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Technological performance of different rabbit meat cuts in processing cured cooked ready-to-eat meat products

Desempenho tecnológico de cortes diferentes de carne de coelho no processamento de produtos cárneos curados cozidos prontos para consumo

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Abstract
There is a worldwide demand for new protein sources through environmentally responsible production, and rabbit farming is a sustainable activity. Therefore, this study aimed to characterize meat from different cuts of rabbit carcasses and evaluate their use in the processing of restructured cured cooked ready-to-eat (RTE) products. Rabbit raw meats from different cuts were technologically characterized, and the RTE products were processed from the meats of the entire carcass (RABB), hind legs (RHIND), loin (RLOIN), and foreleg, thoracic cage, and flank (RBACK). Restructured pork cooked ham (PHAM) was used as the reference. Rabbit raw meat from different anatomical parts differed in proximate composition, total collagen and heme-pigment content, water-holding capacity, and CIE color, affecting the characteristics of processed products. RBACK products had higher fat content (5.46%), cooking and reheating losses (7.50% and 5.61%), and poor hardness and chewiness (11.1 N and 17.37 N×mm). Higher values of lightness (L^* ~70.27), hue (h ~68.61°), and a slight cured color were observed in RLOIN, with a pale yellowish color described by sensory evaluation. RABB and RHIND were correlated with the sensory attributes of traditional PHAM, being preferred more often and with greater purchase intent than RLOIN and RBACK. It is concluded that cooked ham development from whole carcass meat (RABB) is a potential opportunity for the rabbit industry to offer value-added technological products of high quality to consumers.
Keywords: rabbit meat quality; restructured cooked ham; sensory analysis; check-all-that-apply; technological characteristics

Resumo
Há uma demanda mundial por novas fontes proteicas de produções ambientalmente responsáveis, e a cunicultura se enquadra perfeitamente como uma atividade sustentável. Neste contexto, este estudo teve como objetivo caracterizar a carne de diferentes cortes da carcaça de coelho e avaliar sua utilização no processamento de produtos curados cozidos prontos para o consumo (RTE). As carnes cruas de coelho de diferentes cortes foram caracterizadas tecnologicamente, e os produtos RTE foram processados a partir das carnes de carcaça inteira (FC-INT), patas traseiras (FC-PERNIL), lombo (FC-LOMBO), patas dianteiras, caixa torácica e flanco (FC-APARAS). Um produto RTE com carne de pernil suíno (APRESUNTADO) também foi elaborado como referência. A carne de coelho de diferentes partes anatômicas diferiu na composição centesimal, conteúdo total de colágeno e pigmento heme, capacidade de retenção de água e cor (CIE), afetando as características dos produtos elaborados. Os produtos FC-APARAS apresentaram maior teor de gordura (5.46%), perdas por cozimento e reaquecimento (7,50% e 5,61%), baixa dureza e mastigabilidade (11.1 N e 17.37 N×mm). Maiores valores de luminosidade (L^* ~70.27), matiz (h ~68.61°) de cor e uma fraca cor curada foram observados no FC-LOMBO, com uma coloração amarelada pálida descrita pela avaliação sensorial. FC-INT e FC-PERNIL foram correlacionados com os atributos sensoriais do tradicional APRESUNTADO, sendo mais preferidos e com maior intenção de compra do que FC-LOMBO e FC-APARAS. Concluiu-se que o desenvolvimento de produtos curados cozidos a partir de carcaças inteiras (FC-INT) é uma oportunidade potencial para a indústria de cunicultura oferecer produtos tecnológicos de valor agregado e de alta qualidade aos consumidores.
Palavras-chave: qualidade da carne de coelho; fiambres; análise sensorial; teste CATA; características tecnológicas

1. Introduction

The world's population is expected to grow to almost 10 billion by 2050, boosting food production demand, especially protein supply (by approximately 70%), under a scenario of modest economic growth [(1)]. Moreover, persistent and widespread hunger and malnutrition remain huge challenges in many parts of the world. In addition to protein, micronutrient deficiencies (especially iron, iodine, zinc, and vitamins A and B12) form an important global health issue, with malnutrition affecting key developmental outcomes, including poor physical and mental development and general losses in productivity and potential [(2)].

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Meat plays a key role in food security by providing high-quality protein and essential micronutrients, such as iron and B-vitamins, many of which are difficult to obtain in adequate quantities from foods of plant origin [3]. Currently, the major marketed sources of animal protein are traditional livestock systems (cattle, sheep, pigs, and poultry), which are broadly questioned in terms of their negative environmental impacts, such as the generation of greenhouse gas emissions, production efficiency (requiring more water and land), and some health concerns [4, 5]. Therefore, alternative sustainable meat protein sources are needed to meet the protein demand for human consumption.

Lagomorphs such as rabbits have many qualities that make them viable and sustainable alternatives for meat production. In addition to good zootechnical productive performance, such as prolific, short life cycle, rapid growth rate, notable daily weight gain, and feed conversion ratios [6], rabbit meat is considered healthy food with appealing taste [7, 8]. The nutritional and quality characteristics of rabbit meat are similar to those of other commonly traded animal species, and its technological characteristics are highly suitable for processing [9], allowing the production of industrialized products with greater added value.

The processing of rabbit meat is an alternative method for increasing its production and commercialization. In a recent survey investigating consumer perceptions of rabbit meat in Brazil, Magalhães *et al*.[10] concluded that the main limiting factor for this meat consumption is the unavailability of the product. Most commercial rabbit meat is still sold as whole carcasses, and little effort has been directed towards the research and development of rabbit meat products [11-13]. Processing makes it possible to add higher value to cuts with less potential for fresh consumption and to generate differentiated products, improve their appearance and sensory characteristics, and offer convenience and diversity to consumers [9]. Research aimed at introducing industrialized processed rabbit meat products is scarce compared to the scientific literature reports of restructured products such as burgers [14] and ready-to-eat (RTE) products such as fermented [15] and frankfurter-type [16, 17] sausages.

