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ARTICLE

Effect of Different Drying Methods on the Chemical and Antioxidant Properties of Avocado Seed Powder

Rebecca Olajumoke Oloniyo [1*], *Blessing Abeni Ekele* [1], *Jabiru Daddy Aliyu* [1], *Mary Anuoluwapo Ajatta* [2], *Opeyemi Banke Abiodun* [3]

[1] *Department of Food, Nutrition and Home Science, Prince Abubakar Audu University, Anyigba P.M.B. 1008, Nigeria*

[2] *Department of Food Science and Technology, Bamidele Olumilua University of Education, Science and Technology, Ikere Ekiti P.M.B. 250, Nigeria*

[3] *Department of Food Science and Technology, Wesley University, Ondo P.M.B. 507, Nigeria*

ABSTRACT

Avocado fruits are considered the healthiest fruit in the world due to their high nutritional value. It is rich in valuable bioactive compounds that could be used in the treatment of degenerative diseases, but its seeds remain underutilized. This study investigates the effect of three different drying methods on the chemical and antioxidant properties of avocado seed powder. Ripe avocado fruits were selected and washed manually; the skin and pulp were removed, and the seed was subjected to three different drying methods: oven drying (60 °C; 8 h), sun drying (ambient conditions), and greenhouse drying (controlled conditions). The dried avocado seed was pulverized to a fine powder using a blender, and the powder was analyzed for proximate, mineral, and antioxidant activities using standard methods. The results showed significant differences ($p < 0.05$) between the drying methods. Moisture content ranged from 5.07 to 7.51%, and protein content ranged from 8.93 to 14.37%. The crude fiber content ranged between 3.86 and 4.40%, and the ash content ranged between 1.78 and 2.01%. Potassium content ranged from 637.60 to 740.20 mg/100 g, calcium content ranged from 117.62 to 140.60 mg/100 g, and iron content ranged from 7.60 to 15.45 mg/100 g. Total carotenoid content ranged from 25.12 to 79.29 mg/100 g, and beta-carotene content ranged between 66.32 and 618.23 μg/g. The

*CORRESPONDING AUTHOR:
Rebecca Olajumoke Oloniyo, Department of Food, Nutrition and Home Science, Prince Abubakar Audu University, Anyigba P.M.B 1008, Nigeria; Email: oloniyo.ro@ksu.edu.ng

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inhibitory concentration (IC_{50}) of the antioxidant properties of avocado seed powder was observed to be less than (<) 2. Thus, avocado seed powder could be used as a nutraceutical ingredient in functional food formulations.

Keywords: Avocado Seed Powder; Drying Methods; Green-House Drying; Antioxidants; Inhibitory Concentration **(**IC_{50})

1. Introduction

The avocado (*Persea americana*) is an edible fruit that belongs to the Lauraceae family [1]. It is native to the Western Hemisphere from southern Mexico to the Andean regions and is widely cultivated in warm climates [2]. It is a global fruit crop known for its nutritional value and economic importance [3]. It is also known as alligator pear or avocado pear; botanically, it is a large berry containing a single large seed. The avocado fruit is climacteric in nature [4]. Avocado fruits have yellowish-green flesh with a buttery consistency and a rich, nutty flavor [5]. It is often eaten in salads and in most parts of the world. It is consumed as a dessert [6]. Avocado has a butter-like mesocarp when ripe, and it depends on the variety; its varieties vary in terms of colour and shape; it varies in colour, such as green, brown, purplish, or black skin, and can be pear-shaped, egg-shaped, or spherical [7].

It is rich in antioxidants, fatty acids, and other bioactive substances that have significant potential for various applications in the food, pharmaceutical, and nutraceutical industries [8]. Despite the growing recognition of avocado seeds as a potential source of valuable bioactive compounds, their high potential for nutraceutical and functional food applications is bogged down by the lack of optimized processing techniques that can preserve their nutritional properties [3,8]. Among these processing techniques are drying methods. Drying is the main effective preservation method for both domestic and industrial purposes to preserve foods with high moisture content in agricultural products, including cereals, legumes, nuts, fruits, and vegetables [9].

