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Dry cured low-fat rabbit sausage: A much healthier disruptive food that enhances rabbit meat consumption

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A B S T R A C T

The main objective of this research was to develop a fuet from rabbit meat with reduced fat and salt content to encourage rabbit consumption and to find out consumer preference for this innovative food compared to retail fuet. Two products were designed: F5, containing fat and F4, where fatty tissue was substituted by konjac gum. In both, salt was partially substituted by KCl. These products, in comparison to commercial ones (pork, chicken and turkey), showed a reduction of at least 40% in the total energy value while protein raised on average 57.81% because of the lower fat content of rabbit and konjac gum use. In addition, there was a decrease in the salt content of approximately 19.50%. The above represents a huge competitive advantage for these new products from a nutritional point of view. The rabbit fuets were characterised by a spicy taste, slightly sour smell, and succulence, lower than in commercial fuets. It could be concluded that the rabbit fuet had a higher protein and lower fat and salt content than commercial fuets. However, they were less juicy and less succulent and therefore consumers preferred the commercial ones. The use of konjac gum does not seem to have any effect on this type of cured product.

1. Introduction

Rabbit meat has been consumed since 1100 BCE in some Mediterranean countries (Dalle Zotte, 2014). Because of this, some countries such as Spain, France or Italy are among the highest rabbit meat producers, with 55,824, 43,886 and 23,741 t/year respectively (FAOSTAT, 2021).

It is a white meat, easy to cook, tasty and adaptable to all diets, suitable for consumption by children, the elderly, or the convalescents, and is industrialised as deboned meat in the manufacturing of baby foodstuffs (Cury et al., 2011). Nutritionally, its low-fat content (5.3%) and the predominance of unsaturated (56% of total fat) and polyunsaturated fatty acids (31%) stand out (BEDCA, 2022). They include linolenic acid (21 mg/100 g), eicosapentaenoic acid -EPA- (0.15 mg/100 g) and docosahexaenoic acid -DHA- (0.31 mg/100 g) which decrease LDL cholesterol levels and cardiovascular risk (Whitney and Rolfes, 2002). They also help brain and vision development in children and brain maintenance in adults (Combes, 2004).

Furthermore, the protein contained in this meat provides all the essential amino acids, especially lysine and threonine (INTERCUN 2011). It is also a good mineral source such as potassium (430 mg/100 g), phosphorus (228 mg/100 g) and selenium (12 µg/100 g), which take part in different physiological functions (Dalle Zotte and Szendrő, 2011). However, despite these characteristics, production rates have shown a decrease, especially in the period 2009–2019 and due to changes in people's beliefs, animal welfare, or its price (Kallas and Gil, 2012). Therefore, given the good nutritional properties of this meat, it is worth trying to promote its consumption.

In this sense, although there is a rich history of recipes based on rabbit meat in the Mediterranean area, it is difficult to find rabbit meat derivatives at retail: foodstuffs prepared wholly or partly from meat or offal of different species and subjected to specific operations before being released for consumption, irrespective of the species of origin of the raw material (Real Decreto 474, 2014). It is true that new products are currently being developed from white meat due to its beneficial nutritional profile, but companies are using meat from other species such as poultry, because they have similar nutritional characteristics, with the advantage that production costs are much lower than in the case of rabbit meat (Petracci and Cavani, 2013).

The main promising approaches for the development of processed rabbit products involve the industrialization of traditional rabbit meat dishes and culinary practices and the manufacturing of already existing

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products, ranging from all kinds of fresh meat derivatives to cured-matured and marinated, among others. Several studies have been carried out to develop a range of rabbit-based meat derivatives. Leines et al. (2018) and Real Decreto 474 (2014) developed a chorizo sausage with rabbit meat, which was highly accepted by the evaluating judges, who considered this product to have a pleasant flavour. Petracci and Cavani (2013) produced rabbit meat-based frankfurters but using pork fat (>7%). Similar formulations were made in the study by Cury et al. (2011). Fresh sausages (Honrado et al., 2022) as well as cooked ham (Luna Guevara et al., 2016) have also been produced with a similar procedure to that used with other meats.

