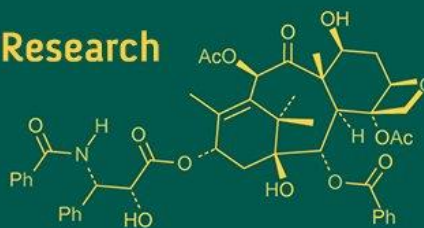


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Effect of dragon fruit (*Hylocereus polyrhizus*) peel powder on antioxidant activity, physicochemical characteristics and sensory quality of functional chicken sausages

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Abstract

This study was conducted to evaluate the antioxidant effect of dragon fruit peel powder on the physicochemical, antioxidant and sensory characteristics of chicken sausages. Dragon fruit peel powder was incorporated into the sausage formulation at levels of 2.0%, 2.5% and 3.0% (w/w). A significant ($p < 0.05$) increase was observed in emulsion pH, product pH, emulsion stability, cooking yield, water-holding capacity, moisture retention, fat retention, drip loss, total phenolic content, DPPH radical scavenging activity and reducing power as the level of dragon fruit peel powder increased in the formulation. A similar trend was observed in the proximate composition of the chicken sausages. Chicken sausages incorporated with 2.5% dragon fruit peel powder received significantly higher sensory scores for all evaluated attributes. Based on the physicochemical characteristics, proximate composition, antioxidant properties and sensory evaluation, chicken sausages incorporated with 2.5% dragon fruit peel powder were found to be the optimum formulation. In addition, the study demonstrated that dragon fruit peel powder has the potential to reduce lipid oxidation in chicken sausages.

Keywords: Dragon fruit peel powder, chicken sausages, antioxidant property, DPPH radical scavenging activity

Introduction

Poultry meat contributes 49.27% of India's total meat production, with a production of 5.18 million tonnes out of the national total of 10.50 million tonnes during 2024-25 (Basic Animal Husbandry Statistics, 2025) [5]. India ranks fourth in the world in overall meat production, while poultry meat production places the country approximately fourth to fifth globally, depending on the specific metrics used for chicken and broiler production. Foods of animal origin are particularly rich in highly bioavailable protein, iron, zinc, vitamins A, B2 and B12, which are often deficient or absent in vegetarian diets (Bruyn *et al.*, 2015) [8]. Processing of meat into meat products involves several operations, including physical alteration (e.g., mincing), heat treatment (e.g., frying and baking) and storage under controlled conditions (e.g., marination). These processing activities lead to the generation of oxygen free radicals, which initiate the oxidation of polyunsaturated fatty acids, resulting in the deterioration of the natural antioxidant system (Karakaya *et al.*, 2011) [12]. Meat preservation has traditionally been achieved through the addition of synthetic preservatives. However, regular consumption of these synthetic compounds over prolonged periods may pose significant health risks. Fruits and vegetables are rich sources of antioxidant and antimicrobial compounds and their frequent consumption has been associated with a reduced risk of various diseases, including cancer (Renaud *et al.*, 1998; Temple, 2000) [20, 23].

Dragon fruit (*Hylocereus polyrhizus*) peel is rich in dietary fibre (56.91%), predominantly insoluble dietary fibre and contains considerable amounts of phenolic compounds (36-39 mg GAE/100 g), with high radical scavenging activity and reducing power. Dragon fruit peel constitutes more than 20% of the fresh fruit by weight and is generally discarded as waste after consumption (Putra *et al.*, 2024) [19]. Dragon fruit peel is emerging as a functional food ingredient because of its high dietary fibre content and antioxidant capacity.

Recent studies have reported the incorporation of dragon fruit peel into ice cream, bread, noodles, cookies and sausages (Vilcapoma *et al.*, 2023) [24].

Sausages are among the most popular value-added meat products consumed worldwide. However, they are deficient in dietary fibre and are highly susceptible to lipid oxidation, quality deterioration and the development of warmed-over flavour during storage. These limitations can be overcome by incorporating antioxidant dietary fibre (ADF) derived from fruits and vegetables, which enhances antioxidant potential, increases dietary fibre content and improves product functionality. Although a few studies have reported the potential benefits of dragon fruit peel powder in meat and meat products, limited information is available regarding its effects on the antioxidant properties and overall quality characteristics of chicken sausages. Therefore, the present study was undertaken to evaluate the effect of dragon fruit peel powder incorporation on the antioxidant properties and quality attributes of chicken sausages.