Drying is a mass transfer process that removes moisture or liquid from a solid, semi-solid, or liquid substance [10], usually through evaporation, to achieve a stable, dry, and often preserved food product, thereby reducing the volume and increasing the cost of the produce, resulting in an increase in shelf life and reducing food weight [11].

Drying helps to improve the safety of food products, thereby preventing microbial growth [12]. Some physical, structural, and nutritional changes occur due to the drying of food products [13]. In addition, drying reduces post-harvest losses, thereby ensuring year-round product availability, reducing the volume/quantity of food products, and helping to facilitate the storage and transportation of agricultural products. There are different techniques used to achieve this drying process. These techniques include: Sun drying (solar drying), greenhouse drying, freeze drying, oven drying, etc. Solar drying is an ancient method and global practice of utilizing energy from the sun for crop preservation. The dried crop has various advantages such as enhanced product quality, increased shelf life, and low post-harvest losses [14]. Heat transfer in the form of conduction, convection, and radiation plays a vital role in the solar drying process [15].

Numerous drying techniques, such as spray, mechanical, oven, solar drying, greenhouse, etc., have been developed by researchers.

A greenhouse drier basically operates either in passive (natural convection) or active mode (forced convection). In the passive mode of greenhouse dryer, a ventilator or chimney is provided at the chimney for the natural circulation of air entering inside the dryer, while in the active mode of greenhouse dryer, an exhaust fan is provided for moving humid air outside the dryer [16,17]. The greenhouse offers significant advantages over open-sun drying by protecting agricultural produce from insects, dust, rain, and animals [18], resulting in higher quality, hygienic products [19]. It reduces post-harvest losses, speeds up drying time, and is eco-friendly [18,20]. Drying is a fundamental step to transform avocado seeds into a stable powder, and this method remains insufficiently viewed [21]. Despite the promising advancement of avocado seeds, they remain underutilized, and there is a paucity of information on the effects of different drying methods on the quality of avocado seed powder. Therefore, this study aimed to examine the effect of three different drying methods on the physicochemical and nutritional properties of avocado seed powder.

2. Materials and Methods

2.1. Materials

Matured and ripe avocado (*Persea americana*) fruits were purchased from Anyigba markets in Kogi State, Nigeria.

Sample Preparation: Preparation of Avocado Seed Powder

The avocado seed was processed into powder using the method described by Siol and Sadowska [21] with slight modifications. The seeds were manually sorted, cleaned, and washed to remove all residual pulp, and the seeds were removed from the pulp. The seeds were rinsed and air-dried at room temperature for 24 h to reduce surface moisture before the drying processes began. After drying at room temperature, the seeds were initially ground into smaller sizes, spread on a tray and dried under three different conditions (sun drying, oven drying, and greenhouse drying) to a constant weight, then ground into powder using a blender to obtain fine avocado powder. The powder obtained from avocado seeds was stored in an airtight container and kept in a cool, dry place before use.

- Oven Drying Avocado (ODA): The grated avocado seeds were placed in an electric oven and dried at 60 °C for 8 h.
- Sun Drying Avocado (SDA): The grated avocado seeds were spread on clean trays and exposed to direct sunlight at temperatures ranging between 30 and 35 °C for 72 h.
- Greenhouse Drying Avocado (GHDA): The grated avocado seeds were placed in a greenhouse under controlled conditions for 48 h, with temperature (44 °C) and humidity monitored (<60%) to ensure consistent drying. The seeds were dried until they reached a moisture level similar to those dried by oven and sun methods.

2.2. Methods

- **Determination of Proximate Composition of Avocado Seed Powder**

The proximate composition (moisture, protein, fat, ash, and crude fiber contents) of avocado seed powder was determined in triplicates according to the Association of Official Analytical Chemists [22]. The carbohydrate content was calculated by difference using the standard procedure described by Oloniyo et al. [23].