Currently, several cured-matured derivatives are available on the Spanish market. An example of this is fuet: sausages made with meat and fat, generally pork, although they can also be made with meat and fat from other animals, with a degree of course or fine mincing, subjected to a salting process. Pepper is added as a characterising ingredient, although other spices, seasonings, ingredients, and additives may be included. They are kneaded and stuffed into natural or artificial casings and subjected to a curing-maturing process, with or without fermentation, and optionally smoked, which gives them a typical aroma and flavour (Real Decreto 474, 2014).

However, fuet has nutritional weaknesses. In fact, the high-fat content of these products and the fat saturated character may be a negative aspect from a nutritional point of view. This increases the lipid content to over 30% in most cases, becoming an unhealthy product. Furthermore, the p/s ratio is far from the recommended value of 1 due to the high content of unsaturated fats in these products (Kromhout et al., 2011). For that, alternatives such as the use of fat-substituting ingredients are explored (Petracci and Cavani, 2013). Thus, carrageenans and some gums, such as konjac gum, represent an important option due to their water retention and gel-forming properties, which allow the preservation of certain organoleptic and processing characteristics that may vary due to fat reduction (Pacheco et al., 2011). Another fact to consider is salt content. As stated by Astiasarán and Ansorena (2015), a great effort to reduce the amount of salt used in dry fermented sausages has been undertaken, as there are still some products on the market with sodium concentrations of 1650 mg/100 g. Excessive fat and sodium intake has been linked to cardiovascular diseases including hypertension, stroke, and coronary heart disease (Mora-Gallego et al., 2016). Although many alternatives have been studied, the usage of KCl (alone or combined with potassium lactate) seems to be the most adequate, as it can substitute up to a 50% (molar basis) of NaCl in different small-diameter products. In that sense, the research carried out by Guàrdia et al. (2008) on small-diameter fermented sausages demonstrated that treatments prepared with a high level of salt substitution by KCl showed sensory attribute scores like those of the control.

Therefore, the main objective of this research was to develop a fuet from rabbit meat with reduced fat and salt content to encourage rabbit consumption and to find out consumer preference for this innovative food in comparison to retail fuets.

2. Materials and methods

2.1. Materials

A total of 50 rabbit carcasses (*O. cuniculus*) aged 2 months and weighing about 1.2 kg each were selected randomly from a slaughterhouse belonging to INCO SL (Valderrobres, Spain). They were transported to the Pilot Plant of the Faculty of Veterinary (Zaragoza, Spain) at 4 °C in polystyrene boxes with flaked ice. After quartering, loins, legs, and flanks were frozen at − 20 °C in 15 batches: 9 of 1 kg and 6 of 2.5 kg. Lamb (*Ovis* spp.) casings were purchased from a local butcher's shop. Salt, nutmeg, black pepper, garlic powder and dried rosemary were purchased from a local supermarket. Sodium nitrite (E 250) and potassium chloride (E 508) were from Panreac, ascorbic acid (E 300) and citric acid were from Labkem® and Konjac gum (E 425i) was purchased from Innovative Cooking SL (Spain).

2.2. Experimental design

To obtain the optimal formulations, an iterative and heuristic development process was carried out, in accordance with other similar study developed by Honrado et al. (2022). Each day, 3 batches of the same formulation were made. For this, an initial formulation based on the research carried out by Zamora et al. (2021) and the ingredients of traditional fuet found at retail were used as a starting point (Fig. 1).