Materials and Methods

Meat source: Live broiler chickens were procured from the local market and slaughtered following standard procedures at the Department of Livestock Products Technology, Veterinary College and Research Institute, Orathanadu. The carcasses were trimmed to remove external fat, skin and connective tissue, thoroughly washed, and deboned. The

deboned meat was stored overnight at -20°C in a deep freezer and minced the following day using a meat mincer (Model: Primus MEW 713, Mado GmbH, Germany) for further processing.

Preparation of dragon fruit peel powder: Fresh dragon fruit peels were collected from commercial fruit juice processing units in Thanjavur. The peels were thoroughly washed under potable running water to remove adhering extraneous matter, shade-dried for 2-4 days and subsequently dried in a hot-air oven at 60°C for 5-6 h. The dried peels were ground using a mixer, sieved to obtain a fine powder, packed in sterile polyethylene pouches and stored under refrigeration until use. The required quantity of dragon fruit peel powder was incorporated into the chicken sausage formulations for the development of functional chicken sausages.

Selection of the optimum level of dragon fruit peel powder in chicken sausages: Chicken sausages were prepared by incorporating dragon fruit peel powder at three different levels (2.0%, 2.5% and 3.0%) through partial replacement of chicken meat in the formulation. Control sausages were prepared without the addition of dragon fruit peel powder. Six independent trials were conducted, and the products were evaluated for physicochemical and sensory characteristics.

Table 1: Chicken sausages formulations with dragon fruit peel powder

Ingredients (%)	Control	Level of dragon fruit peel powder		
		T ₁	T ₂	T ₃
Chicken meat	73.0	71.0	70.5	70.0
Dragon fruit peel powder	-	2.0	2.5	3.0
Salt	1.5	1.5	1.5	1.5
Sodium tri poly phosphate	0.5	0.5	0.5	0.5
Dry spice mix	1.5	1.5	1.5	1.5
Condiments mix	3.0	3.0	3.0	3.0
Vegetable oil	7.5	7.5	7.5	7.5
Refined wheat flour	3.0	3.0	3.0	3.0
Ice flakes	10.0	10.0	10.0	10.0

Preparation of functional chicken sausages: Frozen chicken meat was thawed overnight under refrigeration, cut into small chunks and minced using a meat mincer (Model: Primus MEW 713, Mado GmbH, Germany) fitted with a 6 mm plate followed by a 4 mm plate. The other ingredients, including common salt, vegetable oil, refined wheat flour, sodium tripolyphosphate, spice mixture and condiment mixture, were accurately weighed according to the formulation. Meat emulsion was prepared using a bowl chopper (Model: TC 11, Schaefer, Germany). Minced meat was first blended with salt and sodium tripolyphosphate for 1.5 min, followed by the addition of crushed ice and further mixing for 1 min. Refined vegetable oil was then added gradually and chopping was continued until the oil was uniformly dispersed throughout the emulsion. Subsequently, the spice mixture, condiment mixture and refined wheat flour were added and mixing was continued for an additional 1.5-2 min to obtain a fine, viscous emulsion. Care was taken to maintain the final emulsion temperature below 18°C .

The prepared emulsion was stuffed into artificial cellulose casings using a sausage filler (Model: SF-260) and linked at

approximately 12 cm intervals. The sausages were cooked in a steamer (ALS, Chennai, India) until the core temperature reached 75°C (approximately 30 min), as monitored using a probe-type thermometer (Winner, DTM 993, India). After cooking, the sausages were cooled to room temperature, aerobically packed in LDPE pouches using a packaging machine and stored overnight under refrigeration at $4 \pm 1^{\circ}\text{C}$. The sausage samples were subsequently subjected to physicochemical and sensory analyses to determine the optimum incorporation level of dragon fruit peel powder in functional chicken sausages.

Physicochemical parameters: The pH of the emulsion and cooked sausage samples was measured using a digital pH meter (Model LMPH 9, Labman, India). Emulsion stability was determined according to the method of Baliga and Madaiah (1971) [4] with slight modifications. Water-holding capacity (WHC) was estimated following the procedure described by Wardlaw *et al.* (1973) [25]. Cooking yield was determined according to Anna Anandh *et al.* (2008) [1], whereas moisture retention and fat retention were calculated using the methods described by El-Magoli *et al.* (1996) [9].

