

Research Article

Technofunctional Properties of Stinging Nettle (*Urtica dioica* L.) Leaf Flour and Its Enhancing Pasting, Physical and Sensory Characteristics in Gluten-Free Rice Waffles

Mary Nkongho Tanyitiku ^{1,2} and Igor Casimir Njombissie Petcheu²

¹Food and Markets Department, Natural Resources Institute, University of Greenwich, London, UK

²Women's Network for Biodiversity and Food Science, Yaounde, Centre, Cameroon

Correspondence should be addressed to Mary Nkongho Tanyitiku; mary.tanyitiku@greenwich.ac.uk

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The study investigated the technofunctional properties of *Urtica dioica* L. leaf flour and its effect on the pasting, physical and sensory characteristics of gluten-free rice waffles. Compared with commonly used gluten-free rice and corn flour, *Urtica dioica* L. leaf flour had the lowest swelling capacity (2.71 mL), oil absorption capacity (89.55%) and water activity (0.31), and the highest nitrogen solubility index (20.85%), foaming capacity (13.91%) and stability (93.66%). Its Carr's index, Hausner's ratio and angle of repose were 20.05%, 1.24° and 32.76°, respectively, which indicated a fair flowability. In addition, the incorporation of nettle leaf flour did not affect ($p > 0.05$) the fat and starch contents of waffles, but significantly ($p < 0.05$) increase the ash, protein, fibre, total phenolic, antioxidant and total flavonoid contents. The peak and trough velocity significantly decreased about 876 times and 1022 times in the 20% nettle-incorporated waffle mix, respectively. Although this decrease indicated a lesser ability for nettle-incorporated waffle mixes to absorb water, the breakdown viscosity (ranging from 644.71 cP to 352.0 cP) showed that the formed paste, and subsequently the cooked waffles, could resist disintegration and became stable against increasing cooking temperature and shear forces. Furthermore, the sensory test indicated no significant ($p > 0.05$) difference in the sweetness and overall liking of all formulated waffle samples; however, attributes such as appearance, aroma, flavour, bitterness, mouthfeel and aftertaste slightly varied when compared with the control (100% rice waffles). The findings revealed promising characteristics of *Urtica dioica* L. leaf flour as a low-cost natural functional food ingredient, particularly in gluten-free bakery products. The study offers novel insights into gluten-free food formulations and contribute to the development of technofunctional nettle leaf flour for the food industry.

Keywords: celiac disease; food formulation; functional food ingredient; gluten-free bakery products; stinging nettles; *Urtica dioica* L. leaf flour

1. Introduction

Stinging nettle (*Urtica dioica* L.) is a highly nutritious perennial herb that was found to grow abundantly in Europe, Asia, North America and Africa [1–3]. The plant is a common garden weed and can easily be identified by its stinging hairs (trichomes) on the leaves and stems [4, 5]. To date, statistics on nettle global production and/or economic value appear inexistent, and a recent rediscovery of its nutritional value has prompted research that develop nettle-derived

foods, for example, in noodles [6–8], bread [9–12], infant food [2], cakes and cookies [3, 13, 14], chocolates [15], drinks and beverages [16], meat and fish coatings [17–19]. In fact, nettle leaf flour is nutritionally richer than wheat and barley flours, containing higher protein (33.8%), fibre (9.1%), ash (16.2%), carotenoids (3497 µg/g) and phenolic compounds (129 mg GAE/g), with bioactive attributes such as antioxidative, antihyperglycaemic, antimicrobial, antiulcer and anti-inflammatory [10, 20, 21]. However, the technofunctional properties of nettle leaf flour that could

enhance its suitability in specific food systems, such as in gluten-free foods, are underresearched.

Currently, the development and production of gluten-free food products remain high especially in developed countries. In the European market, for example, estimates for the demand of gluten-free foods have experienced a yearly growth rate of 10.4% between 2014 and 2019 [22]. In fact, global demand for gluten-free foods is increasing as celiac disease continues to affect more than 5% of most ethnic groups worldwide [23]; National Institutes of Health [3, 22, 24]. Celiac disease occurs when the ingestion of foods containing gluten causes damages to the mucosa of the small intestine [24]. According to the United States Food and Drug Administration, foods labelled 'gluten-free' must contain less than 20 parts per million of gluten, an amount too small to harm celiac patients [24].

However, the main cereals produced worldwide are barley (146.8 m tonnes), corn (1269.1 m tonnes) and wheat (806.7 m tonnes) [25]. These cereals seem irreplaceable food ingredients in baking due to consumer desirable viscoelasticity formed within its wheat-based doughs and the final product. As such, a limited amount of gluten in gluten-free bakery foods indicates the formation of weak protein viscoelastic networks, which often leads to undesirable characteristics, such as crumbling texture, poor colour, low specific volume, shorter shelf life, among others [26–28]. Recently, the incorporation of nontraditional protein-rich ingredients (such as indigenous vegetables, pulses and herbs) was found to resolve these gluten-free baking challenges [22, 29, 30].

To understand the quality characteristics of *Urtica dioica* L. leaf flour and enhance its application in gluten-free food product formulations, the current study investigated the functional and flow properties of stinging nettle leaf flour and compared it with commonly used gluten-free flours such as brown rice flour and corn flour. It also investigated the effect of incorporating stinging nettle leaf flour at different levels (5%, 10%, 15%, 20%) on the pasting, physical and sensory properties of gluten-free rice waffles. Waffles made with 100% brown rice flour served as the control.

2. Materials and Methods

2.1. Raw Materials. *Urtica dioica* L. leaves were harvested on selected farms in Buea (Cameroon), and as previously described [3], the leaves were processed into flour by freeze-drying (Harvest Right, USA). Notably, the plant was identified by its morphological characteristics, which included bright, vibrant hairy green leaves with strongly serrated edges, and clearly visible venation [3]. Other ingredients: brown rice flour (Pams, New Zealand), corn flour (Pams, New Zealand), iodised salt (Saselsa, Cameroon), granulated sugar (SOSUCAM, Cameroon), whole milk powder (Pams, New Zealand), and 98% sodium bicarbonate (ALSA, Cameroon), were purchased from local supermarkets. All chemicals and reagents used were of analytical grade.

