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Physicochemical, Antioxidant, Organoleptic, and Anti-Diabetic Properties of Innovative Beef Burgers Enriched with Juices of Açaí (*Euterpe oleracea* Mart.) and Sea Buckthorn (*Hippophae rhamnoides* L.) Berries

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Abstract: Background: The aim of this study was to evaluate the selected quality parameters of innovative beef burgers produced with the addition of açaí and/or sea buckthorn berry juices. Methods: Five variants of innovative burgers were obtained, differing in the proportion of juices in the recipe. The pH of meat stuffing, thermal losses, production yield, color (CIE L*a*b*), content of polyphenolic compounds, degree of oxidation of the lipid fraction (TBARS), and antioxidant activity against ABTS radicals were determined. Anti-diabetic activity was measured as the ability to inhibit α-glucosidase and dipeptidyl peptidase−4 activity. A sensory evaluation was also performed. Results: Beef burgers formulated with açaí and sea buckthorn juices had up to five times higher total polyphenol content than burgers without added juices. The addition of the juices increased antioxidant activity against ABTS radicals (from 42 to 440 µmol/L/100 g) and effectively inhibited oxidation of the lipid fraction of the beef burgers. Recipe modifications resulted in changes in the color parameters of the beef burgers and had a positive effect on the sensory quality attributes evaluated. Beef burgers containing 0.5 g of açaí juice and 1.0 g of sea buckthorn juice were rated the best in terms of acceptability of appearance, aroma, color, juiciness, and tenderness. The addition of açaí and sea buckthorn juice did not increase the inhibitory activity against α-glucosidase and dipeptidyl peptidase-IV of the innovative beef burgers. Conclusions: The proposed recipe modification may be an effective way to fortify beef burgers with phytochemicals with antioxidant properties while maintaining their sensory properties.

Keywords: meat quality; beef burgers; sea buckthorn; açaí; antioxidant activity; α-glucosidase

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1. Introduction

Modern consumers expect food not only to satisfy hunger but also to be nutritious, tasty, safe to eat, and convenient. They are looking for natural, organic, short-formulation products free of synthetic food additives [1]. Health-oriented consumers are interested in foods that contain ingredients that promote health and well-being [2]. Superfoods meet these expectations. Superfoods are known as foods that have a high nutritional and biological value due to a high concentration of bioactive compounds with a satisfactory bioavailability [3]. These include many raw materials of plant origin, such as goji, blueberries, tea, camu-camu, quinoa, chia seeds, flaxseeds, and pomegranate [4,5]. Açaí (*Euterpe oleracea* Mart.) and sea buckthorn fruits (*Hippophae rhamnoides* L.) are also mentioned.

Açaí fruits have strong antioxidant effects, slow down the aging process, and inhibit cancer [6]. The anthocyanins they contain strengthen eyesight, seal and nourish fine capillaries, and counteract the formation of blood clots [7]. Açaí fruits also exhibit cognitive effects, like adaptogens, improving thought processes and enhancing concentration, regulating blood sugar levels, maintaining proper cholesterol levels, improving digestion, and increasing vitality [8].

Sea buckthorn fruits are also attributed with medicinal properties. They are used to treat avitaminosis, intestinal and gastrointestinal diseases, inflammation of the lungs and joints, skin diseases, hypertension, and asthma. The fruits of this shrub increase the efficiency of the immune system, have atherosclerotic potential, and delay the aging process. Sea buckthorn fruits also show antimicrobial activity [9–11].

The potential of açaí is being utilized in the development of innovative products, such as yogurts [12,13], smoothies, energy drinks [14], and yanggaeng [15]. In turn, the bioactive compounds of sea buckthorn, including polyphenols, fatty acids, vitamins, and phytosterols, are used in popular foods, like bread, yogurt, and jam, and beverages such as tea [16,17]. The use of açaí as a natural antioxidant in pork patties during cold storage was studied by Bellucci et al. [18]. A dose of 250 $mg.kg^{-1}$ of açaí extract improved the antioxidant status and can replace sodium erythorbate to preserve the quality and extend the shelf life of chilled pork patties. On the other hand, Hanula et al. [17] demonstrated that lyophilized hydrogels enriched with encapsulated açaí oil can be used as a fat substitute in beef burgers while improving the nutritional value of the burger by reducing saturated fatty acids and enriching polyunsaturated fatty acids.

