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Bioactive and Physicochemical Properties of Exotic Fruit Seed Powders: Mango (*Mangefiera indica* L.) and Rambutan (*Nephelium lappaceum* L.) Obtained by Various Drying Methods

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Abstract: Exotic fruits, which are becoming more and more popular in European countries, contain seeds, which are an unused and useless byproduct of fruit processing. Research conducted in recent years suggests that these unused waste products can be a source of nutrients and bioactive compounds in much more concentrated amounts than those found in the flesh of the fruit. Research on the physicochemical properties and the content of bioactive compounds in fruit seeds may allow the assessment of the possibility and purposefulness of their wider application in the production of functional food. Therefore, the aim of this study was to determine the physicochemical and bioactive properties of exotic, tropical fruit seed powders, such as mango (*Mangefiera indica* L.) and rambutan (*Nephelium lappaceum* L.) seeds, obtained by convective drying (CD) and sublimation drying (FD). In the tested powders, the water-holding capacity and water solubility were determined, the color was measured using the 'electronic eye' instrumental method, the taste profile was determined using the 'electronic tongue', and the content of selected bioactive compounds—such as tannins (titration method), total polyphenols and antioxidant activity was also determined using the spectrophotometric method. It was found that the studied powders were characterized by low water-holding capacity (1.2–1.6 g/1 g of powder), low solubility in water (9.5–17.4%), neutral color and varied taste profile, depending on the origin of the tested powder. Rambutan seed powders were characterized by a more bitter taste with a higher umami-flavor intensity compared to mango seed powders, which showed a more intense acidic and sweet taste. The conducted research shows that the applied methods of powder production, i.e., drying (to similar a_w values) by convection vs. sublimation, had a much greater impact on changes in the content of bioactive compounds than on the tested physicochemical parameters. The freeze-dried seed powders were characterized by a higher content of polyphenolic compounds and a higher antioxidant activity than convection-dried seed powders. Considering the high content of polyphenols and high antioxidant activity, the studied powders may find applications in the production of dietary supplements and in the design of functional foods. Due to the low water solubility index, mango and rambutan powders can be used in the design of products where particle sensitivity is indicated. The use of the investigated exotic fruit seed powders, i.e., mango and rambutan, may not only be beneficial for nutritional reasons, but also may contribute to the reduction of post-production waste, in line with the recently widespread "zero waste" trend.

Keywords: exotic fruit seed powders; mango (*Mangefiera indica* L.); rambutan (*Nephelium lappaceum* L.); convective drying; sublimation drying; tannins; polyphenols; antioxidant activity; volatile compounds; taste profile; L*a*b*

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1. Introduction

Exotic fruits are gaining popularity all over the world due to their taste and nutritional value. The edible part of these fruits is the flesh. The wastes resulting from fruit processing—the peel and seeds—may constitute from 5 to 35% of the whole fruit weight and usually remain unused [1,2]. The lack of commercial utilization of these wastes is associated with insufficient knowledge of their nutritional and functional properties, as well as fear of the presence of antinutritional compounds in them [3,4]. The appropriate use of waste could reduce the problem of overconsumption, especially in countries where these fruits are produced on a large scale [5], while fitting in with the "zero waste" trend. This idea was created to counter the effects of food waste, and it aims to get consumers to emulate sustainable natural cycles in which all materials used are resources for use by others [6]. There are concerns among consumers about the presence of anti-nutritional compounds in seeds, which is mainly due to the lack of knowledge about their actual amount and the possibility of their elimination. In order to eliminate the presence of antinutritional compounds, the seeds should be subjected to appropriate treatment, i.e., soaking, cooking, drying or fermentation [3,7,8]. In addition, antinutritional compounds, mainly oxalates and phytates, may be present in some seeds—such as those from mangoes—but their content is often described as trace [8–10].

Taking into account the available literature data on the high content of bioactive compounds with antioxidant properties in exotic fruits [11–13], it can be assumed that their seeds can also be a valuable source of these compounds [14,15]. Antioxidants are characterized by multidirectional effects, and the consumption of products that are sources of antioxidants is essential for maintaining health [4,16,17]. One of the most important functions of antioxidants is counteracting the formation of free radicals, whose excessive accumulation in the body translates into accelerated aging processes and decreased efficiency of the immune system. Moreover, free radicals may damage cellular molecules and structures, resulting in their malfunction [18,19]. A diet rich in antioxidants reduces the risk of diseases such as diabetes, atherosclerosis, hypertension, heart disease, cardiovascular disease and cancer [19–21]. Food processing methods, especially in the effects of high temperatures and the presence of oxygen, have a significant impact on the content of bioactive ingredients in food. Convection drying, due to the use of high temperatures and long processing times, can contribute to high losses of bioactive components [22–24]—higher than in the case of sublimation drying, which, due to the use of low temperature and lack of oxygen, allows the preservation of high biological, chemical and physical properties of dried raw materials and causes lower loss of bioactive compounds [25–27]. Nevertheless, the use of freeze-drying processes is limited mainly due to the higher cost of these processes compared to other commonly used drying methods (convection drying, spray drying) [23,25].

The available literature lacks comparative data on the functional properties of exotic fruit seed powders obtained with various drying methods; therefore, this study compares the effects of various drying methods, i.e., convection (CD) and freeze-drying (FD), of fruit seeds on the content of tannins, total polyphenols, antioxidant activity, color and taste profile of powders obtained from mango (*Mangefiera indica* L.) and rambutan (*Nephelium lappaceum* L.), originating in Southeast Asia (Malaysia).

