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Research article

Nutritional and functional characterization of *Washingtonia filifera* fruit as a natural antioxidant ingredient

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Abstract: *Washingtonia* fruit, an underutilized Egyptian resource, was characterized as a novel functional ingredient for bakery fortification through comprehensive analyses of chemical composition, minerals, vitamins, phytochemicals, and sensory attributes in flesh and seeds. The flesh exhibits high moisture (13.90%) and fiber (16.77%; $p < 0.01$ vs. seeds), promoting hydration and digestive health, while the seeds provide protein (8.20%), lipids (17.82%), and bioavailable iron/zinc. Prominent phytochemicals include betulin and campesterol (flesh) alongside myristic acid isobutyl ester (seeds), with β-carotene at 33 mg/kg (flesh) and Vitamins A/C in both (HPLC-validated). Sensory optimization revealed that 1-3% flesh powder incorporation significantly enhances cupcake aroma, flavor, and overall acceptability (ANOVA, $p<0.05$ vs. control), whereas 5% compromise the texture. These findings position *Washingtonia* fruit as a sustainable antioxidant/nutraceutical source, guiding precise formulations for functional foods amid global demand for natural bakery enhancers.

Keywords: *Washingtonia* fruit; natural antioxidants; functional bakery; organoleptic properties; phytochemical profiling; sensory optimization; nutraceutical ingredients; waste valorization

1. Introduction

The *Washingtonia filifera* fruit, derived from the genus of palm trees commonly known as the desert fan palm, has gained attention for its nutritional and functional properties. The fruit is characterized by its high moisture content and phytochemical composition, which may contribute to its potential health benefits [1,2]. The flesh and seeds of the *Washingtonia* fruit offer distinct nutritional profiles, which are essential for understanding their applicability as food sources [3]. The flesh of the fruit is noted for its hydration properties due to its high moisture content, making it an appealing option for direct consumption [4]. In contrast, the seeds are recognized for their elevated concentrations of proteins, lipids, and minerals, suggesting to be a valuable source of dietary supplements and functional foods [5]. Studies have highlighted the potential of *Washingtonia* fruit to provide not only essential nutrients but also bioactive compounds with antioxidant and anti-inflammatory properties [6]. Furthermore, understanding the proximate composition and phytochemical content of flesh and seeds will facilitate the development of nutraceutical applications and promote the utilization of *Washingtonia* fruit in dietary contexts [7]. Using natural antioxidants as food ingredients to bakery products, especially cupcakes, can significantly improve their nutritional profile and appeal to health-conscious consumers. Ingredients such as berries, dark chocolate, nuts, and spices like cinnamon are rich in antioxidants, which help combat oxidative stress and may reduce the risk of chronic diseases [8]. For example, incorporating blueberry puree or cocoa powder into cupcake recipes not only enhances flavor but also increases the antioxidant capacity, providing additional health benefits [2]. Furthermore, the *Washingtonia* fruit is a promising option that contains bioactive compounds with antioxidant properties, making it suitable for fortifying baked goods [4]. By utilizing these natural sources, bakers can create delicious cupcakes that not only satisfy sweet cravings but also contribute positively to overall health, promoting the idea of indulgence without compromise [9]. In this study, we aim to characterize the techno functional properties of the *Washingtonia* fruit to utilize it as a natural antioxidant food ingredient in cupcake baking. We also evaluate the organoleptic properties of cake production to optimize the *Washingtonia* powder level in cupcakes.

2. Materials and methods

2.1. Materials and chemicals

The fruit from *Washingtonia filifera* trees was harvested (season 2023) in a fully mature state from cultivated trees at the Agricultural Research Center Giza, Egypt. The fruit was thoroughly washed, the seeds were removed, ground, and stored at −20 °C until analysis (Figure 1). All chemicals and reagents were in food grade from Sigma Aldrich Company.

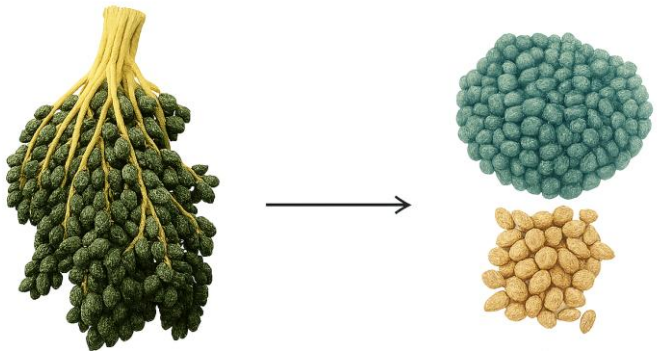

Figure 1. *Washingtonia filifera* fruit flesh and seeds.

2.2. Chemical analysis

2.2.1. The proximate chemical composition

Moisture, fat, ash, protein, and fiber content of *Washingtonia* fruit flesh and seeds were determined according to AOAC [10].

2.2.2. Determination of carbohydrates

Non-nitrogen extract or total carbohydrate was calculated according to AOAC [10] by the difference, as shown in the following equation:

$$\text{Total Carbohydrate} = 100 - (\text{moisture} + \text{ash} + \text{protein} + \text{fat} + \text{fiber}) \quad (1)$$

2.2.3. Element determination

Calcium (Ca), Magnesium (Mg), Iron (Fe), Phosphorus (P), Potassium (K), and Zinc (Zn) were analyzed according to AOAC [10] methods using a Perkin-Model 3300 atomic absorption spectrophotometer (USA).

2.3. Phytochemical analysis

2.3.1. Vitamin determination

Vitamin C (ascorbic acid) was measured following the method outlined in [11] by blending a known sample mass with oxalic acid–EDTA, filtering, and centrifuging. A measured aliquot of the extract (or juice plus reagent) was treated with color-developing reagents, left for 15 minutes, and the blue solution's absorbance at 760 nm was compared with a calibration graph., while vitamin E (tocopherol) and vitamin A (β-carotene) were assessed according to the procedures described in[12].

2.3.2. Total flavonoid determination

Total flavonoid content was determined using the aluminum chloride colorimetric method in [13].

TFC was measured at 510 nm using a UV-V spectrophotometer (Jenway 6800, UK). Quercetin was used as a standard for TFC assays, with quantification based on standard curves for quercetin (10–100 mg/L).

2.3.3. Antioxidant capacity

The total antioxidant capacity of the samples was determined in [14]. A 0.5 mL aliquot of sample methanol extract (0.02g/mL) was mixed with a 4.5 ml reagent solution (DPPH) and incubated in a boiling water bath. The absorbance of each sample was then measured at 695 nm against a blank using a UV-2450 spectrophotometer.

2.3.4. Total phenol determination

The Folin-Ciocaltiou method in [15] was used to determine total phenolic content. TPC was assessed at a wavelength of 750 nm, using a UV-V spectrophotometer (Jenway 6800, UK). Gallic acid was used as standards for TFC assays, with quantification based on standard curves for gallic acid (10–100 mg/L).

