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Nutritional, Antioxidant, Sensory, Energetic, and Electrical Properties of Enriched Pasta

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Abstract: The aim of the presented study was to determine the nutritional properties (dry matter, total protein, ash, and selected amino acid content), antioxidant properties (antioxidant activity; total polyphenol, flavonoid, and phenolic acid content; total carotenoid, chlorophyll, and anthocyanin), and sensory profile (general appearance, flavor, taste, aftertaste, overall acceptability) of pasta enriched with powdered nettle leaves, elderberry fruit, and carrot in additions of 3%. A control variant without the addition of plant material was prepared for comparison of the results. Two of our samples of pasta (with nettle and carrot) had lower calorific values by approximately 17%. However, the energy value of the pasta was not significantly affected by added substances. Electrical properties (resistance, impedance) were also measured, and resistivity was calculated. We found that impedance and resistivity were influenced by added components in pasta. In the frequency range from 20 kHz to 100 kHz, we were able to use the measured dependencies of the mentioned electrical properties to identify the type of addition to the pasta. Correlations exist between the electrical properties and nutritional properties of enriched pasta samples, and could be used to indetify value-added pasta in processing chain digitalization.

Keywords: cereal product; carrot; nettle; elderberry; polyphenols; gross calorific value; impedance; resistivity

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1. Introduction

Pasta belongs to the cereal product food group, with strong popularity by consumers due to its high value, energy, short time of preparation, long self-life, and low cost of production. Different varieties of pasta can be found, of different shapes, quality, dimensions, and value-added ingredients on the market [1–4]. After bread, pasta is one of the most popular and attractive cereal products; it is easy to prepare, and it is considered as a versatile food product rich in protein (11–15%), complex carbohydrates (75%), and a poor source of total fat, amino acid, and sodium. Pasta is typified by a low content of bioactive compounds (vitamins and polyphenols) and dietary fiber. A diet enriched with bioactive compounds plays an important role in the prevention of diabetes, cancer, and cardiovascular diseases. Pasta prepared from wholemeal wheat flour is highly nutritive, but its sensory attributes are poor [5,6]. Pasta is a very good cereal product for the development of food with added value. Medicinal plants, fruits, vegetables, and spices rich in different kinds of bioactive compounds are very attractive to the food industry due to their health benefits. Carrot (*Daucus carota* L.) belongs to the most used vegetable group in the human diet. This type of vegetable is rich in carbohydrates, as well as mineral compounds, mainly, calcium, phosphorous, iron, potassium, copper, manganese, and sulfur. Carrot is of interest due to its high levels of vitamins A, B_1, B_2, C, E, thiamine, folic acid, and riboflavin. Fat and protein are present only in trace amounts [7]. Nettle (*Urtica dioica* L.) from the *Urticaceae* family, of the genus *Urtica*, is a perennial wild plant. Nettle is traditionally used in the cosmetics, food, and pharmaceutical industries due to its healthy and nutritional potential, as all parts of nettle (leaves, stalks, and roots) show a rich composition of biologically active compounds with high biological activity. Nettle stalks and leaves have a high level of vitamins B, C, and A, mineral compounds (calcium, iron, magnesium, potassium), pigments (especially carotenoids and chlorophyll), polyphenols (such as flavonoids), and phenolic acids [8]. Elderberries (genus *Sambucus*) are small trees, herbs, or shrubs widely grown throughout the world, especially in subtropical and temperate parts of the northern hemisphere. Their fruits are very popular, especially in folk medicine, for their high content of several active organic compounds (e.g., phenolic compounds, organic acids, sugars, and ascorbic acid) [9].

Calorific value is an essential parameter in the specification of food quality to set the price of the product. Moreover, it is an important characteristic for the diet and control of food energy balance. Gross calorific value (GCV) is an important value for people who suffer from health problems such as overweight and obesity. These risks have reached epidemic proportions, and are associated with a significant number of related diseases, such as diabetes, cardiovascular, and bone and endocrine disorders [10]. In dietary supplements, herbal, glucose, or starch syrups are used as a base for the preparation of supplements in the forms of different foods, such as pasta, lollipops, and cookies. They can be the carriers of vitamin extracts and mineral components, and additionally, they determine the taste of the product [9]. It is well known that the consumption of food of higher GCV can have an impact on people's health and body condition [10]. The GCV of pasta is lower than of the other foods, but consumption could increase glycemic index (GI). Foods containing carbohydrates that are easily digested, absorbed, and metabolized have a high GI (GI $\geq$ 70 on the glucose scale), while low-GI foods (GI $\leq$ 55) have slowly digestible carbohydrates that elicit a reduced postprandial glucose response. The calorific value is an important piece of physical data for measuring the quality of materials. It can provide a new idea and method for evaluating the quality of similar foods from the energy point of view. The caloric value of a foodstuff can be determined by measuring the heat produced when a given amount is completely burnt in oxygen. Understanding the calorific value of pasta had a certain guiding and referencing significance for the development, utilization, storage, and consumption of pasta foods [10].

In practice, there is a need for simple, accurate, and low-cost measurement techniques, models, and correlations between different properties of food. Electrical properties of food are essential for scientists and engineers solving the problems in food preservation, processing, storage, marketing, consumption, and even after consumption. Food is examined from various points of view, e.g., the addition of energy, interaction with the human senses, its efficacy in promoting human health and well-being [1,2]. Information on the electrical properties of value-added pasta is not to be found in the literature. The quality evaluation of food products using electrical measurements has gathered the attention of food scientists because of its simplicity and non-destructive characteristic [11]. In this study, the authors found a meaningful correlation between the electrical resistance and the three types of bread dough and fermentation time. The authors of [12] studied the effect of different proportions of white and whole wheat flour into a pizza base using yeast-based fermentation properties. The impedance of the pizza samples decreased when there was an increase in the whole wheat flour content. Overall, the pizza base that was developed with 50% of the whole wheat flour and 50% of the white flour ratio displayed acceptably firm yet sufficient viscoelastic properties for human consumption. Ramasamy et al. [13] concluded that every edible substance has various dielectric properties. Edible flours and liquids have different microwave absorption capabilities, based on their natural molecular structure. The work was focused on identifying the fiber content present in edible flours. Conclusions were made based on the attenuation, dielectric losses, and relative permittivity of the samples. Electrical properties can be used in many cases, e.g., for identifying the moisture content in chickpea flour [14], and Łuczycka et al. [15] found a relationship between electrical properties and the oat meal admixture in wheat flour. The research presented in [16] examined the effect of storage time on the dielectric constant, physico-chemical, and rheological properties of two wheat cultivars. Electrical properties were also used as characteristics of fruits and vegetables [17], i.e., nutrient plunder capacity of in the evaluation of certain plants [18], as an effective method for non-invasive classification of basal stem rot disease in oil palm trees [19], and so on.