Other authors used the functional properties of sea buckthorn fruits to improve selected quality characteristics of pork sausages. Salejda, Tril, and Krasnowska [19]; Salejda, Nawirska-Olszańska, Janiewicz, and Krasnowska [20]; and Mesárošova et al. [21] confirmed that incorporation of sea buckthorn fruits in dried form or extracts slowed oxidative deterioration of pork sausages during storage. In addition, studies by Salejda, Nawirska-Olszańska, Janiewicz, and Krasnowska [20] confirmed that a 3% addition of sea buckthorn fruit extract exhibited antimicrobial properties by significantly reducing the total number of bacteria in pork sausages compared to the control. Similar results were obtained by Wagh and Chatli [22], who used sea buckthorn extract as an additive to ground pork stored at -18 ± 1 °C for 9 days.

Despite the beneficial effects of the compounds found in both açaí and sea buckthorn on selected quality attributes of meat products, there are no reports in the literature on the use of their combination for this purpose. Therefore, the aim of this study was to evaluate the effect of the combination of açaí and sea buckthorn fruit juices on the physicochemical, antioxidant, organoleptic, and anti-diabetic properties of innovative beef burgers.

2. Materials and Methods

2.1. Reagents

All reagents and organic solvents were of analytical grade. The water was distilled and deionized. The standard of gallic acid (GA) was purchased from Extrasynthese (Genay, France). 2,2′-azino-bis (3-ethylbenzthiazoline−6-sulphonic acid) (ABTS), 6-hydroxy−2,5,7,8-tetramethylchroman−2-carboxylic acid (Trolox), α-glucosidase, p-nitrophenyl-α-D-glucopyranoside (pNPG), Gly-Pro-p-nitroanilide, and 2-thiobarbituric acid (TBA) were obtained from Sigma Chemical Co. (Steinheim, Germany). Folin–Ciocalteu reagent, methanol, trichloroacetic acid, sodium carbonate, potassium persulfate, and potassium phosphate were obtained from POCh (Gliwice, Poland).

2.2. Material

The experimental material consisted of burgers obtained from boneless beef class I (Meat Processing Plant Dworecki, Golejewo, Poland) with the addition of salt (Żuk-Pol, Wrocław, Poland) with different proportions of açaí (Bio Planet S.A., Leszno, Poland) and sea buckthorn juices (Polska Róża, Raszyn, Poland). The juices were shop-bought. According to the label, they were made from 100% organic farm fruit, pressed, unglazed, and pasteurized. The experiment was planned in two stages. The first consisted of a pilot study in which experimental variants were selected for the second, main stage of the work.

In the first stage of this study, nine beef burger variants were prepared, where each variant had a different content of açaí (A) and sea buckthorn (R) juices. In the second stage, four variants were selected with the highest sensory acceptability (A05R0, A05R05, A05R1, A0R05). The reference sample (variant A0R0) consisted of beef burgers made without juices in the recipe. The formulation of the innovative beef burgers is shown in Table 1.

Table 1. Formulation of beef burgers with açaí (A) and sea buckthorn juices (R).

Formulation	Ingredients (g)			
	Beef	Salt	Açaí Juice (A)	Sea Buckthorn Juice (R)
A0R0 *	98.8	1.2	0.0	0.0
A05R0 *	98.3	1.2	0.5	0.0
A1R0	97.8	1.2	1.0	0
A05R05 *	97.8	1.2	0.5	0.5
A0R1	97.8	1.2	0	1.0
A05R1 *	97.3	1.2	0.5	1
A1R05	97.3	1.2	1	0.5
A05R1	97.3	1.2	0.5	1.0
A0R05 *	98.3	1.2	0.0	0.5

* variants selected to the main stage of this study.