The purpose of this study was to evaluate the technical processing and sensory characteristics of restructured RTE-cooked meat products produced using different cuts of rabbit carcasses.

2. Material and methods

2.1. Animals and raw material

Meat from different parts of 40 rabbit carcasses was obtained from 84-days-old white New Zealand × Botucatu crossbred reared and slaughtered in the Minas Gerais Federal Institute (IFMG; Bambuí-MG, Brazil) following the ethical standards of the National Council for Animal Experimentation approved by the IFMG Ethics Committee (License No:011/2017). To obtain sufficient meat to manufacture the products, the carcasses were randomly separated into four groups containing six carcasses and four groups containing four carcasses. In each group, cuts of the forelegs, hind legs, loins (M. *Longissimus thoracis et. lumborum*), and back (thoracic cage and flank) were obtained as described by Paula *et al*.[9] and manually deboned. Meat from each cut (from each group) was vacuum-packaged, stored at -20°C, and sent to the Laboratory of Meat Science and Technology (LabCarnes) at the Federal University of Lavras (UFLA, Lavras, Brazil) for further analysis and processing. Deboned pork hind legs (Large White × Landrace crossbred pigs) were purchased from a local market (in four different batches) on the day of product manufacturing.

2.2. Treatments

The potential use of meats from different parts of the rabbit carcass was investigated processing four restructured RTE cooked products: RABB = produced with all carcass meats; RHIND = produced with only hind leg meats; RLOIN = produced with the loin; and RBACK = produced with foreleg, thoracic cage, and flank meats. The products were manufactured in four batches (repetitions), in which the meat of each treatment group was obtained from one of the groups of separated carcasses. A reference product based on pork hind legs (PHAM) was manufactured for each batch. Meats from different cuts were grouped to prepare each formulation. For each batch, meats from all cuts of one of the groups of four carcasses were used in the preparation of RABB products. For the other rabbit products, meats from the hind leg, loin, or back (meats from forelegs, thoracic cage, and flank) cuts were used from the separated groups that contained six carcasses. All batches of frozen meat were thawed at 4°C for 24 h and ground (Beccaro Ltd., Rio Claro-SP, Brazil) using a 20-mm disc. Before RTE product manufacturing, all ground meat samples were sampled for characterization analysis.

2.3. RTE products manufacturing

The RTE product selected for this study was a restructured cured cooked ham type, commercially available in Brazil under the names of “Apresuntado" (formulations with pork legs only) or "Fiambre” (formulations with meat from other species). Four batches (repetitions) of each RTE product were formulated using 75% rabbit meat (or pork hind legs in PHAM treatment) and 19.5% water, with the remainder consisting of commercial ingredients: 1.6% salt, 2.0% cassava starch, 0.5% sodium tripolyphosphate (New Max Industrial Ltd., Americana-SP, Brazil), 0.3% curing salt (sodium nitrite; IBRAC; Rio Claro-SP, Brazil), 0.3% antioxidant (sodium erythorbate; IBRAC; Rio Claro-SP, Brazil), 0.3% monosodium glutamate (Ajinomoto Ind., São Paulo-SP, Brazil), and 0.5% ham flavoring/seasoning (New Max Industrial Ltd. Americana-SP, Brazil). Thawed minced meat (4°C) was mixed (Stang-364 mixer; Anodilar, Caxias do Sul-SC, Brazil) for 15 min, vacuum-packaged (BD420; R. Baião Indústria e Comércio Ltda, Ubá-MG, Brazil) in nylon-polyethylene bags shaped in 1-kg stainless steel oval forms and stored at 4°C overnight. Thereafter, the products were heated in a water bath until their internal temperature reached 72°C (monitored using a thermocouple connected to a MT525 Thermometer; Minipa do Brasil, Joinville-SC, Brazil), chilled in an ice bath, and stored at 4°C for 24 h before analysis.

2.4. Raw meat characterization

The raw meat was homogenized (Turratec TE102; Tecnal Equip. Científicos, Piracicaba-SP, Brazil) in distilled water (1:10 w/v) for approximately 30 s, and pH was measured using a digital DM20 pH meter (Digimed Analítica Ltd., São Paulo, SP, Brazil). The total moisture (AOAC 950.46B), fat (AOAC 960.39), protein (AOAC 981.10, using 6.25 as conversion factor), ash (AOAC 950.46), and collagen (mg/g; AOAC 960.39) contents were analyzed according to the Association of Official Analytical Chemists [18]. The total content of heme pigment (µg hematin/g) was determined as described by Hornsey [19], and the water holding capacity (WHC) was assessed using the filter paper press method (FPPM), as described by Aroeira *et al*. [20]. All analyses were conducted in triplicates.

The ground raw meat was placed in Petri dishes and exposed to atmospheric air for 15 min for blooming, and CIE color was measured using a Minolta CM-700 colorimeter (Konica Minolta Sensing Inc., Osaka, Japan) with illuminant A, aperture of 8 mm, observer angle of 10°, at specular component exclusion (SCE) mode. CIE lightness (L^*), redness (a^*), yellowness (b^*), chroma (C^*), and hue angle (h, °) were recorded from the average of five surface readings.

2.5. RTE water losses and physicochemical analysis

Product mass loss (%) was evaluated using the cooking loss, fluid loss during storage (syneresis), and reheating loss (RHL) methods. The cooking loss was measured by determining the percentage of mass loss during the cooking process. Syneresis was determined (in triplicate) as the mass loss of ten vacuum-packed cubes (10-mm edge) of RTE products after storage (4°C) for seven days under simulated stress conditions (packages were placed at room temperature for 2 h and then returned to the cooler every two days) [21]. RHL was measured as described by Dutra *et al*.[22], determining (in triplicate) the percentage of mass loss of three segments (20 × 20 × 60-mm) of RTE products after boiled in ~ 300 mL of water for 6 min.

The proximate composition of the RTE products was determined (in triplicate) using the AOAC[18] method, as described for raw meat characterization, and the pH was measured by inserting a puncture electrode coupled to an HI99163 potentiometer (Hanna Instruments, Woonsocket, RI, USA) into the product at three different points.