The main aim of this study was to determine nutritional, antioxidant, sensory, energetic, and electrical properties of pasta enriched with carrot, nettle leaves, and elderberry powder. The secondary aim was to find correlations between electrical properties and nutritional properties of enriched pasta samples, which could be used to indentify value-added pasta in processing chain digitalization.

2. Materials and Methods

The carrot roots (*Daucus carrota* L.) were collected in autumn (September 2020), nettle leaves (*Urtica dioica* L.) in spring (May 2020), and elderberry fruits (*Sambucus nigra* L.) were collected in autumn (September 2020), in the village of Liešt'any, situated in Central Slovakia at an altitude of 333 m above sea level. The plant parts were botanically identified at the Institute of Food Sciences of the Faculty of Biotechnology and Food Sciences. All parts (fruits, leaves, and roots) were crushed to powder using a mortar.

Pasta samples were prepared using an extruder (Gina, Italy) for the production of the extruded pasta. Here, 500 g of wholemeal wheat flour was mixed with carrot, nettle leaves, and elderberry powder (3%), one egg (60 g), salt (7 g), and tap water in a rotary shaft mixer at 25 °C for 20 min, to obtain a dough with 30% moisture content. A screw (length 30 cm; diameter 5.5 cm) that ended with a bronze die (hole diameter, 1.70 mm) was used to extrude the dough into an elbow shape. The screw speed was 50 min^{-1}. The extrusion pressure was approximately 3.4 bar (0.34 MPa), and the temperature of the pasta after the extrusion was from 27 °C to 28 °C. Each type of pasta was prepared separately. Extruded pasta was dried in a drying chamber (8 h at 40 °C) to a final moisture content of approximately 12.5%. Before analyzing, pasta was homogenized to a particle size of 0.5 mm.

The total protein, dry matter, and ash content were determined using the AACC standard method 08–01 [20]. Protein content was detected using the semi-micro Kjeldahl method, and factor 5.7 was used for converting of proteins. The total fat content was determined using a Fat Extractor Ancom XT15 (Ancom, Fairport, NY, USA) according to the method recommended by the producer. Ion exchange chromatography, with a strong cation exchanger and a sodium–citrate elution buffer system, followed by post-column derivatization with ninhydrin and spectrophotometric detection, was used for measuring amino acid composition, according to method described by manufacturer of the amino acid analyzer (Ingos, Prague, Czech Republic). The amino acid standard solution was used for the calibration of the amino acid analyzer. Amino acid tryptophan was not evaluated because this compound was destroyed during acid hydrolysis, and glutamine and asparagine changed to glutamic acid and aspartic acid; thus, they were determined in this form.

Antioxidant activity of the samples was evaluated using the DPPH method according to Sánchéz-Moreno et al. [21] with slight modifications. The spectrophotometric method using the Folin–Ciocalteu reagent was used for total polyphenol content detection according to Singleton and Rossi [22]; the spectrophotometric method was also used for the total phenolic acid content, according to Farmakopea Polska [23], using Arnova reagent. Total chlorophyll content was determined spectrophotometrically according to the Lichtenthaler and Wellbum method [24]. The absorbance of the reaction mixture was determined using the spectrophotometer Jenway (6405 UV/Vis, England) at 649 nm and 664.5 nm. Anthocyanin content was measured according to the method of Fuleki and Francis [25] with modifications [26]. For pH 1.0, a sample (0.4 mL) was diluted with 0.025 M of potassium chloride (3.6 mL). For pH 4.5, a sample was diluted (0.4 mL) with 0.4 M of sodium acetate. The absorbance of sample was measured at 520 nm and 700 nm against a blank reagent (distilled water). The concentration of total anthocyanins was expressed as cyanidin-3-glucoside (Cy-3-glc) equivalent. The total carotenoid content was determined from the molar absorption coefficient of β-carotene according to the STN method [27].

The taste panel of 20 evaluators (average consumers) was used for the evaluation of the sensory properties of samples. The panelists evaluated overall acceptability, taste (overall), taste (intensity), aftertaste, the flavor of the product (overall), the flavor (intensity), and foreign flavor (presence). All parameters were compared with a control sample without any enrichment. A nine-point hedonic scale ranging from 9 (like extremely) to 1 (dislike extremely) for all indicators except for foreign flavor (presence) and aftertaste, where a scale was applied ranging from 9 (presence) to 1 (non-presence). All the evaluators signed ethical approval before the sensory analysis.

All determinations were realized in triplicate, and the results are presented as the mean of the replicate determinations with standard deviations. All obtained data were evaluated with analysis of variance (ANOVA) using Duncan's test to determine the level of significance between experimental groups at the confidence level of 0.05 using SAS software [28].

The calorific values of the pasta samples were determined by bomb calorimeter IKA C 5000 (IKA Works, Inc., Wilmington, NC, USA). The adiabatic method, which is more convenient for loose samples, was used for measurement. In the bomb calorimeter, the sample was placed into a crucible and was electrically ignited to burn with the presence of pure oxygen. Samples were weighed using external scales (Libra Axis AG1000C, Gdańsk, Poland), and were in the range of 0.63 mg to 0.89 mg. The sample was ignited with a cotton thread in a quartz crucible with a diameter of 20 mm and height of 20.5 mm. During combustion, the heat was released and a rise in temperature was measured. The dry benzoic acid was used as a calibration to measure the effective heat capacity of water in the calorimeter. The heat of combustion differs from the heat released from the metabolism of foods in the body when they are used as a source of energy. Not all combustible energy is available to the human body for maintaining energy balance, because foods are not completely digested and absorbed, and consequently, food energy is lost in the feces. Furthermore, compounds derived from the incomplete catabolism of protein are lost in the urine, and the capture of energy (conversion to adenosine triphosphate ATP) from food is less than completely efficient in intermediary metabolism. The energy conversion factors and the models used in the present study assumed that each component of a food item has an energy factor that is fixed, and that does not vary according to the proportions of other components in the food or diet [29].