2. Materials and Methods

2.1. Materials

The material for this study consisted of seeds of selected exotic fruits; mango (*Mangefiera indica* L.) of the Palmer cultivar and rambutan (*Nephelium lappaceum* L.) of the Maharlika cultivar, originating in Southeast Asia (Malaysia), were purchased on the Polish food market. Fruits from three independent batches were cleaned, the flesh was separated, and the seeds obtained in this way were then used for further research. Convective drying (CD) was carried out in a laboratory heat test chamber SUP-200G (Wamed Company, Warsaw, Poland) operating with forced air circulation at a temperature of 70°C ± 2°C for 10 h.

Sublimation drying (FD) was carried out using a single-chamber lyophilizer (Donserv Lyophilizer model Espilon), at −50 °C, under 10 Pa pressure, with a shelf temperature of 21 °C, after freezing the raw materials at −30 °C. This process lasted for 72 h. The drying process was carried out until the water activity in the dried seeds was <0.3. After the drying process was completed, the seeds were brought to powder form using a grinder with grinding knives (MKM 6003, Bosch, Stuttgart, Germany). The obtained convection-dried mango seed powder (MSCD), freeze-dried mango seed powder (MSFD), convection-dried rambutan seed powder (RSCD) and freeze-dried rambutan seed powder (RSFD) were stored for further research in sterile plastic containers at a temperature of −20 °C.

2.2. Methods

2.2.1. Water Activity (a_w) and pH

The a_w value was measured using a manual AquaLab Water Activity Meter (Decagon Devices, Inc., Pullman, WA, USA). The pH was measured using a Laboratory pH-meter (Elmetron CP-511).

2.2.2. The Water Holding Capacity (WHC)

The water holding capacity (WHC) was determined according to the procedure described by Sudha et al. (2007) [28]. To the test tubes, 1 g of the powder sample was measured and 50 mL of distilled water was added. They were then centrifuged at 12,076× *g* (centrifuge MPW-380 R, MPW Med. Instruments, Warsaw, Poland) for 15 min and the excess water was discarded. The powder with absorbed water was weighed again. WHC was expressed as g water/1 g of powder.

2.2.3. The Water Solubility Index (WSI)

The water solubility index (WSI) was measured by the modified method described by Yousf et al., (2017) [29]. After mixing 2.5 g of powder with 30 mL of distilled water, the sample was incubated at 37 ± 1 °C for 30 min and then centrifuged for 20 min at 12,076× *g* (centrifuge MPW-380 R, Poland). The supernatant was collected in a pre-weighed weighing vessel and dried at 103 ± 2 °C to constant weight. WSI was expressed as % dissolved powder.

2.2.4. Instrumental Color Measurement

Computer image analysis using Visual Analyzer 400 (Alpha M.O.S., Toulouse, France) was used to instrumentally assess the colour of the powders. The test powders were placed in a closed measuring chamber under controlled light conditions. Images of the samples were taken with a Basler camera (acA2500-14gc; Basler AG, Ahrensburg, Germany). The measurements were made using the CIE L*a*b* system (L—brightness, +a—red, -a—green, +b—yellow, -b—blue). The results of the color analysis are given in graphs showing the share of individual colour shades and in a table containing the values of color parameters.

2.2.5. Evaluation of the Taste Profile

The taste profiles of the mango and rambutan seed powders were measured using an Astree electronic tongue (Alpha MOS, Toulouse, France). The e-tongue is composed of an automatic sampler, seven potentiometric chemical sensors (sensor set #7: AHS, SCS, ANS, CPS, NMS, CTS, PKS), a reference electrode of Ag/AgCl and a data acquisition system. The chemometrics sensor array measures substances dissolved in liquid samples. The e-tongue sensors have detection thresholds similar to or even better than human receptors. The potentiometric difference between each sensitive electrode and the Ag/AgCl reference electrode in the equilibrium state was recorded as a response signal. Each sensor gives a different spectrum of reactions. The electronic tongue sensor was preconditioned and calibrated using a 0.01 mol/L hydrochloric acid solution. The diagnostics started when the calibration passed. For the diagnostics, a 0.01 mol/L hydrochloric acid solution, MSG and sodium chloride were used to judge the sensitivity and discernment of the electronic tongue sensors. The sourness, saltiness and umami flavor of the samples were measured using 0.1 M HCl, 0.1 M NaCl and 0.1 M MSG as reference materials for the electronic tongue sensor, respectively. Samples (0.5 g) were dissolved in 100 mL of deionized water, homogenized using an ultrasonic homogenizer (Hielscher UP400ST, Berlin, Germany) for 2 min, and then centrifuged in a centrifuge (MPW-380 R, MPW Med Instruments, Warsaw, Poland) for 15 min (2 °C, 12,076× *g*). The obtained supernatant was transferred into the electronic tongue sample beaker. Ten replicate measurements were conducted for each sample, and five points after stabilization were used for further data processing. The signal of each electrode was recorded per second, and the detection time was set to 120 s to ensure the sensors acquired enough taste information for each sample. Afterward, the sensors were rinsed in ultrapure water for 10 s to reach a stable state and prepared for the detection of the next sample.