The innovative beef burgers were prepared as follows: beef was cut into pieces and subsequently ground (ø 5 mm, Zelmer MM1200.88, BSH Sprzęt Gospodarstwa Domowego Sp. z o.o., Warszawa, Poland); then, the meat mass was mixed with the remaining ingredients (salt, açaí and/or sea buckthorn fruit juices) and formed on a manual burger press into discs with a diameter of 10 cm, a thickness of approximately 15 mm, and a weight of approximately 98 g. Subsequently, the formed burgers were subjected to heat treatment (baking in a convection oven) at 180 ± 5 °C for 6 min or until a temperature of 75 °C was reached at the geometric center. Next, the beef burgers were put on a paper towel and subjected to relaxation to obtain room temperature. The burgers were then divided into two parts: the first for analysis at "day 0" and the second, which was vacuum-packed in PA/PE bags and stored at 4 ± 2 °C for 14 days, for further analysis. The beef burgers were produced in two independent production batches.

2.3. Methods

2.3.1. pH Value

The pH measurement was carried out using a Fisherbrand™ accumet™ AE150 Benchtop pH Meter (Thermo Fisher Scientific, Waltham, MA, USA) by immersing a single junction gel electrode (Fisherbrand™ accumet™ AE series, Thermo Fisher Scientific, Waltham, MA, USA) directly into the açaí and sea buckthorn fruit juices and meat stuffing of all the innovative burger formulations. The assay was performed in duplicate.

2.3.2. Thermal Losses and Yield

The weight losses (WL) of the beef burgers after heat treatment and the yield of the production process (Y) were determined using the weight method, equally for each variant. The burgers were weighed with an accuracy of 0.01 g before and after heat treatment. Weight losses and yield of production were calculated according to the following formulas:

$$WL (\%) = (a - b)/a \times 100\%$$

$$Y (\%) = (b \times 100\%)/a$$

a—weight of burger before heat treatment b—weight of burger after heat treatment

The determination was made in three repetitions for each variant.

2.3.3. Determination of Total Polyphenols Content

The determination of total polyphenols content (TPC) in the açaí and sea buckthorn juices and innovative beef burgers was based on the method of Gao et al. [9] with the slight modification proposed by Przybylska et al. [23]. A total of 0.5 g of each test sample was weighed into 15 mL falcon tubes. The falcon tubes were supplemented with 8 mL of 80% methanol. The tubes were placed in an ultrasonic water bath for 15 min (Elmasonic P30H, Elma, Singen, Germany). The samples were then placed in a refrigerator for 24 h. After the cooling time, they were again subjected to sonication and centrifuged (13,900 rpm/5 min). Then, 0.1 mL of filtrate was placed in each well of a 96-well plate and then mixed with 0.2 mL of Folin–Ciocalteu reagent, 2 mL of H_2O, and 1 mL of 10% sodium carbonate and shaken automatically for 30 s. The samples were left in a dark place at room temperature for one hour. The absorbance was then measured on a UV spectrophotometer (2401 PC Shimadzu, Kyoto, Japan) at 765 nm against distilled water. The absorbance measurement was performed in triplicate for each sample. The standard curve was prepared using different concentrations of gallic acid. The results were calculated as mg of gallic acid equivalent (GAE) per 100 g of the extract.

2.3.4. ABTS Radical Scavenging Activity

The determination of ABTS radical scavenging activity of the açaí and sea buckthorn fruit juices and innovative beef burgers was performed according to the method described by Re et al. [24] and Nawirska-Olszańska et al. [25]. ABTS was dissolved in distilled water to obtain a concentration of 7 mmol/L and then mixed with 2.45 mmol/L potassium persulfate to form the cation radical. The solution thus prepared was stored without light at room temperature for 20 h. To prepare the calibration curve, the absorbance of samples with appropriate concentrations of the standard substance, namely 0–15 µmol/L Trolox, was measured at 734 nm. The ABTS radical solution was diluted with distilled water until the absorbance reached 0.70 at 734 nm. For the analysis, 0.03 mL of the samples (juices and beef burgers supernatant) was added to 3 mL of the diluted ABTS reagent, respectively. After 6 min, the absorbance at 734 nm was measured (UV spectrophotometer 2401 PC Shimadzu, Kyoto, Japan). The absorbance measurement was performed in triplicate for each sample. The results were averaged and expressed as uMol TE (Trolox eq.)/100 g.