A GoodWill Instek LCR meter 821 (GW Instrument Co., Ltd., Taipei, Taiwan) instrument was used to measure the low-frequency electrical properties of pasta with a four-electrode (tetra polar) system. We measured the resistance, R, and the impedance, Z, of all samples. They were situated in a cylindrical sensor with two parallel electrodes. The electrode diameter, d, was 37.8 mm, and the distance between the electrodes h was 49.2 mm. The upper electrode was equipped with a spring so that the sample was uniformly compressed in the sensor, and the sample always had the same height. The measurement frequency range was from 0.5 to 200 kHz. At all frequencies, each property was measured three times. The average value was computed, and standard deviations were calculated. The resistivity ρ of pasta samples was determined according to Equation (1)

$$\rho = \frac{RS}{h} \quad (1)$$

where S is the electrode surface, m^2.

The frequency dependencies of electrical properties were constructed, and regression analysis was applied. In addition, we also modeled the curves in a complex variable through a transfer function. The order of the transfer function was chosen by the minimum mean square deviation criterion, and at the same time, it had to be odd due to the inflection of the frequency characteristic. The number of zeros in the numerator corresponded to the physics of the input quantity, which was represented by a harmonic signal, variable in time with a known frequency (up to 200 kHz). Based on the existence of the time derivative, we modeled impulse characteristics for impedance and resistivity. The identification of dynamic systems in the complex plane is expressed by the transfer function $G(s)$, a complex variable [30]

$$G(s) = \frac{Y(s)}{X(s)} = \frac{\sum a_m \times s^m}{\sum a_n \times s^n} \tag{2}$$

where $G(s)$ is the transfer function of a complex variable, $Y(s)$ is the output vector of dynamic system in complex variable, $X(s)$ is the input vector of dynamic system in complex variable, s is the complex variable, a_m is the constant coefficients of numerator, a_n represents the constant coefficients of denominator, m is the number of transfer function zeros, n is the number of transfer function poles.

The degree of the polynomial in the denominator reveals the order of the dynamic system. The amplitude–frequency characteristic $f_f\,(\omega)$ in dB is valid

$$f_f = [G(s)]_{s \to j\omega} \tag{3}$$

where j is the complex unit and ω is the angular frequency in rad/s.

To determine the specific frequency f_{crit} (Hz) for the purposes of modeling electrical properties, we established a condition based on the sampling theorem

$$f_{crit} = \frac{\omega_{f\max}}{\pi} \tag{4}$$

where $\omega_{f\max}$ is ω at the maximum amplitude–frequency characteristic in rad/s.

When evaluating the agreement of the modeled transfer function $G(s)$ with the experimental data, we used the minimum root mean square deviation ($RMSE$) criterion [31]

$$RMSE = \sqrt{\frac{1}{x_n - x_0} \int_{x_0}^{x_n} e_n^2(x)dx} \tag{5}$$

where x_n and x_0 are the maximum and minimum values of the independent variable of the model, respectively, e_n is the difference between the given point of the model and the experiment, and x is the independent variable of the model.

The confidence of the modeled transfer function with the experiment is expressed by the coefficient of determination R^2 (%).

3. Results

3.1. Nutritional Composition

The control sample of pasta contained lower levels of ash and fat. Dry matter (~93%), and crude protein (~11%) were similar in all types of pasta. Fat content was the highest in pasta with elderberry. This is not surprising, because elderberry fruits are rich in fat. Fats are presented mainly in elderberry seeds (20%). Dominant are polyunsaturated fatty acids, especially α-linolenic, linoleic, and oleic acid. Ash content was the highest in pasta with nettle. The dry matter, crude protein, and ash contents are shown in Table 1.

Table 1. Nutritional composition of prepared pasta.

Pasta	DMC [%]	CP [%]	AC [%]	FC [%]
Control	92.76 ± 1.58 a	10.71 ± 1.03 a	0.93 ± 0.05 c	0.13 ± 0.01 c
With nettle	92.54 ± 1.21 a	11.46 ± 0.99 a	1.25 ± 0.11 a	0.33 ± 0.11 c
With carrot	92.78 ± 1.03 a	10.94 ± 1.09 a	1.10 ± 0.03 b	0.73 ± 0.21 b
With elderberry	92.76 ± 1.58 a	10.37 ± 1.15 a	1.10 ± 0.01 b	1.33 ± 0.25 a

Mean value ± standard deviation; DMC, dry matter content; CP, crude protein; AC, ash content; FC, fat content; different letters in a column denote mean values that statistically differ from one another.

The content of total protein in enriched pasta was similar in all samples; however, the results for the amino acid composition (Table 2) are interesting as the amounts of phenylalanine, valine, proline were slightly higher than in the control sample, especially in pasta with nettle addition. In cereals, lysine is generally a limited amino acid. In prepared samples, the level of lysine was higher in comparison with the control sample in the variant enriched with nettle leaf powder; thus, this raw material can be an effective tool for lysine increase in cereal products.

Table 2. Selected amino acid composition in prepared pasta.

Parameter (mg/g)	Control Pasta	Pasta with Nettle	Pasta with Carrot	Pasta with Elderberry
Aspartic acid (Asp)	9.41 ± 1.23 b	11.97 ± 1.44 a	8.03 ± 1.01 b	8.60 ± 1.01 b
Threonine (Thr)	3.32 ± 0.75 a	3.60 ± 0.66 a	3.23 ± 0.13 a	3.03 ± 0.66 a
Serine (Ser)	5.98 ± 0.33 ab	6.46 ± 1.05 a	5.65 ± 0.22 b	5.32 ± 0.28 ab
Glutamic acid (Glu)	29.94 ± 1.78 a	31.47 ± 2.25 a	28.90 ± 1.85 a	28.29 ± 1.31 a
Proline (Pro)	10.03 ± 0.49 a	11.38 ± 1.09 a	10.55 ± 1.74 a	11.55 ± 1.11 a
Glycine (Gly)	3.84 ± 0.22 ab	4.14 ± 0.14 a	3.54 ± 0.33 ab	3.40 ± 0.21 b
Alanine (Ala)	3.50 ± 0.13 b	4.09 ± 0.19 a	3.39 ± 0.22 b	3.34 ± 0.19 b
Valine (Val)	3.89 ± 0.28 b	4.57 ± 0.22 a	3.85 ± 0.13 b	3.66 ± 0.13 b
Isoleucine (Ile)	3.21 ± 0.45 ab	3.64 ± 0.23 ab	3.25 ± 0.21	2.92 ± 0.25 b
Leucine (Leu)	7.56 ± 1.22 a	8.22 ± 0.98 a	7.42 ± 0.78 a	6.84 ± 1.12 a
Tyrosine (Tyr)	3.75 ± 0.33 b	4.25 ± 0.17 a	3.59 ± 0.16 b	3.51 ± 0.12 b
Phenylalanine (Phe)	5.69 ± 1.02 a	6.11 ± 0.21 a	5.66 ± 0.24 a	5.14 ± 0.44 a
Histidine (His)	2.58 ± 0.11 a	2.63 ± 0.11 a	2.44 ± 0.29 a	2.28 ± 0.12 b
Lysine (Lys)	3.23 ± 0.14 b	3.59 ± 0.12 a	3.11 ± 0.11 b	2.84 ± 0.11 c
Arginine (Arg)	5.66 ± 1.05 a	5.51 ± 0.44 a	4.92 ± 0.97 a	4,56 ± 0.25 a

Mean value ± standard deviation; different letters in a column denote mean values that statistically differ from one another.