2.6. RTE instrumental color and fading

RTE products were sliced in half, five measurements were taken from inner cross-section surface points with a Minolta CM-700 colorimeter (illuminant D65, 8 mm aperture port, 10° observer angle, and SCE mode), and the CIE indices (L^*, a^*, b^*, C^*, and h) were recorded.

After color readings, 1-cm thick slices of each product were obtained, wrapped in Styrofoam trays, packed with oxygen-permeable polyvinyl chloride film, and stored for 4 h at room temperature. The surface color was evaluated at 0, 30, 60, 120, and 240 min, and the reflectance spectrum (360 nm at 740 nm) and the CIE indices were recorded. The cured color intensity and stability during storage (fading) were monitored as reflectance ratios at 650 and 570 nm (R650/570 nm), with values > 2.2 indicating excellent cured color and < 1.6 indicating moderate fade to absent cured color [23].

2.7. RTE instrumental texture

Instrumental texture was assessed by texture profile analysis (TPA), using a universal texture analyzer TA.XT2i (Stable Micro Systems Ltd., Godalming, UK). Five cubes (25-mm edge) of RTE samples were uniaxially and sequentially compressed twice (using a flat probe of 50-mm in diameter) to 60% of their original height with a cross-head speed of 200 mm/min. Force–time curves were recorded, and the attributes of hardness (N), springiness (mm), adhesiveness (N×mm), cohesiveness, and chewiness (N×mm) were calculated as previously described by Jorge *et al*.[24].

2.8. RTE sensorial evaluation

The sensory qualities of the RTE products were evaluated using the check-all-that-apply (CATA) method after obtaining approval from the National Research Ethics System (SISNEP, Brazil) under the protocol CAAE 30844314.5.0000.5148. Tests were conducted in individual cabins under white light at the Sensorial Laboratory of the Food Science Department (DCA/UFLA).

First, CATA questions (terms that describe product characteristics) were defined by 10 untrained participants (undergraduate and graduate students who were declared to be regular consumers of cooked ham) using the network method [24]. The frequently listed descriptors among the terms selected for the CATA questions were pale, pink, bright, soft, firm, dry, rubberlike, homogeneous appearance, non-uniform appearance, salty, sandy, ham flavor, smooth flavor, aftertaste, and rancid. In the second stage, 100 untrained undergraduate and graduate students (48 males and 52 females; age range: 18–46 years) were randomly recruited at the UFLA. All participants confirmed regular consumption of cooked ham. The sensory analysis proceeded in a single session, during which sample cubes (approximately 15-mm edge) were served (at 4°C) in a randomly balanced monadic sequence to each panelist in plastic cups labelled with a three-digit code. Mineral water was provided to clean the palate during sample trials. The panelists evaluated the samples using a hedonic scale of 1 (very much disliked) to 9 (very much liked) for acceptance and from 1 (certainly would not buy) to 5 (certainly would buy) for purchase intention and recorded their impressions on sensory evaluation forms. Similarly, the panelists were also instructed to check all terms of the defined CATA questions that they considered appropriate for describing each product.

2.8. Statistical analysis

Experiments involving raw meat and RTE product characterization were conducted using a completely randomized design (CRD), with four repetitions (batches) per treatment. The fading analysis was designed as CRD in a split-plot scheme, with five treatments in the plot and five storage times in the split plot. The data were tested using F-tests (ANOVA), considering a significance level of 5%. Means between rabbit raw meat and RTE products were separated using Tukey's test and compared with the reference (pork) using Dunnett's test (P<0.05).

Acceptance and purchase intention in the RTE sensory analysis were evaluated using frequency analyses. Relationships between CATA terms selected for each sample were identified using external preference maps (EPM), in which only slopes from panelists that provided valid models (P≤0.30) were plotted [24].

All data were statistically analyzed using SAS® System for Windows™ software version 9.0 (SAS Institute Inc., Cary, NC, USA), and EPM was analyzed using SensoMaker statistical software version 1.7 (UFLA, Lavras-MG, Brazil).

3. Results and discussion

3.1. Raw meat characterization

The proximate composition and technological characteristics of the raw meat used in this study are described in Table 1. Overall, the proximate composition data reinforce the high protein (~22%) and low fat (~5%) content of the rabbit meat, as reported in the literature [8, 9, 12]. Furthermore, the largest proportion of fat was observed in meats from the back (deboned foreleg, thoracic cage, and flanks), and although the protein content did not differ from hind leg meat, the total collagen and heme pigment contents were significantly higher than those in other rabbit meats. These differences are due to the anatomical position of the retail cuts, with greater fat deposition and collagen content in the belly and thoracic meat [25]. Lower percentage values of fat in the rabbit loin muscle compared to those in the foreleg, hind leg, and abdominal wall were also reported by Pla *et al.*[26].

Table 1. Composition and technological characteristics (mean ± standard deviation) of the evaluated rabbit cuts and pork hind leg (as reference) ground meats used in the preparation of the ready-to-eat (RTE) cured cooked products.

Characteristics	Rabbit			Pork
	Hind leg	Loin	Back	Hind leg
Moisture (%)	73.60±1.56^{a}*	72.89±1.97^{a}*	69.54± 0.60^{b}	70.94±0.75
Protein (%)	21.39±0.06^{b}	23.31±0.86^{a}*	21.90±1.30^{b}	21.13±0.50
Fat, ether extract (%)	3.66±0.43^{b}*	2.75±0.80^{c}*	9.06±0.24^{a}*	5.29±0.27
Ash (%)	1.45±0.21^{a}	1.63±0.18^{a}	1.12±0.06^{b}	1.50±0.36
pH	5.47±0.10^{b}*	5.50±0.06^{b}*	5.69±0.11^{a}	5.63±0.21
Water holding capacity, WHC	0.31±0.14	0.23±0.05*	0.31±0.02	0.42±0.05
Total collagen (mg/g)	5.72±2.41^{b}*	5.71±2.38^{b}*	7.97±2.87^{a}	8.07±1.4
Heme pigment (µg acid hematin/g)	17.91±2.55^{b}*	14.73±1.04^{b}*	27.03±2.64^{a}*	97.36±8.01
CIE Color				
Lightness, *L**	63.22±3.57^{b}	69.23±3.40^{a}*	65.35±1.32^{ab}*	58.76±2.20
Redness, *a**	12.22±1.29^{a}*	9.10±0.16^{b}*	13.45±0.31^{a}*	18.86±1.04
Yelloness, *b**	14.31±0.90*	16.29±1.42*	15.07±2.05*	18.62±0.13
Chroma, *C**	18.84±0.16*	18.66±1.32*	20.23±1.32*	26.50±0.83
Hue angle, *h* (°)	49.53±4.77^{b}	60.74±1.72^{a}*	48.10±4.54^{b}	44.65±1.37