2.3.5. Degree of Lipid Oxidation—TBARS Analysis

The degree of lipid oxidation was evaluated by spectrophotometric measurement of the amount of substances color-reacting with 2-thiobarbituric acid (TBARS) according to the method of Buege and Aust [26], modified and described by Jin, Choi, Lee, Lee, and Hur [27]. The analysis was performed immediately after production (0 day) and on the 14th day of storage in three repetitions. The absorbance was measured at a wavelength of 531 nm (UviLine SI 5000, Xylem Analytics, Weilheim, Germany) against a blank. TBARS was expressed as mg malondialdehyde (MDA) per kg of sample.

2.3.6. Color Measurement

The color measurement of the beef burgers was performed using a Minolta CR−400 (Konica Minolta Sensing, Osaka, Japan) reflective colorimeter immediately after production (0 day). The colorimeter was set at D65 illuminant and 10° standard observer and calibrated before each measurement against a standard white tile (Y = 93.8, x = 0.313, y = 0.319). The measurement was made in triplicate for each production variant, taking three measurements of non-overlapping surface zones of each burger. Lightness (L*), redness (a*), and yellowness (b*) coordinates in the CIE Lab system were determined.

2.3.7. Sensory Evaluation

The sensory evaluation was carried out on the day of production of the beef burgers (0-day) by 10 evaluators selected from the staff of the University of Environmental and Life Sciences in Wroclaw. They were all regular consumers of meat products and were trained according to ISO 8586 [28,29] and ISO 13299 [30]. The evaluators were informed about the principles of the sensory evaluation before the evaluation and fulfilled the criteria for the sensory evaluation of beef burgers. The following distinguishing features were evaluated: appearance, aroma, taste, color, hardness, juiciness, and overall acceptability. Five samples of the beef burgers (2 cm × 2 cm), marked with a 4-character code, were subjected to the evaluation at room temperature (22 ± 1 °C) under white light. A five-point acceptance rating scale was used (from 1 to 5, where 5 means the highest degree of acceptance).

2.3.8. Anti-Diabetic Activity

The analysis of α-glucosidase inhibitory activity was performed according to the method of Yu et al. [31]. A total of 5 μL of the α-glucosidase solution (10 U/mL, in 0.1 M potassium phosphate buffer, pH 6.8) was premixed with 10 μL of extract from burger meat in 620 μL of 0.1 M potassium phosphate buffer (pH 6.8). Following incubation at 37.5 °C for 20 min, 10 μL of 10 mM p-nitrophenyl-α-D-glucopyranoside (pNPG) as substrate was added to the reaction mixture to start the enzymatic reaction and was then incubated at 37 °C for 30 min, followed by the addition of 650 μL of 1 M Na_2CO_3 solution to terminate the reaction. The amount of released p-nitrophenol was measured at λ = 410 nm. The inhibition activity was calculated using the following equation:

$$\text{Inhibition activity (\%)} = [(A - B)/A] \times 100\%$$

A—Reaction blank, of which the mixture contained the same volume of the buffer solution instead of the enzyme inhibitor sample; B—reaction in the presence of both enzyme and its inhibitor.

The half maximal inhibitory concentration (IC50) was estimated from a dose–response curve of an inhibitor versus the % of the α-glucosidase activity.

DPP−4 inhibitory activity (IC50) was determined using the method of Lacroix and Li-Chan [32]. The extract from a burger meat (25 μL) was mixed with 0.1 M Tris–HCl buffer, pH 8.0 (25 μL), and preincubated with an equal volume of DPP−4 (0.01 U/mL, in 0.1 M Tris–HCl buffer, pH 8.0) at 37 °C for 15 min. Afterwards, 50 μL of the substrate Gly-Pro-p-nitroanilide (1.6 mM) of DPP−4 (0.01 U/mL, in 0.1 M Tris–HCl buffer, pH 8.0) was added, and the reaction mixture was incubated at 37 °C for 60 min. The reaction was stopped by the addition of 100 μL of 1 M sodium acetate buffer, pH 4.0. The released p-nitroanilide was measured at λ = 405 nm. The IC50 value was defined in the same way as for α-glucosidase.