2.2.6. Preparation of Extracts for Antioxidant Properties and Total Polyphenol Content Analysis

To 4 g of powdered samples, 30 mL of a 70% (*v*/*v*) solution of methanol in water was added. The samples prepared in this way were incubated in an incubator with a vortex (KS 4000i Control, IKA, Staufen, Germany) for 60 min at 30 °C. After the incubation process, the sample was shaken again in a vortex for 60 s to receive a thorough mixing, and then spun in a centrifuge with a cooling system (MPW-380 R, MPW Med. Instruments, Warsaw, Poland) Determinations were performed on the obtained supernatant.

2.2.7. Total Polyphenolic Compounds

The total polyphenol content was determined by the spectophotometric method described by Singelton and Rossi (1965) [30]. The principle of this method is based on the color reaction between Folin–Ciocalteu (F–C) reagent and polyphenolic compounds in an alkaline medium. The intensity of the resulting color was measured spectophotometrically at a wavelength of 720 nm. The content of polyphenolic compounds was expressed as GAE (Gallic Acid Equivalent), i.e., the amount of mg of gallic acid per 1 g of dry matter of powder.

2.2.8. Tannins Content

Preparation of samples: 250 mL of boiling water was added to approx. 6 g of powders, left covered for 10 min and then filtered, and 175 mL of the infusion (volume controlled—V) was quantitatively transferred to a 250 mL beaker. The filtrate was heated to boiling, then 20 mL of a 4% copper (II) acetate solution was added and transferred quantitatively to a 200 mL volumetric flask, cooled, made up to the mark with distilled water and filtered through a pleated filter. After that, 100 mL of the filtrate were measured into a conical flask with a capacity of 200 mL; 25 mL of 50% acetic acid and 20 mL of potassium iodide solution were added. The released iodine was titrated with 0.1 mol/L $Na_2S_2O_3$ solution in the presence of starch as an indicator. A control sample was prepared under the same conditions, taking for analysis 90 mL of water, 10 mL of copper (II) acetate, 25 mL of acetic acid and 20 mL of potassium iodide.

The number of tannins in the controlled volume of the infusion was calculated from the formula:

$$X = \frac{(a - b) \cdot 0.01039 \cdot V}{87.5}$$

X—the tannin content in the entire volume of the controlled brew (175 mL), [g]
(a − b)—the difference in the amount of $Na_2S_2O_3$ at a concentration of 0.1 mol/L between the proper and control samples, [mL]
V—the volume of the controlled infusion (175 mL), [mL]
0.01039—conversion factor.

The tannin content in 100 g of dry matter of seeds was calculated from the formula:

$$A = \frac{X \cdot 100 \cdot V1}{V \cdot m}$$

A—the tannin content expressed in g/100 g of powders d.m.
X—the tannin content in the entire volume of the controlled brew (175 mL), [g]
V—the volume of the controlled infusion (175 mL), [mL]
V_1—the initial amount of boiling water used to pour the powders (250 mL), [mL]
m—the amount of powder weighed out to prepare the sample, based on the dry matter content (about 6 g), [g].

2.2.9. Antioxidant Properties

The antioxidant activity of the powders was determined using $ABTS^{+\cdot}$ (diammonium salt of 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) cation radicals according to the methods of Re et al. (1999) [31]. The principle of this method is to measure the ability to deactivate synthetic $ABTS^{+\cdot}$ cation radicals by antioxidant compounds contained in the tested material. These compounds, as a result of the reaction, cause a decrease in the color intensity of the radical solution, which was determined spectrophotometrically at a wavelength of λ = 734 nm. The antioxidant activity was expressed as mmol TEAC (Trolox Equivalent Antioxidant Capacity) per 100 g dry matter of the tested powder.

2.2.10. Statistical Analysis

Statistica 13.0 (Tibco Software Inc., Palo Alto, CA, USA) software was used for all statistical processing. The analysis of variance (ANOVA) was used for dependent groups with a post hoc analysis of Duncan's test at a significance level $p < 0.05$.

3. Results and Discussion

3.1. Physicochemical Properties of the Seed Powders

Table 1 presents the physicochemical results of the mango and rambutan seed powders obtained by the CD and FD methods. Freeze-dried seeds had a lower water activity level ($a_w < 0.03$, for both mango and rambutan seed powders) compared to convection-dried seeds, (0.21 and 0.23 for mango and rambutan, respectively). The lower water activity of freeze-dried powders is mainly due to the method of removing water during this process. Lyophilization allows for the removal of water from the product by sublimation, i.e., direct phase transformation of a solid (ice) into gas (water vapor), bypassing the liquid phase, and then by desorbing water molecules [32,33]. The water present in the products is free water (and only this part of it can be removed by convection drying) and water associated with the matrix with different forces [33]. The freeze-drying process allows for the removal of both free and bound water during sublimation [34], ensuring a much lower water activity of products dried with this method compared to convection drying. The low water activity of the seeds is necessary due to the possibility of bringing them to powder form; moreover, it ensures the microbiological stability of the powders during storage [27]. The powders were characterized by fairly low values of water absorption (1.22–1.59 g H_2O/1 g of powders) and low solubility in water (9.5–17.4%). Analyzing the results obtained, it can be observed that the method of drying the seeds did not significantly affect the water-binding capacity of the given powders. Regardless of the drying method, the mango seed powder absorbed about 1.6 g water/1 g d.m. of powder, while the rambutan seed powder absorbed 1.22 g water/1 g FD powder and 1.29 g water/1 g d.m. of CD powder. The drying method of the studied powders had a statistically significant ($p < 0.05$) effect on their solubility in water. The powders obtained from the sublimation-dried seeds were characterized by a higher solubility index. The freeze-dried mango seed powder had the highest solubility (17.4%), while the lowest solubility was found in convection-dried rambutan seed powder (9.5%). The available literature lacks data on the water-binding capacity and water solubility of exotic fruit seed powders, such as mango and rambutan. Comparing the WHC and WSI results obtained for the seed powders with the literature results for fruit powders, it was noticed that these indices show lower values for the powders tested in this work. For comparison, freeze-dried strawberry powder absorbed about 2.8 g water/1 g d.m. of powder, while convection-dried strawberry powder absorbed 2.3 g water/1 g d.m. of powder, and its solubility in water was 62% for freeze-drying and 55% for convection-drying, respectively [35,36]. Compared to fruit powders, the powders obtained from the tested seeds absorbed about two times less water and their water solubility was about three times lower. These differences may be due to the presence of more carbohydrates and fiber, with higher solubility in the fruit than in the tested seeds [37].