$^{a-c}$ Means of the rabbit meat characteristics in the same line followed by different letters differ (P<0.05). * Means of the rabbit meat characteristics differ (P<0.05) from the reference (pork hind leg) meat according to Dunnett's test.

Appropriate selection of raw meat material is essential for producing uniform products and is indispensable for efficient producing high quality processed meat. Therefore, in addition to water, fat, and protein content, the constituents of protein fractions, such as collagen and heme pigments, should be known because of their positive role in meat protein gel matrix formation. Heme pigments are sarcoplasmic proteins that play a decisive role in the final color, whereas collagen, the main connective tissue protein, has low binding and emulsifying capacities affecting the texture of meat products [9, 27]. Compared to the pork hind legs, the rabbit hind legs had a higher moisture/protein ratio, less fat, and lower collagen and heme pigment contents.

The pH values differed significantly between the evaluated cuts, with lower values for boneless meat from the hind legs and loins than for the back. This difference might also be due to the anatomical location of the carcass, which is predominantly associated with higher red fibers in the muscle from the back cut (supported by higher heme pigment), especially in foreleg meats. This is reinforced by the observation of Króliczewska *et al.*[28] that the forelegs of rabbits are characterized by higher pH values and heme iron content than the hind legs and loin portions. However, although meat pH is directly associated with its water holding capacity (WHC), WHC was not significantly affected by the type of rabbit cut.

Despite the lower pigment heme content, the CIE color of the hind leg and back meat had the same red tone (*h* value) as pork, although it was lighter (higher L^* values) and had a less intense (or saturated) color (lower C^* values). This agrees with the fact that C^* values are directly associated with heme pigment content in meat [27]. Overall, the color indices for hind leg and back meats were similar, being darker and redder than the loin muscle.

3.2. RTE technological characteristics

Table 2 shows the average proximate composition and technological traits of cooked RTE rabbit meat products. Overall, the evaluated RTE differed significantly in terms of moisture and fat content. Protein levels did not differ (P>0.05) among the evaluated RTE, including the reference, with a mean value (16.76 ± 2.86%) close to the protein content of the major processed, cooked, and cured meat products from conventional species that are currently marketed. In fact, the nutritional composition of rabbit RTE products is healthy and they are a reliable source of high-quality animal protein with low fat, especially RABB, RHIND, and RLOIN.

Table 2. Composition and technological Characteristics (mean ± standard deviation) of the cured cooked ready-to-eat (RTE) rabbit products produced with rabbit meat and pork (as reference).

Characteristics	Rabbit RTE				Pork RTE
	RABB	RHIND	RLOIN	RBACK	PHAM
Moisture (%)	71.99±1.21^{ab}	74.91±1.84^{a}	74.32±0.81^{a}	70.71±0.18^{b}	72.03±1.30^{ab}
Protein (%)	16.15±2.11	16.47±6.71	15.55±2.78	18.30±1.63	17.36±2.15
Fat, ether extract (%)	3.22±0.66^{bc}	2.13±0.79^{c}	1.96±0.31^{c}	5.46±1.17^{a}	4.28±0.23^{ab}
Ash (%)	4.36±0.26^{a}	4.03±0.15^{ab}	3.97±0.11^{ab}	3.87±0.05^{bc}	3.46±0.17^{c}
pH	6.22±0.39	6.28±0.34	6.17±0.34	6.36±0.33	6.33±0.37
Cooking loss (%)	6.27±1.33^{ab}	5.75±1.25^{b}	5.73±0.20^{b}	7.50±0.89^{a}	5.02±0.99^{b}
Syneresis (%)	7.87±1.73	7.37±0.46	6.84±1.62	6.46±0.64	7.44±1.65
Reheating loss, RHL (%)	4.34±1.28^{b}	3.71±0.97^{b}	4.08±1.11^{b}	5.61±1.07^{a}	3.43±1.51^{b}
CIE Color					
Lightness (L^*)	67.67±0.32^{b}	67.57±1.63^{b}	70.27±0.69^{a}	66.48±0.49^{b}	60.33±1.15^{c}
Chroma (C^*)	11.69±0.28^{b}	11.27±0.28^{b}	11.46±0.04^{b}	11.92±0.25^{b}	13.18±0.36^{a}
Hue (*h*, degrees)	58.96±0.58^{bc}	61.68±1.67^{b}	68.61±1.53^{a}	56.72±1.45^{c}	39.94±1.16^{d}
Texture attributes					
Hardness (N)	13.75±1.02^{b}	14.97±1.13^{b}	15.89±4.77^{ab}	11.1±0.81^{c}	22.22±5.91^{a}
Cohesiveness	0.30±0.01^{bc}	0.33±0.02^{bc}	0.34±0.04^{ba}	0.29±0.03^{c}	0.39±0.02^{a}
Adhesiveness (10×N×mm)	0.65±0.14^{bc}	0.56±0.11^{bc}	0.99±0.32^{a}	0.50±0.04^{c}	0.86±0.15^{ab}
Springiness (mm)	5.73±0.57	5.35±0.15	5.44±1.15	5.45±0.60	5.96±0.31
Chewiness (N×mm)	23.88±3.31^{bc}	26.45±2.50^{bc}	31.2±8.81^{b}	17.37±2.79^{c}	51.60±9.00^{a}

Note: RABB = produced with rabbit carcass meat (all meat cuts); RHIND = produced only with rabbit hind leg meats; RLOIN = produced only with rabbit loins (*L. thoracis et lomburum*); RBACK = produced with rabbit foreleg, thoracic cage, and flank meats; PHAM = reference product elaborated with pork hind legs. $^{a-d}$ Means in the same row followed by different letters differ (P<0.05) according to Tukey's test.