2.3.5. Total oxalate determination

Total oxalate was determined through the titration method reported in [16]. Samples were oven-dried at 45 °C for 72 h, finely ground, sealed in polyethylene bags, and stored at −4 °C until analysis. A 0.1 g portion was extracted with 75 mL of 3 M H_2SO_4 under magnetic stirring for 1 h, and then filtered through Whatman No. 1 paper. An aliquot (25 mL) of the filtrate was titrated hot with 0.05 M $KMnO_4$ until a persistent faint pink color appeared (30 s). Oxalate content was calculated assuming that 1 mL of 0.05 M $KMnO_4$ corresponded to 2.2 mg oxalate.

2.3.6. Phytic acid determination

Phytic acid was determined by HPLC based on metal replacement of iron (III) from the iron (III)–thiocyanate complex, followed by reversed-phase separation and UV detection at 460 nm. Quantification was performed using external calibration, while spectrophotometric confirmation relied on iron (III)–5-sulfosalicylic acid displacement measured at 500 nm [17].

2.4. The GC-MS phytochemical compound determination

Phytochemical compound determination was done according to the method described in [18] using the GC-MS technique. The analysis was carried out using a GC (Agilent Technology 7890A) coupled with a mass selective detector (MSD, Agilent 7000 Triple Quad) equipped with an Agilent HP-5ms capillary column. The identification of components was based on a comparison of their mass spectra with the authentic compounds and by computer matching with a NIST library as well as by comparing the fragmentation pattern of the mass spectral data with those registered in the literature.

2.5. Protein advance analysis

2.5.1. Amino acid determination

The determination of amino acids was done according to the method in [10]. Nutritional quality of the samples was determined using amino acid profiles and the calculated essential amino acid index (EAAI) according to the method in [1], as reported by [19], using the following equation:

$$\text{EAAI} = \frac{\sqrt[8]{(\text{Lys}\times\text{Iso}\times\text{Val}\times\text{Thr}\times\text{Leu}\times\text{Phe}\times\text{His}\times\text{Meth})\text{a}}}{(\text{Lys}\times\text{Iso}\times\text{Val}\times\text{Thr}\times\text{Leu}\times\text{Phe}\times\text{His}\times\text{Meth})\text{b}} \times 100 \quad (2)$$

where n = number of essential amino acids, a= the concentration of essential amino acids [lysine, isoleucine, valine, threonine, leucine, phenylalanine, histidine and methionine] in test sample, and b= the same amino acids in standard protein (%).

The biological value (BV) was calculated according to [20] using the following equation:

$$\text{BV} = 1.09\ \boldsymbol{x}\ \text{Essential amino acid index (EAAI)} - 11.7 \quad (3)$$

The nutritional index percentage of samples was calculated using the following equation, according to the method in [21]:

$$\text{Nutritional index (NI\%)} = \text{EAAI}\boldsymbol{x}\ \%\text{protein}/100 \quad (4)$$

Protein Efficiency Ratio (C-PER) was calculated using the equations developed in [22]:

$$\text{PER} = -0.468 + 0.454(\text{LEU}) - 0.105(\text{TYR}) \quad (5)$$

2.5.2. Other protein quality parameter calculations

From the amino acids profile in the seed and flesh, the total amino acids (TAA), total essential amino acids (TEAA), total neutral amino acids (TNAA), total acidic amino acids (TAAA), total aromatic amino acids (TArAA), and total basic amino acids (TBAA) were calculated, and the ratio of TEAA/TAA and % Cysteine/TSAA were calculated, as described in [23].

2.6. Cupcake preparation

The cupcakes were made following the method outlined in [24]. The ingredients included 21.1 g of flour, 21.1 g of sugar, 1.6 g of milk powder, 0.25 g of emulsifier, 0.45 g of salt, 0.45 g of vanilla powder, 1.35 g of baking powder, 24.7 g of raw egg whites, and 15.76 mL of vegetable oil. To prepare the batter, the raw egg was whipped at high speed for 10 minutes using a Bosch CNCM57 mixer (1100 W, Slovenia), after which water and vegetable oil were added. Finally, *Washingtonia* fruit powder (WFP) was blended into the mixture at concentrations of 1%, 3%, and 5%, and the batter was mixed until it achieved a uniform consistency. The cupcakes baked at 175 °C for 18–20 minutes, as shown in Figure 2.

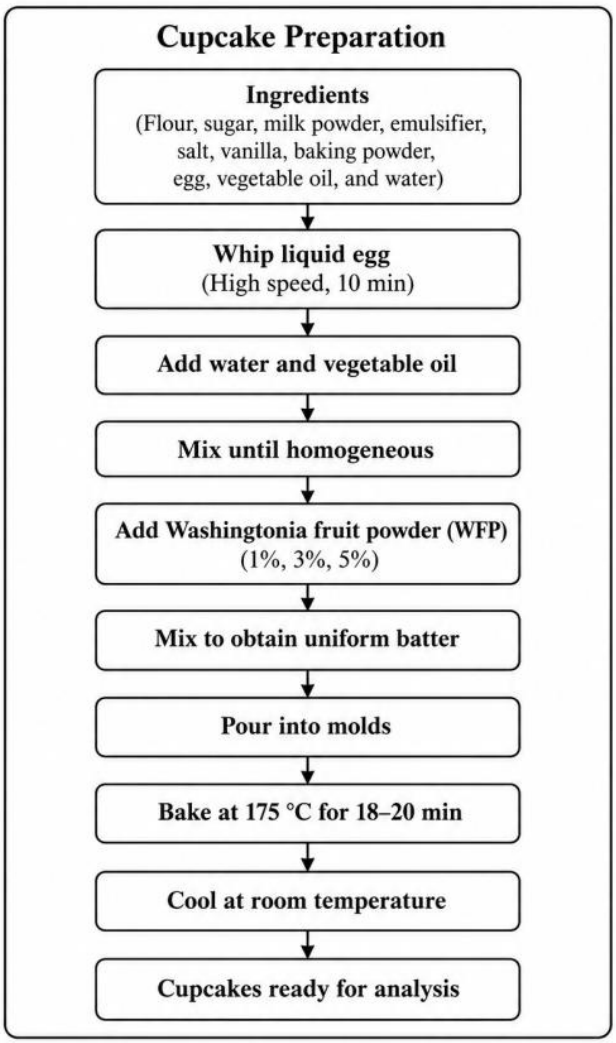

Figure 2. Flow diagram illustrating cupcake preparation fortified with *Washingtonia* fruit powder (1, 3, and 5%), including whipping of raw egg, addition of water and oil, mixing to a uniform batter, and baking at 175°C for 18–20 min.

2.7. Sensory analysis

Sensory properties of cupcake formulations were evaluated by a trained panel (n = 25) using a 10-point hedonic scale, with randomized sample coding and serving order [25].

2.8. Statistical analysis

All analyses were carried out in triplicate. The obtained data was reported as mean ± STDEV. The data was then compared to the independent samples by a T-test. The one-way variance was applied at a 95% confidence interval with the SPSS 20.0 package program (SPSS Inc., Chicago, USA) [26].