Table 1. Physicochemical properties of mango and rambutan seed powders dried by different methods.

Powders	Water Activity [a_w]	WHC [g H_2O/1 g of Powder]	WSI [%]	pH
MSCD	$0.21^{b} \pm 0.002$	$1.57^{a} \pm 0.13$	$12.6^{a} \pm 0.08$	6.18 ± 0.02
MSFD	$0.03^{a} \pm 0.001$	$1.59^{b} \pm 0.11$	$17.4^{b} \pm 0.06$	6.21 ± 0.02
RSCD	$0.23^{B} \pm 0.002$	$1.29^{B} \pm 0.16$	$9.5^{A} \pm 0.12$	7.02 ± 0.01
RSFD	$0.03^{A} \pm 0.001$	$1.22^{A} \pm 0.13$	$11.2^{B} \pm 0.10$	7.06 ± 0.02

Means in columns with different letters within the same type of powder (^{a,b} for mango seed powder, ^{A,B} for ranbutan seed powder) differ significantly ($p < 0.05$); MSCD—convectionally dried mango seed powder; MSFD—freeze-dried mango seed powder; RSCD—convectionally dried rambutan seed powder; RSFD—freeze-dried rambutan seed powder.

3.2. Taste Profile of Seed Powders Using an "Electronic Tongue"

An electronic tongue known as an artificial tongue or taste sensor is an analytical instrument used to classify flavors in liquid food samples. Its principle of operation mimics the human sense of taste. The analysis uses the sensors responsible for each primary flavor, which, when placed in the sample, can detect a given flavor and compare it quantitatively with the flavor present in the sample [38]. In the electronic instrument, the interpretation of the taste quality perception is achieved by the e-tongue's statistical software, which interprets the sensor data into taste patterns. This is due to practical considerations, preparing dilution series of tastants is highly time-consuming—as is the determination of thresholds; therefore, based on the combination of all the sensors' results, the unique fingerprint of each tasted powder was generated.

Figure 1 shows the differences in the intensity of the basic tastes: salty (CTS), sweet (ANS), sour (AHS), umami (NMS) and bitter (SCS) in the seed powders tested, as determined by electronic tongue. Considering the results obtained, it can be observed that the samples differed more from fruit to fruit than from drying method to drying method. The mango seed powders, those obtained by both convective and sublimation drying, were characterized by a higher intensity of sour (AHS), salty (CTS) and sweet (ANS) flavors in the rambutan powders, which in turn showed more intense bitter (SCS) and umami (NMS) flavors. The aforementioned relationships are also presented in Figure 2a–c, which shows the graphs formed on the plane formed by the different flavors: salty (CTS), sour (AHS) and umami (NMS). Considering the obtained results distributed on the plane formed by the sour (AHS) and salty (CTS) flavors (Figure 2a), it can be observed that the mango seeds were characterized by a higher intensity of these tastes, while on the plane formed by umami (NMS) and salty (CTS) taste (Figure 2b), or umami (NMS) and sour (AHS) taste (Figure 2c), rambutan seeds showed a higher intensity of umami (NMS) taste and a lower salty (CTS) or sour (AHS) taste in comparison to mango seeds. Considering the method of obtaining the seeds (sublimation vs. convection drying), the greatest taste discrepancies were obtained for rambutan seeds in terms of salty taste (CTS). No data were found in the available literature regarding the taste profile of powders obtained by different drying methods from exotic fruit seeds, such as mango and rambutan. Considering the literature data on the applicability of the electronic tongue, it was concluded that it could be useful in food quality control—such as for fruit juices. The sensitivity of the system to processes occurring in juices is based on the direct sensitivity of the sensors in detecting the presence of organic acids present in juices, even in low concentrations [39].