3.2. Antioxidant Activity

Antioxidant activity (Table 3) tested via the DPPH method was highest in pasta enriched with nettle leaf powder and elderberry fruit powder. These samples also, compared to the control sample, had higher content of total polyphenols as well as total phenolic acids.

Table 3. Antioxidant profile of evaluated pasta.

Pasta	DPPH (mg TEAC/g)	TPC (mg GAE/g)	TPAC (mg CAE/g)
Control	0.36 ± 0.03 c	0.65 ± 0.03 b	0.58 ± 0.10 c
With nettle	0.54 ± 0.04 a	1.23 ± 0.09 a	0.74 ± 0.05 bc
With carrot	0.46 ± 0.01 b	0.67 ± 0.11 b	0.78 ± 0.08 b
With elderberry	0.56 ± 0.03 a	1.28 ± 0.04 a	0.98 ± 0.12 a

Mean ± standard deviation; DPPH, radical scavenging activity; TPC, total polyphenol content; TPAC, total phenolic acid content; TEAC, Trolox equivalent antioxidant capacity; GAE, gallic acid equivalent; CAE, caffeic acid equivalent; different letters in a column denote mean values that statistically differ from one another.

The addition of nettle, carrot, and elderberry positively influenced the content of natural colorants in prepared pasta (Table 4). Natural colorants belong to the biologically active compounds that are very attractive due to their positive effect on the human body. Pasta with color, especially of natural origin, is very attractive for consumers nowadays, mainly among younger generations.

Table 4. Natural colorant in evaluated pasta.

Pasta	Carotenoids (mg/g)	Chlorophylls (mg/g)	Anthocyanins (mg/g)
Control	n.d.	n.d.	n.d.
With nettle	n.d.	0.81 ± 0.05	n.d.
With carrot	4. 01 ± 0.87	n.d	n.d
With elderberry	n.d.	n.d.	0.09 ± 0.01

n.d., not detected.

3.3. Sensory Analysis

The results of sensory attributes, such as overall acceptability, taste, and flavor of pasta, showed no strong differences (Figure 1). The aftertaste characteristics varied significantly, and some evaluators described a "grassy taste" of pasta with 3% nettle powder, while another noted a pleasant fruity and spicy aftertaste of pasta with 3% elderberry powder.

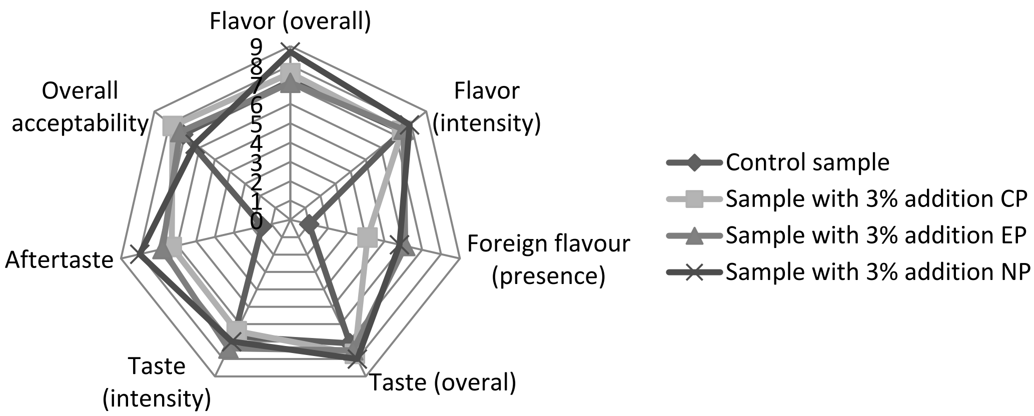

Figure 1. Sensory properties of evaluated types of pasta (sum of all panelists): CP, carrot powder; EP, elderberry powder; NP, nettle powder.

Generally, it can be concluded that all evaluated samples were harmonic, with pleasant characteristics. The best score was detected, according to the panelists, for pasta enriched with 3% nettle powder.

3.4. Calorific Value of Pasta Samples

The gross calorific value was measured for all samples three times, and the ranges of measurement values are shown in Table 5. In this table, the range of sample mass (m) and standard error can be found.

Table 5. Mass, gross calorific value, and standard error.

Sample	m (g)	GCV (J/g)	Standard Error (J/g)
control	0.86–0.89	17,053–17,065	9
with nettle	0.70–0.86	16,650–16,803	39
with carrot	0.65–0.76	16,484–16,957	150
with elderberry	0.63–0.70	17,074–17,209	31

GCV, gross calorific value.

The results show that the pasta with a higher GCV than the control is the pasta with elderberry, the other enriched samples have lower GCV than the control pasta. In Figure 2, the mean GCVs with standard errors are shown.

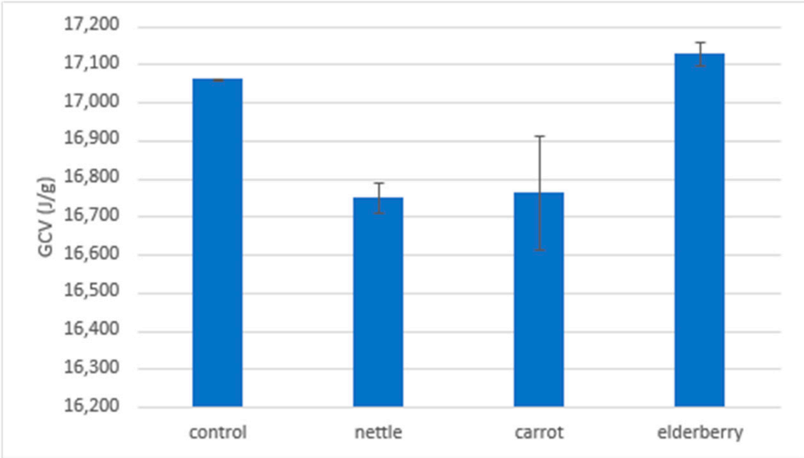

Figure 2. Mean of gross calorific value of all samples with standard error.

