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Total Phenolic Content and Antioxidant Activity of Yacon (*Smallanthus Sonchifolius* Poepp. and Endl.) Chips: Effect of Cultivar, Pre-Treatment and Drying

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Abstract: Recent studies have associated the consumption of yacon root as a functional plant food with reduced glycemic index and, due to its considerable phenolic acid levels, a protection of cell membranes against free radical damage. This study examined the effect of four different treatments including: (1) storage duration after harvest (one and three weeks after harvest); (2) pre-treatment before drying (untreated, pre-treatment with diluted lime juice); (3) drying method (freeze drying (FD) and convective hot air drying (CHAD)); and (4) cultivar (white and red), on the quality of yacon (*Smallanthus sonchifolius* Poepp. and Endl.) chips in terms of their total phenolic content (TPC) and antioxidant activity (AA) (ABTS (2,2'-Azino-Bis (3-Ethylbenzothiazoline-6-Sulfonic Acid) Diammonium Salt) radical scavenging activity, DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity and ferric reducing antioxidant power (FRAP)). Overall, the chips that were produced using pre-treatment with diluted lime juice and FD had the highest amounts of TPC and AA. Regarding the chips produced by means of CHAD, retention of higher TPC and AA was possible with lime-juice pre-treatment and use of higher hot air temperatures. Moreover, chips produced from the white cultivar had higher TPC and AA than chips produced from the red cultivar.

Keywords: functional foods; yacon; *Smallanthus sonchifolius* Poepp. and Endl.; convective hot air drying; freeze drying; total phenolic content; ABTS radical scavenging activity; DPPH radical scavenging activity; ferric-reducing antioxidant power

1. Introduction

Consumption of plant food, particularly fruits, has been shown to be directly or indirectly positively associated in reducing the risk of chronic diseases such as cancer, coronary heart disease, stroke, type 2 diabetes, obesity, hypertension, etc. owing to their nutrients and non-nutritive constituents [1]. The beneficial effects of fruit consumption have been associated with their high content of bioactive compounds (e.g., phenols) which can act as antioxidants and protect the body from oxidative stress, lower energy content and dietary fibre content [1–4]. Accordingly, the phenolic content of plant foods, their antioxidant activity, health-promoting effects, and prospective potential for the development of functional food products, plant-based nutraceuticals and pharmaceuticals have been the focus of ample investigations [3,5]. Moreover, there is growing interest in the neglected plant foods for reasons such as their favourable nutritional characteristics, their potential to diversify the diet and enhance the status of food security, and optimistic prospects in some of the rising mega trends in food supply chain (e.g., “food for beauty and health”, “food that meets our expectations”, “more food from less resources”, and “food for a healthy planet”) [6–8].

Yacon (*Smallanthus sonchifolius* Poepp. and Endl.) belongs to the plant family Asteraceae and is an underutilized tuberous crop. Although it has its origin in the Andean region, it has been cultivated in other regions such as Brazil, Czech Republic, Ecuador, Germany, Japan, and New Zealand. Yacon tubers taste relatively sweet, have a crunchy juicy texture and are consumed as fresh fruits. They received recognition during the past two decades due to their nutritional, functional constituents, and health beneficial effect. In particular, yacon tubers have high contents of bioactive compounds (e.g., phenolic compounds), fructooligosaccharides (FOS) and low sugar content [9,10]. On that account, yacon has gained attention as an interesting crop for production of functional foods with low sugar content [7,11]. Like other fruits, the availability of fresh yacon is seasonal. Therefore, food processing such as drying, evaporation, and fermentation can be used to develop food products such as yacon chips, flour, syrup, vinegar, etc. to extend the shelf life of yacon tubers [9].

Drying of fruits is one of the oldest preservation methods that has been widely used to produce durable food commodities such as final products like fruit chips. Dried fruits can be considered as a concentrated form of fruit, which allows for considerable extension of their shelf life by removal of water as well as easing transport and packaging [12]. Several factors including the quality of raw material, pre-treatment of raw material before drying and the method of drying can have an impact on the physicochemical quality of the final product [13,14]. In this regard, the physicochemical characteristics of fresh fruits depend on cultivar, environmental conditions during cultivation and conditions of post-harvest handling. Moreover, pre-treatments such as sulphur-fumigation, osmotic treatment and blanching used before drying can also affect the physicochemical quality of the final dried fruit products [14]. With regard to the drying method, various drying techniques have been investigated and developed including sun drying, convective hot air drying (CHAD), vacuum drying, hybrid drying techniques such as microwave and ultrasound assisted drying, fluidized bed, spouted bed, freeze drying (FD) etc. [15,16]. However, the final choice of the drying technique depends on the nature of the product, desired quality of the final product, energy consumption as well as the availability of the desired drying technology [13]. One of the most common drying techniques that has the advantage of technological simplicity is CHAD which operates according to the application of heat based on the principles of a convection mechanism for evaporation of water and removal of vapor by forced air [13]. FD is a technique in which water in food materials is removed by sublimation under a vacuum, and owing to the low temperature used, this technology results in products with premium quality. However, its application is contested as a consequence of the high cost of its operating system [17].

In particular, preservation of yacon using drying has been investigated before, and the production of certain dried products from yacon tubers including yacon chips, whole yacon flour, yacon juice powder, yacon peel flour and yacon pulp flour have been studied [18–22]. Most of these studies have evaluated the effects of various drying processes on the quality of final dried yacon products regarding their sugar and FOS content [19,22,23]. In addition, the focus of some studies has been on the determination of bioactive compounds such as phenolic compounds and antioxidant activity of fresh yacon tubers [11,24,25]. It has been noted that fresh yacon tubers possess high amounts of phenolic compounds including chlorogenic acid, ferulic acid, coumaric acid, quercetin, caffeic acid and its derivatives [24,26,27]. However, few studies have investigated the effect of drying on bioactive constituents and antioxidant activity yacon tubers. Castro et al. showed that drying of yacon slices at 50 °C in a cabinet dryer results in yacon chips with a higher total phenolic content (TPC) and antioxidant activity compared to those which were dried at 40 °C and 60 °C [18]. Moreover, yacon slices dried at 55 °C in a forced air oven with and without soaking of them in a solution of sodium hypochlorite (20 mg L⁻¹) and 0.1% sodium disulfide to produce yacon flour, showed that retention of TPC and individual phenolic compounds namely, chlorogenic acid, ferulic acid and caffeic acid, were better when pre-treatment was applied before drying [20]. On the other hand, the quality of yacon dried products can be influenced by the quality of the fresh yacon tubers. The quality of fresh tubers in terms of their chemical composition depends on the cultivar, conditions during the cultivation, as well

as conditions during the storage of tubers [28–30]. In particular, storage conditions and duration of storage after the harvest of tubers before processing them may change their phytochemical quality [28]. For example, sunning tubers after the harvest has been used traditionally to yield a sweeter taste in the tubers which is due to the conversion of FOS to simple sugars [30,31]. Phenolic compounds of yacon tubers may also undergo changes during storage and food processing. Specifically, yacon tubers darken during storage, cutting and processing. Enzymatic oxidation of phenolic compounds (e.g., chlorogenic and caffeic acids) catalyzed by native polyphenol oxidase may occur during storage and food processing as a result of changes in cellular integrity, which leads to browning of products [32–34]. Moreover, heterogeneity in the profile of phenolic compounds and polyphenol oxidase of different cultivars of the same species may affect such alternations as well as the intensity of such changes in composition under the influence of storage and food processing [2,35].