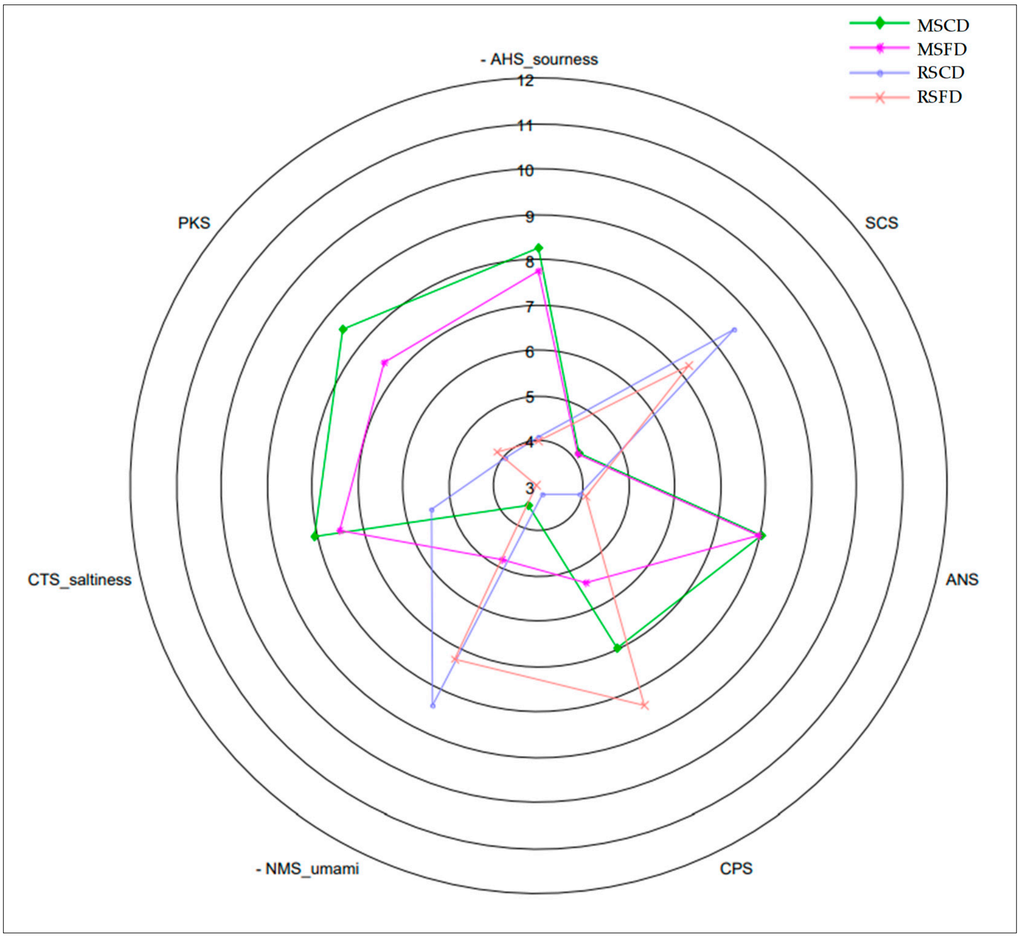


Figure 1. Radar fingerprint of E—tongue data for exotic fruit seed powders obtained by FD and CD drying methods; MSCD—convectionally dried mango seed powder; MSFD—freeze-dried mango seed powder; RSCD—convectionally dried rambutan seed powder; RSFD—freeze-dried rambutan seed powder.

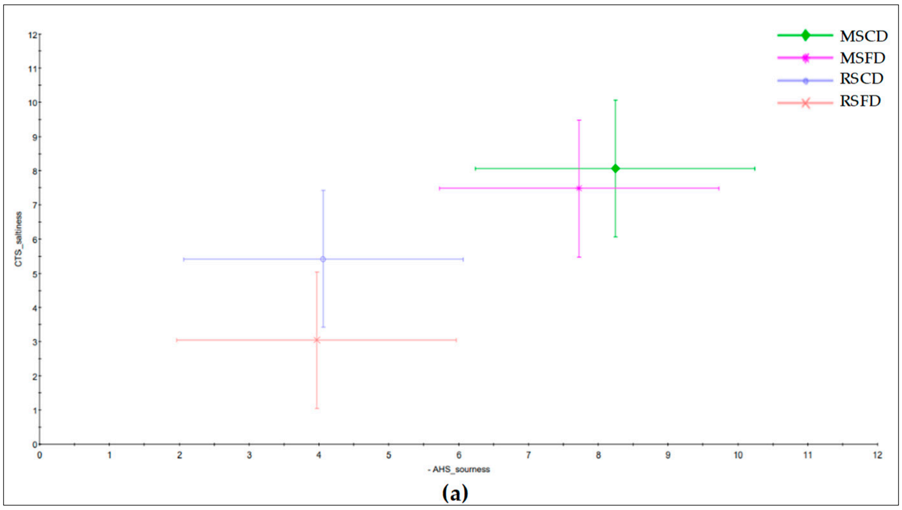
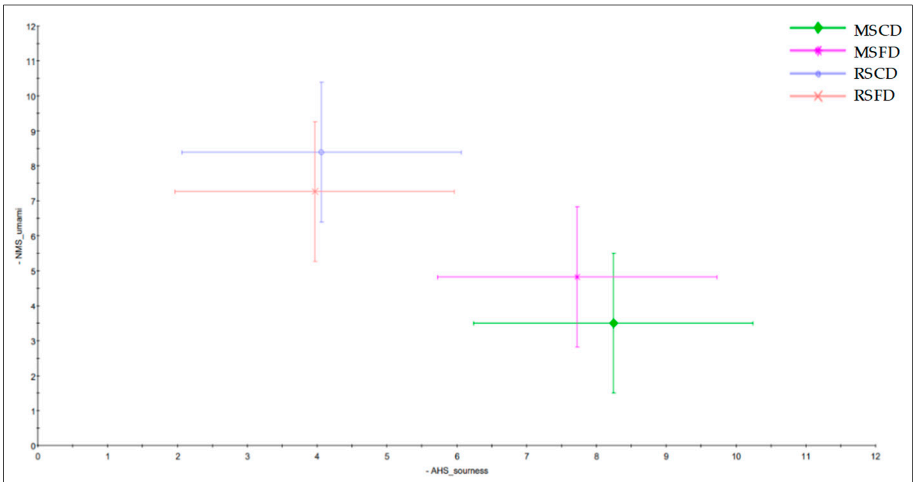
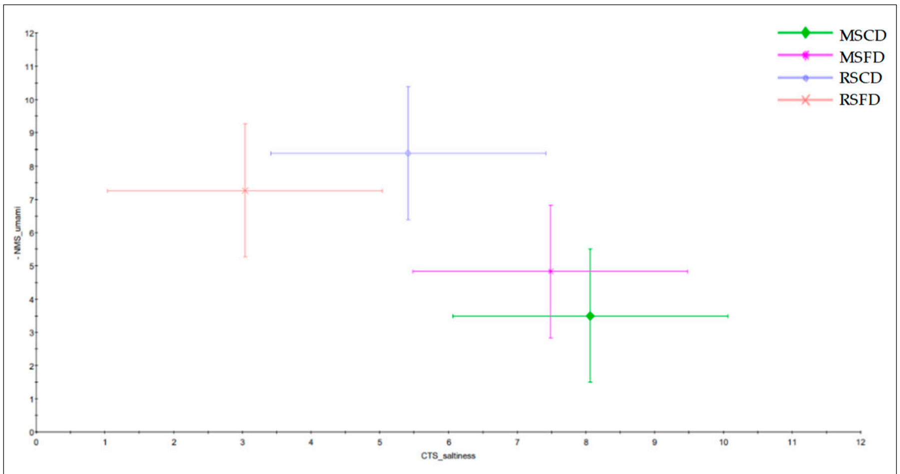