2.2. Functional Properties of Nettle, Brown Rice and Corn Flour. Stinging nettle leaf flour, brown rice flour and corn flour were analysed for swelling capacity, water absorption capacity (WAC) and oil absorption capacity (OAC), foam capacity, foam stability, dispersibility, nitrogen solubility index (NSI), water activity and colour, according to Chandra et al. [31] and Tanyitiku et al. [3] with slight modifications. Swelling capacity was the volume (mL) occupied by the hydrated flour when deionised water (50 mL) was added to a 100-mL graduated cylinder containing 10 mL of flour, centrifuged at 2200 rpm for 15 min and allowed to stand for 20 h. Subsequently, it was filtered, and the NSI was obtained as the ratio of the amount of nitrogen in the filtered sample to the amount of nitrogen in the initial flour sample. WAC or OAC was the percentage of water or oil bound per gram of flour when 1 g of flour was mixed with 10 mL of deionised water or soybean oil, allowed to stand at room temperature for 30 min and then centrifuged at 3000 rpm for 30 min. Foam capacity and stability were the volume of foam obtained after 30 s and 1 h, respectively, when the flour (1 g) was mixed with deionised water (50 mL) and vortexed for 5 min. Dispersibility was determined by dissolving 10 g of flour in 100 mL of distilled water, stirred for 1 min and then left for 30 min to settle. The supernatant was discarded, and the weight of the dispersed solid was calculated as the difference in the weight of the supernatant from that of water.

Water activity was measured using a water activity meter (Aqualab, United States), according to the manufacturer's guidelines. Colour was measured using a MiniScan EZ spectrophotometer (Hunter Associates Laboratory, USA), to obtain the L^* , a^* and b^* values. In this coordinate system, the L^* value is a measure of lightness, the a^* value; redness (+) and greenness (–), and the b^* value; yellowness (+) and blueness (–). Total colour difference, ΔE , between each sample and a calibrated white tile was obtained as: $\Delta E = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}$

2.3. Flow Properties of the Flours. Common markers of flour flowability, namely, tap density, bulk density, Carr's index, Hausner's ratio (HR) and angle of repose were determined according to Etti et al. [32]. Here, 100 g of each flour was poured into a 250-mL measuring cylinder and tapped on a hard surface. The bulk density was the weight-to-volume ratio of the flour when no visible decrease in volume was observed. Tapped density was the ratio of the weight of the flour to the volume of the flour after 100 taps [33]. Carr's index was the ratio of the difference between the tapped and the bulk density to the tapped density, and HR was the ratio between the tapped and bulk density. The angle of repose was determined as the angle between the flour and a horizontal surface when each flour (100 g) was allowed to pass through a funnel (100-mm mouth diameter, 10-mm stem diameter), previously fixed on a 2.9-cm tripod [34].

2.4. Waffle Preparation. Gluten-free waffles were prepared as shown in Figure 1. Brown rice flour (5.80% moisture, 0.1% ash, 73% carbohydrate, 8% protein, 3% fat, 0% fibre) and

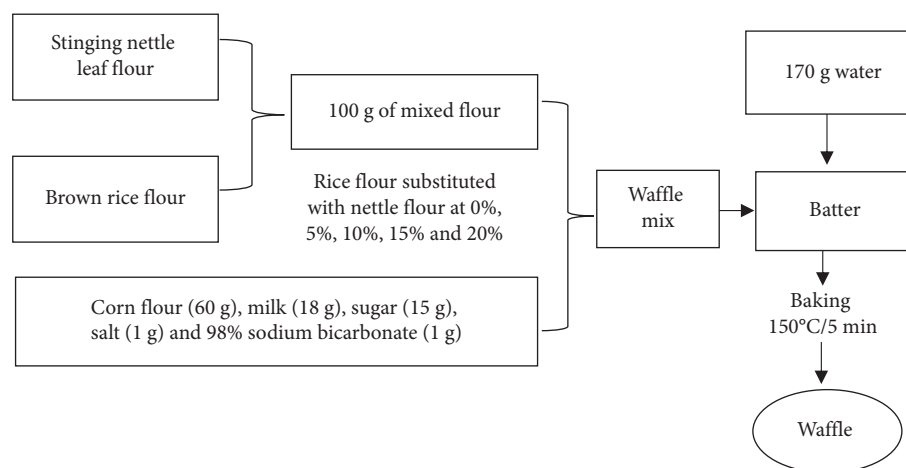


FIGURE 1: Formulation of rice and stinging nettle leaf waffles.

stinging nettle leaf flour were individually weighed and combined as follows: 0NW (100 g rice flour + 0 g stinging nettle leaf flour), 5NW (95 g rice flour + 5 g stinging nettle leaf flour), 10NW (90 g rice flour + 10 g stinging nettle leaf flour), 15NW (85 g rice flour + 15 g stinging nettle leaf flour) and 20NW (80 g rice flour + 20 g stinging nettle leaf flour). Then, 60 g of corn flour, 18 g of milk, 15 g of sugar, 1 g of salt and 1 g of 98% sodium bicarbonate were added to each formulation to obtain five waffle mixes. Each formulation was mixed for 3 min using an electric mixer (Breville, Australia), rotating at 10,000 rpm, and 170 g of water was added until a smooth batter was formed. Subsequently, each formulation (195 g) was manually poured into a domestic crisp control waffle maker (Breville, Australia), which was set near light and preheated for 2 min. The batter was then spread evenly over the plate with a spatula and baked at 150°C for 3 min. The process was repeated severally to produce 10 batches of waffles, and waffles were allowed to cool for 1 h at room temperature. The weight/thickness of 10 randomly selected waffles was recorded as 98 ± 2.60 g, 9.66 ± 1.54 cm across and 1.20 ± 0.99 cm thick, respectively. The samples were then packed in sterile polythene pouches during analysis.

2.5. Pasting Properties of Waffle Mix. Pasting properties of the waffle mix were evaluated using a Brabender Amylograph-E (Anton Paar GmbH & Co. Germany), according to the manufacturer's guidelines. A slurry (1:2 ratio of flour to water) was prepared and heated from 30°C to 95°C at 2.5°C/min, then held at 95°C for 15 min and cooled to 50°C. The peak viscosity, trough, breakdown, final viscosity, setback, peak time and pasting temperature were obtained from the amylograph.

2.6. Proximate Composition of Waffles. Total ash, moisture, protein and fat contents were obtained according to AOAC [35]. Total ash was the residue when 10 g of each sample was calcinated at 550°C for 24 h. Moisture was the difference in weight when 5 g of each sample was oven-dried at 105°C for 24 h. Crude protein was determined by the Kjeldahl method

with a conversion factor of 6.25. Fat content was determined by Soxhlet extraction method using petroleum ether. Total starch content was determined using the Megazyme total starch kit (Megazyme International, Ireland).