Juiciness was evaluated using the filter paper press method described by Mallikarjunan and Mittal (1994)^[17], and drip loss was determined after storing the samples at 4 ± 1 °C for 24 h by recording the percentage weight loss. Total phenolic content (TPC) was estimated using the Folin-Ciocalteu method (Escarpa and González, 2001)^[10] and expressed as mg gallic acid equivalents (GAE)/g of sample. Antioxidant activity was assessed by measuring 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity according to Fargère *et al.* (1995)^[11], while reducing power was determined following the method of Oyaizu (1986)^[18].

Proximate composition: The moisture, protein, fat, ash and crude fibre contents of the control and functional chicken sausages were determined using standard methods involving a hot-air oven, Kjeldahl apparatus, Soxhlet extraction apparatus and muffle furnace, respectively (AOAC, 1995)^[2]. The dietary fibre content of the functional chicken sausages was estimated using the modified enzymatic-gravimetric method described by AOAC (2012)^[3].

Sensory evaluation: The organoleptic qualities of the chicken sausage samples were evaluated for appearance, colour, flavour, juiciness, tenderness, texture and overall acceptability using a 9-point hedonic scale (9 = extremely desirable; 1 = extremely undesirable), as described by Keeton (1983)^[13]. Sensory evaluation was carried out by a panel comprising trained and semi-trained faculty members

and postgraduate students of the Veterinary College and Research Institute, Orathanadu.

Statistical analysis: The data generated from six independent trials of each experiment were analysed using SPSS software (Version 20.0). Analysis of variance (ANOVA) was performed following the procedures described by Snedecor and Cochran (1989)^[22]. Treatment means were compared and the effects of treatment were interpreted for the various parameters evaluated.

Results and Discussion

Physicochemical parameters: The effects of dragon fruit peel powder incorporation on the physicochemical and antioxidant properties of chicken sausages are presented in Table 2. The emulsion pH values showed a non-significant decrease from the control (6.48 ± 0.03) to T₃ (6.32 ± 0.03), whereas the product pH values decreased significantly ($p < 0.01$) from the control (6.44 ± 0.01) to T₃ (6.32 ± 0.02). The lowest emulsion and product pH values were observed in T₃, followed by T₂, T₁ and the control. The decrease in pH with increasing levels of dragon fruit peel powder might be attributed to the presence of organic acids and phenolic compounds in the dragon fruit peel. The present findings are in agreement with those of Bellucci *et al.* (2021)^[6], who reported reduced pH values in pork patties incorporated with dragon fruit peel owing to its acidic nature and phenolic composition.

Table 2: Effect of incorporation of dragon fruit peel powder on physico-chemical and antioxidant properties of chicken sausages

Parameters	Level of dragon fruit peel powder				P Value
	Control (0%)	T ₁ (2%)	T ₂ (2.5%)	T ₃ (3%)	
Physico-chemical parameters*					
Emulsion pH	6.48 ± 0.03	6.40 ± 0.02	6.38 ± 0.03	6.32 ± 0.03	0.0851
Emulsion stability (%)	90.75 ± 2.15	93.40 ± 2.19	94.26 ± 1.86	94.56 ± 1.68	0.5280
Cooking yield (%)	96.45 ± 0.78	97.04 ± 0.49	97.20 ± 0.34	97.87 ± 0.20	0.2914
Product pH	6.44 ± 0.01 ^a	6.40 ± 0.01 ^b	6.37 ± 0.01 ^b	6.32 ± 0.02 ^c	0.001**
Water holding capacity (%)	25.79 ± 2.62 ^a	37.25 ± 5.77 ^b	41.75 ± 5.00 ^b	45.87 ± 3.11 ^b	0.0220
Moisture retention (%)	62.78 ± 0.50 ^a	63.19 ± 0.33 ^a	64.56 ± 0.09 ^b	67.44 ± 0.13 ^c	0.0001***
Fat retention (%)	83.32 ± 0.71 ^a	93.46 ± 0.48 ^b	94.08 ± 0.35 ^b	95.11 ± 0.18 ^b	0.0001***
Juiciness (%)	4.67 ± 0.34 ^a	9.51 ± 1.36 ^b	10.49 ± 1.00 ^b	12.66 ± 1.47 ^b	0.0001***
Drip loss (%)	0.67 ± 0.08	0.79 ± 0.09	0.96 ± 0.07	1.43 ± 0.39	0.0858
Total phenolic content (mg GAE/gm)	1.60 ± 0.27	2.33 ± 0.32	2.55 ± 0.38	2.83 ± 0.45	0.1336
1, 1 diphenyl 2-picrylhydrazyl inhibition percent (DPPH) (%)	7.21 ± 0.17 ^a	55.82 ± 4.80 ^b	56.91 ± 4.63 ^b	67.59 ± 4.16 ^b	0.0001***
Reducing power (%)	0.05 ± 0.01 ^a	0.41 ± 0.05 ^b	0.45 ± 0.07 ^b	0.54 ± 0.06 ^b	0.0001***