- **Determination of Mineral Elements of Avocado Seed Powder**

Mineral contents of avocado seed powder were determined by atomic absorption spectrometry, flame photometry, and spectrophotometry according to the methods of AOAC [22].

- **Total Carotenoid, β-Carotene, and Vitamin A Contents of Avocado Seed Powder**

The total carotenoids and β-carotene of avocado seed powder were determined as described in AOAC [22], while the β-carotene was separated from the extract by column chromatography using aluminum oxide and eluted using hexane + acetone (96 + 4). The concentration of total carotenoids and β-carotene was calculated using a calibration curve with β-carotene as a standard. β-carotene (a) was converted to vitamin A (μgRAE) by dividing (a) by 14 [24,25].

- **Vitamin C Content of Avocado Seed Powder**

The vitamin C (ascorbic acid) concentration of avocado seed powder was determined using the standard protocol of the Association of Official Analytical Chemists International method [22]. The sample and standard L-ascorbic acid were prepared using a 3% meta-phosphoric acid solution and thereafter titrated against 2,6-dichlorophenol-indophenol dye-DIP until a light pink color lasted for at least 15 s. Vitamin C content of avocado seed powder was calculated using the equation below and recorded as mg/100 g.

$$Vitamin\ C = \frac{Titre\ value \times Dye\ factor \times Volume\ makeup \times 100}{Weight\ of\ sample \times Volume\ of\ aliquot\ taken}$$

$$Dye\ factor = \frac{0.5}{Titre\ value\ of\ standard}$$

- **Determination of Total Phenolic Compounds of Avocado Seed Powder**

The total phenol content of avocado seed powder was determined as suggested by Charoenphun and Klangbud [26]. Briefly, appropriate dilutions of the extracts were oxidized with 2.5 mL of 10% Folin-Ciocalteau's reagent (v/v) and neutralized by 2.0 mL of 7.5% sodium carbonate (Na2CO3). The reaction mixture was incubated for 40 min at 45 °C, and the absorbance was measured at 765 nm using a Visible Spectrophotometer (Model 721 Visible Spectrophotometer, Axiom Medical Ltd., UK). The total phenol content of the sample was calculated as mg Gallic Acid Equivalent (mg GAE)/g.

- **Determination of Total Flavonoid Compounds of Avocado Seed Powder**

The total flavonoid content of avocado seed powder extract was determined using aluminium chloride ($AlCl_3$) colorimetric method as described by Muhtadi and Ningrum [27]. Firstly, in a 10 mL volumetric flask, 0.5 mL of the sample was mixed with 4.0 mL of distilled water and 0.3 mL of 5% (w/v) sodium nitrite ($NaNO_2$). After 5 min, 0.3 mL of 10% (w/v) aluminium chloride ($AlCl_3$) was added to the mixture and left again for another 5 min. Next, 4.0 mL of 1 M sodium hydroxide (NaOH) and distilled water were added to reach the boundary mark in the volumetric flask. The absorbance value of the mixture was determined using a spectrophotometer at a wavelength of 510 nm. Its content was calculated and recorded as mg Quercetin Equivalents per gram (mg QE/g).

- **Determination of Ferric Reducing Antioxidant Property (FRAP)**

Ferric reducing antioxidant power (FRAP) of avocado seed powder extract was determined by assessing the ability to reduce the $FeCl_3$ solution as described by Oyaizu [28]. About 2.5 mL of the extract was mixed with 2.5 mL of 200 mM sodium phosphate buffer at pH 6.6 and 2.5 mL of 1% potassium ferricyanide (KFC). The mixture was incubated at 50 °C for 20 min; thereafter, 2.5 mL of 10% trichloroacetic acid (TCA) was also added and centrifuged at 650 rpm for 10 min, 5 mL of the supernatant was mixed with an equal volume of distilled water (5 mL), and 1 mL of 0.1% of ferric chloride ($FeCl_3$). The absorbance was measured using a visible spectrophotometer at 700 nm, and the ferric reducing antioxidant property was subsequently calculated.