Figure 2. *Cont*.



(b)



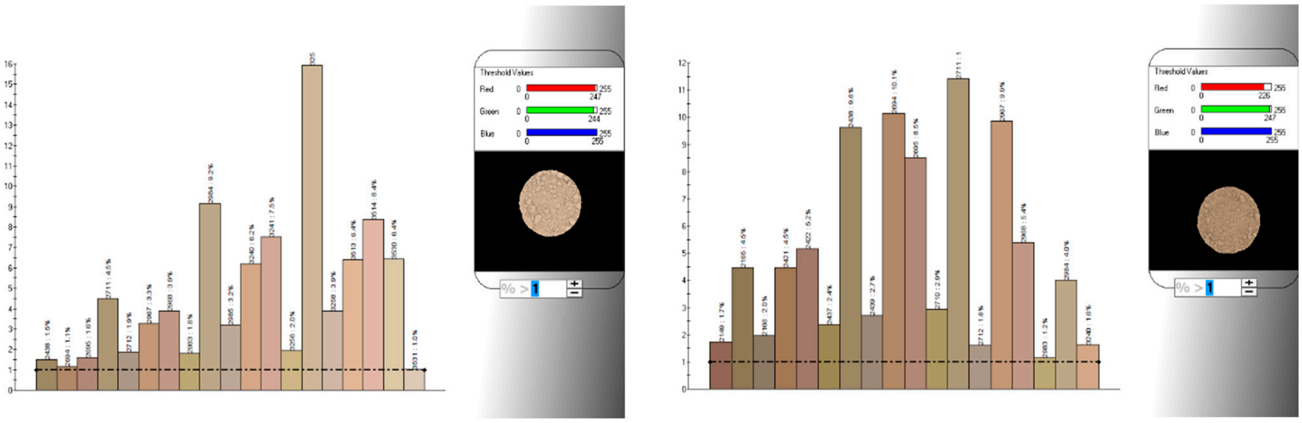
(c)

Figure 2. The fingerprint of E—tongue data ((**a**) saltiness/sourness; (**b**) umami/sourness; (**c**) umami/saltiness) for exotic fruit seed powders obtained by FD and CD drying methods; MSCD—convectionally dried mango seed powder; MSFD—freeze-dried mango seed powder; RSCD—convectionally dried rambutan seed powder; RSFD—freeze-dried rambutan seed powder.

3.3. Color Analysis Using the "Electronic Eye"

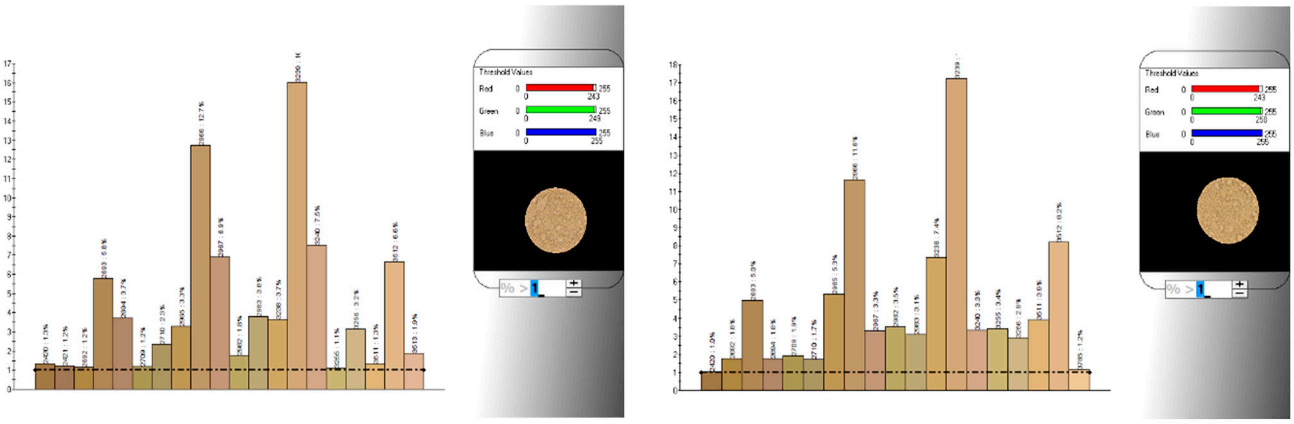
Figures 3 and 4 and Table 2 show the color analysis of the powders dried by various methods, obtained from mango and rambutan seeds by the instrumental method ("electronic eye"). Analyzing the results obtained, it can be concluded that the tested seeds were characterized by a neutral, low-intensity color.