3. Results

3.1. Proximate chemical composition

Figure 3 illustrates the analysis of the proximate chemical composition of the *Washingtonia* fruit. The flesh contained 13.90% moisture, 3.10% protein, 8.29% total lipid, 16.77% fiber, 5.7% ash, and 52.24% carbohydrates. In comparison, the seeds had a moisture content of 8.80%, 8.2% protein, 17.82% total lipid, 7.29% fiber, 11.0% ash, and 46.89% carbohydrates.

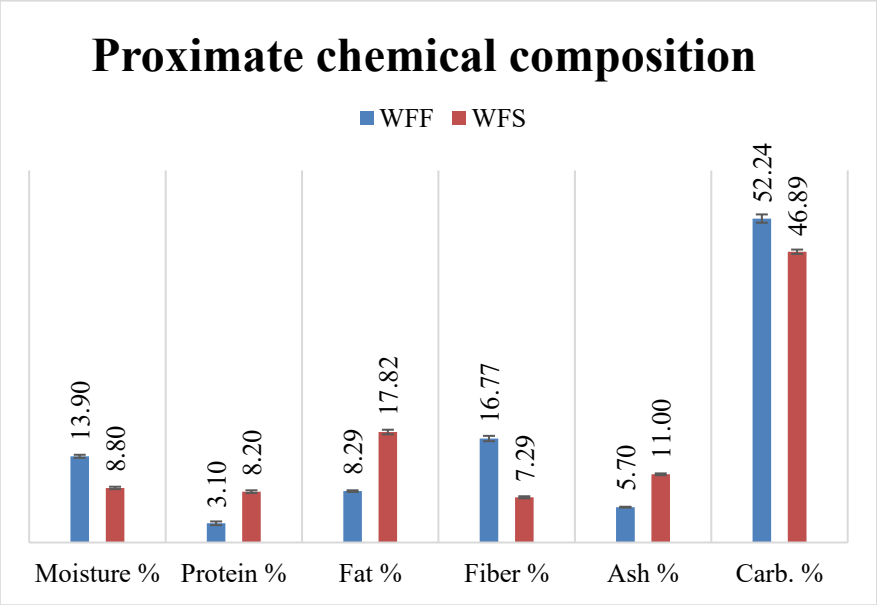

Figure 3. The proximate chemical composition of the *Washingtonia* fruit flesh (WFF) and seeds (WFS).

3.2. The mineral content of Washingtonia flesh and seeds

Table 1. The mineral content of *Washingtonia* fruit flesh and seeds.

Samples	Minerals					
	Ca (%)	Fe (mg/kg)	Mg (%)	P (%)	K (mg/kg)	Zn (mg/kg)
Washingtonia flesh	0.31 ± 0.06^{a}	117.3 ± 2.20^{b}	0.12 ± 0.02^{a}	0.11 ± 0.009^{b}	2.14 ± 0.06^{a}	9.68 ± 0.09^{b}
Washingtonia seeds	0.098 ± 0.008^{b}	351 ± 2.60^{a}	0.12 ± 0.03^{a}	0.3 ± 0.07^{a}	0.38 ± 0.06^{b}	20.78 ± 0.20^{a}

Note: All values are represented as mean ±S.D. Means with different letters are significantly different at ($p < 0.05$).

Table 1 shows the mineral composition analysis of *Washingtonia* fruit flesh and seeds. For the flesh, calcium was at 0.31%, iron at 117.3 mg/kg, magnesium at 0.12%, potassium at 2.14 mg/kg, phosphorus at 0.11%, and zinc at 9.68 mg/kg per specified amount. Conversely, the seeds contained lower calcium (0.098 %) and potassium (0.38 mg/kg) levels but higher iron (351 mg/kg) and zinc (20.78 mg/kg), with magnesium at 0.12% and phosphorus at 0.3%. This analysis indicates significant

differences in mineral content between the flesh and seeds of the *Washingtonia* fruit, particularly highlighting the higher iron and zinc levels in the seeds.

3.3. The GC-MS of Washingtonia flesh and seeds

The phytochemical composition of *Washingtonia* fruit (flesh and seeds) was investigated using GC–MS analysis. The identified compounds, along with their retention times and relative abundances, are summarized in Table 2, while the corresponding chromatographic profiles are illustrated in Figures 4 and 5. The results revealed a range of phytochemicals distributed across both fractions, with noticeable variations in the composition and relative abundance of major constituents between flesh and seeds.

The GC–MS chromatogram of *Washingtonia* fruit flesh (Figure 4 and Table 2) revealed a diverse phytochemical screening by several prominent peaks across the retention time range. The major constituents were identified as betulin and campesterol, which showed the highest relative abundance, followed by heptadecanoic acid and dl-α-tocopherol. Minor compounds such as short-chain alcohols and fatty acids were also detected. This profile indicated that the flesh contains a mixture of sterols, fatty acids, and bioactive compounds that contribute to its nutritional and functional properties.

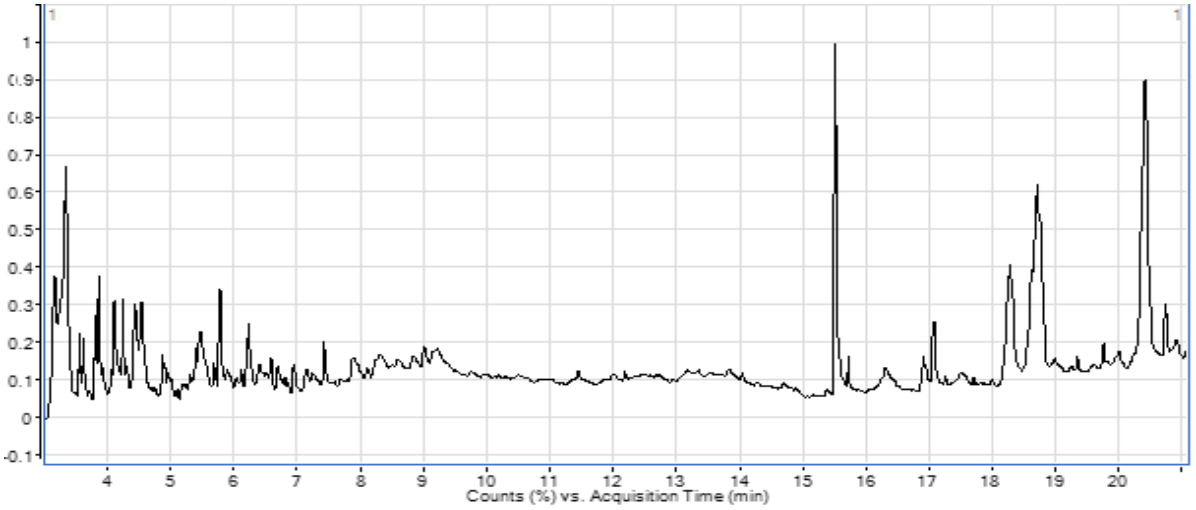

Figure 4. GC–MS chromatogram of *Washingtonia* flesh samples showing major identified compounds. The predominant peaks correspond to: (1) betulin (23.64%), (2) campesterol (21.17%), (3) heptadecanoic acid (10.55%), (4) dl-α-tocopherol (8.74%), and (5) 1-decanol (3.06%).