2.7. Antioxidant Assays. Total phenolic content (TPC), and antioxidant activity of stinging nettle leaf flour and waffles were determined as described by Tanyitiku & Petcheu [2]; using Folin–Ciocalteu reagent and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assay, respectively. Total flavonoid content (TFC) was determined as described by Alara et al. [36]. Here, 2 g of each sample was mixed with 10 mL of 80% ethanol and incubated in a shaker incubator (Thermo Scientific, USA) at 25°C, 150 rpm for 24 h, under dark conditions. It was then centrifuged at 10,000 g for 10 min, and the supernatant was filtered using Whatman No. 4 paper to obtain the flour extract. Subsequently, 0.5 mL of the flour extract was mixed with 5 mL of deionised water and 5 mL of Folin–Ciocalteu phenol reagent for 3 min. In a shaker incubator, 2 mL of 10% Na₂CO₃ was added, stirred and incubated at 30°C for 1 h. The absorbance at 765 nm was measured using a Hitachi spectrophotometer (Tokyo, Japan) with gallic acid (40–200 mg/L gallic acid) as standard. Also, 0.2 mL of each extract was mixed with 2.5 mL of DPPH solution (0.35 mM DPPH dissolved in 50% ethanol) and incubated at room temperature for 10 min. The absorbance was read at 517 nm, and antioxidant activity was obtained using Trolox solution (100–1000 µM) as a standard. For TFC, 2% aluminium chloride (in ethanol) was mixed with each extract (1:1). After 1 h of incubation at 25°C, the absorbance was measured at 420 nm using quercetin (50–500 mg/mL) as standard.

Although the Folin–Ciocalteu assay used could be nonspecific, since other substances, such as reducing sugars and ascorbic acid which are highly abundant in plant food extracts, can reduce the reagent, leading to biased Folin–Ciocalteu assay results [37], a combination of Folin–Ciocalteu and DPPH free radical scavenging assays for antioxidant colorimetric measurements was found to be the most accessible and commonly used method to evaluate

the antioxidant activities of biological samples [37], thereby validating the accuracy of the results obtained.

2.8. Physical Analysis of Waffles. The colour of the formulated waffles was measured as described in Section 2.3. Texture was measured using a TA.XT Plus texture analyser (Stable Micro Systems, United Kingdom) with a three-point bending rig (HDP/3PB) of dimensions: L12.00 X W20.00 X H37.00 and setting; 30 kg force in compression mode, 5 mm distance, 0.5 mm/s test speed and 5 g of trigger force. Hardness was the maximum resistance of the waffle to the rounded edge blade when the waffle began to break [38]. Crispiness was the number of peaks obtained when the waffles were compressed at 50% of their original height. The results were obtained after eight measurements per formulation.

2.9. Sensory Analysis. The sensory test was carried out in the Wonet-bioscience laboratory of the Women's Network for Biodiversity and Food Science, Yaounde, Cameroon. As a preliminary test, three trained panellists participated in a focus group to evaluate and brainstorm on the sensory criteria for the developed gluten-free waffles. The 9-point hedonic scale (from 1 = *extremely dislike* to 9 = *extremely like*), according to Peryam and Pilgrim [39], was adopted for waffle sensory attributes, namely, appearance, aroma, flavour, sweetness, bitterness, aftertaste, mouthfeel and overall liking. Subsequently, 35 participants (male = 16 and female = 19), between 20 and 38 years of age from the University of Yaounde I, Cameroon, were recruited via email to participate in the sensory experiment. The prescreening criteria for the participants were that they should be familiar with batter-mixed baked products (waffles, pancakes, masa rice cake, etc.) that incorporated gluten-free ingredients and that they were nonallergic to any of the waffle ingredients. Although the products were undisclosed to participants and they were not trained prior to the test, they had previously participated in a sensory panel involving similar food ingredients. The general procedure for the sensory evaluation was given to the participants, and they provided written consent prior to participation. Freshly prepared samples were served with Supermont mineral water (Source du pays, Cameroon) as a palate cleanser between samples.

2.10. Cost Estimation of Formulated Waffles. The cost of the formulated waffles was estimated as described by Indumathy and Kausika Varshini [40] with slight modifications. Here, the cost for 100 g of the formulated rice waffles was estimated on the basis of the price (in pound sterling) of each ingredients used to include brown rice flour, corn flour, nettle leaf flour, salt, sugar, milk powder and sodium bicarbonate, and compared to the control (100% rice waffles). Notably, stinging nettle leaves were randomly collected from vegetable gardens (the wild), and thus, it was assumed at zero cost (£0). Other ingredients, that is, salt and sodium bicarbonate that cost less than a penny (< £0.00), were also assumed at £0.

2.11. Statistical Analysis. All experiments were carried out in triplicate and analysed using IBM SPSS Statistics 23. The results were expressed as mean \pm standard deviation, and the mean differences were determined using ANOVA. When significant ($p < 0.05$) differences between means were observed, the means were separated using Tukey's test. Using the R language (v.3.2.1), Pearson correlation was carried out at $p < 0.05$, $p < 0.01$ and $p < 0.001$ for significant, quite significant and highly significant, respectively.

3. Results and Discussion

3.1. Functional and Flow Properties of Flour. The functional properties of stinging nettle leaf flour, brown rice flour and corn flour are presented in Table 1. Our choice of using brown rice and corn flours to compare with nettle leaf flour was based on their availability, and cost-effectiveness as gluten-free food products [41]. Comparably, all parameters were significantly ($p < 0.05$) different from each other. Stinging nettle leaf flour had the lowest swelling capacity (2.71 mL), OAC (89.55%) and water activity (0.31). Specifically, its swelling capacity and OAC were approximately 28 times and 43 times, and 21 times and 28 times lower than those of corn flour and brown rice flour, respectively. NSI, WAC, foaming capacity and stability were significantly ($p < 0.05$) higher in stinging nettle leaf flour than in rice and corn flour. Chandra and Samsheer [42] recorded similar functional properties in commonly used wheat, rice, green gram and potato flours. Likewise, Nawaz et al. [43] recorded varying foaming capacity (2.29%–19.61%) and stability (93.85%–97.05%) in wheat, maize and chickpea flours. In contrast, Ozolina et al. [44] reported higher swelling capacity (10.50–28 mL), OAC (135.32%–187.33%) and WAC (152.07%–322.90%) in faba bean and lentil flours. Nasabi et al. [45] reported lower WACs in wheat (52.3%) and wheat-blended rye, barley, oats and corn flours (WAC ranging between 53.1% and 59.5%). Like high-protein nettle leaf flour, Culetu et al. [46] highlighted that water absorption tends to increase with high protein content which is desirable to improve the food texture of bread products. Similarly, WAC tends to increase with increase in the cellulose content of fibre-rich foods specifically due to an increase in the number of free hydroxyl groups existing in fibres [47]. Culetu et al. [46] further highlighted that gluten-free products are characterised by high starch content, low fibre content, that greatly affects texture. As such, the high fibre content of nettle leaf flour (8.56%) could contribute to high WAC of waffle mixes, a desirable characteristic for gluten-free products [46].