Both mango and rambutan seeds dried by sublimation had a brighter color in comparison with convection-dried seeds, as evidenced by the significantly ($p < 0.05$) higher value of the L* color parameter. The a* and b* color parameters of the tested powders were positive, indicating the presence of red and yellow color in the powders. Freeze-dried mango seed powder was characterized by a significantly ($p < 0.05$) lower value of color parameter a* and color parameter b* compared to convectively dried seeds. The powder showed a smaller shift in color towards red (evidenced by the color parameter a*), as well as a smaller shift towards yellow (evidenced by the color parameter b*). Freeze-dried rambutan seed powder had a significantly ($p < 0.05$) higher value of color parameter b* compared to convection-dried seed, indicating a greater shift in color toward yellow. The value of color parameter a* was significantly ($p < 0.05$) lower for the sublimation-dried seed, i.e., it showed less of a color shift towards the red color than the convection-dried seed. In the available literature, there is no information on the color of the powders from these examined seeds obtained by the methods discussed. The available literature lacks information on the comparison of the color of the powders from the tested seeds (mango and rambutan) obtained by different methods, i.e., convection and freeze-dried.



(a) (b)

Figure 3. Graphical interpretation of the color distribution of powder obtained from mango seed using the instrumental method ('electronic eye'); (**a**) CD powder; (**b**) FD powder.



(a) (b)

Figure 4. Graphical interpretation of the color distribution of powder obtained from rambutan seed using the instrumental method ('electronic eye'); (**a**) CD powder; (**b**) FD powder.

Table 2. Color parameters in the L*a*b* space of mango and rambutan seed powders obtained by different drying methods.

Powders	L*	a*	b*
MSCD	73.15 ^{a} ± 0.03	4.75 ^{b} ± 0.02	24.01 ^{b} ± 0.01
MSFD	82.09 ^{b} ± 0.02	4.00 ^{a} ± 0.02	19.81 ^{a} ± 0.03
RSCD	68.06 ^{A} ± 0.04	5.20 ^{B} ± 0.04	37.35 ^{A} ± 0.01
RSFD	68.79 ^{B} ± 0.04	4.76 ^{A} ± 0.03	38.82 ^{B} ± 0.03

Means in columns with different letters within the same type of powder (^{a,b} for mango seed powder, ^{A,B} for ranbutan seed powder) differ significantly ($p < 0.05$); MSCD—convectionally dried mango seed powder; MSFD—freeze-dried mango seed powder; RSCD—convectionally dried rambutan seed powder; RSFD—freeze-dried rambutan seed powder.

Studies on the influence of the drying method on the color of dried fruits show that freeze-dried fruits were characterized by higher values of color parameters L*, a* and b* compared to convection-dried fruits, i.e., their color was more intense [35,40]. In the case of seed powders, freeze-dried fruits were characterized by higher values of color parameter L*, but lower values of parameter a* and b* (the exception was rambutan seeds). Thus, it can be concluded that freeze-dried seed powders were characterized by a brighter but less intense color than convection-dried seed powders. The darker color of the powders obtained from convection-dried seeds may be due to the longer drying time at higher temperatures and the presence of characteristically dark Maillard reaction products formed during convection drying [41]. Additionally, the presence of oxygen during convection drying may have caused oxidation of the pigments in the seeds, which may have contributed to the darker color [40].

3.4. Content of Bioactive Compounds in Seed Powders

Table 3 shows the total polyphenol, tannin content and antioxidant activity of mango and rambutan seed powders obtained by convective drying (CD) and sublimation drying (FD).

Table 3. Total polyphenol, tannin content and antioxidant activity of mango and rambutan seed powders dried by different methods.

Powders	Total Polyphenols [mg GAE/1 g d.m.]	Tannins [g/100 g]	Antioxidant Activity [mmol Trolox/100 g d.m.]
MSCD	$42.92^{a} \pm 0.47$	$0.33^{a} \pm 0.12$	$93.40^{a} \pm 0.62$
MSFD	$111.67^{b} \pm 0.29$	$0.49^{b} \pm 0.09$	$143.85^{b} \pm 0.15$
RSCD	$1.18^{A} \pm 0.12$	$2.25^{B} \pm 0.22$	$50.96^{A} \pm 0.14$
RSFD	$2.69^{B} \pm 0.10$	$1.66^{A} \pm 0.10$	$67.60^{B} \pm 0.16$

Means in columns with different letters within the same type of powder (^{a,b} for mango seed powder, ^{A,B} for ranbutan seed powder) differ significantly ($p < 0.05$); MSCD—convectionally dried mango seed powder; MSFD—freeze-dried mango seed powder; RSCD—convectionally dried rambutan seed powder; RSFD—freeze-dried rambutan seed powder.