To the best of our knowledge, there is a gap in literature regarding the effect of post-harvest handling conditions of yacon tubers on phenolic compounds and antioxidant activity of yacon chips from different yacon cultivars. Therefore, the main objective of this work was to determine the effect of storage duration after harvest, pre-treatment before drying, and the drying of yacon slices using FD techniques and various drying temperatures during CHAD on the TPC and antioxidant activity of yacon chips produced from two cultivars grown in the environmental conditions of south-west Germany.

2. Materials and Methods

2.1. Chemicals

Ascorbic acid, Folin–Ciocalteu’s reagent, FeCl_3 , FeSO_4 , HCl , and NaOH were purchased from Merck (Darmstadt, Germany). 2,4,6-Tris(2-pyridyl)-1,3,5-triazine (TPTZ) and 2,20-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), were provided by Sigma (Darmstadt, Germany). 2,2-diphenyl-1-picrylhydrazyl (DPPH) (CalBiochem, Darmstadt, Germany), Gallic acid (Scharlau, Barcelona, Spain), Na_2CO_3 (AppliChem, Darmstadt, Germany), potassium persulfate (Bernd Kraft, Duisburg, Germany), and Trolox (Cayman, Ann Arbor, MI, USA) were used. Methanol was purchased from Chemsolute (Hamburg, Germany).

2.2. Plant Material

The yacon tubers used in the present work were taken from a field trial carried out in 2015 at the organically operating research station of Kleinhohenheim of the University of Hohenheim (Stuttgart, Germany). The tubers of two yacon cultivars were specified in accordance to the color of the tubers’ peels: red and white. Yacon tubers, which were cultivated at the same field under the same growing conditions and management to ensure *ceteris paribus*, were bulked across replicates, sorted, washed with tap water, and left in the open air to drain for two hours one day after harvest. Afterwards, the tubers from each cultivar were divided into two batches. The first batch was kept at ambient temperature in a closed dark box before drying for one week after harvest. The second batch was stored at ambient temperature in a closed dark box for three weeks after harvest before drying.

2.3. Drying of Yacon Slices

Table 1 shows the process variables for drying trials.

Drying of yacon slices was carried out on two dates within a two-week interval. The first batch of yacon tubers was dried one week after harvest and considered as tubers that had undergone no curing and the second batch which was stored at ambient temperature for three weeks after harvest was considered to as cured tubers (Table 1). Sample preparation at each drying trial date was done as follows: tubers of yacon from each cultivar were peeled using manual peelers. Yacon slices with a thickness of 3 ± 0.5 mm were prepared using manual slicers (Graef, Gebr. Graef GmbH & Co. KG, Arnsberg, Germany). Afterwards, yacon slices were divided into two parts: a first part that had

undergone no pre-treatment before drying and was regarded as untreated. Yacon slices belonging to this group were put into perforated plastic bags immediately after slicing in a single layer where each plastic bag contained approximately 80–100 g of yacon slices. The second part of the yacon slices were dipped in a diluted lime juice ($\text{pH} = 2.50 \pm 0.05$, $3.3 \pm 0.2^\circ \text{Brix}$) for 10 min, then left to drain at room temperature for 10 min, which was regarded as pre-treated with diluted lime juice, and then were arranged in a single layer in perforated plastic bags. Plastic bags containing these yacon slices were placed in a convective hot air dryer (Vötsch Industrietechnik, Reiskirchen, Germany) operating at 40°C , 50°C and 60°C and drying was carried out for 20 h. After the drying process, samples were left to cool down before being ground. In the case of FD, yacon slices from each treatment were placed in plastic bottles, and were frozen immediately by means of liquid nitrogen. Afterwards, the frozen samples were kept at -18°C before FD. FD was performed using a freeze dryer (Dieter Piatkowski, Munich, Germany) with the maximum temperature inside the chamber of the freeze drier reaching to 30°C . Therefore, the following samples were produced:

- Yacon chips produced from white (W) or red (R) cultivar without curing without pre-treatment in diluted lime juice by means of FD or CHAD using hot air drying at 40°C , 50°C and 60°C (hot air dried at 40°C (HA40), HA50, and HA60, respectively) including: white, freeze dried (WFD), WHA40, WHA50, WHA60, red, freeze dried (RFD), RHA40, RHA50, and RHA60.
- Yacon chips produced from white (W) or red (R) cultivar without curing with pre-treatment in diluted lime juice (L) by means of FD or CHAD using hot air drying at 40°C , 50°C and 60°C (HA40, HA50, and HA60, respectively) including: white, freeze dried, pre-treatment in diluted lime juice (WFDL), WHA40L, WHA50L, WHA60L, red, freeze dried, pre-treatment in diluted lime juice (RFDL), RHA40L, RHA50L, and RHA60L.
- Yacon chips produced from white (W) or red (R) cultivar with curing without pre-treatment in diluted lime juice by means of FD or CHAD using hot air drying at 40°C , 50°C and 60°C (HA40, HA50, and HA60, respectively) including: white, freeze dried, cured (WFDC), WHA40C, WHA50C, WHA60C, red, freeze dried, cured (RFDC), RHA40C, RHA50C, and RHA60C.
- Yacon chips produced from white (W) or red (R) cultivar with curing and pre-treatment in diluted lime juice by means of FD or CHAD using hot air drying at 40°C , 50°C and 60°C (HA40, HA50, and HA60, respectively) including: white, freeze dried, cured, pre-treatment in diluted lime juice (WFDCL), WHA40CL, WHA50CL, WHA60CL, red, freeze dried, cured, pre-treatment in diluted lime juice (RFDCL), RHA40CL, RHA50CL, and RHA60CL.

Table 1. Process variables for drying of yacon slices.

		Process Variables		
Row Material		Pre-Treatment Before Drying	Drying Method	
Cultivar	Red	No curing	CHAD	40°C 50°C 60°C
			FD	
		No pre-treatment	CHAD	40°C 50°C 60°C
			FD	
	White	Curing	CHAD	40°C 50°C 60°C
			FD	
		No pre-treatment	CHAD	40°C 50°C 60°C
			FD	

CHAD = convective hot air drying, and FD = freeze drying.

Dried samples were grounded by means a laboratory mill (Retsche GM 200, Haan, Germany) and yacon powders were kept in closed plastic bottles in a cool dark place until the chemical analysis was carried out.

The initial and final dry matter content of yacon slices were determined gravimetrically. The previously ground samples were dried at 105 ± 1 °C for 5 h and the weight of samples was recorded before and after drying. Equation (1) was used to calculate the total dry matter content.

$$\text{Total dry matter content} = \left(\frac{\text{weight of samples after drying}}{\text{weight of samples before drying}} \right) \times 100 \quad (1)$$

2.4. Extraction of Phytochemicals

The extraction was carried out by adding 5 mL of methanol to 0.25 g of dried yacon chip powder. This was followed by shaking the mixture for 30 min at room temperature. Afterwards, the mixture was centrifuged (5810R, Eppendorf AG, Hamburg, Germany) at 4000 rpm for 10 min (20 °C) to separate the supernatant from the solid residuals. The methanolic extracts were used for the following analysis.

