23.22 ± 0.62^c
Microwave$_{360}$	36.05 ± 0.36^b	25.83 ± 0.67^b
Microwave$_{600}$	38.22 ± 0.44^a	29.54 ± 0.36^a
Freeze-drying	31.12 ± 0.64^c	23.91 ± 0.28^b

Mean of thirty determination ± standard error. Means have same letters in the same line do not differ at p<0.05

Table 5. Effects of drying methods on sensory properties

Treatments	***Appearance***	***Texture***	***Flavor***	***Overall impression***
Fresh seeds	3.76 ± 0.03^b	3.12 ± 0.11^b	2.12 ± 0.03^b	2.90 ± 0.10^b
Microwave$_{180}$	4.62 ± 0.02^a	4.42 ± 0.02^a	4.14 ± 0.05^a	4.50 ± 0.07^a
Microwave$_{360}$	4.78 ± 0.04^a	4.62 ± 0.03^a	4.82 ± 0.04^a	4.66 ± 0.04^a
Microwave$_{600}$	2.78 ± 0.12^c	2.52 ± 0.09^c	1.20 ± 0.15^c	1.96 ± 0.05^c
Freeze-drying	4.65 ± 0.03^a	4.46 ± 0.02^a	4.22 ± 0.03^a	4.55 ± 0.03^a

Mean of three determination ± standard error. Means have same letters in the same line do not differ at p<0.05

Furthermore, vitamin C and the β-carotene contents of the freeze dried and microwave dried samples at 180 W were not different significantly ($p>0.05$).

The results of this study indicated that microwave drying at low powers is a promising innovative alternative for the rapid production of freeze-dried fruit materials while keeping fruit quality.

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