The GC–MS chromatogram of *Washingtonia* seeds (Figure 4 and Table 2) demonstrated a complex phytochemical screening with distinct dominant peaks compared to the flesh. The most abundant compound was myristic acid isobutyl ester, followed by betulin, while notable levels of octanoic acid, pentadecanoic acid, and anethole were also observed. The chromatographic pattern suggested that the seed fraction is particularly rich in fatty acids, esters, and other bioactive constituents, reflecting its higher chemical complexity and potential functional value.

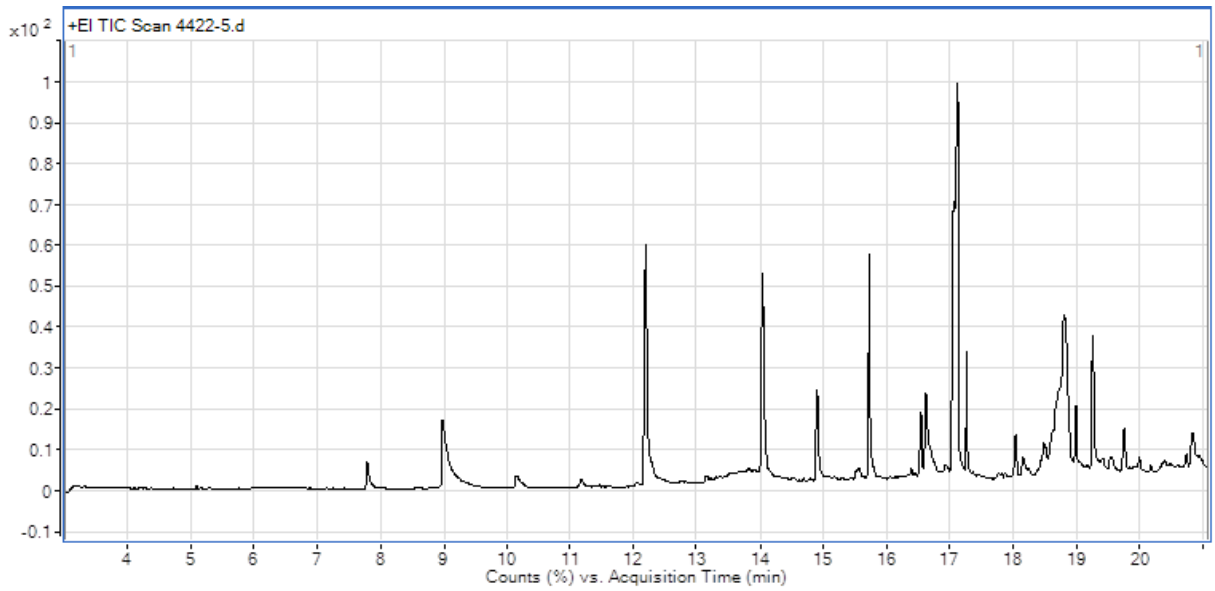

Figure 5. GC–MS chromatogram of *Washingtonia* seed samples showing major identified compounds. The predominant peaks correspond to: (1) myristic acid isobutyl ester (23.36%), (2) betulin (17.56%), (3) octanoic acid (9.76%), (4) pentadecanoic acid (7.36%), and (5) anethole (5.86%).

Table 2. Phytochemical compounds identified in the ethanolic extracts of *Washingtonia* fruit flesh and seeds by GC–MS, expressed as retention time (RT) and relative peak area (%).

No	r.t	Compound	Area sum%	
			Flesh	Seed
1	4.5	2-Heptene, (E)-	2.87	
2	5.4	2-Undecanol	2.61	
3	5.7	1-Decanol	3.06	
4	6.2	Furaneol	3.03	
5	6.9	Cetene	1.14	
6	7.4	Pentadecanoic acid	2.04	
7	7.8	n-Decanoic acid	2.23	2.56
8	8.2	Allyl isovalerate	2.53	
9	8.9	Anethole		5.86
10	10.1	Eicosanoic acid		0.96
11	11.1	Palmitoleic acid		1.13
12	11.4	Retinol	1.59	
13	12.1	Octanoic acid	0.25	9.76
14	13.1	Stigmasterol	0.32	
15	13.8	Vitexin	0.58	
16	14	Pentadecanoic acid		7.36
17	14.6	1-Tricosanol	0.58	
18	14.8	Oleic Acid		3.87
19	15.5	Heptadecanoic acid	10.55	0.97

Continued on the next page

No	r.t	Compound	Area sum%	
			Flesh	Seed
20	15.7	Hexadecanoic acid, ethyl ester	0.37	6.94
21	16.3	Batilol	2.87	
22	16.5	Myristic acid isobutyl ester		23.36
23	16.6	Octadecanedioic acid, dimethyl ester		2.88
24	16.8	Octadecanal	2.04	
25	17.1	Oleic acid, butyl ester	2.23	1.19
26	17.2	Undecanoic acid, ethyl ester		4.26
27	17.4	Lupeol	1.61	
28	18	2-Hexadecanol		1.11
29	18.2	dl-α-Tocopherol	8.74	
30	18.7	Betulin	23.64	17.56
31	18.9	Cymarin		1.31
32	19.2	Palmitoleic acid		4.83
33	19.3	Diosgenin	0.6	
34	19.7	Geranyl isovalerate	0.43	1.29
35	19.9	Docosanoic acid, ethyl ester	1.15	0.31
36	20.4	Campesterol	21.17	
37	20.7	Hexacosane	1.76	
38	20.8	Desmosterol		2.47

3.4. The vitamin content of Washingtonia flesh and seeds

Table 3. The antioxidative vitamins content of *Washingtonian* fruit flesh and seeds.

Samples		Antioxidative vitamins		
		(β carotene) Vitamin A (μg/100g)	(Ascorbic acid) Vitamin C (μg/100g)	(αTocopherol) Vitamin E (g/kg)
Washingtonia	Flesh	33 ± 0.92^{a}	1.69 ± 0.22^{a}	1.14 ± 0.06^{b}
	Seeds	19.5 ± 0.54^{b}	1.7 ± 0.38^{a}	1.28 ± 0.04^{a}

All values are represented as mean ± S.D. Means with different letters are significantly different at ($p < 0.05$).

Table 3 presents the antioxidative vitamin content of *Washingtonian* fruit flesh and seeds measured in dry weight. Beta-carotene was quantified as a provitamin A carotenoid to evaluate its potential contribution to vitamin A equivalents. In the flesh, the levels of antioxidative vitamins were as follows: β-carotene at 33 (μg/100g), vitamin C (ascorbic acid) at 1.69 (μg/100g), and vitamin E (α-tocopherol) at 1.14 g/kg. In the seeds, β-carotene was at 19.5 μg/100g, vitamin C at 1.7 μg/100g, and vitamin E at 1.28 g/kg.