Number of observations: * = 6 ($p < 0.05$), ($p < 0.01$ **), ($p < 0.001$ ***).

Means bearing different superscripts row-wise differ significantly ($p < 0.05$).

The emulsion stability (%) values showed a non-significant increase from the control (90.75 ± 2.15) to the treatment groups, with T₃ (94.56 ± 1.68) exhibiting the highest emulsion stability. However, no significant differences were observed among the treatment groups. The improved emulsion stability in dragon fruit peel powder-incorporated sausages might be due to the presence of soluble dietary fibre in the peel, which enhances water- and fat-binding capacity. Similar improvements in emulsion stability were reported in fish nuggets enriched with dragon fruit peel (Biswas *et al.*, 2022)^[7].

The cooking yield (%) increased from the control (96.45 ± 0.78) to the treatment groups, with the highest value observed in T₃ (97.87 ± 0.20), followed by T₂, T₁ and the

control. However, the differences in cooking yield between the control and treatment groups were not significant. The slight increase in cooking yield might be attributed to the high water-binding and gel-forming ability of the polysaccharides present in dragon fruit peel (Biswas *et al.*, 2022)^[7].

The water-holding capacity (WHC, %) increased significantly from the control (25.79 ± 2.62) to the treatment groups. The highest WHC was recorded in T₃ (45.87 ± 3.11), followed by T₂, T₁ and control. However, no significant differences were observed among the treatment groups. This improvement might be due to the high pectin and soluble dietary fibre contents of dragon fruit peel, which enhance water retention within the sausage matrix (Madane

et al., 2020) [16]. Madane *et al.* (2020) [16] further reported that the incorporation of dragon fruit peel powder at levels of 1.5% and 3.5% significantly increased the water-holding capacity of chicken nuggets compared with the control. The moisture retention (%) values increased significantly ($p < 0.001$) with increasing levels of dragon fruit peel powder, ranging from 62.78 ± 0.50 in the control to 67.44 ± 0.13 in T₃. Fat retention followed a similar trend, with the highest value recorded in T₃ (95.11 ± 0.18). The higher moisture and fat retention values might be attributed to the enhanced water-and fat-absorbing capacities of the dietary fibre present in dragon fruit peel, which improved retention within the emulsion matrix during cooking. Soluble dietary fibre from fruit peels has been reported to enhance moisture and lipid retention, thereby reducing fat loss during cooking and strengthening the emulsion matrix (Rindhe *et al.*, 2008) [21].

The juiciness (%) values increased significantly ($p < 0.001$) from the control (4.67 ± 0.34) to the treatment groups, with the highest value observed in T₃ (12.66 ± 1.47), followed by T₂, T₁ and the control. The increased juiciness in the treatment groups may be attributed to the superior water-binding capacity of dragon fruit peel powder, which enhanced moisture retention within the product matrix. Drip loss (%) showed a non-significant increase from the control (0.67 ± 0.08) to the treatment groups, with the highest value observed in T₃ (1.43 ± 0.39). The slightly higher drip loss in the treatment groups might be due to moisture redistribution associated with increased dietary fibre levels rather than actual processing losses. However, the drip loss values remained within acceptable limits.