2.4.1. Total Phenolic Content (TPC)

The TPC was conducted according to the Folin-Ciocalteu methodology [36]. Briefly, 0.5 mL of prepared extract was added to 30 of distilled water in a 50 mL volumetric flask. Then 2.5 mL of Folin-Ciocalteu's reagent was added to the flask and mixed with it. After 6 min, 7.5 mL of sodium carbonate solution (20%) was added to the mixture and the final volume was adjusted to 50 mL. The mixtures were left at room temperature for 2 h. Then, the absorbance at 760 nm was measured by a ultraviolet (UV)/Visible spectrophotometer (Ultrospec 3100 Pro, Amersham Bioscience, Buckinghamshire, UK). Gallic acid solution (0.3–3 mg gallic acid /mL distilled water) was used to draw the standard curve. Finally, TPC was expressed as gallic acid equivalent per 100 g of dry weight (mg GAE 100 g⁻¹ DW).

2.4.2. Determination of Antioxidant Activity

2.4.2.1. ABTS (2,2'-Azino-Bis (3-Ethylbenzothiazoline-6-Sulfonic Acid) Diammonium Salt) Radical Scavenging Assay

The ABTS radical scavenging activity was determined in accordance with the method used by Dudonne et al. [37]. Firstly, potassium persulfate (2.45 mM) and ABTS solution (7 mM) was mixed and left to stand in the dark at room temperature for 12–16 h to produce the ABTS radical cations (ABTS^{•+}). The ABTS^{•+} solution was diluted so the absorbance of the solution was 0.700 ± 0.02 at 734 nm before the analysis. For the analysis, 3.0 mL of diluted ABTS^{•+} solution was mixed to 0.1 mL of extract and the reaction solution was maintained at 30 °C for 10 min. Then, the absorbance was measured at 734 nm with a UV/Visible spectrophotometer (Ultrospec 3100 Pro, Amersham Bioscience). The standard curve was drawn with trolox solution (60–200 (μM)) as the reference substance. ABTS radical scavenging activity was expressed as trolox equivalent per 100 g of dry weight (μM TE 100 g⁻¹ DW).

2.4.2.2. DPPH (2,2-Diphenyl-1-Picrylhydrazyl) Radical Scavenging Activity

To determine the DPPH radical scavenging activity, 0.1 mL of the extract was added and mixed with 3 mL of freshly prepared 6×10^{-5} mol/L DPPH[•] solution in methanol. Then, the reaction mixture was maintained at 37 °C for 20 min before measuring the absorbance at 515 nm using a UV/Visible spectrophotometer (Ultrospec 3100 Pro, Amersham Bioscience) [37]. Ascorbic acid solution (0.02–0.2 mg ascorbic acid/mL distilled water) was used to draw the standard curve. DPPH radical scavenging activity was expressed as mg ascorbic acid equivalent per 100 g of dry weight (mg AAE 100 g⁻¹ DW).

2.4.2.3. Ferric-Reducing Antioxidant Power (FRAP)

The FRAP assay was carried out as follows: Fresh FRAP solution was prepared by mixing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ (2,4,6-Tris(2-pyridyl)-1,3,5-triazine) in HCl (10 mM) and 20 mM FeCl₃ solution in a 10:1:1 (*v/v/v*) ratio. Then, 0.15 mL of the extract was mixed with 2.85 mL of the FRAP solution. The mixture was incubated at 37 °C for 30 min before the absorbance of Fe²⁺-TPTZ was measured at 593 nm with a UV/Visible spectrophotometer (Ultrospec 3100 Pro, Amersham Bioscience) [38]. The results of the FRAP assay was reported as Fe²⁺ (mM) equivalent per 100 g of dry weight (mM Fe²⁺ 100 g⁻¹ DW).

2.5. Statistical Analysis of Data

Data was analysed using a mixed model approach. The model can be described as:

$$y_{ijk} = \mu + \tau_i + d_j + b_k + e_{ijk} \quad (2)$$

where μ is the general effect, τ_i is the *i*th treatment effect, d_j is the random effect of the *j*th day and b_k is the random effect of the *k*th bag within the CHAD/FD. e_{ijk} is the error associated with observation y_{ijk} . Treatments were further split in a 2 × 2 × 2 × 4 factorial design with two cultivars, two pre-treatments, two storage durations and four drying methods (three temperatures in case of CHAD and FD). In this case, τ_i is modelled as:

$$\tau_i = c_n \times p_m \times s_o \times t_p \quad (3)$$

where c_n , p_m , s_o and t_p are the main effects for cultivar *n*, pre-treatment *m*, storage duration *o* and drying method *p*. The crossing operator × between two main effects indicates that both main effects and their interactions are included. Residuals were checked graphically for homogeneous variances and normal distribution. Furthermore, the fitting of drying method specific variances were checked by comparing the Akaike Information Criteria (AIC) with and without this heterogeneous variance [39]. Note, that due to the sampling procedure, there is no true replicate for cultivar-by-storage-combinations, as all material from one cultivar and one storage duration were treated together. Thus, care should be taken in interpreting the significance of these effects, as their true error variances can be underestimated by the estimated repeated measures error. After finding significant differences via the F test, a simple multiple t test (the Least Significant Difference (LSD) test) and a letter display were performed. Additionally, to simplify interpretation, especially for traits with several significant three-way-interactions, means and their standard error for the four-way-interactions were presented. Note that results are presented separate for each cultivar, as there is no true replicated sample of cultivars.

For calculating the correlation between traits, a bivariate model was fitted [40]. The model in (1) can be extended for a bivariate model as follows:

$$y_{ijkl} = \mu_l + \tau_{il} + d_{jl} + b_{kl} + e_{ijkl} \quad (4)$$

where $\mu_l = \begin{pmatrix} \mu_t \\ \mu_{\bar{t}} \end{pmatrix}$ is a vector of two fixed general effects for traits *t* and \bar{t} . τ_{il} is a vector of length 64 with elements for all treatments at both traits. A Kronecker product of an ID matrix for the 32 treatments and an unstructured variance covariance structure for two traits were fitted. This allows a trait specific variance of treatment effects and a covariance between treatment effects. A similar variance–covariance matrix was fitted to day, bag, and error effects, respectively.

3. Results and Discussion

3.1. Total Dry Matter Content

The statistical analysis of data determined that the total dry matter of yacon chips was under the significant effect of four-way interactions of studied variables (storage duration after harvest (curing or no curing), pre-treatment before drying, drying temperature, and cultivar) ($p = 0.018$) (Table 2). The total dry matter of yacon white and red yacon slices one week after harvest was 10.91 ± 0.65 and $15.65 \pm 0.89\%$ respectively, while it ranged between 11.58 ± 0.26 and $16.84 \pm 0.47\%$ for white and red cultivar, respectively, three weeks after harvest. The total dry matter content of yacon chips produced one week after harvest from the white cultivar ranged between 91.20 ± 0.32 and $92.80 \pm 0.32\%$ for WHA40L and WHA40, respectively, while it ranged between 91.47 ± 0.45 and $92.92 \pm 0.45\%$ for WHA40CL and WHA40C, for white yacon chips which were produced three weeks after harvest (Table 3). Table 4 reports the total dry matter content of yacon chips produced from the red cultivar one week after harvest which was between 90.64 ± 0.32 and $92.08 \pm 0.32\%$ for RHA40L and RFD, respectively. The total dry matter of red yacon chips produced three weeks after harvest ranged between 91.85 ± 0.45 and $92.56 \pm 0.45\%$ for RHA40CL and RHA50C, respectively (Table 4). Higher dry matter contents were achieved when yacon slices were dried by FD or by means of CHAD at lower hot air temperatures. This could be due to the fact that at higher hot air drying temperatures, case hardening might occur [41]. As a consequence, the external surface becomes rigid which may reduce the rate of drying and result in lower dry matter content in product at the end of the drying process.