From now on, two aims were set: reducing the fat content and decreasing the salt amount in the product. Once this formulation was produced, an 8 expert sensory assessors panel (ISO 8586, 2012) belonging to the rabbit's company (INCO SL) and their research centre was used to conduct a penalty analysis (Rothman and Parker, 2009). This analysis consisted of a hedonic scale -structured from 1 to 9- (Hough et al., 1992) and a 5-point JAR (just about right) scale (1 not at all, 2 not enough, 3 just enough, 4 too much & 5 excessive). The following attributes were evaluated according to Alastrue (2015): touch consistency, cut homogeneity, dough binding, characteristic fuet colour, characteristic fuet aroma, rancid smell, sour smell, firmness, succulence, chewiness, characteristic fuet taste, salty taste, rancid taste, sour taste, and aftertaste. The samples were chosen according to a Simple Random Sampling (Yates et al., 2006) so each fuet of the subset had an equal probability of being chosen. For this purpose, the 7 fuets of the batch were numbered, and the statistical software XLSTAT (2016) chose 2 of them. This procedure was repeated for each formulation replicate and formulation (1, 2.1, 2.2, F4 & F5). For the analysis of the fuet, the ends were removed and the central part was cut into rectangular prism-shaped pieces of 1.5 × 0.5 × 0.5 cm to avoid variability due to a more heterogeneous external appearance. A pairwise comparison was performed using Fisher's test with a threshold of 20%. A Spearman correlation was also developed due to the ordinal nature of the data.

2.3. Production of rabbit fuet

The production process of each fuet of the iterative process and the final ones took place at the Food Science and Technology Pilot Plant of the University of Zaragoza. Rabbit meat was thawed at 4 °C the night before production. For final formulations, over 2 consecutive days, 110 fuets of approximately 70 g (final product weight) were produced following the same technological procedure and modifying their formulations: F4, including konjac gum and reduced fat content due to fatty tissue remotion; F5, including rabbit fat and no konjac gum. Three replicates of each formulation were produced. In F4 predominantly fatty tissue was manually removed before mincing. The meat was conditioned and minced using a mincer with an 8 mm perforated plate (Gesame, Mod. M-94-32). All the optional ingredients were then added to the dough and kneaded in a vacuum mixer (Castellvall, Mod. AVT-50, Spain) in the following percentages: sodium chloride (0.50%), potassium chloride (0.50%), garlic powder (0.20%), nutmeg (0.15%), pepper (0.10%), ascorbic acid (0.05%), rosemary (0.05%), sodium nitrite (0.015%) and, in the case of fuet F4, Konjac glucomannan (1.00%) was added in addition to the above ingredients. Rosemary was added not only for its flavour but also for its antioxidant effect (Astiasarán and Ansorena, 2015). This in combination with ascorbic acid on a 1:1 ratio shows the greatest antioxidant activity, according to Perlo et al. (2018). After mixing, the dough was left refrigerated at 4 °C for 24 h. After this time, the fuet was stuffed into lamb casings of 20–22 mm diameter, previously soaked in water acidified with citric acid (pH < 4.0) for 24 h. A stuffing machine (Mainca, Mod. EM-30) was used for this purpose. Afterwards, the fresh fuets were hung in the maturation room (Memmert, Mod. ICH750) and kept there at 12 °C and 70% relative humidity until weight losses were approximately 50% after 8–10 days (Marcos et al., 2020; Mora-Gallego et al., 2016). Once the fuets maturing process was finished, they were vacuum-packed in a vacuum packer (Tecnotrip,