2.3.9. Statistical Analysis

The collected data of two production batches of beef burgers were analyzed statistically using TIBCO Statistica, version 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). Analysis of variance (ANOVA) and Duncan's multiple range test allowed for the determination of the statistically significant differences ($p < 0.05$). The results are presented as the mean ± SE (standard error).

3. Results

The pH values of the meat mass prepared to obtain the innovative beef burgers ranged from 4.6 to 5.4 (Figure 1). The lowest pH values were measured in the beef burgers manufactured with the addition of 0.5 g açaí juice and 1.0 g sea buckthorn juice (A05R1), and the highest pH values were measured in the control samples (A0R0) of the beef burgers, prepared without juices in the formulation. It was observed that the addition of the juices decreased the pH of the meat mass, especially with the increasing amount of sea buckthorn juice in the formulation. This may be related to the acidity of the açaí and sea buckthorn juices used (5.2 and 4.6, respectively). Studies by other authors also confirm a reduction in the acidity of the stuffing after the addition of high-acid fruits, e.g., chokeberry [33], cranberry and rose [34,35], sea buckthorn [19,20], cornelian cherry [36], and guelder rose [37].

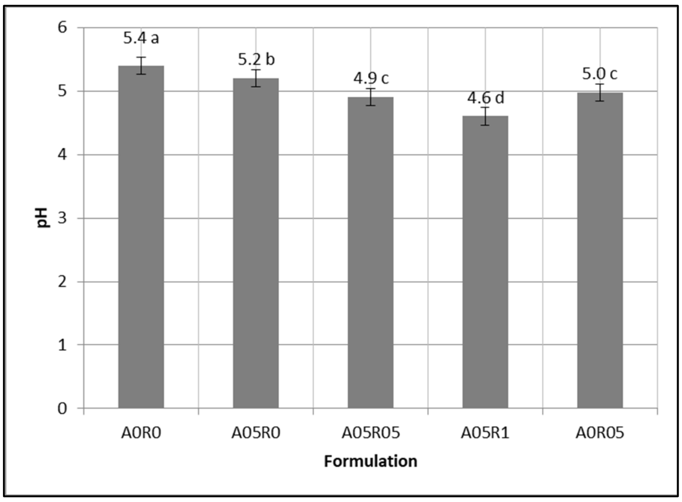

Figure 1. pH values of the meat mass for innovative beef burgers. a–d—means with superscript for the same parameter differ significantly at the level of $p \leq 0.05$.

The addition of açaí and sea buckthorn juices had no significant effect on the weight losses of the beef burgers during heat treatment and, at the same time, on the yield of the production process of the beef burgers. After heat treatment, samples of the beef burgers lost from 41.2% (A0R0) to 38.9% (A05R1) of their initial weight. Lower weight loss resulted in higher production yield. The highest production yield was obtained in the samples with the highest addition of juices (A05R1, 62%). This could be related to the high dietary fiber content of açaí and sea buckthorn berries [38–40]. The addition of fiber to the meat matrix can lead to a reduction in cooking loss, pH adjustment, and an increase in water–oil emulsion stability, resulting in higher production efficiency of emulsion-type meat products [41].

Plants and fruits contain phenolic compounds than can help to protect human cells from the oxidative damage caused by free radicals and reduce the risk of degenerative diseases, various types of cancer, and neurological diseases [42]. These phytochemicals can be used as natural ingredients and exert an antioxidant capacity in meat systems [43]. The utilization of antioxidants in meat products contributed to the inhibition of the activities of various radicals (e.g., DPPH, ABTS, and hydroxyl radicals), thiobarbituric reactive substances (TBARS), free fatty acids, volatile basic nitrogen, and peroxide value [44]. The açaí and sea buckthorn juices used in this study contained a high amount of polyphenols (10,472.6 mg/100 g and 2758.9 mg/100 g, respectively); hence, a high antioxidant activity against ABTS radicals was measured (Table 2, 8235.0 µmol/L/100 g and 2145.1 µmol/L/100 g, respectively). The addition of the juices increased the bioactive compound content of the innovative beef burgers. The highest polyphenol content, five times higher than in the control samples, was observed in the samples with the highest amount of both açaí and sea buckthorn juices (A05R1). The highest ABTS radical scavenging activity was also determined in these samples. Numerous studies have confirmed our findings and demonstrated that plant-based antioxidant materials can act as antiradical agents in meat products, i.e., ethanol extracts of black currant [45], ethanol extracts of curry leaf and water extract of mint leaf in pork patties [46], ethanol extract of rosemary and rosemary essential oil [47], fermented blueberry in emulsion-type sausage [48], ethanol extracts of green leafy vegetables [49], and water extract of hibiscus in beef patties [50].