Table 2. Analysis of variance (ANOVA) of results of total dry matter content, total phenolic content, ABTS radical scavenging activity, DPPH radical scavenging activity, and ferric-reducing antioxidant power as a function of the process variables of the yacon chips.

Effect	Total Dry Matter Content	Total Phenolic Content	ABTS Radical Scavenging Activity	DPPH Radical Scavenging Activity	Ferric-Reducing Antioxidant Power
Cultivar	0.0065	<0.0001	<0.0001	<0.0001	<0.0001
Curing	0.0054	<0.0001	<0.0001	<0.0001	<0.0001
Drying temperature	0.7668	<0.0001	<0.0001	<0.0001	<0.0001
Pre-treatment	0.0001	<0.0001	<0.0001	0.7390	<0.0001
Cultivar \times curing	0.0770	0.1957	0.0016	0.0035	0.0358
Drying Temperature \times cultivar	0.0213	0.2298	<0.0001	<0.0001	0.0003
Pre-treatment \times cultivar	0.4215	0.4629	0.1261	0.2297	0.4920
Drying Temperature \times curing	0.1895	<0.0001	<0.0001	0.0152	0.0008
Drying temperature \times Pre-treatment	<0.0001	<0.0001	<0.0001	0.0018	0.1602
Pre-treatment \times curing	0.1424	0.0079	0.9512	<0.0001	0.0001
Pre-treatment \times Drying temperature \times curing	0.6443	0.0753	<0.0001	0.0390	0.3708
Drying Temperature \times curing \times cultivar	0.3803	<0.0001	<0.0001	<0.0001	0.0002
Pre-treatment \times curing \times cultivar	0.9251	<0.0001	<0.0001	0.0148	0.0337
Pre-treatment \times Drying temperature \times cultivar	0.0485	0.0002	0.2016	0.3993	0.0006
Pre-treatment \times Drying temperature \times cultivar \times curing	0.0189	0.1652	<0.0001	<0.0001	0.5791

Table 3. The total dry matter content, total phenolic content, ABTS radical scavenging activity, DPPH radical scavenging activity, and ferric-reducing antioxidant power of the yacon chips produced from white yacon cultivar.

Sample	Total Dry Matter Content (%)	Total Phenolic Content (mg GAE 100 g ⁻¹ DW)	ABTS Radical Scavenging Activity (μ M TE 100 g ⁻¹ DW)	DPPH Radical Scavenging Activity (mg AAE 100 g ⁻¹ DW)	Ferric-Reducing Antioxidant Power (mM Fe ²⁺ 100 g ⁻¹ DW)
WFD	92.38 ^{abcd} \pm 0.32	1434.81 ^b \pm 29.36	4,603,298 ^c \pm 198,865	1473.36 ^a \pm 34.99	17,264.45 ^{ab} \pm 523.53
WHA40	92.80 ^a \pm 0.32	336.83 ^k \pm 29.36	2,478,116 ⁱ \pm 198,865	879.13 ^g \pm 34.99	8924.44 ^g \pm 523.53
WHA50	91.55 ^{cdef} \pm 0.32	559.77 ^j \pm 29.36	1,869,012 ^j \pm 198,865	1068.07 ^{de} \pm 34.99	10,371.17 ^g \pm 523.53
WHA60	91.72 ^{bcd} \pm 0.32	703.40 ⁱ \pm 29.36	2,696,786 ^{hi} \pm 198,865	1291.05 ^b \pm 34.99	9751.33 ^g \pm 523.53
WFDL	92.08 ^{abcde} \pm 0.32	1655.34 ^a \pm 29.36	8,564,803 ^a \pm 198,865	1442.56 ^a \pm 34.99	17,941.17 ^{ab} \pm 523.53

Table 3. Cont.

Sample	Total Dry Matter Content (%)	Total Phenolic Content (mg GAE 100 g ⁻¹ DW)	ABTS Radical Scavenging Activity (μM TE 100 g ⁻¹ DW)	DPPH Radical Scavenging Activity (mg AAE 100 g ⁻¹ DW)	Ferric-Reducing Antioxidant Power (mM Fe ²⁺ 100 g ⁻¹ DW)
WHA40L	91.20 ^f ± 0.32	791.84 ^{gh} ± 29.36	3,567,287 ^{ef} ± 198,865	874.72 ^g ± 34.99	13,067.62 ^{ef} ± 523.53
WHA50L	91.40 ^{ef} ± 0.32	1033.50 ^{ef} ± 29.36	2,963,810 ^{ghi} ± 198,865	1139.00 ^{cd} ± 34.99	14,344.79 ^{de} ± 523.53
WHA60L	91.76 ^{bcd} ± 0.32	963.56 ^f ± 29.36	3,031,599 ^{ghi} ± 198,865	1074.84 ^{de} ± 34.99	14,276.69 ^{de} ± 523.53
WFDCL	92.84 ^a ± 0.45	1182.67 ^{cd} ± 29.36	4,594,690 ^c ± 198,865	1460.17 ^a ± 34.99	15,726.19 ^{cd} ± 523.53
WHA40C	92.92 ^a ± 0.45	714.34 ^{hi} ± 29.36	2,989,000 ^{ghi} ± 198,865	950.48 ^{fg} ± 34.99	12,067.90 ^f ± 523.53
WHA50C	91.48 ^{def} ± 0.45	864.06 ^g ± 29.36	3,446,631 ^{fg} ± 198,865	1212.28 ^{bc} ± 34.99	12,518.07 ^f ± 523.53
WHA60C	92.38 ^{abc} ± 0.45	1010.13 ^f ± 29.36	3,188,069 ^{gh} ± 198,865	1211.72 ^{bc} ± 34.99	12,784.27 ^f ± 523.53
WFDCL	91.74 ^{bcd} ± 0.45	1477.23 ^b ± 29.36	5,480,063 ^b ± 198,865	1435.27 ^a ± 34.99	18,171.17 ^{ab} ± 523.53
WHA40CL	91.47 ^{def} ± 0.45	1112.70 ^{de} ± 29.36	3,975,272 ^{de} ± 198,865	980.84 ^{ef} ± 34.99	16,437.41 ^{bc} ± 523.53
WHA50CL	92.89 ^a ± 0.45	1222.92 ^c ± 29.36	423,6791 ^{cd} ± 198,865	1237.05 ^{bc} ± 34.99	17,458.59 ^{ab} ± 523.53
WHA60CL	92.85 ^a ± 0.45	1131.69 ^d ± 29.36	4,197,870 ^{cd} ± 198,865	1209.25 ^{bc} ± 34.99	17,072.86 ^{abc} ± 523.53

Reported values are presented as mean values ± standard deviation ($n = 4$, for each sample two bags of sample were dried and measurements of each parameter in laboratory were carried out twice.). * Mean values with the same small letter in a column are not significantly different ($p < 0.05$). (W = white, FD = freeze dried, HA40 = hot air dried at 40 °C, HA50 = hot air dried at 50 °C, HA60 = hot air dried at 60 °C, L = pre-treated in diluted lime juice, C = cured).