3.5. Electrical Properties of Pasta Samples

We found out that resistance R, impedance Z, and resistivity ρ decrease with frequency in the range of 0.5 to 200 kHz. We used the power function as a model describing these dependencies

$$\rho = \rho_0 \left(\frac{f}{f_0} \right)^{-k} \tag{6}$$

where ρ_0 is the reference value of resistivity in kΩ·m, f is frequency, f_0 represents 1 kHz, k is the constant.

In Figure 3, the frequency dependencies of resistivity for all samples are presented.

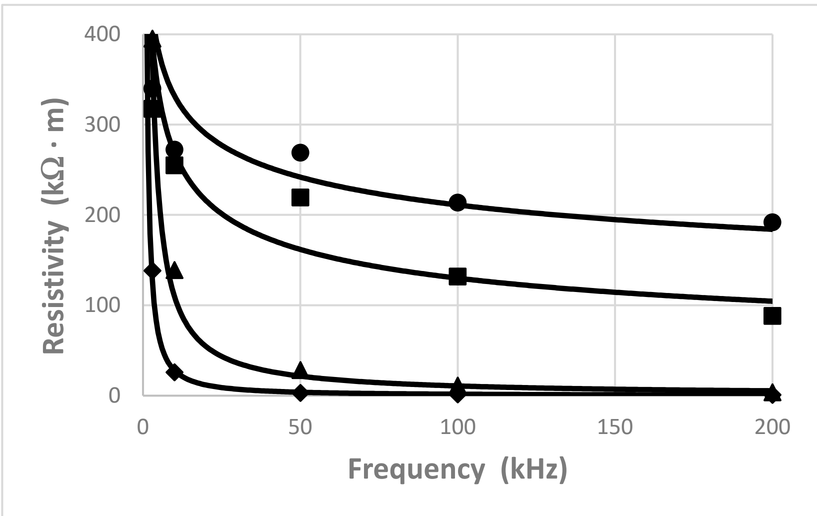

Figure 3. Frequency dependencies of resistivity for value-added pasta samples: ●, control; ■, with nettle; ▲, with carrot; ♦, with elderberry.

All dependencies have very high coefficients of determination, ranging from 0.8384 to 0.9967; this means that the model described these dependencies very well. At lower frequencies from 20 kHz to 100 kHz, displacements between the curves exist, but above 100 kHz, the curves for pasta with carrot and elderberry are almost identical.

Similar frequency dependencies were obtained for impedance (Figure 4). In particular, the control pasta and pasta with nettle powder had the higher impedance values, and the lower values were exhibited by the pasta with carrot and elderberry.

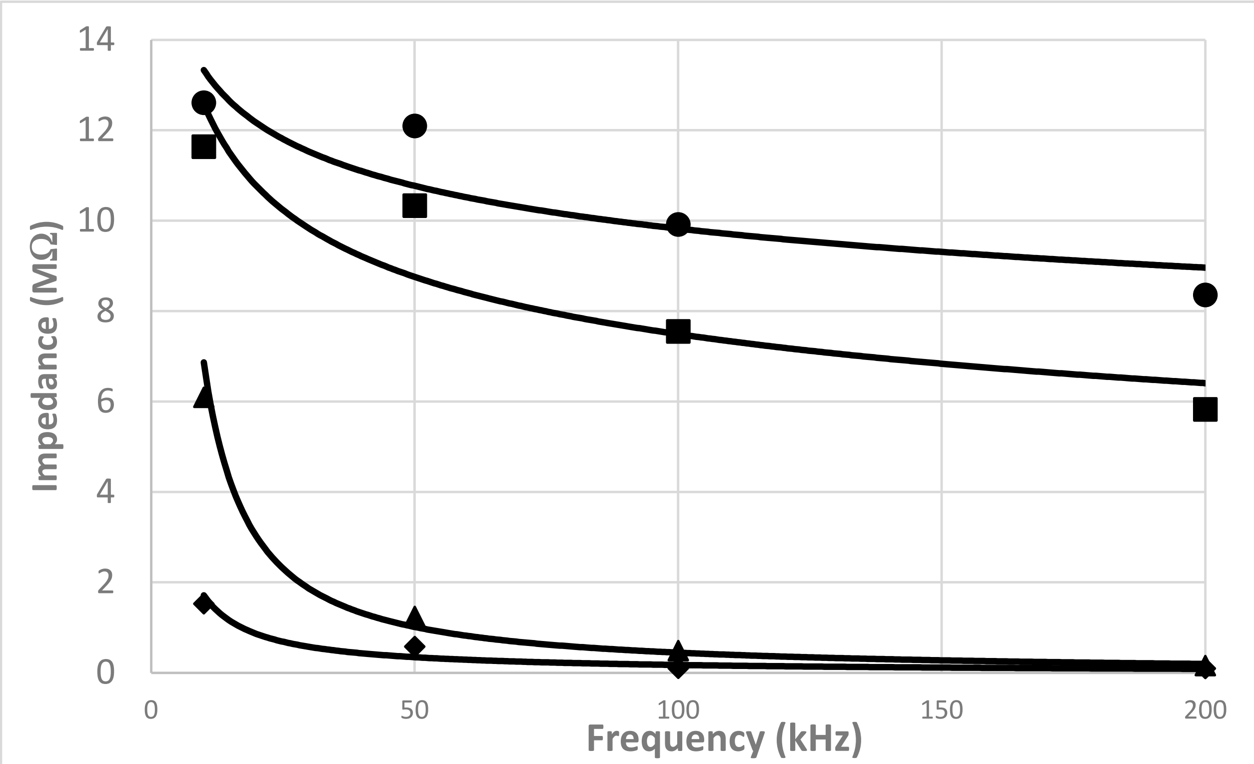

Figure 4. Frequency dependency of impedance for all samples: ●, control; ■, with nettle; ▲, with carrot; ⧫, with elderberry.

In addition to regression analysis, we also modeled frequency-dependent electrical characteristics in a complex variable through a transfer function $G(s)$ in the shape

$$G(s) = \frac{A\,s + B}{s^3 + C\,s^2 + D\,s + E} \quad (7)$$

where s is the complex variable, and A, B, C, D, and E are coefficients of transfer function.

The values of these coefficients and coefficients of determination are presented in Table 6.

Table 6. The coefficients of transfer function (7) and coefficient of determination for all samples.