The reference restructured cooked pork ham (PHAM) meets the Brazilian technical regulations for the identity and quality of "Apresuntado" that defines maximum levels of 75% moisture, 12% fat, and a minimum of 12% protein [29]. Regarding future commercial exploitation in Brazil, RHIND fits the commercial name "Rabbit Apresuntado" because it is made using rabbit hind legs only. The other rabbit RTE products obtained from loin (RLOIN), back (RBACK) and whole rabbit carcass meat (RABB) might fall under the denomination, "Fiambre" or "Lanches", if the formulations are adjusted to meet the maximum required moisture level of 70% (especially RLOIN).

The pH values of the RTE products did not differ significantly (average of 6.28 ± 0.35). This average pH was similar to that of other marketed products and might be due to the buffering effect of added ingredients, such as phosphate [30].

Weight loss is an important parameter in the processing of meat products. Water and soluble materials are frequently released during cooking and storage of meat products. In this regard, only cooking loss differed significantly between the products, as syneresis (loss during storage) was stable among the formulations. Product formulation and processing methodology are the key determinants of weight loss during cooking. In restructured meat products, cooking loss is affected by many factors, including the temperature of cooking, degree of protein denaturation, fat/protein and water/protein ratios, fat and water binding capacities of the ingredients, pH of the muscle, and ratio of myofibrillar to collagen protein fractions in the protein matrix [27, 30]. Therefore, the higher (P<0.05) cooking loss observed for RBACK than for other processed products might be due to the higher fat and collagen content in raw meat from rabbit backs (Table 1).

As observed for cooking loss, the reheating loss (RHL) was higher (P<0.05) in RBACK than in all other processed rabbit and pork RTE products. Clearly, RBACK was problematic in terms of added brine stabilization compared to rabbit RTE and PHAM. This is an important issue, since in addition to economic losses, cooked RTE products are commonly used in diverse frozen ready meals (such as pizza and lasagna), and liquid release during thawing cycles or reheating can result in dough softening, excessive exudation, and purge [22]. Nevertheless, technological alternatives for WHC improvement, including formulations and processing, should be explored to render back meat utilization feasible by eliminating these technological hurdles.

Regarding the instrumental texture and color attributes of products that can directly affect consumer acceptance, the texture profile of rabbit RTE behaved differently from the pork RTE reference. Overall, rabbit products had poorer mechanical properties, namely lower hardness, cohesiveness, adhesiveness, and chewiness, than pork RTE. However, except for chewiness, the texture profile of RLOIN was similar (P>0.05) to that of the reference sample PHAM, whereas RBACK had the lowest values. For the color indices, the behavior of the raw meat (Table 1) was reflected in the finished RTE cooked products, with the pink cured color of all rabbit RTE being significantly lighter (higher L^*), with a less reddish (higher h), and more intense (lower C^*) tone than the product reference made with pork. These characteristics are also associated with differences in the heme pigment content of raw meat, which may affect product marketing. Since the color of meat products such as cooked ham is of major importance for the consumer acceptance, future commercial exploitation may require the inclusion of a colorant (such as carmine, commonly used in cooked products) to improve this attribute.

Overall, the color fading behavior was similar for the rabbit RTE products and the PHAM reference, with the R650/570 nm ratio decreasing over time (Figure 1). This was expected because when exposed to air and light, pink cured color fading occurs because of the light-catalyzed dissociation of nitric oxide (NO) from the nitrosylhemochrome (or nitroso hemochromogen) pigment, followed by the oxidation of NO and heme groups by oxygen [27, 31]. However, rabbit RTE products presented a less intense cured color (lower initial values of the R650/570 nm ratio) than the conventional restructured cooked ham product (PHAM), and the discoloration differed depending on the type of cut used in the product formulation. The pink cured color of PHAM (R650/570 nm > 2.2) displayed progressive discoloration during the first 120 min of display storage, while the poorly cured color of RLOIN (R650/570 nm < 1.5) faded moderately in the first 60 min and remained unchanged over time on the display. The other rabbit RTE products (RBACK, RHIND, and RABB) had a noticeable cured color (R650/570 nm, 1.6 - 1.7) with reduced rates of discoloration, but practically did not cease in the 240 min of evaluation.

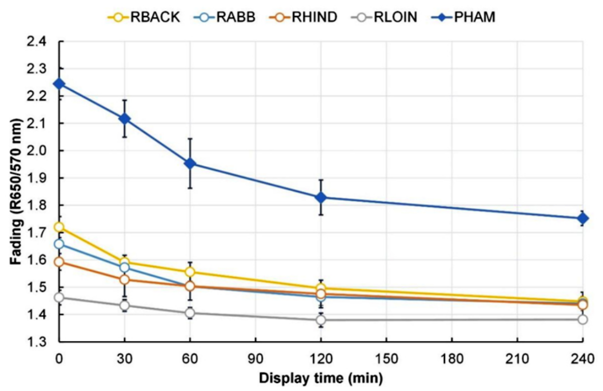

Figure 1. Reflectance ratio (R650/570 nm) during display exposition (room temperature) of sliced cooked RTE products elaborated with meats from back (RBACK), loin (RLOIN), hind legs (RHIND) and entire carcass (RRAB) of rabbits and from pork hind leg (PHAM) as reference.