3.5. The phytochemical content of Washingtonia flesh and seed

Table 4 provides the phytochemical content and activity of *Washingtonia* fruit flesh and seeds, measured in dry weight. In the flesh, the total phenol content was 566.9 ppm, total flavonoids were

7.6 ppm, phytic acid was 0.98 %, oxalate was 2.20 mg/100g, and the antioxidant activity as an IC_{50} value was 0.482 mg/kg. In contrast, the seeds exhibited significantly higher levels: total phenols at 8910 ppm, total flavonoids at 70.4 ppm, phytic acid at 1.07%, oxalate at 1.10 mg/100g, and a much lower IC_{50} value of 0.054 mg/kg.

Table 4. The phytochemical content and activity of *Washingtonia* flesh and seeds.

Samples		Total phenol (ppm)	Total flavonoids (ppm)	Phytic acid (%)	Oxalate (mg/100g)	Antioxidant activity (IC_{50}) mg/mL
Washingtonian	Flesh	566.9±3.20^{b}	7.6±0.22^{b}	0.98±0.10^{b}	2.20±0.23^{a}	0.482±0.05^{a}
	Seeds	8910±80.0^{a}	70.4±0.62^{a}	1.07±0.12^{a}	1.10±0.11^{b}	0.054±0.002^{b}

All values are represented as mean ±S.D. Means with different letters are significantly different at ($p < 0.05$).

3.6. The amino acid profile and other protein parameters of Washingtonia flesh and seed

Table 5 compares the amino acid profile of *Washingtonia* fruit flesh and seeds to standard casein, presenting essential amino acids (EAA) such as threonine (2.26% in flesh, 3.05% in seeds), valine (2.58% in flesh, 5.00% in seeds), and leucine (2.90% in flesh, 5.85% in seeds), with total EAA being 17.42% in flesh and 30.73% in seeds versus 39.28% in casein. Non-essential amino acids (NEAA) such as aspartic acid (6.13% in flesh, 8.78% in seeds) and glutamic acid (8.06% in flesh, 16.34% in seeds) are also noted, with total NEAA at 32.90% in flesh and 54.63% in seeds. Key protein quality parameters include the Essential Amino Acid Index (EAAI%) at 44.87% for flesh and 79.27% for seeds, with a protein efficiency ratio (PER) of 0.51 for flesh and 1.88 for seeds, as well as biological values (BV%) of 37.21% for flesh and 74.70% for seeds, indicating a significantly higher nutritional quality in the seeds.

3.7. The amino acid composition of Washingtonia fruit flesh and seeds

Table 6 shows clear differences in relative percentage and protein content. Glutamic acid was the most abundant amino acid in both fractions, with higher values in seeds (19.14% and 16.34 g/100 g protein) compared to flesh (16.03% and 8.06 g/100 g protein). Seeds also exhibited higher levels of several essential amino acids, including leucine (6.86% vs. 5.77%), valine (5.86% vs. 5.13%), isoleucine (3.71% vs. 3.21%), lysine (6.00% vs. 5.77%), and arginine, which showed a marked increase (14.86% vs. 6.41%). In contrast, the flesh contained relatively higher proportions of certain amino acids such as glycine, alanine, tyrosine, and cysteine. Aspartic acid was more abundant in the flesh (12.18%) than in the seeds (10.29%), although its protein content was higher in seeds (8.78 g/100 g protein) compared to flesh (6.13 g/100 g protein). Overall, the seed fraction demonstrated a higher concentration of most amino acids on a protein basis, indicating a comparatively richer amino acid profile than the flesh.

Table 5. The amino acid profile of *Washingtonia* fruit flesh and seeds compared with the standard casein.

Amino acid %	*Washingtonia* fruit		Standard casein
	flesh	Seeds	
		Essential AA %	
Threonine (Thr)	2.26	3.05	3.78
Valine (Val)	2.58	5.00	5.82
Isoleucine (Ile)	1.61	3.17	4.54
Leucine (Leu)	2.90	5.85	8.28
Phenylalanine (Phe)	2.90	4.39	4.55
Histidine (His)	1.29	2.20	2.55
Lysine (Lys)	2.90	5.12	7.09
Methionine (Meth)	0.97	1.95	2.57
TEAA	17.42	30.73	39.28
		Non-essential AA %	
Aspartic acid (Asp)	6.13	8.78	6.32
Serine (Ser)	3.23	4.02	4.96
Glutamic acid (Glu)	8.06	16.34	19.90
Glycine (Gly)	4.19	4.27	1.66
Alanine (Ala)	3.55	4.27	2.65
Tyrosine (Tyr)	3.23	2.93	5.08
Arginine (Arg)	3.23	12.68	3.29
Cysteine (Cys)	1.29	1.34	0.36
		Protein quality parameters	
TNEAA	32.90	54.63	54.02
TARAA(Phe+Tyr)	6.13	7.32	
TSAA(Meth+Cys)	2.26	3.29	
TAAA(Asp+Glu)	11.29	20.37	
TBAA (Arg+Lys)	6.13	17.80	
EAAI%	44.87	79.27	
PER	0.51	1.88	
BV%	37.21	74.70	
Nutritional index	1.39	6.50	

Essential amino acid index (EAAI), biological value (BV), the value of protein efficiency ratio (PER), total aromatic amino acids (TARAA), the total sulfur amino acid (TSAA), total acid amino acids (TAAA), and total base amino acids (TBAA).

Table 6. The amino acid profile of *Washingtonia* fruit flesh and seeds compared the protein content.

Amino acid	Amino acid Percentage %		Content (g/100g protein)	
	Flesh	Seeds	Flesh	Seeds
Aspartic acid (ASP)	12.18	10.29	6.13	8.78
Threonine (THR)	4.49	3.57	2.26	3.05
Serine (SER)	6.41	4.71	3.23	4.02
Glutamic acid (GLU)	16.03	19.14	8.06	16.34
Glycine (GLY)	8.33	5.00	4.19	4.27
Alanine (ALA)	7.05	5.00	3.55	4.27
Valine (VAL)	5.13	5.86	2.58	5.00
Isoleucine (ILE)	3.21	3.71	1.61	3.17
Leucine (LEU)	5.77	6.86	2.90	5.85
Tyrosine (TYR)	6.41	3.43	3.23	2.93
Phenylalanine (PHE)	5.77	5.14	2.90	4.39
Histidine (HIS)	2.56	2.57	1.29	2.20
Lysine (LYS)	5.77	6.00	2.90	5.12
Arginine (ARG)	6.41	14.86	3.23	12.68
Cysteine (CYS)	2.56	1.57	1.29	1.34
Methionine (Meth)	1.92	2.29	0.97	1.95

3.8. The Organoleptic properties of cupcake supplemented by Washingtonia fruit flesh powder (WFP) with 1, 3, and 5% compared to the original cupcake

The evaluation of the organoleptic properties of cupcakes supplemented with *Washingtonia* fruit flesh powder (WFP), presented in Table 7 and Figures 6 and 7, reveaked significant variations linked to the percentage of WFP added. This assessment covered five sensory dimensions: Odor, taste, color, texture, and general appearance, scored on a scale from 1 to 10.