	Pasta	A	B	C	D	E	R^2 (%)
Z (kΩ)	control	1.075×10^8	2.43×10^5	7754	7.59×10^5	7.48×10^7	88.50
	nettle	9.92×10^7	2.20×10^5	1.28×10^4	7.29×10^5	5.95×10^7	99.99
	carrot	1.59×10^6	3824	1214	5.61×10^4	2.097×10^5	99.99
	elderberry	2.84×10^6	-1.34×10^9	563.2	5.34×10^5	7.32×10^7	99.99
ρ (kΩ·m)	control	1.051×10^5	-3.18×10^4	689	1823	1.26×10^6	90.60
	nettle	1.30×10^5	-4.72×10^4	-4.72×10^4	235.7	1.70×10^6	94.87
	carrot	-6.71×10^5	-3.38×10^5	179.7	1.19×10^5	2.13×10^7	90.45
	elderberry	-1.71×10^5	-3.51×10^5	452.3	8.26×10^4	1.16×10^7	96.89

The frequency at the maximum amplification of the function of the complex variable was chosen as the quantifier of specific frequency. The modeling procedure is illustrated in the flowchart (Figure 5).

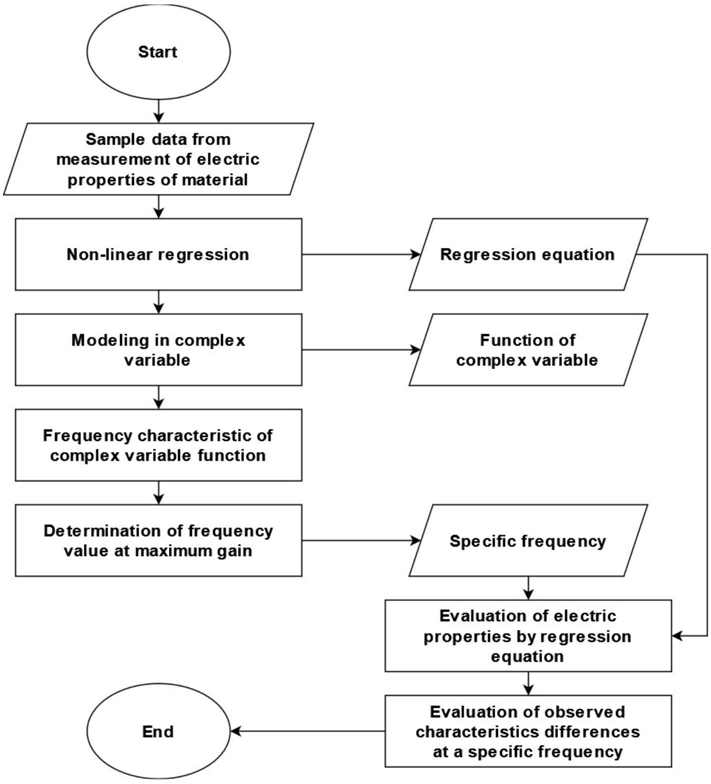

Figure 5. Flowchart for modeling of electrical characteristics, in relation to the value-added foods, in a complex variable.

For input data sampling we used Nyquist's theorem, where, considering the frequency band with the value of 200 kHz, the sampling period was $T = 2.50$ ms. This time should be taken as an indicator of data propagation in the model. The sampled impedance signal for the control sample is shown in Figure 6. The frequency varied in steps up to a value of 200 kHz.

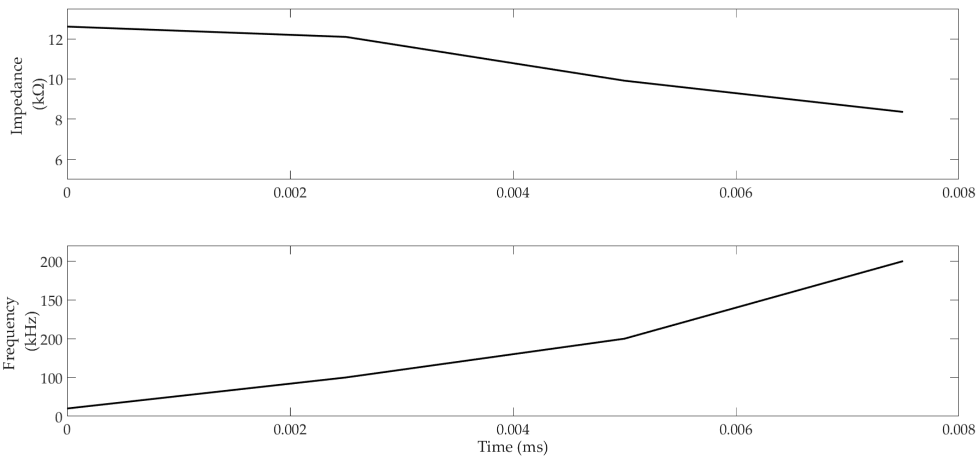

Figure 6. Control sample impedance sampling for modeling in a complex variable.

Sampling of control impedance measurement values for frequencies up to 200 kHz in a complex variable model represents the transfer function. For a sampling period of experimental data, the following equation is valid:

$$T \leq 0.50\, T_m \tag{8}$$

where T is the period of data sampling(s) and T_m is the period of frequency band(s).

The specific frequency identification procedure is presented as an innovative analytical tool for explicitly determining the discrimination of the measured food material based on the evaluation of the monitored parameter differences at a given frequency.

Calculated specific frequencies of electrical properties dependencies are provided in Table 7.

Table 7. Specific frequency for the impedance model f_Z and for the resistivity model f_ρ.

Sample	f_Z (kHz)	f_ρ (kHz)
control	32.12	13.59
with nettle	22.23	1.64
with carrot	4.59	109.66
with elderberry	10.14	60.51

In the Figures 7 and 8, amplitude–frequency characteristics for impedance and resistivity are shown.

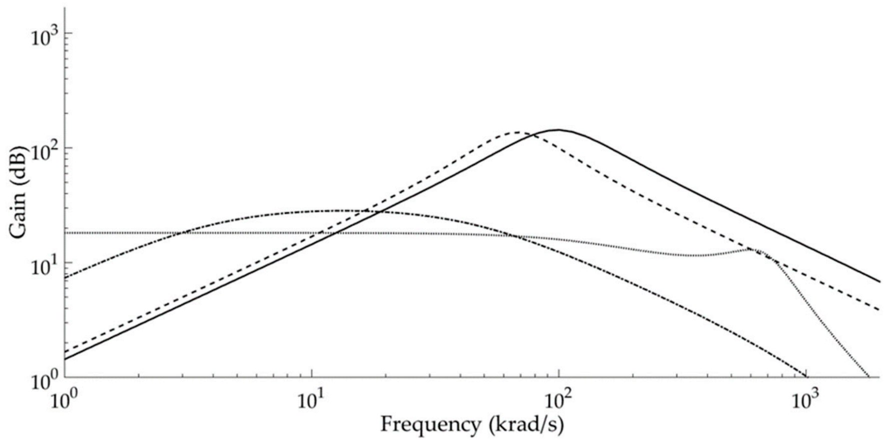

Figure 7. Amplitude–frequency characteristic for impedance: control, solid line; nettle, dashed line; carrot, dot–dashed line; elderberry, dotted line.