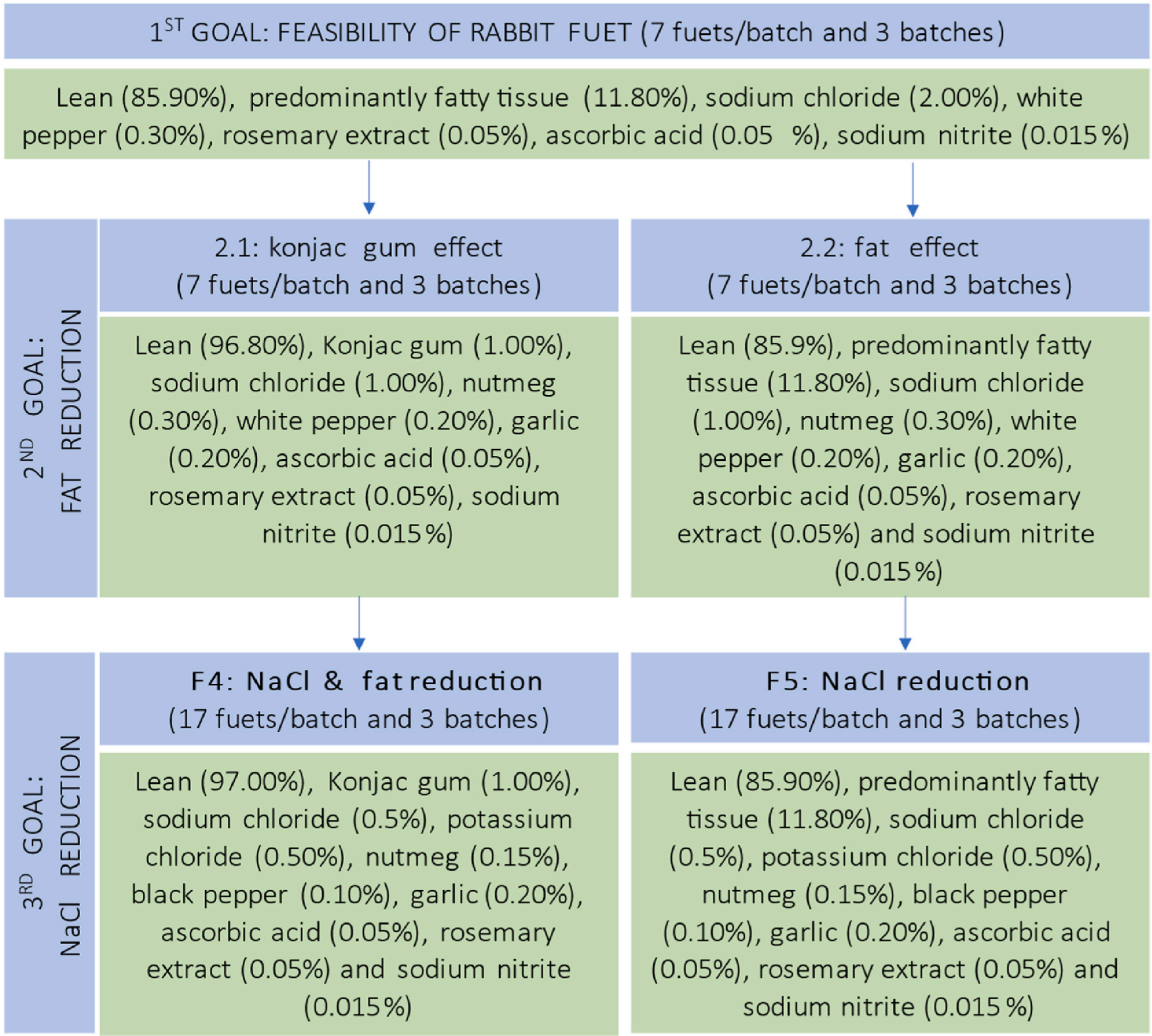

Fig. 1. Formulations developed during the iterative development process and final formulations (F4 & F5).

Mod. EV-13-L-CD-SC) and stored under refrigeration at 4 °C.

2.4. Physico-chemical characterization

Moisture of commercial and rabbit fuets determination was carried out using an oven (Selecta, Mod.Ref. 2005167, Spain) at a temperature of 105 °C determining weight losses according to the method AOAC 950.46 (AOAC, 1990). The total protein content of the fuet was determined on a distillation unit (Velp, Mod. UDK 129, Italy) by the Kjeldahl Method according to methodology AOAC 2.062 (AOAC, 1984). The results were expressed as a protein percentage from nitrogen content using the correction factor 6.25. Fat determination was carried out according to the method AOAC 24.005 (AOAC, 1980) in a semi-automatic Soxhlet extractor (Selecta, Mod. DET-GRAS N, Spain). The salt content was established following AOAC 937.09 (AOAC, 1995). The energy provided by the fuet expressed as total kcal per 100 g was calculated using the conversion factor of 4 kcal/g for protein and 9 kcal/g for fat (Merril and Watt, 1955). The pH was determined with a digital puncture pHmeter (XS Instruments, Mod. PH25, Italy) by inserting the electrode directly into the samples (Alastrue, 2015). Previously, the equipment was calibrated according to the manufacturer's instructions with buffers of pH 4.01 and 7.00 (XS Instruments). Finally, water activity was determined directly on the samples using a water activity meter Decagon Devices, Mod. CX-1 (Alastrue, 2015). A Pearson correlation test was performed to find relationships between variables.