Table 7. Sensory evolution of odor, taste, color, texture, and general appearance of cupcakes supplemented with 1, 3, and 5% WFP.

Cupcake formula	Odor	Taste	Color	Texture	General appearance
Control	7.60 ± 0.95	7.73 ± 1.06	9.13 ± 0.34	8.80 ± 1.28	8.60 ± 0.95
1% WFP	8.00 ± 0.73	8.60 ± 0.88	7.20 ± 0.75	9.20 ± 0.83	9.00 ± 0.73
3% WFP	9.33 ± 0.79	9.07 ± 0.85	5.13 ± 1.02	8.00 ± 0.73	9.00 ± 0.73
5% WFP	5.20 ± 0.79	5.87 ± 0.85	5.60 ± 1.02	3.13 ± 1.15	5.47 ± 0.81

All values are represented as mean ±S.D. Means with different letters are significantly different at ($p<0.05$).

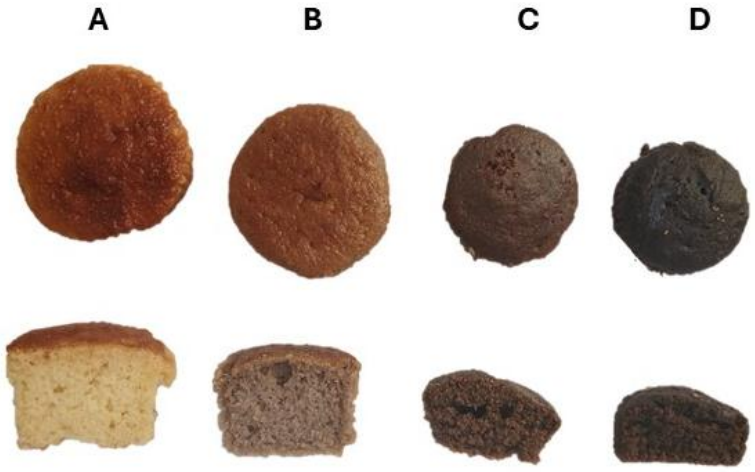

Figure 6. Cupcake control (A), with 1% WFP (B), with 3% WFP (C), and with 5% of WFP (D).

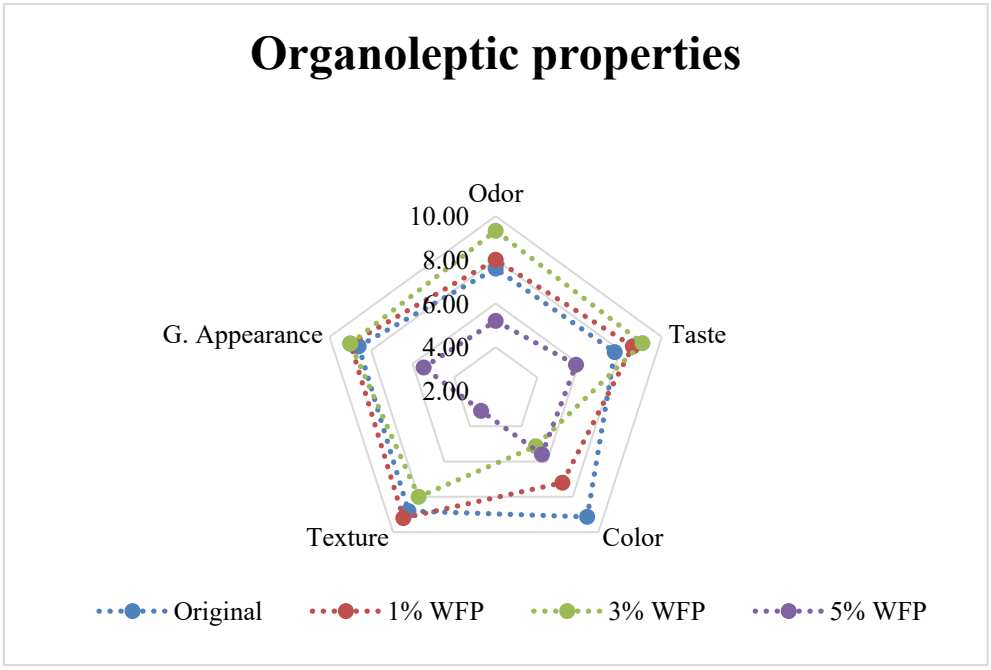

Figure 7. Sensory evolution of odor, taste, color, texture, and general appearance of the cupcakes supplemented with 1, 3, and 5% WFP.

4. Discussion

4.1. Proximate chemical composition

Figure 3 shows the nutritional differences between *Washingtonia* flesh and seeds. The flesh has a moisture content of 13.90%, rendering it juicier and more perishable than the seeds, which have a

moisture content of 8.80%. This higher moisture content makes the flesh particularly appealing for direct consumption due to its hydrating properties. For content, the seeds significantly outperform the flesh, containing 8.20% protein compared to only 3.10% in the flesh. This suggests that the seeds could function as a concentrated protein source, making them suitable for various food products or dietary supplements. Additionally, the lipid content is more pronounced in the seeds, with 17.82% compared to 8.29% in the flesh, highlighting the seeds as a valuable source of dietary fats, including essential fatty acids, as noted in [27]. Similar findings were reported in [28] concerning the seeds of Egyptian radish (*Raphanus sativus*), where higher levels of protein and lipids were observed in seeds compared to other plant tissues. The flesh excels in fiber content, boasting 16.77% compared to just 7.29% in the seeds. This high fiber content makes the flesh an excellent option for enhancing digestive health and regulating blood sugar levels. Furthermore, the seeds have a greater ash content (11.0%) than the flesh (5.7%), indicating they are richer in essential minerals. In terms of carbohydrates, the flesh contains 52.24%, while the seeds have 46.89%. Our findings align with those of [5], who reported that *Washingtonia robusta* (cultivated in Mexico) seeds comprise 73% sugars, 7.4% protein, 8.4% moisture, 4.3% ash, and 8.7% fat, while the flesh contains 71% sugars, 10.8% protein, 1.6% moisture, 5.5% ash, and 9.4% fat. This suggests the flesh of *Washingtonia* fruit is beneficial for hydration and fiber, while the seeds offer a higher concentration of protein, lipids, and minerals, providing nutritional advantages for potential food and dietary applications [29,30]. The collected data also reflect patterns similar to the findings in [2,4,31,32] with minor discrepancies likely attributed to environmental factors, as noted by [33].