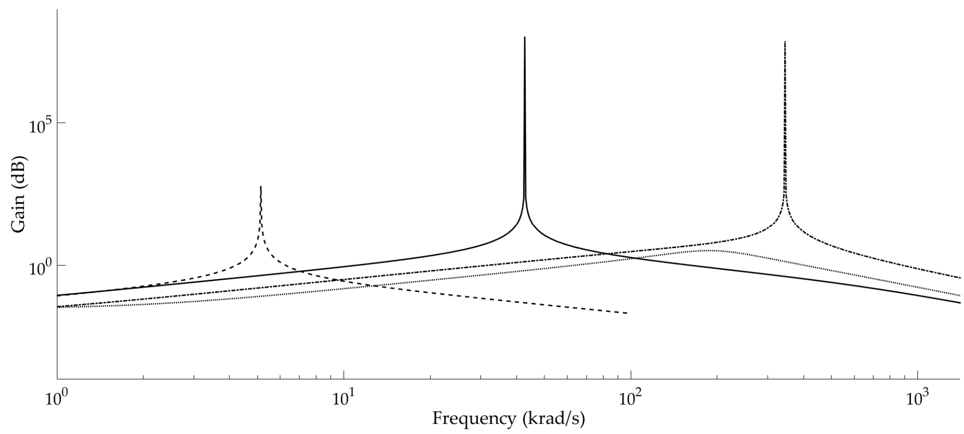

Figure 8. Amplitude–frequency characteristic for resistivity: control, solid line; nettle, dashed line; carrot, dot–dashed line; elderberry, dotted line.

By substituting these frequencies into the regression relations, we determined the values of the electrical properties and their relative differences δ_Z and δ_ρ compared to the control sample; these values are provided in Table 8.

Table 8. Relative differences of impedance δ_Z and resistivity δ_ρ compared to the control.

Sample	Z (kΩ)	δ_Z (%)	ρ (kΩ·m)	δ_ρ (%)
control	12854.114	-	312.440	-
nettle	11918.586	−7.278	475.447	52.172
carrot	6483.345	−49.562	9.715	−96.891
elderberry	1693.924	−86.822	2.938	−99,060

It can be seen that in the case of samples with elderberry and carrot compared to the control sample, the difference between the resistivity is 2.17%, which was the lowest value we achieved regarding relative differences between each pasta type. In the case of impedance, there was an almost uniform relative shift in the impedance of the samples to the control sample. In the case of the resistivity, for the samples with nettle, an increase of 52.172% was observed compared to the control sample, which is an inverse phenomenon in comparison with the difference found between the regression curves in Figure 4.

4. Discussion

Enriched pasta is very popular and attractive, not only to the pasta industry, but also to consumers. Plant raw materials are very beneficial ingredients to improve nutritional and antioxidant properties of cereal products. Nettle leaf, carrot, and elderberry fruit powder addition in amounts of 3% positively influenced nutritional, antioxidant, and sensory profiles of pasta. Nettle powder addition increased the amount of ash; likewise, with carrot and elderberry, the amount was higher compared to the control variant. Zarzycki et al. [4] used flaxseed flour as an addition to pasta, and the ash content was higher (4.94%) compared to control variant (0.91%). Biernacka et al. [3] prepared pasta with leek (0, 1, 2, 3, 4, 5 g/100 g), and the ash content was also higher than in compared control sample. Fat content was significantly higher in pasta with elderberry powder addition. Elderberry fruits are a very good source of bioactive compounds and fatty acids. Polyunsaturated omega-3 and omega-6 fatty acids were determined in the study of Dominguez et al. [32]. These authors detected 38.12 g/100 g of omega-3 and 39.54 g/100 g omega-6 fatty acids in elderberries, and the authors also argued that this fruit can be a potential source of antioxidant compounds for the food industry. Amino acids in foods are very important for human health and for the normal functioning of the human body. Especially, the amount of essential amino acids is the key factor for cereal products, which are at the base of the human diet according to the food pyramid. Unfortunately, lysine is only present in cereals at low levels; therefore, the addition of plant-based raw materials can be an ideal tool to increase these levels. The addition of nettle leaves increased the amount of lysine as well as the amount of serine, glycine, alanine, and tyrosine. A higher value of essential amino acids was obtained in the study of Filip and Vidrih [33]. These authors analyzed pasta enriched with 3% spinach powder and found higher values, especially for lysine and threonine, in comparison to the control variant without any addition. Antioxidant activity, as well as polyphenol and phenolic acid contents, were higher in enriched pasta when compared to the control variant. Nettle leaves are rich in polyphenol groups, mainly in ferulic, syringic and vanillin acids. Nettle has some antimicrobial effects because of its phenolic contents. Nettle could inhibit *Staphylococcus aureus*, *Bacillus cereus*, and *Listeria monocytogenes* [34]. According to this information, it can be argued that pasta with the nettle addition can be stored for a long time compared to the control variant. Carrot is a very good source of bioactive compounds, such as carotenoids, which also positively influence the color of enriched cereal products. Out of the polyphenol groups in carrot, it is possible to find chlorogenic acid, *p*-hydroxybenzoic acids, along with numerous cinnamic acid derivatives [35]. All these compounds can increase the antioxidant activity of enriched products compared to control sample. Carrot powder at 5, 10, 15, 20, 25, and 30% was incorporated into wheat flour to produce pasta in the study of Sule et al. [36]. The quality of the resulting wheat-carrot pasta was very good from a nutritional point of view. Increments in vitamins B_1 (0.41 to 0.44 mg/100 g), B_3 (3.35 to 3.80 mg/100 g), B_6 (0.38 to 0.54 mg/100 g), C (0.54 to 3.14 mg/100 g), E (0.68 to 1.54 mg/100 g), K (1.81 to 29.28 μg/100 g), and beta carotene (1.03 to 6.13 mg/100 g) content was observed with carrot incorporation in a concentration dependent manner. Calcium, iron, potassium, and sodium contents increased significantly ($p < 0.05$) from 33.47 to 84.03 mg/100 g, 3.55 to 3.70 mg/100 g, 359.30 to 960.70 mg/100 g, and 2.00 to 64.37 mg/100 g, respectively. Our results are in accordance with these findings, whereas the addition of carrot powder to pasta increased nutritional properties. Elderberries are a very good raw material for the increase in the nutritional and sensory profiles of cereal products. In our study, the levels of ash, fat, antioxidant activity, polyphenols, and phenolic acids were higher in elderberry pasta than in the control variant. Freeze-dried elderberries were proposed as natural colorants for gluten-free wafers in the study of Rózylo et al. [37]. Wafers with a 5% addition of elderberry, in comparison to control wafers, had significantly higher contents of minerals, including iron, potassium, calcium, magnesium and sodium. The total flavonoid content was also higher in the wafers containing elderberry (37 mg QE/100 g, control variant 2.3 mg QE/100 g; QE, quercetin equivalent). In the modern world, the food we consume must not only provide us with a source of energy and nutrients, but also have a beneficial influence on our health. Responding to high proportion of civilization diseases in society, and the ever-increasing demand for innovative foods, the manufacturers of food products introduce new items with good sensory attributes and health-supporting properties [38]. The addition of nettle, carrot, and elderberry powders positively influenced the sensory profiles of pasta. The evaluators positively evaluated the color, the taste, and overall acceptability with the best score for pasta with nettle leaves. Incorporation of nettle powder in amounts of 5–15% to noodles was conducted in the study of Alemayehu et al. [39]. The sensory acceptability test revealed that nettle-supplemented (5–15%) noodles were accepted above the average in all sensory attributes; however, the highest acceptability was exhibited in wheat noodles (control). In our study, pasta with nettle was evaluated higher due to the lower nettle content. In our study, the addition of 3% powder was used, while the authors of [39] used 5–15%; higher addition also brings a negative, grassy aftertaste. Therefore, it is very important to find an optimum level of addition—good from both nutrition and sensory points of view.