Table 2. Results of total polyphenolic content (TPC) and ABTS radical scavenging activity.

Formulation	TPC (mg GAE/100 g)	ABTS (µmol TE/100 g)
A0R0	123.1 ^{a} ± 1.13	42.4 ^{a} ± 0.11
A05R0	342.6 ^{b} ± 2.06	114.3 ^{b} ± 1.25
A05R05	433.7 ^{c} ± 2.54	225.2 ^{c} ± 1.05
A05R1	606.1 ^{e} ± 9.29	437.3 ^{e} ± 33.70
A0R05	506.2 ^{d} ± 0.90	353.9 ^{d} ± 4.05
Sea buckthorn juice	2758.9 ± 53.80	2145.1 ± 129.90
Açaí juice	10472.6 ± 302.60	8235.0 ± 943.00

The results are presented as mean and standard error (SE); a–e—means with superscript for the same parameter differ significantly at the level of $p \leq 0.05$.

In our study, the introduction of açaí and sea buckthorn juices into the formulation resulted in low TBARS levels in the innovative beef burgers (Figure 2). Malondialdehyde (MDA) concentration ranged from 0.14 mg/kg (A05R05 formulation samples) to 0.29 mg/kg (A0R0 formulation samples). In our study, a significant increase in MDA concentration was observed in all experimental variants after the storage time (14 day), but the addition of the juices effectively slowed down the oxidation. This may be related to the high amount of phytochemicals in the juices used. Phytochemicals with antioxidant properties can inhibit lipid oxidation by scavenging oxidation-initiating radicals, breaking chain reactions, decomposing peroxides, reducing local oxygen concentrations, and binding with metal ions [44]. The limitation of lipid oxidation by phytochemicals of fruit-based materials in beef meat products has been confirmed by, among others, studies on ground beef with added mustard [51]; beef patties with plum puree [52], with white grapes [53], and with black chokeberry, blackberry, red currant, and blueberry [54]; and beef jerky with Japanese apricot and yuzu [55].

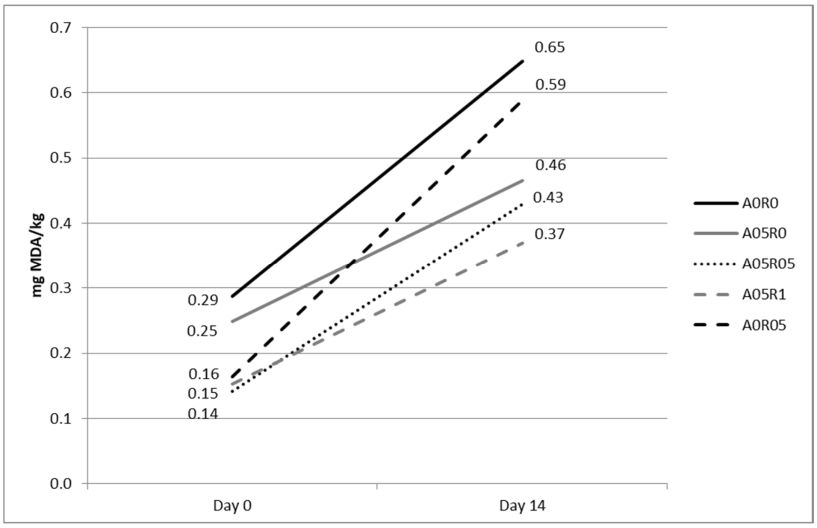

Figure 2. TBARS values of innovative beef burgers.