Table 4. The total dry matter content, total phenolic content, ABTS radical scavenging activity, DPPH radical scavenging activity, and ferric-reducing antioxidant power of the yacon chips produced from red yacon cultivar.

Sample	Total Dry Matter Content (%)	Total Phenolic Content (mg GAE 100 g ⁻¹ DW)	ABTS Radical Scavenging Activity (μM TE 100 g ⁻¹ DW)	DPPH Radical Scavenging Activity (mg AAE 100 g ⁻¹ DW)	Ferric-Reducing Antioxidant Power (mM Fe ²⁺ 100 g ⁻¹ DW)
RFD	92.08 ^{a*} ± 0.32	731.82 ^d ± 29.36	3,286,318 ^{cd} ± 198,865	1402.22 ^{ab} ± 34.99	12,396.13 ^{cd} ± 523.53
RHA40	91.77 ^{abc} ± 0.32	236.47 ^h ± 29.36	2,179,701 ^{fg} ± 198,865	820.73 ^{de} ± 34.99	7180.02 ⁱ ± 523.53
RHA50	91.93 ^{ab} ± 0.32	321.90 ^g ± 29.36	1,816,080 ^h ± 198,865	828.63 ^d ± 34.99	7560.53 ^{hi} ± 523.53
RHA60	91.07 ^{cd} ± 0.32	328.07 ^g ± 29.36	2,000,191 ^{gh} ± 198,865	722.08 ^{fg} ± 34.99	7259.57 ^{hi} ± 523.53
RFDL	90.66 ^d ± 0.32	978.97 ^b ± 29.36	4,650,806 ^b ± 198,865	1306.14 ^b ± 34.99	16,130.51 ^b ± 523.53
RHA40L	90.64 ^d ± 0.32	471.15 ^f ± 29.36	2,568,722 ^{ef} ± 198,865	681.28 ^{gh} ± 34.99	9549.82 ^{fg} ± 523.53
RHA50L	91.77 ^{abc} ± 0.32	560.25 ^e ± 29.36	2,418,077 ^{efg} ± 198,865	750.08 ^{defg} ± 34.99	9605.81 ^{fg} ± 523.53
RHA60L	91.21 ^{bcd} ± 0.32	494.71 ^{ef} ± 29.36	2,532,742 ^{ef} ± 198,865	729.60 ^{efgh} ± 34.99	10,258.89 ^{ef} ± 523.53
RFDCL	92.41 ^a ± 0.45	908.45 ^{bc} ± 29.36	3,728,362 ^c ± 198,865	1447.94 ^a ± 34.99	12,911.06 ^{cd} ± 523.53
RHA40C	92.20 ^a ± 0.45	205.51 ^h ± 29.36	2,161,129 ^{fg} ± 198,865	644.75 ^h ± 34.99	6641.70 ⁱ ± 523.53
RHA50C	92.56 ^a ± 0.45	361.26 ^g ± 29.36	2,159,616 ^{fg} ± 198,865	810.27 ^{def} ± 34.99	6580.29 ⁱ ± 523.53
RHA60C	92.42 ^a ± 0.45	526.28 ^{ef} ± 29.36	2,748,104 ^{de} ± 198,865	1044.84 ^c ± 34.99	8704.07 ^{gh} ± 523.53
RFDCL	91.93 ^{abc} ± 0.47	1369.73 ^a ± 29.36	5,823,222 ^a ± 198,865	1470.97 ^{ab} ± 34.99	18,366.23 ^a ± 523.53
RHA40CL	91.85 ^{abc} ± 0.45	521.66 ^{ef} ± 29.36	3,622,481 ^c ± 198,865	948.23 ^c ± 34.99	11,442.73 ^{de} ± 523.53
RHA50CL	92.19 ^a ± 0.45	841.21 ^c ± 29.36	3,492,729 ^c ± 198,865	951.27 ^c ± 34.99	12,312.45 ^{cd} ± 523.53
RHA60CL	92.19 ^a ± 0.45	842.40 ^c ± 29.36	3,490,626 ^c ± 198,865	970.48 ^c ± 34.99	12971.19 ^c ± 523.53

Reported values are presented as mean values ± standard deviation ($n = 4$, for each sample two bags of sample were dried and measurements of each parameter in laboratory were carried out twice.). * Mean values with the same small letter in a column are not significantly different ($p < 0.05$). (R = red, FD = freeze dried, HA40 = hot air dried at 40 °C, HA50 = hot air dried at 50 °C, HA60 = hot air dried at 60 °C, L = pre-treated in diluted lime juice, C = cured).

3.2. TPC

Phenolic compounds are secondary metabolites in plants which contribute to sensorial (taste, flavor, color etc.) and functional (antioxidant activity, antidiabetic, anticancer activity etc.) characteristics of food products [5,42]. The amount of TPC in fresh fruits can be influenced by several factors such as cultivar, geographical origin, and environmental factors during the cultivation period, or by the harvest date of the plant. Storage duration and conditions of fruits between harvest and processing also affects the TPC of raw material at the time of processing [43].

The TPC of yacon chips was analyzed to attain an overall understanding of the changes in phenolic constituents of yacon after harvest and under the influence of drying processes. In accordance with the statistical analysis, the TPC of yacon chips was not significantly influenced by the four-way-interactions while three of the three-way interactions had a significant effect on it (Table 2).

The TPC of yacon chips produced from the white cultivar is presented in Table 3. The TPC of chips produced with FD were significantly higher in contrast to those which were processed by means of CHAD (Table 3). Comparing to the chips produced from the white cultivar at the same time after harvest using the same temperature of drying, with chips that were treated by dipping in diluted lime juice, the lime juice treated chips indicated higher TPC compared to those that had no pre-treatment before drying. The TPC of chips produced from the white cultivar one week after harvest ranged between 336.83 ± 29.36 (mg GAE 100 g⁻¹ DW) and 1655.34 ± 29.36 (mg GAE 100 g⁻¹ DW) for WHA40 and WFDL, respectively (Table 3). TPC of chips that were produced by CHAD one week after harvest, pre-treated with diluted lime juice and processed at 50 and 60 °C was at 1033.50 ± 29.36 (mg GAE 100 g⁻¹ DW) and 963.56 ± 29.36 (mg GAE 100 g⁻¹ DW), respectively. They were statistically non-significantly different from each other (Table 3). The TPC of yacon chips produced three weeks after harvest varied from 714.34 ± 29.36 (mg GAE 100 g⁻¹ DW) to 1477.23 ± 29.36 (mg GAE 100 g⁻¹ DW) for WHA40C and WFDCL, respectively. Among chips produced using the white cultivar three weeks after harvest and dried using CHAD, the two highest TPCs were noted for WHA50CL and WHA60CL at 1222.92 ± 29.36 (mg GAE 100 g⁻¹ DW) and 1131.69 ± 29.36 (mg GAE 100 g⁻¹ DW), respectively (Table 3).