2.5. Sensory characterization

The sensory characterization of fuets developed in this study was carried out using a Quantitative Descriptive Analysis -QDA- (general sensory profile) according to the standard ISO 13299 (2016), as well as a general texture profile (specific sensory profile) based on ISO 11036 (2020). The same process was carried out on five types of fuets of similar format already existing on the market (Table 1) but manufactured with

Table 1
Commercial fuets employed in the comparative study.

CODE	MEAT USED	INGREDIENTS
P1	Chicken	Chicken meat, salt, milk powder, corn dextrin, corn dextrose, spices, flavourings, antioxidant (E−331) & preservatives (E−250, E−252)
P2	Pork	Pork, salt, milk powder, corn dextrin, corn dextrose, spices, flavourings, antioxidant (E−331) & preservatives (E−250, E−252)
P3	Pork	Pork, salt, lactose, milk powder, spices, dextrose, antioxidant (E 316) & preservatives (E 250, E 252)
P4	Pork	Pork, salt, lactose, dextrose, spices, herbs, antioxidants (E−300), preservatives (E−250) & starters
P5	Pork & turkey	Pork, turkey meat, salt, lactose, dextrose, spices, natural flavouring, preservatives (E−250, E−252), colouring (E−120) & starters

pork, chicken, or turkey meats to carry out a comparative study. These sessions were developed on three consecutive days to evaluate possible differences between the batches.

A trained sensory panel of evaluators from the Faculty of Veterinary of Zaragoza composed of 10 people was used. The evaluators had previously demonstrated sensory sensitivity in preliminary tests, received considerable training and they were able to make consistent and repeatable assessments of various commercial fuet samples. This training also allowed the assessors to acquaint themselves with the attribute terms and the scoring system. Samples presentation was designed considering a complete block design, so each assessor evaluated all the samples to achieve a correct balance (XLSTAT®, 2016). The fuet ends were removed and the central part was cut into rectangular prism-shaped pieces of 1.5 × 0.5 × 0.5 cm. These samples were given in a monadic way to each sensory assessor according to a random order. The sessions took place in the Pilot Plant's tasting room of the in accordance with ISO 8589 (2007) Standard. The attributes were selected according to the results obtained in the penalty analysis and considering the Sensory vocabulary according to ISO 5492 (2008), after a meeting with the expert sensory assessors to select the best descriptors for this kind of food.

For the QDA, the attributes chosen were dough homogeneity, fuet colour, fuet aroma, acid smell, firmness, chewiness, succulence, fuet flavour, salty flavour, spicy flavour, and aftertaste. A structured linear scale from 1 to 10 was used. Afterwards, a product characterization analysis was carried out. For the sensory Texture Profile (Szczesniak, 2002) a linear structured scale (0, the attribute is not present – 5, the attribute is very present) was used with different preestablished attributes: elasticity, firmness, and juiciness as primary attributes; fibrousness, gumminess, chewiness, crumbliness, toughness and succulence as secondary attributes.

2.6. Overall assessment

A comprehensive study based on Principal Component Analysis (PCA) was carried out, using XLSTAT® (2016) software, by integrating the physicochemical parameters determined in the developed fuets and commercial samples together with values obtained from Quantitative Descriptive Analysis (General Sensory Profile) made in all of them. In this way, a Biplot graph was obtained which by showing all the attributes and products at the same time, provides a broader, global vision. Sensory texture profile data were not included to avoid obtaining an overly complex model. Prior to the PCA, a correlation matrix (Pearson model) was carried out to verify the existence of interactions between variables.