It is well known that the production of gluten-free bakery foods poses several technological challenges since the functional properties of its flours reflect the complex interactions between the composition and structure of its food components [22, 42]. For example, swelling capacity indicates the ability of its starch to absorb water and swell due to noncovalent bonding between the molecules of starch granules in flour [43]. NSI reflects the solubility of available proteins and predicts the ability of these proteins to stabilise foams, emulsions and/or gels [43]. Likewise, foaming is

TABLE 1: Functional properties of stinging nettle leaf flour, brown rice flour and corn flour.

Properties	SNLF	BRF	CF
Swelling capacity (mL)	2.71 ± 0.43 ^c	23.88 ± 0.94 ^b	28.91 ± 2.65 ^a
Nitrogen solubility index (%)	20.85 ± 0.22 ^a	4.06 ± 0.00 ^b	3.54 ± 0.08 ^c
Water absorption capacity (%)	154 ± 0.88 ^a	92.00 ± 0.08 ^b	61.78 ± 1.62 ^c
Oil absorption capacity (%)	89.55 ± 0.02 ^c	117.03 ± 0.10 ^b	132.71 ± 0.80 ^a
Foam capacity (%)	13.91 ± 2.37 ^a	3.67 ± 0.08 ^c	8.84 ± 0.04 ^b
Foam stability (%)	93.66 ± 0.66 ^a	87.24 ± 0.55 ^b	82.64 ± 0.35 ^c
Dispersibility (%)	72.90 ± 0.08 ^b	76.00 ± 0.04 ^a	68.49 ± 0.02 ^c
Water activity a_w	0.31 ± 0.08 ^c	0.44 ± 0.00 ^b	0.48 ± 0.04 ^a
Colour			
L*	36.52 ± 1.13 ^c	69.44 ± 0.11 ^b	94.21 ± 0.40 ^a
a*	-6.88 ± 0.97 ^c	0.45 ± 0.04 ^b	0.71 ± 0.57 ^a
b*	10.44 ± 0.90 ^b	21.29 ± 0.25 ^a	17.88 ± 0.12 ^c
ΔE	7.66 ± 0.63 ^a	11.64 ± 0.90 ^c	13.71 ± 0.52 ^b

Note: Results are expressed as mean ± standard deviation ($n = 3$), and means with different superscripts in the same row are significantly ($p < 0.05$) different. Abbreviations: BRF, brown rice flour; CF, corn flour; SNLF, stinging nettle leaf flour.

mainly due to the protein's ability to form interfacial films and maintain suspended air bubbles as well as slow the coalescence rate [31]. In this study, the lowest swelling capacity of stinging nettle leaf flour and the highest NSI, foaming capacity and stability could be correlated with its low starch and high protein contents, respectively (starch—12.66%, protein—34.76%, as shown in Table 2). In addition, its higher water absorption could have been due to high nettle proteins since flour water absorption is an important parameter that determine the amount of water bound by flour ingredients, including starch, nonstarch polysaccharides and proteins [48].

Furthermore, the bulk density, tapped density, angle of repose, HR and Carr's compressibility index (CI) indicated that stinging nettle leaf flour has acceptable flowability properties (Table 3). Except for the angle of repose that was significantly ($p > 0.05$) not different for stinging nettle leaf flour and corn flour, all other parameters were significantly ($p < 0.05$) different. For stinging nettle leaf flour, tap density and bulk density were lowest at 0.20 g/cm³ and 0.16 g/cm³ respectively, while Carr's index and HR were highest at 20.05% and 1.24, respectively. Corn flour was lowest for Carr's index (15.09%) and HR (1.17). Etti et al. [32] recorded similar CI (17.25 ± 1.02%) and HR (1.21 ± 0.98) in beverage mixes prepared with *Andrographis Paniculata* herbal powder. Likewise, Mochahary et al. [34] recorded CI between 15% and 26.42%, and HR between 1.18 and 1.36 in various indigenous herbal powders including *Alstonia scholaris*, *Centella asiatica*, *Drymaria cordata*, *Hydrocotyle sibthorpioides*, *Oroxylum indicum*, *Senna hirsuta*, *Senna occidentalis*, *Solanum indicum* and *Stephania japonica*. Comparable with industrial food powders, Szulc and Lenart [33] obtained agglomerates with fair flowability (HR 1.2–1.4 and Carr index 18%–25%) when raw food ingredients (lactose, whey protein isolate, soy protein isolate, rice starch, wheat starch, inulin and vitamin C) were mixed to obtain protein-carbohydrate nutrients with compositions similar to milky rice or wheat porridge (baby foods) available on the Polish market. However, deterioration of the flowability of the analysed material (increase in the Hauser ratio and the

Carr index) was noted during the process of agglomeration of the examined nutrients [33].

The flow properties of flours are an indicator of how the flour will move when allowed to freely flow through a system. Specifically, the CI often referred to Carr's index is most related to particulate interactions of flours [51]. It indicates the compressibility of a flour due to its tendency to flow and knowledge about these flowing characteristics is very important when designing and developing flour processing and handling equipment [51]. Although limited research exists on the flow properties of stinging nettle leaf flour, Nallan et al. [52] reported high cohesiveness (HR > 1.4, poor) and compressibility (CI > 45%, poor) in freeze-dried nettle powder. These poor CI and HR values were attributed to the effect of the freeze-drying method on the bulk density where the sublimation of ice at temperatures lower than the glass transition temperature led to a porous structure of the powder [52]. Bulk density represents a measure of a flour heaviness, and variable results in bulk densities from different flour sources were found related to the non-homogeneous particle size distribution of the flours [46]. Moreover, this study has provided useful insights on the fair functional and flow properties of stinging nettle leaf flour, which provides more opportunities for food industries to operate smoothly when nettle leaf flour is incorporated into processes such as mixing, filling, packaging and transportation [53]. Additionally, the obtained data could serve as a guide in the design of nettle leaf flour handling and processing equipment, as correlated with the low water activity obtained (0.31) that indicated the biochemical and microbiological stability of stinging nettle leaf flour during short to long storage [52].

3.2. Pasting Properties of Waffle Mix. The pasting properties of the formulated waffle mixes are presented in Table 4. Except for pasting temperature, the peak viscosity, trough, breakdown, final viscosity, setback and peak time decreased ($p < 0.05$) with increasing incorporation of stinging nettle leaf flour. Although the peak time was slightly constant at about 5 min, the peak and trough velocity decreased about

TABLE 2: Macronutrients and antioxidant capacity of nettle leaf flour and formulated waffles.