- **Determination of 1,1-Diphenyl–2 Picrylhydrazyl (DPPH) Free Radical Scavenging Ability**

The DPPH assay assessed antioxidant activity using a guideline from Xiao et al. [29] with some modifications. Firstly, an ethanolic DPPH solution was prepared by dissolving 7.89 mg of 2,2-diphenyl-1-picrylhydrazyl (DPPH) with 100 mL of ethanol (99.5%) and kept in a dark place for 2 h. Thereafter, 1.0 mL of 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution was mixed with 0.8 mL of Tris-HCl buffer (pH 6.8) and 0.2 mL of avocado seed powder extract. This mixture was kept for 30 min in the dark at room temperature. The absorbance of the solution was determined at 517 nm. This experiment used 1.2 mL of ethanol (99.5%) and 0.8 mL of Tris-HCl buffer as a blank. Meanwhile, 1.2 mL of ethanolic DPPH solution with 0.8 mL of Tris-HCl buffer was used as a control. The radical scavenging activity was obtained using the formula below:

$$\%RSA = \frac{Abs\ Control - ABS\ Sample}{Abs\ Control} \times 100$$

RSA = Radical Scavenging Activity.

Abs control = Absorbance of control solution (DPPH + Tris HCl buffer).

Abs sample = Absorbance of the sample (DPPH solution + Tris HCl buffer + avocado seed powder extract).

The standard curve was plotted with the Y-axis representing the percentage of radical scavenging activity, while the X-axis represented different concentrations of the avocado seed powder extract samples (20–120 µg/mL). The IC_{50} (x value) was calculated from the standard curve equation by substituting the y value with the inhibition ratio (50%).

2.3. Statistical Analysis

Data were obtained in triplicate and subjected to one-way analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version 22. Duncan's new multiple range test (DNMRT) was used to compare the treatment means. Statistical significance was accepted at $p \leq 0.05$.

3. Results and Discussion

3.1. Proximate Composition of Avocado Seed Powder

The proximate composition of avocado seed powder is presented in **Table 1**. The moisture content ranged between 5.07 and 7.50%. The lowest moisture content was observed in oven-dried avocado (ODA) with 5.07%, while the highest moisture content was observed in sun-dried avocado seed powder (SDA) with 7.50%. Higher moisture content in sun-dried avocado seed powder may reduce shelf-life and increase susceptibility to microbial spoilage, making SDA less suitable for long-term storage. This agrees with the findings of Suo et al. [30], who reported that higher moisture content in dried fruits accelerates microbial growth and lipid oxidation thereby leading to fruit spoilage, while the lower moisture content observed in oven-dried avocado (ODA) enhances preservation and storage stability, which is beneficial for commercial packaging and export, as reported by Kefale et al. [31].

Table 1. Proximate composition (%) of avocado seed powder.

Sample Code	Moisture Content	Ash Content	Crude Fibre	Fat Content	Protein Content	Carbohydrate Content
GHDA	$5.18^b \pm 0.1$	$2.01^a \pm 0.2$	$3.86^c \pm 0.1$	$3.07^c \pm 0.2$	$14.37^a \pm 0.1$	$75.75^b \pm 0.0$
SDA	$7.50^a \pm 0.1$	$1.82^b \pm 0.1$	$3.97^b \pm 0.1$	$3.85^a \pm 0.1$	$9.76^b \pm 0.1$	$73.41^c \pm 0.1$
ODA	$5.07^b \pm 0.1$	$1.78^c \pm 0.1$	$4.04^a \pm 0.1$	$3.28^b \pm 0.1$	$8.93^c \pm 0.1$	$76.78^a \pm 0.1$

Note: Values are expressed as mean ± standard deviation (SD). Means in the same column with different superscript letters (a, b, c) are significantly different ($p < 0.05$) according to Duncan's Multiple Range Test (DMRT). GHDA = Greenhouse drying; SDA = Sun-drying; ODA = Oven Drying of Avocado.