From an energetic point of view, pasta with added plant products may have better properties for people with liver problems or diabetes. Perhaps together with pasta as a smooth meal, people will supplement the body with beneficial substances such as antioxidants and vitamins. A similar study was conducted by the authors of [40], who studied the content of important elements in fresh fruit. The authors Piekara et al. [41] researched candies and lollipops with the addition of plants and vitamins. They compared GCV and sweetener concentration of the control and samples with the addition. They found that added ingredients did not affect the calorific value, but the food contained important elements for the human organism. A balanced diet should provide essential nutrients. Two of our samples of pasta (with nettle and carrot) had lower calorific values by approximately 17%. However, the energy value of the pasta is not significantly affected; especially, its nutritional and therapeutic content must be taken into account.

We found that the impedance, the resistance, and the resistivity decreased with frequency for all samples, which could be compared with, e.g., [42], where decreases in dielectric properties for ground hard red winter wheat were reported, or with [15], in which the mixtures of wheat flour and oat meal were described. The control pasta had higher values of resistivity and impedance. This means that it had the lower conductivity at all frequencies. The enriched pastas had lover resistivity, and it is clear that materials added to the pasta increased its conductivity. Water is the most important factor that affects electrical properties, and also the impedance and the resistivity determined in this research. In Table 1, the dry matter content of the samples is listed, and it has almost the same high value in the interval from 92.54 to 92.78%. This means that the moisture content of the samples is low and the same for all samples. It follows that the differences in the impedance and the resistivity were not influenced by moisture, but by added components in pasta. In the frequency range of 20 kHz to 100 kHz, we could use the measured dependencies of the mentioned electrical properties to identify the type of addition to the pasta. Both the resistivity and the impedance were influenced by total phenolic acid content, which was highest in the pasta with elderberry fruit powder, whereas the resistivity and impedance, respectively, of these samples were the lowest. The control pasta had the lowest total phenolic acid content and the highest values of resistivity and impedance at all frequencies. We also modeled frequency-dependent electrical characteristics in a complex variable through a transfer function and calculated the specific frequencies. After this, we determined the values of the electrical properties and their relative differences compared to the control sample. We found that in the case of samples with elderberry and carrot compared to the control sample, the difference between the resistivity is 2.17%, which was the lowest value we achieved for the relative differences between each pasta type. In the case of impedance, there is an almost uniform relative shift in the impedance of the samples compared to the control sample. In the case of the resistivity of the sample with nettle, there was an increase of 52.172% compared to the control sample, which is an inverse phenomenon in comparison with the difference found between the regression curves in Figure 4. In this experimental case, the specific frequency was identified with a value of 1.64 kHz, which we can consider as a low frequency considering the applied frequency band. It can therefore be concluded that, in the case of low frequencies, the dominant polarization of the dielectric prevails in the sample with nettle, which is also reflected in the high impedance value at the specific frequency of 22.23 kHz. The relative impedance differences show a strong negative correlation, as the relative difference differential was 37.26% and 42.28% in the step, and the Pearson's correlation coefficient reached the value—0.968. In the case of resistivity, the relative difference shows a medium negative correlation, as the Pearson's correlation coefficient reached a value of 0.771. These measurable differences can be used as indicators of the composition of the given samples by evaluating the electrical properties at specified frequencies.

The use of electrical properties measurement opens the way towards many applications in food processing and handling. Better information on moisture content and other quality factors in food processing can be helpful in controlling processes to produce better food products, and to obtain energy savings and other economic benefits [42].

5. Conclusions

The determined results indicate that nettle leaf, carrot, and elderberry fruit powders could technically and nutritionally be used to produce pasta with added value. Pasta with additions in terms of sensory quality is certainly a healthier option than the conventional pasta to which consumers are accustomed. The nettle, carrot, and elderberry additions enhanced the nutritional qualities of the products. The results of the nutritional composition and antioxidant properties of prepared pasta indicate that it may be regarded as an important source of nutrition ingredients for pasta production.

We found that the relative impedance differences show a strong negative correlation, as the relative difference differential was 37.26% and 42.28% in the step, and the Pearson's correlation coefficient reached a value of 0.968. Our measurements confirm that meaningful correlations exist between electrical properties and added ingredients in enriched pasta samples, and could be used to indentify value-added pasta in processing chain digitalization. Measurable differences between values of impedance and resistivity can be used as non-destructive indicators of the added value in samples of pasta by evaluating these properties at specified frequencies. Electrical properties have a number of applications in food industry; however, much work still needs to be conducted to exploit its high potential application in various fields.

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