Table 4 reports the TPC of yacon chips produced from the red yacon cultivar. Likewise, the results from white cultivar, a generally higher TPC was indicated in yacon chips from the red cultivar which were produced by FD compared to those that were produced using CHAD (Tables 3 and 4). Moreover, among the chips that were processed under the same conditions with regard to the drying temperature and at the same time after harvest, those which had undergone the pre-treatment with diluted lime juice before drying had higher TPC in comparison to chips that were produced without any pre-treatment (Table 4). The yacon chips from the red cultivar, which were dried one week after harvest, contained TPC in the range of 236.47 ± 29.36 (mg GAE 100 g⁻¹ DW) to 978.97 ± 29.36 (mg GAE 100 g⁻¹ DW) (Table 4). The results showed that the highest TPC in the chips came from the red cultivar that was produced one week after harvest by means of CHAD and was noted at 560.25 ± 29.36 (mg GAE 100 g⁻¹ DW) and 494.71 ± 29.36 (mg GAE 100 g⁻¹ DW) for RHA50L and RHA60L, respectively. There was no significant difference between them (Table 4). The yacon chips produced from the red cultivar three weeks after harvest had a TPC ranging between 205.51 ± 29.36 (mg GAE 100 g⁻¹ DW) and 1369.73 ± 29.36 (mg GAE 100 g⁻¹ DW) for RHA40C and RFDCL, respectively (Table 4). There was no significant difference between the TPC of RHA50CL and RHA60CL at 841.21 ± 29.36 (mg GAE 100 g⁻¹ DW) and 842.40 ± 29.36 (mg GAE 100 g⁻¹ DW), respectively (Table 4).

The results of the present study noted higher TPC in chips produced by white cultivar compared to the TPC of chips developed from the red cultivar (Tables 3 and 4). These results indicate the effect of cultivar on the TPC of yacon chips and are in agreement with the results of previous studies which reported the variation in TPC of different yacon cultivars as well as other fruits and vegetables such as apple, beetroot, figs, and potatoes [25,44–47]. Moreover, the TPC content of sterilized yacon tuber flour produced from tubers grown in Brazil extracted in boiling water with ratio of 8.9% (*w/v*) of yacon, were reported equal to 275 ± 3 (mg GAE 100 g⁻¹ DW) which is lower than the findings of this study (Tables 3 and 4) [24]. However, the TPC of yacon chips produced from tubers grown in Bolivia, pre-treated with solutions of lemon juice and water before drying in a cabinet dryer at 40 °C, 50 °C and 60 °C were reported at around 710, 1010, and 680 (mg GAE 100 g⁻¹ DW), respectively, which is in the agreement range of TPC of the yacon chips in the present work [18]. Such variation in amount of TPC may be influenced by other factors such as differences in post-harvest handling of yacon tubers, processing of yacon tubers, extraction methods and solvents used for extraction of phenolic compounds and analytical methods. Moreover, it was noticed that the amount of TPC in white yacon chips decreased with increasing storage time after harvest before processing with FD, while TPC content in red yacon chips increased with increasing storage time after harvest before processing by means of FD (Tables 3 and 4). The observed different trend regarding the change in amount of TPC between the two investigated cultivars could point to a variation in the nature and

structure of their phytochemical content and enzymes that are active and catalysing the biosynthesis or biodegradation of such compounds in tubers during storage. Variation in the expression of polyphenol oxidase activity with regard to optimal conditions (e.g., pH, and temperature) and substrate specificity has been noted between species and even within the same species [2,35]. For instance, inconsistency in substrate specificity between different cultivars of the same species have been noted in previous studies [2,48]. In addition, biosynthesis of phenolic compounds such as anthocyanins during storage of potato tubers has been reported in the study of Lewis et al. (1999) [49]. They proposed that a rise in sugar as substrates for biosynthesis of anthocyanins contributed to biosynthesis of anthocyanins in potato tubers during storage time [49]. It has been noted that during storage the FOS of yacon tubers may convert to sugars [31]. Therefore, the increase in TPC of yacon chips produced by the red cultivar might be due to conversion of FOS to sugars, which in turn may lead to biosynthesis of phenolic compounds. In addition, higher retention of TPC in samples processed by FD in comparison to samples dried by means of CHAD is in agreement with previous investigations with regard to drying of mango peels and kernels, mango cubes and sour cherries [50–52]. Formation of ice crystals in cellular structure plants during freezing will cause rupture of cellular structure and hence release of compounds during extraction [53]. Besides, operational conditions during FD including low temperature, absence of oxygen, and absence of liquid water plays a role in preventing the destruction of phenolic compounds thermally or enzymatically [54]. Moreover, among the chips produced in CHAD without pre-treatment, the higher TPC was noted for the chips, which were dried at 60 °C. This is in line with the results of previous studies which showed higher TPC in fruit chips produced at higher hot air temperatures due to the formation of phenolic compounds according to the presence of precursors of phenolic compounds, which may undergo non-enzymatic interconversion reactions [55,56]. Moreover, chips that were produced by applying pre-treatment in diluted lime juice, had higher TPC compared to those that were produced under the same conditions without pre-treatment. Various physical (e.g., heating) and chemical (e.g., vitamin C) methods have been investigated to avoid the browning of plant tissue during storage and food processing by influencing the enzymes or substrates or the products involved in browning reactions [34,57]. In this regard, when using acidic pre-treatments like diluted lime juice, low pH and the presence of vitamin C as a chemical inhibitor may have played a role in protection of the phenolic compounds from oxidation and the final products from enzymatic browning.

3.3. Antioxidant Activity

3.3.1. ABTS Radical Scavenging Activity

ABTS radical scavenging activity is a fast and simple method to determine the total antioxidant capacity in food materials. ABTS radical scavenging activity is determined by measuring the reduction in blue-green color of the radical cation ABTS at 734 nm through the donation of hydrogen or electrons by the antioxidant compounds [58]. In the present study, the findings of ABTS radical scavenging activity of yacon chips were reported as μmol equivalent of trolox per 100 g dry weight of yacon chips.

The statistical analysis of the results indicated that the ABTS radical scavenging activity of yacon chips was significantly affected by four-way interactions between cultivar, duration of storage after harvest (curing or no curing), pre-treatment and drying temperature ($p < 0.0001$) (Table 2).

The ABTS radical scavenging activity of yacon chip products from the white cultivar under various conditions is noted in Table 3. The ABTS radical scavenging activity of chips produced by means of FD was higher than those which had undergone the same processing conditions with regard to duration of storage and pre-treatment but were dried by means of CHAD. In addition, the samples pre-treated by diluted lime juice had a higher ABTS radical scavenging activity than chips which were dried untreated. The ABTS radical scavenging activity of chips produced from the white cultivar one week after harvest varied between $1,869,012 \pm 198,865 \mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$ and $8,564,803 \pm 198,865 (\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW})$ for WHA50 and WFDL, respectively (Table 3). Among the chips that were produced

by means of CHAD one week after harvest, the highest ABTS radical scavenging activity was noted at $3,567,287 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) for WHA40L. Chips produced from the white cultivar three weeks after harvest indicated an ABTS between $2,989,000 \pm 198,865$ and $5,480,063 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) for WHA40C and WFDCL, respectively (Table 3). The highest amount of ABTS radical scavenging activity among chips from the white cultivar, which were processed using CHAD three weeks after harvest, was noted for WHA50CL and WHA60CL at $4,236,791 \pm 198,865$ and $4,197,870 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$), respectively (Table 3).