The ash content of avocado seed powder ranged between 1.78 and 2.01%. ODA had the lowest ash content, 1.78%, while GHDA had the highest ash content, 2.01%. A significant difference ($p > 0.05$) is observed in the ash content of avocado seed powder. The higher ash content observed in GHDA avocado seed powder implies better mineral retention, possibly due to controlled heat distribution that minimizes nutrient loss. This agrees with the findings of Fartoosi et al. [32], who reported an improvement in mineral content in foods subjected to constant heat treatment. Ash content is a measure of the total mineral composition of foods [33].

The fiber content of avocado seed powder ranged from 3.86 to 4.04%. The highest fiber content was observed in ODA with 4.04%, while the lowest fiber content was observed in GHDA with 3.86%. The higher fiber content observed in oven-dried avocado seed powder suggests that this drying method could be good for preserving or concentrating the fibrous components of foods, making it suitable as a functional food option for managing diabetes or obesity [34]. Fiber is vital for digestive health and glycemic control [35].

The fat content of avocado seed powder ranged from 3.07 to 3.85%. GHDA had the lowest fat content, 3.07%, while SDA had the highest fat content, 3.85%. Fats are rich in energy and essential for the absorption of fat-soluble vitamins. The higher fat content observed in SDA (sun-dried avocado seed powder) may be due to less exposure to heat, which preserves more oils in the powder. However, this also makes SDA products more prone to oxidative rancidity, which limits their shelf life [36]. The low-fat content in GHDA may be an advantage for people looking for low-fat dietary options.

The protein content of avocado seed powder ranged from 8.93 to 14.37%. The lowest protein content was observed in ODA with 8.93%, while the highest protein content was found in GHDA with 14.37%. This suggests that greenhouse drying is more effective in preserving the protein content of avocado seed powder, possibly due to milder drying conditions that reduce protein denaturation. The protein-rich dried avocado seed powder may support muscle development and immune function, making GHDA ideal as an ingredient in the production of functional foods. The lower protein content observed in ODA may indicate partial thermal degradation due to higher temperatures in the oven.

The carbohydrate content of the sample ranged between 73.41 and 76.78%. The lowest carbohydrate content was observed in SDA with 73.41%, while the highest carbohydrate content was observed in ODA with 76.78%. The increase in carbohydrates observed in AOD (oven-dried samples) could be due to concentration effects resulting from lower levels of moisture and fat, making AOD an excellent source of energy, especially for athletes and physically active individuals. This observation agrees with the report of Michalski et al. [37], who reported a high concentration of carbohydrates in processed fruits with low moisture content.

3.2. Mineral Content of Avocado Seed Powder

The mineral composition of avocado seed powder is presented in **Table 2**. The potassium content ranged between 637.60 and 740.20 mg/100 g. The lowest value was observed in the oven-dried sample (ODA) with 637.60 mg/100 g, while the highest value was observed in the greenhouse sample (GHDA) with 740.20 mg/100 g. Potassium is vital for regulating blood pressure and maintaining nerve and muscle function. The highest potassium value observed in SDA agrees with the findings of Kaur and Sibian [38], who reported that gentle drying methods, such as sun drying, reduce mineral loss by avoiding intense heat that can cause leaching or volatilization. The reduced potassium content observed in potassium for AOD could be due to thermal sensitivity and possible degradation of potassium during oven drying, especially when exposed to high temperatures.

Table 2. Mineral Content (mg/100 g) of avocado seed powder.

Sample Code	Potassium	Magnesium	Calcium	Iron
GHDA	$740.20^{a} \pm 0.1$	$321.35^{a} \pm 0.1$	$140.60^{a} \pm 0.2$	$15.45^{a} \pm 0.1$
SDA	$736.25^{b} \pm 0.1$	$310.70^{c} \pm 0.1$	$138.85^{b} \pm 0.1$	$13.15^{b} \pm 0.1$
ODA	$637.60^{c} \pm 0.2$	$316.10^{b} \pm 0.1$	$117.62^{c} \pm 0.3$	$7.60^{c} \pm 0.1$

Note: Values are expressed as mean ± standard deviation (SD). Means in the same column with different superscript letters (a, b, c) are significantly different ($p < 0.05$) according to Duncan's Multiple Range Test (DMRT). GHDA = Greenhouse drying; SDA = Sun-drying; ODA = Oven Drying of Avocado.