Composition	SNLF	0NW	5NW	10NW	15NW	20NW
Ash (%)	11.23 ± 0.04 ^a	16.88 ± 0.49 ^d	17.89 ± 0.55 ^d	22.05 ± 0.31 ^c	25.33 ± 0.04 ^b	26.71 ± 0.60 ^a
Moisture (%)	6.51 ± 0.76 ^b	9.65 ± 0.20 ^a	8.90 ± 0.45 ^b	8.75 ± 0.54 ^b	8.65 ± 0.08 ^b	8.50 ± 0.22 ^b
Protein (%)	34.76 ± 1.22 ^a	31.22 ± 0.08 ^c	31.45 ± 0.41 ^c	38.65 ± 0.73 ^b	39.05 ± 0.52 ^a	39.41 ± 0.04 ^a
Fats (%)	0.33 ± 0.08 ^c	6.43 ± 0.02 ^b	6.01 ± 0.78 ^a	6.44 ± 0.11 ^a	6.94 ± 0.33 ^a	6.32 ± 0.66 ^b
Starch (%)	12.66 ± 0.33 ^b	32.54 ± 0.50 ^a	33.42 ± 0.02 ^a	33.68 ± 0.24 ^a	32.98 ± 0.72 ^a	33.41 ± 0.22 ^a
Fibre (%)	8.56 ± 1.04 ^c	7.90 ± 0.32 ^c	7.55 ± 0.86 ^c	10.61 ± 0.04 ^b	12.10 ± 1.02 ^a	13.42 ± 0.84 ^a
TPC (mg GAE/g)	22.46 ± 0.08 ^a	9.88 ± 0.46 ^c	11.09 ± 0.55 ^c	12.05 ± 0.31 ^c	18.33 ± 0.04 ^b	18.56 ± 0.60 ^b
DPPH (%)	87.66 ± 0.45 ^a	29.65 ± 0.00 ^e	28.90 ± 0.45 ^e	32.75 ± 0.54 ^d	52.65 ± 0.08 ^c	55.50 ± 0.22 ^b
TFC (mg QE/g)	3.66 ± 0.32 ^a	0.41 ± 0.08 ^d	0.45 ± 0.31 ^d	1.90 ± 0.04 ^c	2.05 ± 0.52 ^b	2.33 ± 0.04 ^b

Note: 0NW (100% rice flour), 5NW (95% rice flour + 5% SNLF), 10NW (90% rice flour + 10% SNLF), 15NW (85% rice flour + 15% SNLF) and 20NW (80% rice flour + 20% SNLF); results are expressed as mean ± standard deviation ($n = 3$), and means with different superscripts in the same row are significantly ($p < 0.05$) different.

Abbreviation: SNLF, stinging nettle leaf flour.

TABLE 3: Flow properties of stinging nettle leaf flour, brown rice flour and corn flour.

Parameter	SNLF	BRF	CF
Tap density (g/cm ³)	0.20 ± 0.23 ^c	0.79 ± 0.08 ^a	0.53 ± 0.30 ^b
Bulk density (g/cm ³)	0.16 ± 0.08 ^c	0.65 ± 0.11 ^a	0.45 ± 0.01 ^b
Carr's index (%)	20.05 ± 0.22 ^a	17.72 ± 0.41 ^b	15.09 ± 0.04 ^c
Hausner's ratio	1.24 ± 0.10 ^a	1.21 ± 0.30 ^b	1.17 ± 0.60 ^c
Angle of repose (°)	32.76 ± 1.40 ^b	35.68 ± 0.61 ^a	31.66 ± 0.53 ^b
Flowability ^a	Fair	Fair	Fair

Note: Results are expressed as mean ± standard deviation ($n = 3$), and means with different superscripts in the same row are significantly ($p < 0.05$) different. Abbreviations: BRF, brown rice flour; CF, corn flour; SNLF, stinging nettle leaf flour.

^aBased on Carr's flowability index (CI: 5%–15% [good], 15%–25% [fair], > 25% [poor]), Hausner's ratio (HR: 1.0–1.1 [easy flow], 1.1–1.25 [fair], 1.25–1.4 [poor flow]), angle of repose (< 30° [good], 30–50 [fair], > 50 [poor] [33, 49, 50]).

TABLE 4: Pasting properties of waffle mix.

Parameter	0NW	5NW	10NW	15NW	20NW
PV (cP)	1732.20 ± 18.06 ^a	1579.54 ± 20.55 ^b	1005 ± 13.31 ^c	933 ± 16.04 ^d	856.85 ± 13.60 ^e
TV (cP)	1492.65 ± 14.19 ^a	1379 ± 17.69 ^b	864.65 ± 17.88 ^c	571.88 ± 15.08 ^d	470.22 ± 5.56 ^e
BDV (cP)	644.71 ± 13.93 ^a	558 ± 24.27 ^b	505.89 ± 5.43 ^c	435 ± 14.39 ^d	352 ± 16.04 ^e
FV (cP)	1973 ± 10.52 ^a	1821 ± 11.14 ^b	1620 ± 8.01 ^c	1194 ± 12.33 ^d	1081 ± 7.12 ^e
SV (cP)	831.89 ± 21.17 ^a	730.61 ± 15.32 ^b	626.83 ± 18.24 ^c	628.69 ± 8.04 ^c	627.31 ± 13.27 ^d
PTe (min)	5.91 ± 0.70 ^a	5.42 ± 0.02 ^b	5.23 ± 0.31 ^c	5.17 ± 0.52 ^d	5.09 ± 0.44 ^e
PT (°C)	85.43 ± 0.04 ^c	85.21 ± 0.04 ^d	86.55 ± 0.00 ^c	86.11 ± 0.02 ^b	87.59 ± 0.02 ^a

Note: 0NW (100% rice flour), 5NW (95% rice flour + 5% SNLF), 10NW (90% rice flour + 10% SNLF), 15NW (85% rice flour + 15% SNLF) and 20NW (80% rice flour + 20% SNLF); results are expressed as mean ± standard deviation ($n = 3$), and means with different superscripts in the same row are significantly ($p < 0.05$) different.

Abbreviations: BDV, breakdown viscosity; FV, final viscosity; PT, pasting time; PTe, pasting temperature; PV, peak viscosity; SBV, setback viscosity; SNLF, stinging nettle leaf flour; TV, trough viscosity.

876 times and 1022 times, that is, from 1732.20 cP (rice waffle mix) to 856.85 cP (20% nettle flour-incorporated waffle mix), and 1492.65 cP (rice waffle mix) to 470.22 cP (20% nettle flour-incorporated waffle mix), respectively. Torres-Gallo et al. [30] recorded a similar decrease in pasting parameters when wheat flour was gradually substituted with different levels (100:0, 75:25, 50:50, 25:75 and 0:100) of high-protein ackee aril flour (*Blighia sapida*). The high pasting properties of wheat flour and its subsequent decrease in ackee aril-incorporated flours were attributed to the higher carbohydrate content of wheat flour-rich doughs and the resulting swelling of starch granules after the addition of water [30]. Likewise, Imoisi et al. [54] reported a decreased in pasting parameters when cassava flour was substituted

with citrus fibre of up to 50%. This decrease was also attributed to the starch in citrus fibre that lead to high gelatinisation and swelling index [54].