The differences in the intensity of the cured color between the formulated products were probably associated with the differences in the concentration of heme pigments present in the raw meat (Table 1). Moreover, according to MA *et al.* [32], color fading is significantly correlates with the oxidizing and reducing power of the meat matrix, being related to free sulfhydryls, carbonyl derivatives formed by protein oxidation, and malondialdehyde and dienes formed by lipid oxidation. Therefore, selection of antioxidants to improve the reducing power of the meat matrix to inhibit oxidation in rabbit RTE products may also be necessary for future commercial exploitation. This is also an important issue for meat processing industries and retailers because the loss of cured color can occur slowly in the absence of light and oxygen, such as inside the product or inside vacuum packaging, although the rate of discoloration is extremely slow in this case ([27]).

3.3. RTE sensory characteristics

The sensory traits of the cooked RTE products, evaluated in terms of overall acceptance and purchase intent, are shown in Figure 2. Overall, the rabbit RTE products had good acceptance, with RHIND, RABB, and RLOIN obtaining scores of 72%, 69%, and 59%, respectively, for “liked very much” or “liked”. By contrast, RBACK was not accepted, as 60% of panelists selected “disliked” or “disliked very much”. Purchase intention responses confirmed that 47% and 43% of the panelists would, “certainly” or, “probably” buy RHIND and RABB, respectively, whereas 58% of panelists would, “certainly not or, “probably not" buy RBACK. However, the most accepted rabbit products still scored below the pork reference RTE (PHAM), where just over 90% of panelists described “liked very much” or “liked” for acceptance and 69% selected “certainly buy” or “probably buy” in the purchase intent.

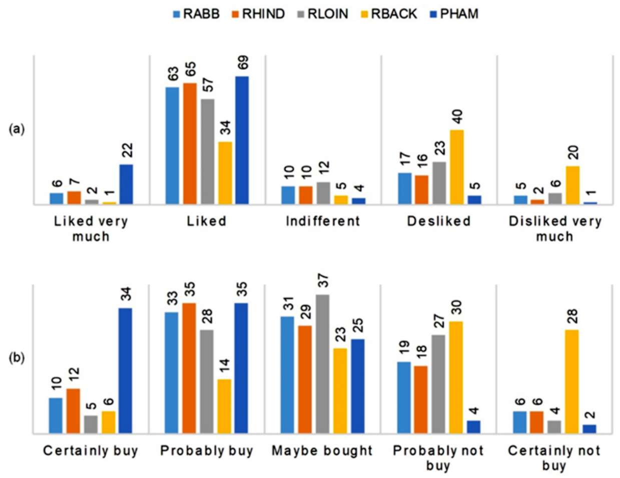

Figure 2. Absolut frequency distribution of overall acceptance (a) and purchase intention (b) of cooked RTE products produced with meats from back (RBACK), loin (RLOIN), hind legs (RHIND) and entire carcass (RRAB) of rabbits and from pork hind leg (PHAM) as reference.

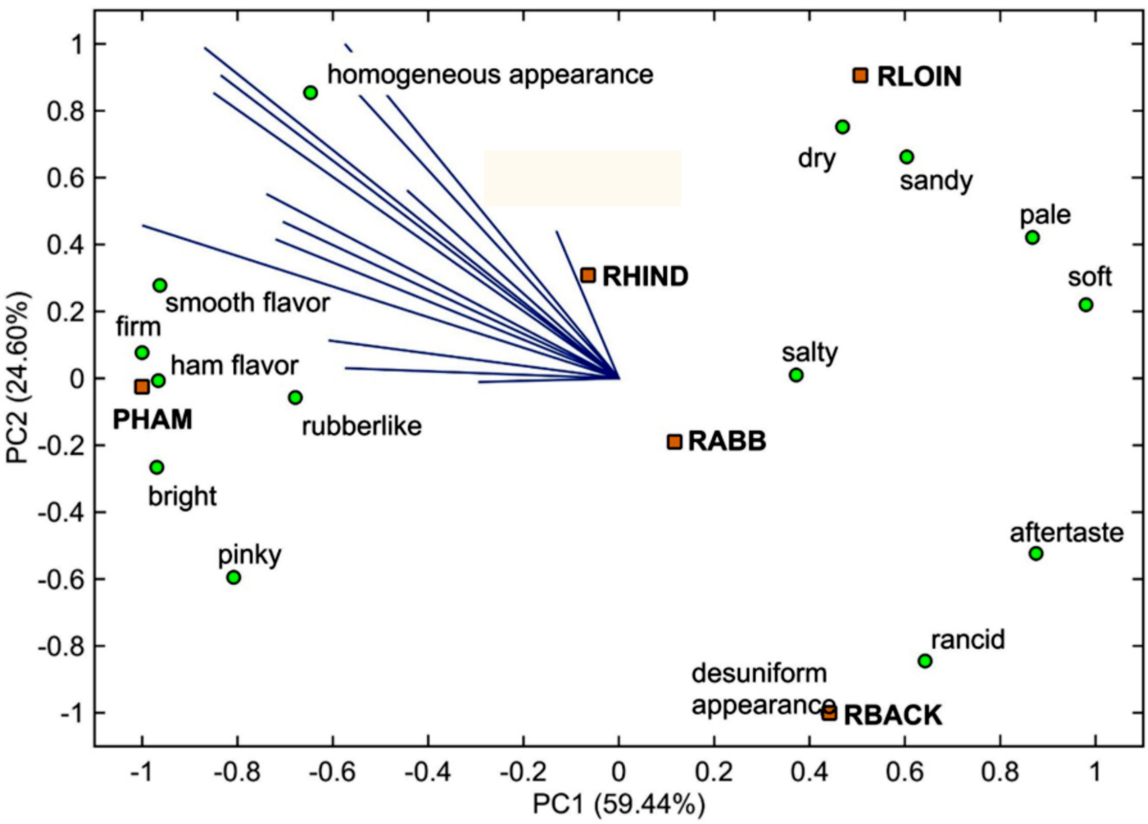

Figure 3. External Preference Map (EPM) of the sensory terms applied in check-all-that-apply questionnaire (CATA) for cured cooked RTE products produced with meats from back (RBACK), loin (RLOIN), hind legs (RHIND) and entire carcass (RRAB) of rabbits and from pork hind leg (PHAM) as reference.