2.7. Consumer preference study

To develop an explorative study of the consumers, with a prospective approach, a sensory analysis was carried out involving 65 people, all of them regular meat consumers that were divided into 5 groups. To establish the Statistic Power of the test with the size of the sample selected β (Type II error) was calculated employing the software G. Power© V.3.9 (Faul et al., 2007) and achieved 70% ($1\text{-}\ \beta = 0.301$). The study was developed in the tasting room of the Pilot Plant of the Faculty of Veterinary at University of Zaragoza in accordance with ISO 8589 (2007). Seven coded samples were tasted in random order: the five commercial fuets (Table 1) and the two definitive rabbit fuets (F4 and F5). The samples were presented in a sequential monadic way (ISO 11136, 2014). Sample presentation was designed considering a complete block design, so each consumer evaluated all the samples to achieve a correct balance. The participants responded to a short survey with sociodemographic aspects, and they answered questions about preferences for the most common meats and cured meat products in Spain. After that the consumers carried out a Hedonic Test, using a Likert Scale with 7 points (from 1-I don't like-to 7 –I like it a lot-) where words were replaced by emoticons. These findings were used to develop an Agglomerative Hierarchical Clustering (AHC) using the statistical software XLSTAT (2016). This procedure used Euclidean distance and Ward's method for clusterization. Consumers were grouped into distinct clusters according to the score they gave to each product, which expressed their degree of acceptance towards the tested products.

With these pleasantness ratings, the clusters obtained from the consumers and the factor loadings from the sensory characterization (trained panel) an External Preference Map (PREFMAP) was drawn up, which allowed to condense and contrast all the information obtained in this study. A two-dimensional vector model was used, so the best model according to the F-ratio calculated by the software was found.

2.8. Statistical analysis

Proximal analysis, physicochemical and sensory data obtained were synthesized using descriptive statistics. The data distribution was plotted to check its normality and detect outliers.

For proximal analysis and physicochemical results, a linear mixed model was carried out to determine differences between treatments F4, F5, P1, P2, P3, P4 & P5. This model included treatments as fixed variables and the three replicates as a random effect. The interaction between them was also studied and approximate F-ratio tests for each fixed effect were conducted and the critical value for a statistical effect was taken at $p < 0.05$. A pairwise comparison between means was carried out using Fisher's multiple comparisons test (LSD). All statistical modelling and presentations were constructed with XLSTAT (2016).

For the sensory results, the performance panel (consistency) was checked following the guidelines established in section 8 titled "Analysis of Results" of ISO 8586 (2012). For that, a panel analysis which again included the judge, session and product effects and their interactions as variables in the model was performed with the statistical software XLSTAT® (2023). Then, for the sensory product characterization, a model that considered judges, products, sessions and their interactions was used. This model also considered the random session and product effect. The coefficients obtained by the cosine-square method from the evaluations given by the judges were represented in spider graphs. To do this, a linear regression was performed and the best coefficients for each of the attributes are searched. As a result, positive or negative values can be obtained depending on whether the dispersion towards the mean value is positive or negative. These maximize the differences and similarities and, therefore, facilitate their interpretation. For the sensory texture profile, an ANOVA (CI 95%) considering products, sessions and their interactions was performed to find differences among samples.

3. Results and discussion

3.1. Experimental design

Penalty analysis was used to identify areas for improvement and manage the final formulations. In the first formulation, most of the characteristics studied were found to be in JAR and therefore were maintained. Other attributes such as rancid smell, sour smell, rancid taste, or sour taste were found to be not at all, which was positive. However, the characteristic flavour was not found in JAR as several judges considered it to be too much present. Furthermore, some of them reported in additional annotations that they found some unpleasant flavours. The salty taste was found to be 50% at JAR and the remaining 50% at too much, so it was interpreted as a parameter that needed to be improved. The aftertaste is an attribute that was not at JAR and 38% of the judges evaluated it as excessive due to pepper excess.