The seed powders obtained by sublimation drying were characterized by a significantly ($p < 0.05$) higher total polyphenolic content and higher antioxidant activity compared to seed powders obtained by convective drying. The powder obtained from sublimation-dried mango seeds was characterized by the highest polyphenol content and the highest antioxidant activity. The content of total polyphenols was about 112 mg GAE/1 g d.m. and its antioxidant potential was about 144 mmol TEAC/100 g d.m. In a study by Abdalla et al., (2007) [42], similar levels of total polyphenols were obtained in convection-dried mango seed powder, and in the study of Soong and Barlow (2004) [4], the powder obtained after sublimation drying of the seed showed similar levels of polyphenols as those in this study for FD powder. The powder obtained from convection-dried seed was characterized by a significantly ($p < 0.05$) lower polyphenol content (about 43 mg GAE/1 g d.m.)—almost three times that of the powder obtained from freeze-dried seeds—and a lower antioxidant activity equal to 93 mmol TEAC/100 g d.m. Despite using the same assay methods, the study of Sogi et al. (2013) [43] obtained higher values than the present work: 172.4 mmol TEAC/100 g d.m. for freeze-dried seeds and 123.3 mmol TEAC/100 g d.m. for convection-dried seeds, respectively. The content of polyphenols in the powder obtained from freeze-dried rambutan seeds was 2.69 mg GAE/1 g d.m., while in the powder from convection-dried seeds, the content of polyphenols was twice lower at 1.18 mg GAE/1 g d.m. In the literature data, the content of these bioactive ingredients ranges from 3.05 mg GAE/1 g d.m. [44] up to 124.14 mg GAE/1 g d.m. [45]. Despite their lower polyphenol content, rambutan seed powders had a high antioxidant potential. The powder obtained from freeze-dried rambutan seeds had an antioxidant activity at the level of about 67 mmol TEAC per 100 g d.m., while the powder obtained from convection-dried seeds showed a slightly lower antioxidant potential—about 51 mmol TEAC per 100 g d.m.

In the available literature, there are few studies on the antioxidant activity of powders from the tested mango and rambutan seeds. The available data on both the antioxidant potential and the total polyphenol content vary depending on the drying methods used or different analytical methods, including the extraction procedures and extraction solvents used. According to the literature data, a higher total polyphenol content and higher antioxidant activity are obtained when acetone, methanol or a mixture of water and acetone are used for extraction, while they are lower when water is used alone as an extractant [8,46]. This is confirmed by the fact that water allows for the extraction of polar compounds, including polyphenols and vitamin C. The mixture of water with acetone or methanol also allows the determination of compounds of a non-polar nature, including carotenoids and vitamin A and E [47,48]. The results obtained are also affected by the time and temperature of sample storage and extraction, or the contact of the powders with atmospheric oxygen [49].

Compared to the powders obtained from berries, considered to be a rich source of bioactive components, mango seed powder was characterized by a higher content of total polyphenols and higher antioxidant potential. According to the literature data [36], the total polyphenol content for freeze-dried chokeberry powder was 22.56 mg GAE/1 g d.m., with an antioxidant potential of 58.36 mmol TEA/100 g d.m. Convection-dried chokeberry powder had a lower polyphenol content of 21.47 mg GAE/1 g d.m. and lower antioxidant activity of 48.95 mmol TEAC/100 g d.m., compared to freeze-dried chokeberry powder [36]. Freeze-dried mango seed powder contained an almost 5-times higher total polyphenol content and had almost 2.5-times higher antioxidant activity compared to freeze-dried aronia powder. Rambutan seed powder had the lowest polyphenol content, regardless of the drying method. Nevertheless, the antioxidant potential of rambutan seed powders dried by both sublimation and convection is high, comparable to that of chokeberry powders dried by both methods discussed above.

Plant tannins, which are macromolecular polyphenolic compounds containing numerous hydroxyl groups, are responsible for the astringent taste of fruits and infusions from plants containing them [50]. The tannin content in the tested mango and rambutan seed powders varied and ranged from 0.3% in mango seed powder to 2.3% in rambutan seed powder. The level of tannins in the studied powders was comparable to the content of these compounds in green tea, ranging from 0.18% [48] to 3.1% [51]. In dried fruits, the tannin content is varied, but usually lower—ranging from 0.67% in quince to 2% in chokeberry [52]. It is noteworthy that rambutan seed powders were characterized by a higher tannin content, and at the same time, showed a more intense bitter taste compared to mango seed powders.

4. Conclusions

The powders of the exotic fruit seeds studied—mango and rambutan—are rich in polyphenolic compounds and exhibit high antioxidant activity, varying according to the method used to obtain the powders. Compared to convection drying, sublimation drying allowed for higher preservation of polyphenolic compounds and higher antioxidant properties. Due to a significant content of bioactive compounds with antioxidant properties, satisfactory physicochemical parameters—partial solubility in water, low intense color and characteristic taste—the powders studied may find applications in the production of dietary supplements and in the design of functional food. Due to their partial solubility index in water, they can be used in the design of products where particle sensitivity and solid consistency are indicated or in the development of high-density beverages. The use of the investigated seed powders may not only be beneficial for nutritional reasons, but may also contribute to the reduction of post-production waste, fitting into the recently widespread "zero waste" trend.

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