Regarding CATA data, 84.04% of the data variation (R^2 = 0.91) could be explained jointly by the first (PC1) and second (PC2) principal components and four distinct groups (Figure 3). The cooked RTE characteristics that are most associated with conventional RTE products using pork raw material (PHAM), such as “pink color” and “ham flavor,” was grouped alone and was clearly more acceptable (vector directions). The terms, “firmness” and, “rubbery” were directly associated with the greater hardness, chewiness, and cohesiveness of the rabbit products (Table 2). The second group was formed only by RBACK, to which the sensory descriptors of “rancid,” “non-uniform appearance” and “aftertaste” were attributed, which clearly explain the low sensory acceptance scores (Figure 2) of this RTE product. The third group was formed only by RLOIN, which was associated with the descriptors “pale,” “white,” “dry, and “sandy”. The “pale” and “white” terms were in accordance with the instrumental color data of this RTE product (Table 2) and the lower pigmentation of the raw loin (Table 1). Also, the terms “dry” and “sandy” might be associated with the lower protein/fat (3.35) and moisture/protein (3.86) rations in this RTE product compared to the PHAM (4.06 and 4.46, respectively) and other rabbit RTE products (6.89 and 4.60, respectively). The fourth group was different from the others and was composed of RABB and RHIND products, which reinforced the acceptance and purchase intent findings (Figure 2). These products had intermediate characteristics compared with the other groups and were perceived as “salty”.

4. Conclusion

Beyond the technological differences and sensory issues mainly associated with cured cooked RTE processed with back (foreleg, thoracic cage, and flanks) rabbit meat, the RTE obtained from hind legs and entire deboned carcass meat was acceptable and, in some instances, comparable to that of a pork RTE reference. This was supported by the overall acceptance scores and purchase intentions for the products. Furthermore, several formulations and processing adjustments can improve RTE traits, and fine-tuning can be oriented using CATA descriptors and preference maps. The diversification of processed rabbit meat products, such as the proposed cured cooked RTE, might help consolidate their consumption and offer value-added technological alternatives to overcome the commonness of whole rabbit carcass meat retail.

Conflict of interests

The authors declare no conflict of interest.

Author contributions

Conceptualization: L.O. Bueno, E.M. Ramos. *Formal Analysis*: A.L.S.Ramos. *Investigation*: L.O. Bueno. *Project Administration*: E.M. Ramos. *Funding Acquisition*: E.M. Ramos. *Resources*: M.T.B. Bittencourt, L.C. Machado. *Supervision*: M.T.B. Bittencourt, L.C. Machado, A.L.S. Ramos, E.M. Ramos. *Validation*: A.L.S. Ramos. *Writing (original draft):* L.O. Bueno. *Writing (review & editing)*: E.M. Ramos.

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References

1. FAO. O futuro da alimentação e da agricultura: caminhos alternativos para 2050. Roma, Itália: Organização das Nações Unidas para a Alimentação e a Agricultura; 2018. 163 p.

2. Miller BDD, Welch RM. Estratégias do sistema alimentar para prevenir a desnutrição de micronutrientes. Política Alimentar. 2013;42:115 -28. available from: https://doi.org/10.1016/j.foodpol.2013.06.008.

3. Pereira PMdCC , Vicente AFdRB . Composição nutricional da carne e papel nutritivo na dieta humana. Carne Sci. 2013;93(3):586-92. available from: https://doi.org/10.1016/j.meatsci.2012.09.018.

4. Henchion M, Hayes M, Mullen AM, Fenelon M, Tiwari B. Oferta e demanda futura de proteínas: Estratégias e fatores que influenciam um equilíbrio sustentável. Alimentos. 2017;6(7):53. available from: https://doi.org/10.3390/foods6070053.

5. Gerber PJ, Mottet A, Opio CI, Falcucci A, Teillard F. Impactos ambientais da produção de carne bovina: Revisão dos desafios e perspectivas de durabilidade. Carne Sci. 2015;109:2 -12. available from: https://doi.org/10.1016/j.meatsci.2015.05.013.

6. Nasr MAF, Abd- Elhamid T, Hussein MA. Desempenho de crescimento, características de carcaça, qualidade da carne e perfil de aminoácidos do músculo de diferentes raças de coelhos e seus cruzamentos. Carne Sci. 2017;134:150 -7. available from: https://doi.org/10.1016/j.meatsci.2017.07.027.

7. Dale Zotte A, Szendrő Z. O papel da carne de coelho como alimento funcional. Carne Sci. 2011;88(3):319-31. available from: https://doi.org/10.1016/j.meatsci.2011.02.017.

8. Cullere M, Dalle Zotte A. Produção e consumo de carne de coelho: Estado do conhecimento e perspectivas futuras. Carne Sci. 2018;143:137 -46. available from: https://doi.org/10.1016/j.meatsci.2018.04.029.

9. Paula MMdO , Bittencourt MT, Oliveira TLCd , Bueno LO, Rodrigues LM, Soares ER, et al. Coelho como fonte sustentável de carne: características de carcaça e qualidade tecnológica da carne e da carne desossada mecanicamente. Res, Soc e Dev. 2020;9(11):e 5029119906. available from: https://doi.org/10.33448/rsd-v9i11.9906.

10. Magalhães LCdC , Costa RB, de Camargo GMF. Consumo de carne de coelho no Brasil: potencial e limitações. Carne Sci.

2022;191:108873 . available from: https://doi.org/10.1016/j.meatsci.2022.108873.

11. Petracci M, Soglia F, Leroy F. Carne de coelho precisa de um hat-trick: da tradição à inovação (e vice-versa). Carne Sci. 2018;146:93 -100. available from: https://doi.org/10.1016/j.meatsci.2018.08.003.

12. Petracci M, Cavani C. Processamento de carne de coelho: perspectiva histórica para direções futuras. World Rabbit Sci. 2013;21(4):10. available from: https://doi.org/10.4995/wrs.2013.1329.