The total phenolic content (mg GAE/g) showed a non-significant increase from the control (1.60 ± 0.27) to T₃ (2.83 ± 0.45). In contrast, DPPH radical scavenging activity (%) increased significantly ($p < 0.001$) from 7.21 ± 0.17 in the control to 67.59 ± 4.16 in T₃. Similarly, the reducing

power increased significantly from the control (0.05 ± 0.01) to the treatment groups, with the highest value recorded in T₃ (0.54 ± 0.06), followed by T₂, T₁ and the control. The improvement in antioxidant activity of dragon fruit peel powder-incorporated chicken sausages might be attributed to the high concentrations of phenolic compounds, flavonoids and betalain pigments present in the peel (Luo *et al.*, 2014) [15]. These findings are consistent with those of Madane *et al.* (2020) [16], who reported enhanced DPPH radical scavenging activity and reducing power in chicken nuggets incorporated with dragon fruit peel extract owing to its rich phenolic profile.

Proximate composition: The effects of dragon fruit peel powder incorporation on the proximate composition of chicken sausages are presented in Table 3. The proximate composition of dragon fruit peel powder-incorporated chicken sausages showed significant ($p < 0.001$) differences between the control and treatment groups. The moisture content (%) increased significantly from the control (65.09 ± 0.02) to T₃ (68.91 ± 0.02). This increase might be attributed to the superior water-binding capacity of dragon fruit peel powder. The protein content (%) also increased from 14.40 ± 0.24 in the control to 16.51 ± 0.03 in T₃. The increase in protein content might be due to concentration effects during formulation and the contribution of protein from the dragon fruit peel powder. Similarly, the fat content (%) increased significantly from 7.86 ± 0.03 in the control to 24.60 ± 0.04 in T₃. The higher fat content might be attributed to improved fat retention during cooking and the ability of dietary fibre to stabilize fat within the product matrix. The ash content (%) also increased significantly from 2.20 ± 0.01 in the control to 2.61 ± 0.03 in T₃, indicated the contribution of minerals naturally present in dragon fruit peel.

Table 3: Effect of incorporation of dragon fruit peel powder on proximate composition of chicken sausages

Parameters	Level of dragon fruit peel powder				P Value
	Control (0%)	T ₁ (2%)	T ₂ (2.5%)	T ₃ (3%)	
Proximate composition*					
Moisture (%)	65.09 ± 0.02 ^a	65.15 ± 0.01 ^a	66.22 ± 0.02 ^b	68.91 ± 0.02 ^c	0.0001***
Protein (%)	14.40 ± 0.24 ^a	15.12 ± 0.21 ^b	15.19 ± 0.02 ^b	16.51 ± 0.03 ^c	0.0001***
Fat (%)	7.86 ± 0.03 ^a	23.86 ± 0.03 ^b	24.05 ± 0.03 ^c	24.60 ± 0.04 ^d	0.0001***
Ash (%)	2.20 ± 0.01 ^a	2.38 ± 0.02 ^b	2.56 ± 0.03 ^c	2.61 ± 0.03 ^c	0.0001***
Crude fiber (%)	0.10 ± 0.02 ^a	1.12 ± 0.02 ^b	1.28 ± 0.03 ^c	1.41 ± 0.06 ^c	0.0001***
Dietary fiber (%)	0.20 ± 0.04 ^a	2.21 ± 0.04 ^b	2.54 ± 0.07 ^c	2.79 ± 0.11 ^c	0.0001***

Number of observations: * = 6 ($p < 0.001$ ***).

Means bearing different superscripts row-wise differ significantly ($p < 0.05$).

Crude fibre and dietary fibre (%) contents increased significantly ($p < 0.001$) with increasing levels of dragon fruit peel powder in the chicken sausages. T₃ exhibited the highest crude fibre ($1.41 \pm 0.06\%$) and dietary fibre ($2.79 \pm 0.11\%$) contents, followed by T₂, T₁ and the control. The increased fibre content in dragon fruit peel powder-incorporated chicken sausages might be attributed to the high fibre content of dragon fruit peel, particularly its soluble dietary fibre and pectin fractions. Madane *et al.* (2020) [16] also reported that the incorporation of dragon fruit peel into chicken nuggets enhanced the fibre content and improved the proximate composition.