One limitation in the use of plant materials is the potential effect of their pigments on the color of meat products. Açaí berries are rich in anthocyanins, which are responsible for their deep purple color [56]. The yellow–orange color of sea buckthorn fruit is due to the presence of carotenoids [57]. The statistical analysis showed that there was no effect of either açaí juice or sea buckthorn juice on the color parameters L*, a*, and b* of the experimental innovative beef burgers (Figure 3). However, differences between the values were observed. On the day of production, the values of the L* parameter in the burger samples with only added açaí juice (A05R0) were similar to those obtained in the control samples (A0R0) produced without added juices (35.3 and 34.8, respectively). Similar results were observed by Salejda, Kucharska, and Krasnowska [36] in beef burgers treated with cornelian cherry juice and by Nuñez de Gonzalez et al. [58] in precooked roast beef produced with fresh and dried plum juice concentrates. The lack of a significant effect of the anthocyanins contained in the açaí juice may be related to its dose, or they may have oxidized to colorless compounds during the heat treatment of the innovative beef burgers [59,60]. In contrast, the introduction of sea buckthorn juice into the recipe resulted in an increase in the lightness (L* values) of the innovative beef burgers due to the abundance of yellow and orange pigments. The same results were observed for the b* parameter, which describes the proportion of yellow in the entire color space of the beef burgers. The redness (a* parameter) of the innovative beef burgers was not only due to changes in myoglobin during heat treatment but was also influenced by the added juices. The highest a* values were measured in the samples containing only ground beef (A0R0). Açaí and sea buckthorn juices added to the meat mass caused a decrease in this parameter, as in the study of [61] on beef patties formulated with dried pumpkin pulp and seeds.

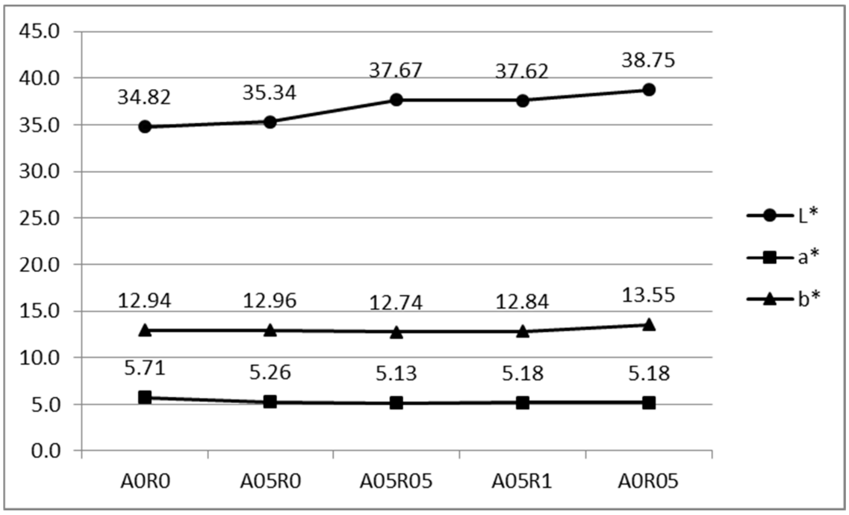

Figure 3. L*, a*, and b* values of innovative beef burgers.

The acceptance of sensory properties of the innovative burgers was also evaluated (Figure 4). Burgers A05R1, containing 0.5 g of açaí juice and 1.0 g of sea buckthorn juice, were rated the best in terms of acceptability of appearance, aroma, color, juiciness, and tenderness. They also received the highest marks in the overall assessment. Samples A05R0, with the addition of 0.5 g of açaí juice, were rated the best in terms of taste acceptability. The control samples were rated the lowest in terms of all assessed factors, except for taste; the acceptability was low and only 0.2 points higher than in the A05R05 samples. The type of plant material used has a significant effect on the perception of organoleptic properties; for example, Fadıloğlu and Çoban [62] showed that the enrichment of meat products (semi-smoked sausages) with plant raw materials (goji berries) has a positive effect on their organoleptic properties. Tril, Salejda, and Krasnowska [33] came to a different conclusion and showed that the introduction of chokeberry juice into meat-fat stuffing resulted in a lower acceptability of the overall appearance, smell, taste, and color of pork sausages. The amount of plant-based additives also makes a difference, as confirmed by studies by Salejda, Kucharska, and Krasnowska [36], where increasing the addition of cornelian cherry juice to beef burgers resulted in a greater aroma acceptability. On the other hand, other organoleptic characteristics, such as taste, color, juiciness, hardness, and overall assessment, were rated highest in the samples with the lowest (0.5 g) addition of cornelian cherry juice.