13. Li S, Zeng W, Li R, Hoffman LC, He Z, Sun Q, et al. Produção e processamento de carne de coelho na China. Carne Sci. 2018;145:320 -8. available from: https://doi.org/10.1016/j.meatsci.2018.06.037.

14. Tavares RdS , Cruz AGd , Oliveira TSd , Braga AR, Reis FAd , Hora IMCd , et al. Processamento e aceitação sensorial de hambúrguer de coelho (*Orytolagus cunicullus*) (em português). Tecnologia em Ciência de Alimentos. 2007;27:633 -6. available from: https://doi.org/10.1590/S0101-20612007000300031

15. Ignacio EO, Santos JMd , Santos SEDJ, Souza CVB, Barretto ACdS . Efeito da adição de carne de coelho nas propriedades tecnológicas e sensoriais de linguiça fermentada. Tecnologia em Ciência de Alimentos. 2020;40:197 -204. available from: https://doi.org/10.1590/fst.02019.

16.Asamoah EA, Barimah J, Akwetey WY, Boateng R, Dapulig CC. Características sensoriais e físico-químicas de salsichas de carne de coelho produzidas com estearina de palma refinada (RPS). SDRP J Food Sci Technol. 2019;4(5):796-803. available from: https://doi.org/10.25177/JFST.4.5.RA.495.

17. Wambui JM, Karuri EG, Wanyoike MMM. Aplicação da metodologia de superfície de resposta para estudar os efeitos da gordura de peito, isolado de proteína de soja e amido de milho nas propriedades nutricionais e texturais de salsichas de coelho. Int J Food Sci. 2017;2017:7670282 . available from: https://doi.org/10.1155/2017/7670282.

18. AOAC. Métodos oficiais de análise da AOAC International. 19ª edição. Gaithersburg, MD: Associação de Químicos Analíticos Oficiais; 2012. 1298 p.

19. Hornsey HC. A cor da carne de porco curada cozida. I. Estimativa do Óxido Nítrico - Pigmentos Heme . J Sci Food Agric. 1956;7(8):534-40. available from: https://doi.org/10.1002/jsfa.2740070804.

20. Aroeira CN, Torres Filho RA, Fontes PR, Gomide LAM, Ramos ALS, Ladeira MM, et al. Efeitos do congelamento, descongelamento e envelhecimento na maciez da carne bovina Bos indicus e Bos taurus. Carne Sci. 2016;116: 118-25. available from: https://doi.org/10.1016/j.meatsci.2016.02.006.

21. Haddad GdBS , Moura APR, Fontes PR, Cunha SdFVd , Ramos AdLS , Ramos EM. Os efeitos do cloreto de sódio e da carne PSE na qualidade do lombo suíno curado e defumado reestruturado: um estudo de metodologia de superfície de resposta. Carne Sci. 2018;137(1):191-200. available from: https://doi.org/10.1016/j.meatsci.2017.11.030.

22. Dutra MP, Cardoso GP, Ramos EM, Ramos ALS, Pinheiro ACM, Fontes PR. Qualidade tecnológica e sensorial de presunto cozido com baixo teor de gordura reestruturado contendo soro líquido. Cien Agrotec . 2012;36:86 -92. available from: https://doi.org/10.1590/S1413-70542012000100011

23. AMSA. Guia de Avaliação da Cor da Carne. Champaign, Il: American Meat Science Association (AMSA); 2012.

24. Jorge EC, Mendes ACG, Auriema BE, Cazedey HP, Fontes PR, Ramos ALS, et al. Aplicação de uma questão check-all-that-apply para avaliação e caracterização de produtos cárneos. Carne Sci. 2015;100: 124-33. available from: https://doi.org/10.1016/j.meatsci.2014.10.002.

25. Lawrie RA. Lawrie's Meat Science. 7h ed: Editora Woodhead; 2006. 464 p.

26. Pla M, Guerrero L, Guardia D, Oliver MA, Blasco A. Características de carcaça e qualidade da carne de linhagens de coelho selecionadas para diferentes objetivos: I. Comparação entre linhas. Livest Prod Sci. 1998;54(2):115-23. available from: https://doi.org/10.1016/S0301-6226(97)00179-6.

27. Ramos EM, Gomide LAM. Avaliação da Qualidade da Carne: Fundamentos e Metodologias . 2ª edição. Viçosa , MG, Brasil: Editora UFV; 2017. 473 p.

28. Króliczewska B, Miśta D, Korzeniowska M, Pecka-Kiełb E, Zachwieja A. Avaliação comparativa da qualidade e perfil de ácidos graxos da carne de lebres marrons e coelhos domésticos oferecidos a mesma dieta. Carne Sci. 2018;145:292 -9. available from: https://doi.org/10.1016/j.meatsci.2018.07.002.

29. Brasil . Ministério da Agricultura, Pecuária e Abastecimento, Secretaria de Defesa Agropecuária. Instrução Normativa nº. 20 de 31 de julho de 2000. Aprova o Regulamento Técnico de Identidade e Qualidade de Almôndegas, Presuntos Reestruturados, Hambúrgueres, Kibes , Presuntos e Presuntos. Diário Oficial da República Federativa do Brasil. 2000, 149. Seção 1 (em português).

30. Feiner G. Meat Products Handbook: Ciência e Tecnologia Práticas: CRC Press; 2006. 672 p.

31. Northcutt JK, Bridges Jr. WC, Dick RL, Acton JC. Cinética do desbotamento da cor induzida pela luz de mortadela de peru embalada a vácuo. J Alimentos Musculares. 1990;1: 169-79. available from: https://doi.org/10.1111/j.1745-4573.1990.tb00362.x.

32. Ma J, Yu C, Guo J, Wu M, Xu Y, Yi H, et al. A causa intrínseca do desbotamento da cor em carne curada cozida fatiada durante o armazenamento refrigerado. Anim Sci J. 2017;88(10):1606-14. available from: https://doi.org/10.1111/asj.12813.