4.2. The mineral content of Washingtonia flesh and seed

The mineral content analysis of *Washingtonia* fruit highlights significant differences between its flesh and seeds, reflecting their distinct nutritional profiles. The flesh contains a calcium level of 0.31 %, which is markedly higher than the 0.098 % found in the seeds. This suggests that the flesh may serve as a better source of calcium, an essential mineral for bone health and metabolic regulation. Conversely, the seeds exhibit a higher iron content at 351 mg/kg compared to 117.3 mg/kg in the flesh, making them a potentially valuable source for addressing iron deficiency, which is vital for oxygen transport in the body; similar findings were reported by [29,30]. The flesh and seeds provide equal amounts of magnesium (0.12%), contributing similarly to biochemical reactions, including energy production [33]. However, phosphorus levels are significantly higher in the seeds (0.3 %) than in the flesh (0.11 %), enhancing their appeal as a source of this mineral, which is crucial for bone health and energy storage. The flesh's potassium content (2.14 mg/kg) far exceeds that of the seeds (0.38 mg/kg), indicating its importance for maintaining fluid balance, nerve function, and muscle contraction, thereby supporting cardiovascular health. Last, zinc levels are substantially higher in the seeds (20.78 mg/kg) compared to the flesh (9.68 mg/kg), agreeing with levels reported in [2,4,31,32]. This marks the seeds as a noteworthy source for this essential mineral, which supports immune function, wound healing, and DNA synthesis [34]. Moreover, *Washingtonia* fruit's mineral content reveals that while the flesh is richer in calcium and potassium, the seeds provide higher concentrations of iron, phosphorus, and zinc, making both parts valuable for nutritional needs and potential dietary applications [35].

4.3. The GC-MS analysis of Washingtonia flesh and seed

The bioactive composition of *Washingtonia* fruit flesh, as revealed through chromatographic

analysis, comprises a diverse array of compounds contributing to its potential health benefits. Among the identified compounds, betulin stands out significantly, accounting for 23.64% of the total area, indicating its prominent role in the fruit's phytochemical profile and suggesting strong anti-inflammatory and antioxidant properties. Another noteworthy compound is campesterol, which contributes 21.17%, known for its cholesterol-lowering effects. Additionally, dl-α-tocopherol, or vitamin E, presents at 8.74%, further enhancing the antioxidative capacity of the *Washingtonia* fruit. Other compounds, such as hexadecanoic acid, ethyl ester (0.37%), and stigmasterol (0.32%), while present in smaller amounts, contribute to the overall health-promoting qualities associated with bioactive composition. The profile also includes compounds like vitexin, known for its potential therapeutic effects (0.58%). Similar data were shown by [2,4,6] for different genotypes of *Washingtonia* fruits. This intricate phytochemical composition not only illustrates the nutritional value of *Washingtonia* fruit but also suggests a broad spectrum of biological activities that may benefit human health [15]. The phytochemical composition of *Washingtonia* fruit seeds reflects a complex mixture of bioactive compounds with diverse chemical structures and potential functional roles. Among the identified constituents, myristic acid isobutyl ester represents the most abundant compound (23.36%), suggesting its significant contribution to the overall chemical profile of the seed extract. Betulin is another major component (17.56%), which has been widely reported for its antioxidant and anti-inflammatory activities, thereby contributing to the biological relevance of the extract. Anethole (5.86%) was also detected, representing an aromatic compound with known functional and sensory properties. Comparable observation [5] described a higher abundance of bioactive phytochemicals such as phenolics, flavonoids, and other secondary metabolites in the seed fraction compared to the pulp. The presence of fatty acids further contributes to the compositional diversity of the seed extract. Medium- and long-chain saturated fatty acids, including octanoic acid (9.76%), pentadecanoic acid (7.36%), and n-decanoic acid (2.56%), were prominent among the identified compounds. These results confirm that a considerable proportion of the lipid fraction in the seeds consists of saturated fatty acids. In addition, the detection of unsaturated fatty acids, such as oleic acid (3.78%) and palmitoleic acid (1.13%), albeit at lower relative abundance, indicates the coexistence of monounsaturated lipid components, which are associated with beneficial nutritional properties. Thus, the lipid composition comprises a mixture of saturated and unsaturated fractions, with a predominance of saturated fatty acid derivatives under the analytical conditions applied. Other identified compounds, including esters (hexadecanoic acid ethyl ester), terpenoids (betulin), sterols, and minor constituents such as geranyl isovalerate and cymarin, further illustrate the chemical complexity of the seed extract. This compositional diversity highlights the multifaceted nature of *Washingtonia* seed phytochemicals; however, it should be noted that the results are based on compositional identification rather than biological activity assays. Overall, the findings support the nutritional relevance of *Washingtonia* seeds and their potential application as a source of functional ingredients, in agreement with other reports.

4.4. The vitamin content of Washingtonia flesh and seed

Table 3 presents the antioxidative vitamin composition of *Washingtonia* fruit, demonstrating notable variations between flesh and seeds that reflect their unique nutritional characteristics. The flesh exhibits a β-carotene concentration of 33 μg/100g dry weight, substantially exceeding the 19.5 μg/100g measured in the seeds. Given that β-carotene serves as a vitamin A precursor, this higher

concentration in the flesh implies superior potential benefits for maintaining vision and skin integrity. Vitamin C (ascorbic acid) levels are nearly equivalent in both tissues, with the flesh containing 1.69 μg/100g and the seeds 1.7 μg/100g, indicating that seeds function as an adequate source of this vital vitamin, which is consistent with findings from *Washingtonia* seed oil research. For vitamin E (α-tocopherol), the flesh contains 1.14 g/kg compared to 1.28 g/kg in the seeds, suggesting seeds may offer marginally better support for immune responses and antioxidant protection at the cellular level due to their higher vitamin E concentration. Overall, the flesh demonstrates superior β-carotene content (and consequently greater potential vitamin A), while seeds exhibit equivalent vitamin C and slightly elevated vitamin E levels, underscoring the complementary nutritional value of both fruit components for antioxidative health [5,7].

4.5. The phytochemical content of Washingtonia flesh and seed

Table 4 outlines the phytochemical composition and bioactivity of the *Washingtonia* fruit, demonstrating notable variations between flesh and seeds that reflect their unique health-promoting properties. The seeds boast an impressive total phenol content of 8910 mg/kg, in contrast to the 566.9 mg/kg found in the flesh. This suggests that the seeds are particularly rich in compounds linked to a range of health advantages, including antioxidant and anti-inflammatory properties [36–38]. Additionally, total flavonoid levels are much higher in the seeds (70.4 ppm) compared to the flesh (7.6 ppm), indicating a greater potential for the seeds to deliver health-promoting effects. The flesh and seeds contain phytic acid, associated with antioxidant properties and potential anti-cancer benefits, but their levels are relatively comparable (0.98% in the flesh vs. 1.07% in the seeds), as noted in similar findings by [5,7]. Interestingly, oxalate content is slightly elevated in the flesh (2.20 mg/100g) compared to seeds (1.10 mg/100g), which may be a consideration for individuals susceptible to kidney stones. When assessing antioxidant activity through IC_{50} values, the seeds demonstrate significantly greater potency (0.054 mg/ml) than the flesh (0.482 mg/mL), suggesting that *Washingtonia* seeds may offer superior protection against oxidative stress, as reported by [8,30]. Overall, this data underscores the seeds as a concentrated source of phytochemicals with enhanced antioxidant activity, while the flesh contributes beneficially to nutritional value [35]. Accordingly, the low IC_{50} value demonstrates the exceptional antioxidant efficiency of *Washingtonia* seeds, establishing them as a highly potent byproduct similar to other bioactive agri-waste kernels, such as date seeds [39].