The magnesium content ranged between 310.70 and 321.35 mg/100 g. SDA had the lowest value of 318.70 mg/100 g, while GHDA had the highest value of 321.35 mg/100 g. Magnesium is essential for energy production, enzyme activity and nerve function. The superior retention in the greenhouse-dried sample suggests that moderate, controlled temperatures help preserve heat-sensitive minerals more effectively. The values obtained agree with those reported by Barzigar et al. [39], who reported that greenhouse drying maintains mineral stability better than uncontrolled or high-heat methods.

The calcium content ranged from 117.62 mg/100 g to 140.60 mg/100 g. ODA had the lowest calcium content of 137.30 mg/100 g, while GHDA had the highest calcium content of 140.60 mg/100 g. In this present study, greenhouse drying had more calcium than other drying methods examined. Kaveh et al. [40] gave a similar report that greenhouse drying effectively minimizes the loss of essential minerals such as calcium in their study.

The iron content ranged from 7.60 to 15.45 mg/100 g, the lowest iron content was observed in ODA with 12.60 mg/100 g, while the highest iron content was observed in GHDA with 15.45 mg/100 g. The high iron value observed in GHDA suggests that this greenhouse drying better retains non-volatile micronutrients, especially when drying is slow and not exposed to intense heat.

Greenhouse drying (GHDA) showed the best retention of magnesium, calcium and iron, suggesting that this method is most suitable for processing mineral-rich foods. Sun drying (SDA) excelled in potassium retention, making it favorable for preserving blood and muscle-related minerals. Meanwhile, oven drying (ODA) resulted in the lowest mineral content of all nutrients measured, emphasizing that while time efficient, it may not be ideal for preserving nutritional quality.

The results of minerals (K, Mg, Ca, and Fe) obtained in this study were slightly different from the values obtained by Fufa et al. [41]. These observed differences could be due to environmental factors and different avocado seed cultivars. In this study, the values observed for calcium (117.30–140.60 mg/100 g) and magnesium (310.70–312.35 mg/100 g) are essential for the development and maintenance of healthy bones and teeth in human nutrition. The high potassium content observed ranged between 637.60 and 740.20 mg/100 g in avocado seed flour, suggesting its potential to help reduce blood pressure. Therefore, the minerals found in avocado seeds may contribute to addressing micronutrient deficiencies in humans, making them a preferable option for human nutrition.

3.3. Total Carotenoid, β-Carotene, and Antioxidant Properties of Avocado Seed Powder

Total carotenoid, β-carotene content, and antioxidant properties of avocado seed powder are presented in **Table 3**. The total carotenoid content of avocado seed powder ranged from 5.12 to 79.29 (mg/100 g). Carotenoids are important for their antioxidant properties, which help protect against cellular damage [42], and for their role as precursors of vitamin A [43]. It is also crucial for eye health, particularly for vision and for protecting against age-related macular degeneration and blue light damage [43]. Additionally, carotenoids have been linked to a reduced risk of certain cancers, chronic diseases, and improved immune function. The beta-carotene content of avocado seed powder ranged from 66.32 to 618.23 µg/g. ODA had the lowest β-carotene value of 66.32 µg/g, while GHDA had the highest β-carotene value of 618.23 µg/g. Beta-carotene is a precursor to vitamin A and a powerful antioxidant essential for visual function and immune system support [44].

Table 3. Total carotenoid, β-Carotene, and antioxidant properties of avocado seed powder.