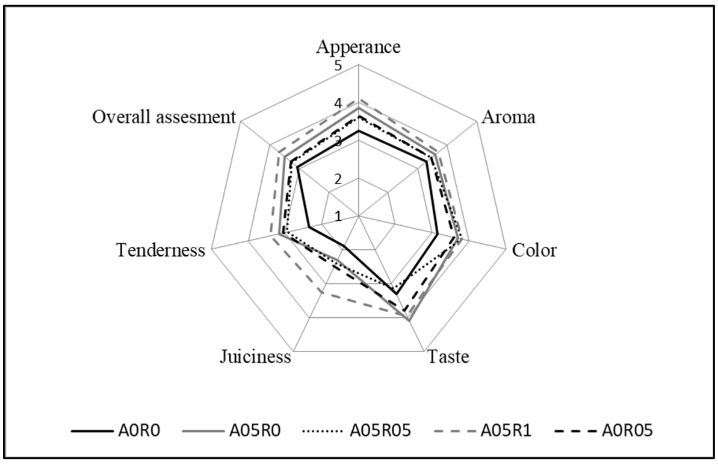

Figure 4. Results of organoleptic evaluation of innovative beef burgers.

Several studies have shown anti-diabetic effects of berries rich in polyphenols, which can affect blood glucose levels by inhibiting the digestive enzymes involved in the breakdown and absorption of carbohydrates [63–65]. Whether the applied juices of açaí and sea buckthorn have such properties was tested in our own research. The in vitro anti-diabetic activity of the juices used in the innovative beef burgers is presented in Table 3.

Table 3. Anti-diabetic activity of innovative beef burgers.

	Formulation				
Inhibition * (%)	**A0R0**	**A05R0**	**A05R05**	**A05R1**	**A0R05**
α-glucosidase	12.1	7.6	7.0	12.0	3.8
DPP-IV	10.1	9.1	6.6	9.2	3.0

* % enzyme inhibition for 10% aqueous extracts of samples; DPP-IV—dipeptidylpeptidase-IV.

The beef burgers made only from beef and salt (A0R0) showed low inhibitory activity against α-glucosidase and dipeptidyl peptidase-IV (12.1% and 10.1%, respectively). Despite the use of açaí and sea buckthorn juices with a high polyphenol content, their addition did not increase the inhibitory activity of the innovative beef burgers. Only the samples (A05R1) of the innovative beef burgers with 0.5 g of açaí juice and 1.0 g of sea buckthorn juice in the recipe showed lower but similar activity against α-glucosidase and DPP-IV as the A0R0 samples. The lack of synergistic effect of the botanical additives used was also observed by Wihansah, Pazra, Wahyuningsih, and Handayani [66] in yogurts using a combination of cinnamon, fenugreek, and aloe vera extract. Knowledge on the anti-diabetic effect of plant raw materials introduced as ingredients in foods of animal origin is scarce, and therefore, further research on the interaction of their bioactive components with components of protein–fat matrices is needed.

4. Conclusions

The aim of this study was to evaluate the effect of açaí and sea buckthorn fruit juice addition on the physicochemical, antioxidant, organoleptic, and anti-diabetic properties of innovative beef burgers. The addition of açaí and sea buckthorn fruit juices increased the total polyphenol content in the innovative beef burgers. Moreover, the addition of açaí and sea buckthorn juices increased the antioxidant properties against ABTS radicals and effectively retarded the oxidation of the lipid fraction. The changes in the recipe did not have a significant effect on the weight loss and yield of the beef burgers and had a positive effect on the sensory quality characteristics evaluated. On the other hand, we did not observe an increase in anti-diabetic activity after the addition of açaí and sea buckthorn fruit juices to the innovative beef burgers. Therefore, we conclude that açaí and sea buckthorn juices could be an interesting natural material, and innovative beef burgers with their addition could be a source of phytochemicals with antioxidant properties in the diet.

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