Table 4 presents the ABTS radical scavenging activity of yacon chips that were produced under different conditions from the red cultivar. Likewise, the results of ABTS radical scavenging activity of yacon chips from the white cultivar the ABTS radical scavenging activity of chips produced from the red cultivar was higher when they were processed by means of FD. Moreover, yacon chips from the red cultivar that were pre-treated by diluted lime juice had higher ABTS radical scavenging activity when compared to those which were produced at the same time after harvest at the same drying temperature. As it can be noted in Table 4, ABTS radical scavenging activity of chips of red cultivar which were dried one week after harvest ranged from $1,816,080 \pm 198,865$ to $4,650,806 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) for RHA50 and RFDL, respectively. With respect to the chips produced from the red cultivar one week after harvest using CHAD at 40°C , 50°C and 60°C higher ABTS radical activity belonged to chips that were pre-treated with diluted lime juice. However, results were not significantly different from each other ($2,568,722 \pm 198,865$, $2,418,077 \pm 198,865$ and $2,532,742 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) for RHA40L, RHA50L and RHA60L, respectively (Table 4). The ABTS radical scavenging activity of chips of the red cultivar that were produced three weeks after harvest ranged between $2,159,616 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) and $5,823,222 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) for RHA50C and RFDCL, respectively (Table 4). The chips produced from the red cultivar using CHAD at 40°C , 50°C and 60°C three weeks after harvest those which had been pre-treated with diluted lime juice had higher ABTS radical scavenging activity $3,622,481 \pm 198,865$, $3,492,729 \pm 198,865$ and $3,490,626 \pm 198,865$ ($\mu\text{mol TE } 100 \text{ g}^{-1} \text{ DW}$) for RHA40CL, RHA50CL and RHA60CL, respectively, which were statistically different from each other.

The results of ABTS radical scavenging activity of yacon chips that were produced from tubers of the white cultivar were higher than those of chips that were produced from tubers of red cultivars which is in line with the results of the TPC (Tables 3 and 4). This may suggest that the TPC of yacon chips may contribute to their ABTS radical scavenging activity. In addition, individual phenolic compounds could be influential on the ABTS radical scavenging activity of yacon chips. Therefore, further studies with regard to the identification of individual phenolic compounds of yacon chips are required. Moreover, the results of previous studies showed a significant effect of cultivar on the ABTS radical scavenging activity of yacon tubers that is in line with differences between ABTS radical scavenging activity of yacon chips from the two cultivars in this study [11,24,25]. It has been noted that the ABTS radical scavenging activity of the yacon tubers of 35 yacon accessions grown in Peru varied between a reported range between 23 and 136 ($\mu\text{M TE g}^{-1} \text{ DW}$), which was lower than our findings [25]. Sousa et al. reported the ABTS radical scavenging activity of sterilized yacon flour produced from tubers grown in Brazil at 222 ± 2 (mg ascorbic acid equivalent $100 \text{ g}^{-1} \text{ DW}$) [24]. In agreement with the outcomes of TPC, the ABTS radical scavenging activity of yacon chips which were produced by means of FD was higher than those which were produced by means of CHAD (Tables 3 and 4). Higher ABTS radical scavenging activity in dried jujubes, saskatoon berries, sour cherries, and strawberries, was also noted by other investigations when FD was applied in comparison to hot air drying [52,59–61]. The ABTS radical scavenging activity of chips that were processed by means of CHAD were highest when a higher drying temperature (60°C) was used in combination with pre-treatment with diluted lime juice for both processing times after harvest. Higher ABTS radical scavenging activity was also reported in dried apple pomace, citrus fruit peels, and pineapple by applying higher temperatures in CHAD [55,62,63]. At higher drying temperatures, production of antioxidant compounds as a result of enzymatic and non-enzymatic browning may contribute to higher antioxidant activity. Other studies

also reported the effect of drying temperature on ABTS radical scavenging of sour cherry and jujube fruits that showed higher ABTS radical scavenging activity when lower hot air drying temperatures were used [52,64]. Such differences in various investigations may be due to differences in native bioactive compounds in different fruits and their behavior and sensibility to drying conditions such as duration and temperature. Moreover, pre-treatment with diluted lime juice may protect the antioxidant compounds responsible for ABTS radical scavenging activity which are present at the cut-surface of yacon slices against degradation by oxidizing. The residual lime juice on the surface of yacon slices could be another factor that contributes to the ABTS radical scavenging activity of yacon chips.

3.3.2. DPPH Radical Scavenging Activity

The DPPH radical scavenging activity method is widely used to determine the ability of antioxidants in a sample to quench free radicals of DPPH by donating hydrogen. DPPH radicals have a purple color, which undergo a color change upon neutralization by receiving hydrogen. Therefore, the intensity of discoloration, which is evaluated at 517 nm, is a measure for antioxidant ability. The results of DPPH radical scavenging activity can be expressed as equivalent of a reference substance (e.g., trolox and ascorbic acid etc.) [58]. In this study, ascorbic acid was used as the reference substance and, therefore, the results were expressed as mg equivalents of ascorbic acid per 100 g dry weight of yacon chips.

According to statistical analysis of data, the DPPH radical scavenging activity of yacon chips in the present study was significantly influenced by a four-way interaction between the studied parameters ($p < 0.0001$) (Table 2). Table 3 presents the DPPH radical scavenging activity of yacon chips produced from the white cultivar under various conditions. The DPPH radical scavenging activity of chips from the white cultivar that were dried one week after harvest was between 874.72 ± 34.99 (mg AA 100 g^{-1} DW) and 1473.36 ± 34.99 (mg AA 100 g^{-1} DW) for WHA40L and WFD, respectively (Table 3). The DPPH radical scavenging activity of WHA60 was the highest (1291.05 ± 34.99 mg AA 100 g^{-1} DW) among those of chips from white cultivar which were dried by CHAD. The yacon chips produced from the white cultivar three weeks after harvest had DPPH radical scavenging activity between 950.48 ± 34.99 and 1460.17 ± 34.99 (mg AA 100 g^{-1} DW) for WHA40C and WFDC, respectively (Table 3).

The DPPH radical scavenging activity of yacon chips produced from the red cultivar is noted in Table 4. According to Table 4, the DPPH radical scavenging activity of yacon chips of red cultivars produced one week after harvest varied between 681.28 ± 34.99 (mg AA 100 g^{-1} DW) and 1402.22 ± 34.99 (mg AA 100 g^{-1} DW) for RHA40L and RFD, respectively. The highest amount of DPPH radical scavenging activity among the chips produced from the red cultivar one week after harvest using CHAD belonged to RHA40 and RHA50 at 820.73 ± 34.99 (mg AA 100 g^{-1} DW) and 828.63 ± 34.99 (mg AA 100 g^{-1} DW), respectively, while their DPPH radical scavenging activity was statistically not significantly different from each other (Table 4). As noted in Table 4, the DPPH radical scavenging activity of yacon chips produced from the red cultivar three weeks after harvest ranged between 644.75 ± 34.99 (mg AA 100 g^{-1} DW) and 1447.94 ± 34.99 (mg AA 100 g^{-1} DW) for RHA40C and RFDC, respectively. The highest amount of DPPH radical scavenging activity among the chips produced from the red cultivar three weeks after harvest in CHAD belonged to RHA60C at 1044.84 ± 34.99 (mg AA 100 g^{-1} DW) while it was not significantly different from those of RHA40CL, RHA50CL and RHA60CL (948.23 ± 34.99 , 951.27 ± 34.99 and 970.48 ± 34.99 (mg AA 100 g^{-1} DW), respectively) (Table 4).