Sample Code	Total Carotenoid (mg/100 g)	Beta-Carotene (µg/g)	Vitamin A (µg RAE)	Vitamin C (mg/100 g)	Total Phenol (mg GAE/g)	Total Flavonoid (mg QE/g)
GHDA	$79.29^a \pm 0.1$	$618.23^a \pm 0.1$	$44.16^a \pm 0.1$	$20.33^a \pm 0.1$	$161.92^a \pm 0.1$	$22.12^a \pm 0.1$
SDA	$18.40^b \pm 0.1$	$286.23^b \pm 0.1$	$20.45^b \pm 0.1$	$15.90^b \pm 0.1$	$137.84^b \pm 0.1$	$13.40^b \pm 0.1$
ODA	$25.12^c \pm 0.1$	$66.32^c \pm 0.1$	$4.74^c \pm 0.1$	$9.58^c \pm 0.1$	$130.50^c \pm 0.1$	$12.70^c \pm 0.1$

Note: Values are expressed as mean ± standard deviation (SD). Means in the same column with different superscript letters (a, b, c) are significantly different ($p < 0.05$) according to Duncan's Multiple Range Test (DMRT). GHDA = Greenhouse drying; SDA = Sun-drying; ODA = Oven Drying of Avocado.

The vitamin A content of the sample ranged between 4.74 and 44.16 µg RAE. GHDA had the highest vitamin A content, 44.16 µg RAE, while oven-dried avocado (ODA) had the lowest vitamin A content, 4.74 µg RAE. One possible explanation is the conversion of beta-carotene to vitamin A (retinol) during the drying process, particularly under greenhouse conditions that could simulate natural ripening processes. The high level of vitamin A in GHDA means greater bioavailability of this essential nutrient, which plays a critical role in vision, growth, and immune function. The low AOD value may be due to the degradation of vitamin A under high oven temperatures.

The vitamin C content of avocado ranged between 9.58 and 20.33 mg/100 g. The highest vitamin C content was observed in GHDA with 20.33 mg/100 g, and the lowest vitamin C content was observed in ODA with 9.58 mg/100 g. The level of vitamin C obtained in this study contributes to satisfying the vitamin C requirements in different age groups.

The dietary reference intake of vitamin C (mg/day) varies by human age group. For example, babies between 7 and 12 months need 50 mg of vitamin C, while children between 1 and 3 years need 15 mg of vitamin C. Additionally, the recommended intake of vitamin C for pregnant women is estimated to be 80 mg for those 18 years and younger, while 85 mg of vitamin C for pregnant women between 19 and 30 years [41].

The Total Phenol content ranged between 130.50 and 161.92 mg GAE/g. The lowest value was observed in ODA with 130.50 mg GAE/g, while the highest value was observed in GHDA with 161.92 mg GAE/g. Phenolic compounds are powerful antioxidants that help protect the body from oxidative stress, inflammation, and cellular damage. The results agree with the report by Nascimento et al. [8] that the total phenol content of avocado seed powder ranged between 45 and 180 mg GAE/g.

The total flavonoid content ranged between 12.70 and 22.12 mg QE/g. The lowest value was observed in ODA with 12.70 mg QE/g, while the highest value was observed in GHDA with 22.70 mg QE/g. Flavonoid compounds are powerful antioxidants that help protect the body from oxidative stress, inflammation, and cellular damage.

Greenhouse drying methods (GHDA) preserve antioxidants more effectively than sun drying methods by providing controlled and moderate temperatures and reduced oxygen exposure, minimizing the thermal and oxidative degradation of compounds such as β-carotene, vitamin C, phenolics, and flavonoids. The use of greenhouse drying systems improves heat distribution and helps reduce moisture-related degradation kinetics, ensuring better nutrient retention and color stability in the food sample.