Pasting properties are important in quality considerations in the food industry since they reflect the texture, digestibility and the end-use of starch-based foods [55]. For example, a significant ($p < 0.05$) decrease in breakdown viscosity from 644.71 cP to 352.0 cP indicated the ability of nettle-incorporated waffles to withstand breakdown, since the higher the breakdown in viscosity, the lower the ability of starch in flours to withstand heating and shearing [55, 56], and a slight decrease in the pasting temperature indicated a slower tendency for paste formation. While peak viscosity is related to the WAC and swelling of starch granules during

heating, the setback velocity indicates the tendency of starch to associate and retrograde during cooling. As such, a decrease in setback values indicated a softer texture and slow staling rate of the nettle-incorporated waffles, which are all desirable properties for gluten-free products [26, 30, 54]. In fact, Mitrović et al. [57] reported similar softer nettle seed-incorporated wheat cookies, and this was evidenced by significantly lower values of firmness and brittleness.

3.3. Chemical Analysis of Waffles. The proximate composition and phytochemical composition of the formulated waffles are presented in Table 2. Although moisture varied slightly between 9.65% (100% rice waffles) and 8.50% (20% nettle-incorporated waffles), the fat and starch contents were not ($p > 0.05$) affected by the gradual incorporation of stinging nettle leaf flour. On the other hand, compositions such as total ash, protein and fibre contents and antioxidant activity, TPC and TFC significantly ($p < 0.05$) increased. In fact, ash, protein and fibre increased approximately 10, 08 and 05 times, respectively, in 20% stinging nettle-incorporated waffles. Similarly, Adhikari et al. [20] reported about 3–9 times higher protein and fibre in nettle powder when compared to traditional cereal foods, such as, rice, wheat and barley, thus indicating it could be used as a protein–fibre-rich supplement in starchy diets associated with poor and undernourished populations. In this study, DPPH and TPC also increased approximately 26 and 08 times, that is, from 29.65% (100% rice waffles) to 55.50% (20% stinging nettle leaf flour) and 9.88 mg GAE/g (100% rice waffles) to 18.56 mg GAE/g (20% stinging nettle leaf flour), respectively. Nettle leaf flour could have contributed to this increase in phenolic content as it was found to be very rich in bioactive compounds (129 mg GAE/g), which is much higher than in wheat flour (1.3 GAE/g) and barley flour (1.7 GAE/g) [20]. As such, the long-term consumption of diets rich in plant polyphenols, such as in this research-formulated waffles, could protect against life-threatening illnesses such as, cancer, cardiovascular disease, diabetes, osteoporosis and neurological diseases [20, 58].

Although waffles are sweet bakery products prepared from a mixture of ingredients such as flour, eggs, milk, sugar and fat, these batter ingredients greatly affect the quality characteristics of the final product (composition, colour, texture, among others) [29, 59–61]. As such, stinging nettle leaf flour could have contributed to the high ash, protein, fibre, antioxidant contents and TPC and TFC of the nettle-incorporated waffles. Consistent with these research findings, Man et al. [62] reported a similar increase in protein and ash when nettle leaf flour was incorporated into wheat bread. Similarly, Tanyitiku et al. [3] recorded an increase in ash and protein contents of 1.89%–2.56% and 18.58%–21.52%, respectively, in gluten-free nettle-incorporated corn cookies. TPC and antioxidant activity also increased approximately 27 and seven times after *in vitro* starch digestion [3].

Furthermore, it is important to highlight that the pasting properties of the waffle mixes (Table 4) were strongly correlated to the proximate composition of the waffles (Table 2).

For example, as the protein, ash, fibre and antioxidant contents increased, the pasting properties (peak viscosity, trough, breakdown, final viscosity, setback, peak time and pasting temperature) decreased in the nettle-incorporated waffles (Table 5). On the other hand, except for pasting temperature ($r = -0.22$, $p < 0.05$), a significant ($p < 0.001$) positive correlation was observed between nettle starch, moisture and the pasting properties of the waffle mixes. Specifically, pasting temperature is essential in the selection of starches for food processing, and this positively correlated with nettle fibre, TPC and TFC. Ocheme et al. [55] reported a similar decrease in pasting properties when wheat flour was gradually substituted with groundnut protein concentrate. This was attributed to a reduction in starch content, as well as the interactions between the starch, fat and protein in the blends [55]. In contrast, Sun et al. [63] observed an increase in pasting properties in corn starch particularly at high sugar concentrations.

Stinging nettle leaves are rich in crude fibre (8.56%), and poor in fat (0.33%), which could explain the high fibre and the insignificant change in fat in the nettle-enriched waffles. In addition to their health benefits, high-fibre foods such as the obtained formulated nettle-incorporated waffles were found to improve quality characteristics such as texture, specific volume, apparent viscosity and consistency in gluten-free bakery products [28].

3.4. Physical Characteristics of Waffles. In Table 6, 100% rice waffles were harder (1668.43 gf), and hardness significantly ($p < 0.05$) decreased to 845.89 gf (20% stinging nettle leaf flour waffles), that is, about 823 times. Also, waffle crispness was highest for the rice waffles (1506.54 gf) and varied between 663.34 gf and 943.76 gf for the nettle-incorporated rice waffles. In particular, there was no significant difference ($p > 0.05$) in hardness and crispness for 15% and 20% nettle-incorporated waffles. Shih et al. [64] recorded a similar hardness in gluten-free rice pancakes when sweet potato flour was gradually added to the batter mix. In contrast, Giau et al. [65] reported an increase in waffle hardness ranging from 96 gf to 152.33 gf when wheat flour was partially substituted with green banana flour and potato starch. Pichaiyongvongdee et al. [66] reported lower hardness (207.51–327.71 gf) and crispness (108.72–224.15 gf) of waffles when three vegetables (Chinese kale, False pak choi and Thai basil) were incorporated into riceberry flour. This was attributed to added fibres that could have diluted wheat gluten and distorted the gluten–starch network [65]. Although rice is the most used cereal flour for gluten-free product development, it was observed to produce almost 50% of sticking waffles due to its crumbly texture [59]. As such, the incorporation of nettle leaf flour could increase gluten-free rice waffle stability and softness, a desirable characteristic for waffles [59].

Furthermore, the values of L^* , a^* and b^* decreased with increasing incorporation of stinging nettle leaf flour, indicating more lightness, redness and yellowness for 100% rice waffles (Table 6). Lightness decreased from 52.25 (100% rice waffle) to 37.54 (20% nettle waffles). As such, 20% nettle-

TABLE 5: Correlation between the composition and pasting properties of waffles.