The higher DPPH radical scavenging activity of yacon chips produced from the white cultivar in comparison to chips produced from the red cultivar was consistent with results of TPC and ABTS radical scavenging activity (Tables 3 and 4). The outcomes of previous investigations are in agreement with the results of the present study, confirming the variation in DPPH radical scavenging activity of yacon tubers from various cultivars [11]. In addition, the DPPH radical scavenging activity of yacon tubers has been investigated by Yan et al. (1999) who reported chlorogenic acid and L-tryptophan

as two antioxidants in yacon tubers [65]. Furthermore, higher DPPH radical scavenging activity of yacon chips when FD was used compared to CHAD was determined. Higher DPPH radical scavenging activity was reported in mango cubes, strawberries, and saskatoon berries when they were dried by means of FD in comparison to CHAD which is in agreement with the findings of the present study [51,60,61]. Moreover, higher DPPH radical scavenging activity in freeze-dried yacon chips is well aligned with the results of their TPC which may suggest that the phenolic compounds are responsible for DPPH radical scavenging activity of yacon chips. Additionally, yacon contains relatively low amounts of vitamin C and it has been noted that in the case of fruits which have low amounts of vitamin C, their antioxidant activity may generally be determined by their phenolic compounds [66–68]. Generally, the DPPH radical scavenging activity of yacon chips processed in CHAD was higher when higher temperatures were applied. This can be due to the formation of antioxidant compounds as a result of reactions like the Maillard [68]. The findings of investigations into the effect of hot air temperature during convective drying on DPPH radical scavenging activity of blueberries, citrus fruit peel, and golden berry also showed greater DPPH radical scavenging activity in fruits dried at higher hot air temperatures [55,69,70]. However, the red yacon chips processed in CHAD at 40 °C and 50 °C one week after harvest without pre-treatment had statistically comparable DPPH radical scavenging activity to each other. Overall, the DPPH of these samples was higher than those of the chips that were processed using CHAD at 60 °C without pre-treatment and with pre-treatment at 40 °C, 50 °C and 60 °C one week after harvest (Table 4). These results are contrary to the results of the TPC as the red yacon chips which were processed in CHAD at 40 °C and 50 °C one week after harvest without pre-treatment had the lowest TPC. This might be explained by taking into account the possibility that at lower temperatures of drying the native polyphenols oxidase of red yacon might still be active and in the presence of oxygen leading to the formation of antioxidant compounds. It has been noted that the polyphenols have higher antioxidant activity in an intermediate stage of oxidation [71].

3.3.3. FRAP

The FRAP assay is another method based on electron transfer for measuring antioxidant characteristics of food materials. In this method, the antioxidants power is determined in an acidic condition by reducing the ferric 2,4,6-tripyridyl-s-triazine complex to the ferrous complex. The later exhibits an intense blue color and its absorbance can be measured at 593 nm. The results of the FRAP assay are reported as equivalents of concentration of ferrous ions (mM) [58].

The statistical analysis of FRAP results of yacon chips showed that the four-way interactions were not significant while three of the three-way interactions were significant (Table 2).

Table 3 notes the FRAP of yacon chips from the white cultivar. The FRAP of yacon chips of the white cultivar which were produced one week after harvest varied between 8924.44 ± 523.53 (mM Fe^{+2} 100 g^{-1} DW) and $17,941.17 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) for WHA40 and WFDL, respectively. The highest FRAP among the yacon chips produced from the white cultivar one week after harvest by means of CHAD belonged to WHA50L and WHA60L at $14,344.79 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) and $14,276.69 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW), respectively (Table 3). Yacon chips from the white cultivar that were produced three weeks after harvest had a FRAP that ranged between $12,067.90 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) and $18,171.17 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) for WHA40C and WFDCL, respectively (Table 3). The highest FRAP value belonged to WHA50CL and WHA60CL among the yacon chips from the white cultivar that were dried by CHAD three weeks after harvest at $17,458.59 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) and $17,072.86 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW), respectively. Their FRAP values were not significantly different from that of WFDCL ($18,171.17 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW)) (Table 3).

The results of FRAP measurements of yacon chips from the red cultivar are presented in Table 4. The yacon chips of the red cultivar which were dried one week after harvest varied between 7180.02 ± 523.53 (mM Fe^{+2} 100 g^{-1} DW) and $16,130.51 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) for RHA40 and RFDL, respectively (Table 4). Among the yacon chips from the red cultivar which were dried one

week after harvest in CHAD, the highest FRAP was indicated for RHA60L at $10,258.89 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) (Table 4). The FRAP of yacon chips from red cultivars which were produced three weeks after harvest ranged between 6641.70 ± 523.53 (mM Fe^{+2} 100 g^{-1} DW) and $18,366.23 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) for RHA40C and RFDCL, respectively (Table 4). The FRAP of yacon chips from the red cultivar dried by CHAD three weeks after harvest was highest at $12,312.45 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) and $12,971.19 \pm 523.53$ (mM Fe^{+2} 100 g^{-1} DW) and was not significantly different from each other for RHA50CL and RHA60CL, respectively (Table 4).

Parallel to the results of TPC, ABTS and DPPH radical scavenging activity, the findings showed that the FRAP of white yacon chips was higher than those of red yacon chips (Tables 3 and 4). These results are in agreement with a study of Khajehei et al. who determined various FRAP for yacon tubers from different cultivars [11]. Higher FRAP was also reported for dried mango powder, strawberries, and sour cherries when they were dried by mean of FD in comparison to CHAD which is in line with the outcomes of the present work [51,52,61]. A drying process using CHAD can result in a decrease in antioxidant compounds of raw material as the process exposes the raw material to thermal treatment for a relatively long time in the presence of oxygen. Degradation of some of the antioxidants may occur under such conditions as they might be unstable or they could undergo enzymatic oxidation. Moreover, there was no significant difference between the FRAP value of yacon chips, which were processed by means of CHAD at the same time and with the same pre-treatment using various hot air temperatures when white yacon was used (Table 3). However, FRAP values were significantly higher in the case of red yacon chips which were produced by means of CHAD under the same pre-treatment conditions and at same time after harvest when higher hot air temperatures were used (Table 4). These results may suggest the difference between antioxidant compounds in two investigated cultivars which are responsible for FRAP and their behavior in response to different temperatures in the drying process.

4. Conclusions

In conclusion, the results of this study determined that the bioactivity of yacon chips is better preserved when pre-treatments with diluted lime juice were used and dried by means of FD. Moreover, when comparing the samples dried by means of CHAD, the findings of this study suggested that drying in higher hot air temperature and application of pre-treatment using diluted lime juice results in yacon chips with higher TPC and antioxidant activity. The outcomes of the present work suggest that for the production of yacon chips with higher phytochemical content from white cultivar, it is better to carry the drying processing out one week after harvest by FD, while for the red cultivar it is better to process the tubers three weeks after harvest using FD. Moreover, the results showed that in general the yacon chips from the white cultivar had higher TPC and antioxidant activity than the yacon chips produced from the red cultivar. These results reveal a considerable influence of genotype of yacon on phytochemical quality of yacon tubers and changes in their content of bioactive compounds during storage. Further studies into the association between the determination of bioactive compounds of yacon tubers, such as individual phenolic compounds, and their biological effects, such as antioxidant activity, are needed.

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