4.6. The amino acid profile and other protein parameters of Washingtonia flesh and seed

The amino acid profile of *Washingtonia* fruit, as presented in Table 5, provides important insights into its nutritional quality when compared with standard casein. The total essential amino acid (TEAA) content is considerably higher in the seeds (30.73%) than in the flesh (17.42%), although both values remain lower than that of casein (39.28%) [2,40]. Essential amino acids such as threonine, valine, and leucine exhibit higher concentrations in seeds compared to the flesh, with threonine levels at 3.05% in seeds and 2.26% in the flesh versus 3.78% in casein. Leucine, a critical amino acid for muscle protein synthesis, is also present at higher levels in seeds (5.85%) than in the flesh (2.90%), although both remain below the value reported for casein (8.28%). Conversely, the total non-essential amino acid content is also more substantial in the seeds (54.63%) compared to the flesh (32.90%), although it remains close to that of casein (54.02%), which agrees with findings

reported by [2,5]. Overall, while *Washingtonia* fruit provides a range of amino acids, its profile suggests it may be less suitable as a complete protein source relative to casein, which is recognized for its high biological value and comprehensive amino acid composition. However, the nutritional indices vary between the two fractions, with values of 1.39 for the flesh and 6.50 for the seeds, indicating that the seed fraction exhibits higher protein efficiency and could play a more significant supplementary role in diverse dietary regimens [4], consistent with reports on palm fruits and oilseeds, where seeds generally exhibit higher protein quality and a more favorable essential amino acid profile. The predominance of glutamic acid in both fractions agrees with earlier findings in *Washingtonia filifera* and other palm species, where glutamic acid is typically the most abundant amino acid and contributes to nutritional and sensory attributes, corroborating findings by [8,30]. The higher concentrations of essential amino acids in seeds, particularly leucine, isoleucine, lysine, and arginine, are in line with studies on seed-derived protein sources, which highlight their superior nutritional value compared to the edible pulp. In contrast, the relatively higher levels of certain non-essential amino acids in the flesh, such as glycine and alanine, reflect its lower protein density and functional role in the fruit matrix, aligning with the findings reported by [5,29,30]. Overall, our results are comparable with those of other studies on underutilized fruit seeds and confirm that *Washingtonia* seeds may serve as a promising alternative protein source, although further evaluation of protein digestibility and bioavailability is required to fully assess their nutritional potential.

4.7. The organoleptic properties of cupcakes supplemented with Washingtonia fruit flesh powder (WFP) at 1%, 3%, and 5%.

The original cupcake receives a score of 7.60 ± 0.95, which improves to 8.00 ± 0.73 with the addition of 1% WFP. A further enhancement to 9.33 ± 0.79 is noted at 3% WFP. However, at 5% WFP, the score drops to 5.20 ± 0.79, suggesting that higher concentrations may produce undesirable aromas (Figure 7). Taste: The control cupcake's taste score starts at 7.73 ± 1.06, increasing to 8.60±0.88 with 1% WFP and reaching 9.07 ± 0.85 with 3% WFP. Nonetheless, the score falls to 5.87±0.85 at 5% WFP, indicating potential bitterness or taste conflicts associated with excessive supplementation. Color: Initially, the original cupcake has a color score of 9.13 ± 0.34, which deccreases to 7.20 ± 0.75 with 1% WFP and further declines to 5.13 ± 1.02 at 3% WFP, reflecting a marked change in visual appeal. Although the score increases slightly to 5.60 ± 1.02 with 5% WFP, it remains lower than that of the original. Texture: Texture scores exhibit a consistent decline, starting at 8.80 ± 1.28 for the original cupcake and improving to 9.20 ± 0.83 with 1% WFP. However, the score decreases to 8.00 ± 0.73 at 3% WFP and dramatically falls to 3.13 ± 1.15 at 5% WFP, as shown in Figure 7. This decline suggests that excessive WFP adversely affects the cupcake's texture and cohesiveness, aligning with the findings by [41] regarding the addition of banana flour in baked goods. General Appearance: The overall aesthetic appeal of the original cupcake is rated at 8.60±0.95 and improves to 9.00±0.73 with 1% WFP. The score remains unchanged at 3% WFP but drops to 5.47±0.81 at 5% WFP, highlighting a critical threshold beyond which quality deteriorates. These results support findings by [42,43], suggesting that fruits and vegetables can enhance the organoleptic properties of cupcakes and other baked products. In summary, lower concentrations of WFP (1%-3%) typically improve sensory qualities, whereas higher concentrations (5%) result in a decline in texture and overall acceptability. This highlights the need for a careful ingredient balance in baking. Additionally, considering the color of WFP, it may be particularly suitable for use in brownies or chocolate cakes.

5. Conclusions

The analysis of *Washingtonia* fruit highlights its distinct nutritional benefits, with the flesh providing hydration and dietary fiber, while the seeds offer a concentrated source of protein, lipids, and essential minerals like iron and zinc. Both parts are rich in bioactive compounds with potential antioxidants and anti-inflammatory properties, indicating their versatility in culinary and functional food applications. Although the flesh may serve as a supplementary protein source, the seeds demonstrate superior essential amino acid content. Organoleptic evaluations of cupcakes made with *Washingtonia* fruit flesh powder show that moderate levels enhance flavor and aroma, while excessive amounts can adversely affect texture and overall acceptability. This underscores the need for a careful ingredient balance in baking. Moreover, *Washingtonia* fruit's nutritional, phytochemical, and sensory qualities suggest its potential as a valuable ingredient in health-focused products and dietary practices.

Washingtonia fruit offers distinct nutritional benefits: The flesh provides hydration and high dietary fiber (16.77%), while seeds are rich in protein (8.20%), lipids (17.82%), and bioavailable iron/zinc. Both contain bioactive compounds (betulin, campesterol) with antioxidant/anti-inflammatory potential, suitable for functional foods. Seeds show superior essential amino acids, while 1–3% flesh powder enhances cupcake aroma/flavor ($p<0.05$) without compromising texture. These findings position *Washingtonia* as a sustainable Egyptian ingredient for health-focused bakery products.

Author contributions

Conceptualization, M.K. and T.A.; methodology, M.K.; T.A. and S.M.; software, M.K. and S.M.; validation, A.F., T.A., M.K. and A.A.; formal analysis, M.K. and S.M.; investigation, M.K., S.M., T.A. and A.A.; resources, A.A., and M.K.; data curation, S.M. and T.A.; writing—original draft preparation, M.K., S.M., and T.A.; writing—review and editing, M.K. and A.A.; visualization, A.F and M.K.; supervision, T.A.; project administration, T.A.; funding acquisition, A.A. All authors have read and agreed to the published version of the manuscript.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflict of interest.

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