Composition	PV	TV	BDV	FV	SBV	PTe
Ash	-0.35	-0.21	-0.68*	-0.31	-0.37	-0.14
Moisture	0.93***	0.93***	0.69**	0.87**	0.77**	-0.19*
Protein	-0.88***	-0.80***	-0.83***	-0.75**	-0.52*	-0.42
Fats	-0.85***	-0.71***	-0.78***	-0.68**	-0.51**	-0.31
Starch	0.91***	0.89	0.87***	0.70***	0.65*	-0.22*
Fibre	-0.84***	-0.72**	-0.66**	-0.64**	-0.52*	0.19***
TPC	-0.91***	-0.89***	-0.67	-0.41*	-0.40	0.66**
DPPH	-0.86***	-0.71*	-0.96*	-0.65	-0.44	-0.71**
TFC	-0.44**	-0.56***	0.27	-0.14**	-0.08	0.22

Abbreviations: BDV, breakdown viscosity; FV, final viscosity; PT, pasting time; PTe, pasting temperature; PV, peak viscosity; SBV, setback viscosity; TV, trough viscosity.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

TABLE 6: Physical parameters of the formulated waffles.

Parameter	0NW	5NW	10NW	15NW	20NW
Hardness (gf)	1668.43 ± 115.53 ^a	1545.21 ± 121.65 ^a	1060.50 ± 128.71 ^b	888.00 ± 152.82 ^c	845.89.34 ± 167.65 ^c
Crispness (gf)	1506.54 ± 45.15 ^a	943.76 ± 21.61 ^b	663.34 ± 14.10 ^d	726.63 ± 25.31 ^c	791.09 ± 52.44 ^c
Colour					
L*	55.25 ± 0.18 ^a	52.00 ± 0.63 ^b	43.42 ± 0.02 ^c	38.56 ± 0.62 ^c	37.54 ± 0.11 ^d
a*	0.78 ± 0.04 ^d	0.39 ± 0.27 ^c	-0.11 ± 0.54 ^d	-1.41 ± 0.08 ^b	-2.96 ± 0.31 ^a
b*	26.55 ± 0.47 ^a	24.03 ± 0.02 ^b	19.53 ± 0.61 ^c	16.09 ± 0.22 ^d	9.70 ± 0.52 ^e
ΔE	12.68 ± 0.04 ^a	10.71 ± 0.00 ^b	9.45 ± 0.45 ^c	7.21 ± 0.90 ^c	7.08 ± 0.02 ^d

Note: 0NW (100% rice flour), 5NW (95% rice flour + 5% SNLF), 10NW (90% rice flour + 10% SNLF), 15NW (85% rice flour + 15% SNLF) and 20NW (80% rice flour + 20% SNLF); results are expressed as mean ± standard deviation ($n = 3$), and means with different superscripts in the same row are significantly ($p < 0.05$) different.

Abbreviation: SNLF, stinging nettle leaf flour.

enriched waffles were observed to be the darkest. Likewise, increasing stinging nettle leaf flour increased waffle greenness ($-a^*$ values) from a redder rice waffle ($a^* = +0.78$), and decreased ($p < 0.05$) yellowness from $b^* = 26.55$ (100% rice waffles) to $b^* = 9.70$ (20% nettle). ΔE values varied between 7.08 (20% nettle-incorporated waffles) and 12.68 (100% rice waffles). Consistent with these results, Mitrović et al. [57] showed that wheat cookies enriched with nettle seeds exhibited darker shades, whereas those with nettle seed extract showed enhanced red tones. Pichaiyongvongdee et al. [66] reported slightly higher L^* (50.29–50.85), and a^* (4.36–4.65) values, and lower b^* (10.73–12.23) within the L^* (black to white), a^* (red) and b^* (yellow) range, respectively, when Chinese kale, False pak choi and Thai basil fresh vegetables were incorporated into rice berry crispy waffles. Likewise, Nasabi et al. [45] reported higher L^* (62.8–87.2), a^* (18.2–38.6), b^* (44.6–61.8) and ΔE (12.7–25.6) values in wheat and wheat-blended rye, barley, oats and corn waffles. ΔE values indicate the human visual perception of two colours and measures the allowable deviation tolerance of the colours [67]. In this study, a decrease in ΔE values from 12.68 to 7.08 indicated that the colour of the nettle-incorporated gluten-free waffles were more perceptible at a glance and increasingly became less similar to the calibrated white tile [67]. Moreover, the colour characteristics of nettle-incorporated waffles could be correlated to the colour of stinging nettle leaf flour in Table 1, that is,

darker (36.52), greener (-6.88), bluer (10.44) and lower colour difference (7.66), as compared with brown rice and corn flours. Notably, vegetables have air between the cell walls of chloroplasts and when heated or exposed to hot water, and this leads to the release of the air in the vegetable cells, thus making them to appear greener [66]. However, this green colour due to chlorophyll is unstable when further exposed to heat and is often converted to pheophytin (brownish green colour) [57, 66].

3.5. Sensory Attributes of Gluten-Free Waffles. The sensory attributes of the formulated waffles are shown in Table 7. The results indicated no significant ($p > 0.05$) difference in the sweetness and overall liking of all the samples; however, appearance, aroma, flavour, bitterness, mouthfeel and aftertaste slightly varied with the control (100% rice waffles). Specifically, waffles incorporated with 5% and 10% stinging nettle leaf flour were significantly ($p > 0.05$) indifferent in appearance, aroma, flavour, sweetness and bitterness, and 15% and 20% nettle-incorporated waffles were significantly ($p > 0.05$) indifferent in aroma and flavour. While 100% rice waffles had the lowest aftertaste score (5.30), 20% nettle waffles were indicated to contain slight bitterness (7.43) and aftertaste (7.63). Aussanasuwannakul et al. [68] and Dorohovych et al. [23] also reported no significant differences in appearance and flavour when gluten-free flours (30% and 40% of soybean residues, rice, corn and buckwheat) were,

TABLE 7: Sensory attributes of gluten-free waffles.

Attributes	0NW	5NW	10NW	15NW	20NW
Appearance	7.22 ± 1.66 ^a	6.89 ± 0.14 ^a	5.99 ± 0.45 ^a	6.33 ± 0.40 ^a	5.56 ± 0.68 ^b
Aroma	6.86 ± 0.01 ^a	6.72 ± 0.02 ^a	6.56 ± 0.11 ^a	5.71 ± 0.08 ^b	5.92 ± 0.04 ^b
Flavour	8.79 ± 0.45 ^a	8.98 ± 0.23 ^a	6.75 ± 0.44 ^b	5.05 ± 0.99 ^b	5.52 ± 1.04 ^b
Sweetness	5.69 ± 0.22 ^a	5.71 ± 0.04 ^a	5.20 ± 0.61 ^a	5.34 ± 0.33 ^a	5.21 ± 0.90 ^a
Bitterness	6.37 ± 0.70 ^b	6.05 ± 0.11 ^b	6.17 ± 0.04 ^b	7.59 ± 0.54 ^a	7.43 ± 1.27 ^a
Mouthfeel	8.44 ± 0.00 ^a	8.04 ± 0.50 ^a	6.80 ± 1.36 ^b	7.51 ± 0.90 ^a	6.20 ± 0.87 ^b
Aftertaste	5.30 ± 0.14 ^b	6.05 ± 0.08 ^a	6.81 ± 0.91 ^a	6.85 ± 0.65 ^a	7.63 ± 0.20 ^a
Overall liking	6.51 ± 0.40 ^a	6.77 ± 0.61 ^a	7.82 ± 0.62 ^a	6.66 ± 1.40 ^a	6.21 ± 1.84 ^a

Note: 0NW (100% rice flour), 5NW (95% rice flour + 5% SNLF), 10NW (90% rice flour + 10% SNLF), 15NW (85% rice flour + 15% SNLF) and 20NW (80% rice flour + 20% SNLF); results are expressed as mean ± standard deviation, and means with different superscripts in the same row are significantly ($p < 0.05$) different.