Sensory evaluation: The effects of dragon fruit peel powder incorporation on the sensory characteristics of

chicken sausages are presented in Table 4. Appearance and colour, flavour and texture scores increased significantly ($p < 0.001$) with the incorporation of dragon fruit peel powder. Among the treatment groups, T₂ received the highest sensory scores, followed by T₁, T₃ and the control. The appearance and colour scores increased significantly from 7.76 ± 0.07 in the control to 8.65 ± 0.04 in T₂. The improvement in appearance and colour might be attributed to the natural betalain pigments present in dragon fruit peel, which imparted an attractive pinkish-red hue to the sausages. However, at the 3% incorporation level (T₃), the appearance and colour scores declined slightly, possibly because excessive pigmentation adversely affected the visual appeal of the product.

Table 4: Effect of incorporation of dragon fruit peel powder on sensory attributes of chicken sausages

Parameters	Level of dragon fruit peel powder				P Value
	Control (0%)	T ₁ (2%)	T ₂ (2.5%)	T ₃ (3%)	
Sensory attributes**					
Appearance and color	7.76 ± 0.07 ^a	8.26 ± 0.05 ^b	8.65 ± 0.04 ^c	7.68 ± 0.05 ^a	0.0001***
Flavor	7.52 ± 0.07 ^a	8.11 ± 0.05 ^b	8.55 ± 0.06 ^{c a}	7.54 ± 0.07 ^a	0.0001***
Juiciness	8.26 ± 0.08 ^a	7.56 ± 0.07 ^b	7.83 ± 0.08 ^b	7.08 ± 0.05 ^c	0.0001***
Texture	7.50 ± 0.06 ^a	8.05 ± 0.08 ^b	8.23 ± 0.05 ^b	7.66 ± 0.08 ^a	0.0001***
Overall acceptability	7.43 ± 0.06 ^a	8.16 ± 0.05 ^c	8.66 ± 0.04 ^d	7.77 ± 0.05 ^b	0.0001***

Number of observations: ** = 36 ($p < 0.001$ ***).

Sensory attributes of chicken sausages were evaluated on a 9-point hedonic scale (wherein 1 = extremely undesirable; 9 = extremely desirable).

Means bearing different superscripts row-wise differ significantly ($p < 0.05$).

Flavour scores increased significantly from 7.52 ± 0.07 in the control to 8.55 ± 0.06 in T₂ but declined slightly in T₃. The slight reduction in flavour scores at the higher incorporation level might be attributed to the stronger plant-derived flavour and mild bitterness associated with the phenolic compounds present in dragon fruit peel. Juiciness scores decreased slightly from 8.26 ± 0.08 in the control to 7.08 ± 0.05 in T₃, despite the higher moisture retention observed in the treatment groups. This reduction in juiciness might be attributed to the firmer texture resulting from the increased dietary fibre content of dragon fruit peel. Texture scores increased from 7.50 ± 0.06 in the control to 8.23 ± 0.05 in T₂, indicating that the moderate incorporation level improved product firmness. However, the texture score declined slightly in T₃, possibly because the higher fibre content adversely affected the textural characteristics.

The overall acceptability score was highest in T₂ (8.66 ± 0.04), followed by T₁, T₃ and the control, indicated that the incorporation of 2.5% dragon fruit peel powder provided the optimum balance of appearance and colour, flavour, texture and juiciness in chicken sausages. Further increasing the incorporation level slightly reduced overall acceptability because of the intensified colour and flavour. Similar findings were reported by Bellucci *et al.* (2021) [6], who observed improvements in sensory attributes, including odour, texture, taste and overall acceptability, in pork patties incorporated with red pitaya extract at different concentrations.

Conclusion

The incorporation of dragon fruit (*Hylocereus polyrhizus*) peel powder significantly improved the functional quality of chicken sausages by enhancing antioxidant activity, dietary fibre content and several physicochemical characteristics, including water-holding capacity, moisture retention and fat retention. Although the highest level of incorporation (3.0%) produced greater antioxidant activity and fibre content, it resulted in a slight decline in sensory acceptability. Chicken sausages containing 2.5% dragon fruit peel powder exhibited the most desirable balance between functional properties and consumer acceptability, achieving superior scores for appearance, flavour, texture and overall acceptability while providing enhanced antioxidant potential. Therefore, incorporation of 2.5% dragon fruit peel powder can be recommended as the optimum level for the development of antioxidant-enriched functional chicken sausages with improved nutritional and quality attributes.

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