3.4. The Inhibitory Concentration (IC_{50}) of Avocado Seed Powder

The DPPH radical scavenging activities of avocado seed powder were expressed as $IC_{50,}$ and are presented in **Table 4**. The IC_{50} of DPPH ranged from 0.72 to 1.86 mg/

mL. Vitamin C was used as a control and exhibited the lowest IC_{50} with a value of 0.72 mg/mL. GHDA emerged as the most effective radical scavenger, showing an IC_{50} value of 1.67 mg/mL. This was followed by SDA and ODA, which recorded IC_{50} values of 1.76 mg/mL and 1.84 mg/mL, respectively. GHDA suggests that it contains a higher concentration or more effective mixture of phytochemicals capable of donating hydrogen atoms to stabilize free radicals; This hydrogen atom transfer (HAT) is recognized as a primary mechanism by which phenolic antioxidants neutralize the DPPH radical [45,46]. The results of the DPPH assay provide a clear assessment of the free radical scavenging capabilities of avocado seed powder as a reference against the potent antioxidant, vitamin C. The IC_{50} value, which represents the concentration required to inhibit 50% of DPPH radicals, is the primary metric of potency, with a lower value indicating greater effectiveness [47].

Table 4. Inhibitory concentration (IC_{50}) of avocado seed powder.

Sample Code	IC_{50} DPPH (mg/mL)	IC_{50} FRAP (mg/mL)
GHDA	1.67	1.50
SDA	1.76	1.68
ODA	1.84	1.80
Vitamin C	0.72	0.79

Note: GHDA = Greenhouse drying; SDA = Sun-drying; ODA = Oven Drying of Avocado; Vitamin C = Inhibitory concentration (IC_{50}) Control; FRAP = Ferric Reducing Antioxidant Property; DPPH = 1,1-Diphenyl–2 Picrylhydrazyl Free Radical Scavenging Ability.

FRAP scavenging activities of avocado seed powder were expressed as IC_{50}, and are presented in **Table 4**. The IC_{50} of ferric reducing antioxidant power (FRAP) ranged between 0.79 and 1.80 mg/mL. Vitamin C again set the potency standard with an IC_{50} of 0.79 mg/mL. Furthermore, in the IC_{50} trend observed in DPPH, GHDA 1 was the most potent among the tested samples, with an IC_{50} value of 1.50 mg/mL, followed by SDA with a value of 1.68 mg/mL, and ODA 3 was the least potent, with an IC_{50} value of 1.80 mg/mL. This result suggests that the antioxidant compounds present in GHDA are versatile and effective through multiple pathways, not only hydrogen atom transfer (measured by DPPH) but also single electron transfer (measured by FRAP).

This dual functionality is highly desirable in a natural antioxidant, since oxidative stress in the body involves a complex network of reactions. The strong performance of GHDA in the FRAP assay implies that it has a significant ability to regenerate other antioxidants and interfere with pro-oxidant metal ions, such as the electron-donating capacity measured by the FRAP assay, which is a scientific method to measure the antioxidant capacity of a substance [48]. It works by measuring how well a sample can reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) in a chemical reaction [49]. The results are expressed as an IC_{50} value, where a lower value indicates a stronger reducing power. The inhibitory concentration (IC_{50}) of some antioxidant properties of avocado seed powder was observed to be less than (<) 2, which agrees with the finding of Omoba et al. [50] that antioxidant properties of a food sample are more effective at less than (<) 2.

4. Conclusions

This study has clearly demonstrated that the drying method has a significant impact on the proximate composition, mineral content and antioxidant activities of avocado seed powder. The results indicate that greenhouse drying (GHDA), sun drying (SDA), and oven drying (ODA) preserve different nutrients to varying degrees, reflecting the influence of temperature control, exposure time, and environmental conditions on nutrient stability. The findings showed that greenhouse drying emerged as the most effective method for preserving heat-sensitive nutrients in avocado seed powder, such as protein, potassium, magnesium, calcium, iron, total carotenoids, beta-carotene, vitamin A, and vitamin C. Sun drying methods emerged as the second best, while the least effective method for drying avocado seed powder was observed in the oven drying method.

Author Contributions

R.O.O. and M.A.A. conceived and designed the research, analyzed the data, and wrote the paper. B.A.E. and

O.B.A. prepared and performed the experiments. R.O.O., J.D.A., and M.A.A. supervised the research draft and edited the manuscript. All of the authors have read and approved the final manuscript.

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All data generated were presented in the article.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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