Abbreviation: SNLF, stinging nettle leaf flour.

TABLE 8: Cost estimate of 100 g of each formulated gluten-free waffle.

Waffle formulation	0NW (£)	5NW (£)	10NW (£)	15NW (£)	20NW (£)
Brown rice flour (£0.19/100 g)	0.19	0.18	0.17	0.16	0.15
Corn flour (£0.50/100 g)	0.30	0.30	0.30	0.30	0.30
Nettle leaf flour (£0/100 g)	0	0	0	0	0
Salt (£0.08/100 g)	0	0	0	0	0
Sugar (£0.10/100 g)	0.01	0.01	0.01	0.01	0.01
Milk powder (£1.50/100 g)	0.27	0.27	0.27	0.27	0.27
Sodium bicarbonate (£0.32/100 g)	0	0	0	0	0
Total cost (£)	0.77	0.76	0.75	0.74	0.73

Note: 0NW (100% rice flour), 5NW (95% rice flour + 5% SNLF), 10NW (90% rice flour + 10% SNLF), 15NW (85% rice flour + 15% SNLF) and 20NW (80% rice flour + 20% SNLF); Q denotes quantity, and £0 indicates the ingredient was evaluated at less than one penny. Cost of nettle leaf flour considered at £0 since it was randomly harvested from vegetable farms (wild) at no cost. Bold values indicate the total cost of producing each formulation, and are estimated from the cost of the blended ingredients.

respectively, incorporated into crispy rice berry and wheat waffles. Phongnarisorn et al. [69] reported similar acceptable scores in appearance, texture, flavour and overall acceptability (ranging from 5.0 to 7.0) when 0.25%–2% xanthan gum was added to gluten-free rice berry pancakes and waffles. In contrast, Nasabi et al. [45] recorded lower sensory scores in colour (2.4–4.1), texture (1.1–4.4) and taste (1.3–3.2) when wheat flour was gradually substituted with rye, barley, oat and corn flours during waffle preparations. Comparable to the addition of stinging nettle leaf flour in this study, a continuous addition of xanthan gum resulted in unfavourable sensory scores in gluten-free rice berry waffles and pancakes [69]. Pichaiyongvongdee et al. [66] also reported a slightly bitter taste when Chinese kale was gradually incorporated into rice berry crispy waffles. Similarly, Kuchtová et al. [38] reported an increase in astringent and bitter taste when grape skin and seed preparations were increasingly incorporated into the dough of wheat cookies. This bitterness was attributed to high phenolic compounds present in grape preparations, caused by the interaction between phenolics, flavan-3-ols including (+)-catechin, (–)-epicatechin and especially proanthocyanidins and saliva in the mouth of panellists, thus reducing the perception of sweetness of the enriched cookies [38]. Stinging nettle leaves were also reported to highly contain phenolic compounds, 755 ± 21 µg GAE/g in fresh weight [10] and 129 mg GAE/g in nettle leaf flour [20], which could have also contributed to the slight bitterness (7.43) and aftertaste (7.63) of the formulated waffles. Moreover, according to Everitt [70], a mean

liking score of 7 or higher on a nine-point scale is usually indicative of highly acceptable sensory quality and a product that achieves this score, as in this current research, could be used confidently as a good illustration of the targeted quality [70]. However, further instrumental sensory analysis is required (e.g., the use of an electronic tongue) to fully capture and understand the bitter and aftertaste of nettle-incorporated gluten-free waffles, as highlighted by sensory participants.

3.6. Cost Estimate of Formulated Waffles. The estimated cost of each formulated waffles is presented in Table 8. The results showed that increased incorporation of nettle leaf flour gradually reduced the cost of the formulated waffles by £0.01, that is, from £0.77 (100% rice waffles) to £0.73 (20% nettle-incorporated rice waffles). Desai and Bodhankar [71] reported a similar decrease leading to a 5% profit per 188 g of gluten-free cookies that incorporated almond and water chestnut flour. Contrarily, Mondal et al. [72] observed an increase in the cost of biscuits, from 14.02 rupees to 25.02 rupees, when oat powder was gradually incorporated into wheat biscuits. Although the same profit margins (40%) were reported between commercial waffles and millet-based waffles, Indumathy and Kausika Varshini [40] also reported slightly higher costs of production when millet-based waffles (210 rupees) were compared with commercial waffles (200 rupees) sold in India. In the current study, the results showed a strong indication that the incorporation of nettle leaf flour may not have a cost benefit if a cost value was

attributed to the harvested leaves; however, the quality characteristics of nettle leaf flour including functional, nutritional and sensory attributes should increase its usage in gluten-free food products.

4. Conclusions

The study provided fruitful insights on the functional and flow properties of nettle leaf flour that are comparable to commonly consumed gluten-free rice and corn flours. In addition, incorporating stinging nettle leaf flour into gluten-free rice waffles of up to 10% led to desirable nutritional, physical and pasting properties. Although sensory participants highlighted a slight bitter and aftertaste following increased incorporation of nettle leaf flour, this did not affect the overall acceptability of nettle-incorporated rice waffles when compared with the control (100% rice waffles). The findings showed an enhanced quality characteristics of gluten-free rice waffles and improved our understanding of the food functional properties of low-cost and readily available stinging nettle leaf flour in the development of healthy gluten-free bakery products. Further research could be carried out to ascertain the quality characteristics of nettle leaf flour obtained from other varieties and/or when alternative processes are used in food formulations.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Mary Nkongho Tanyitiku and Igor Casimir Njombissie Petcheu equally contributed to the conceptualisation and designed of the study, and Mary Nkongho Tanyitiku acquired the raw materials and conducted the laboratory work. Mary Nkongho Tanyitiku and Igor Casimir Njombissie Petcheu analysed and interpreted the results, and Mary Nkongho Tanyitiku wrote the first draft. All authors reviewed and approved the final manuscript.

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