Based on this analysis, for future formulations (2.1 and 2.2), it was decided to decrease salt, include other spices to mask the feed flavour detected by some of the judges in the first experiment and decrease pepper (formulation 2.2). In addition, in formulation 2.1 it was decided to add konjac gum to evaluate its effectiveness as a fat substitute.

In these new formulations, the characteristic flavour was also not found in ''JAR''. The judges' comments on this attribute were about spiciness (too intense) and that both nutmeg and pepper, which were found in excess, masked the meat flavour. This condition was reflected in the aftertaste parameter which the judges again assessed as too much. On the other hand, in both cases, a high percentage of salty taste was achieved in JAR. Comparing these two formulations, the judges determined that the succulence was slightly lower in the fuet containing konjac gum, while in the fuet without konjac it was in JAR (formulation 2.2).

Therefore, to improve the formulations of the second experiment, two new formulations were developed: one with konjac gum (F4) and the other containing fat (F5), decreasing the concentrations of spices to mask the feed flavour without eliminating the meat flavour completely and replacing half of the salt content by KCl. In this case, products with most attributes at or close to -Just about Right (JAR)- were obtained, with no differences in the salting intensity. For that, F4 and F5 were considered the definitive formulations.

3.2. Physico-chemical characterization

Table 2 shows the proximal composition and physicochemical parameters for the final formulations (F4 & F5) and the rest of the studied products (P1, P2, P3, P4 & P5). No differences were observed among replicates and the interaction was not significant ($p > 0.05$). In comparison with theoretical values shown in the Spanish Food Composition Database -BEDCA (2022) for traditional pork fuet, the developed products were characterised by their low-fat content and high protein content. While pork fuet contained 19.50% protein and 42.00% fat rabbit fuet had on average 46.47% protein and 14.55% fat. This value decreased by 4.46% when konjac gum is used instead of rabbit fat. Compared with the most sold commercial fuet in Spain (pork) the reductions in fat are 60.71 and 71.10% when compared to F5 and F4 respectively. In contrast, the protein content rises by 56.96 and 58.65%. In addition, there is a decrease in the salt content of approximately 19.57%, which translates into a 20.35% decrease in sodium content, with a consequent health benefit. Furthermore, it could be labelled as "high protein content" as more than 20% of the energy provided comes from protein (Regulation Nº 1924, 2006). According to BEDCA (2022) 100g of fuet (cured sausage) contributes 456 Kcal to the total energy. In contrast, all the products developed in this study where fat had been partially reduced or completely substituted by konjac gum showed a reduction of at least 40% in the total energy value.

Furthermore, when comparing the rabbit fuet with P1 (chicken) and P5 (turkey/pork), one might expect that the nutritional characteristics would be similar as it is a leaner meat. However, the fat content increased to 32.21% in P1 and 43.20% in P2, compared to 12.32% in F4. Consequently, the energy value was higher and while 100 g of fuet F4 provided 301.12 kcal, 100 g of P1 or P5 provided 411.29 and 494.22 kcal respectively. Likewise, the sodium content in F4 and F5 was 1.63 times lower, with a consequent nutritional benefit. The above represents a huge competitive advantage for these new products from a nutritional point of view to achieve a much healthier diet. Image 1 shows the appearance of the commercial fuets used in this study and the rabbit fuets developed. It is worth highlighting the differences among the commercial ones, not only for those made with different meats, but also between the pork ones (P2. P3 & P4), especially about the presence of fat granules in the meat mixture (Image 1).

The Pearson correlation analysis showed that most of the variables considered were highly significant ($p < 0.01$) between them with $R^2 > 0.898$. The fat content demonstrated a high relationship with energy value as expected, also it had an inverse high correlation with a_w due to the composition in each formulation. The moisture of the products was well correlated with pH; in this kind of product (fuet) the pH values should be 5.00 from 5.50 and a_w between 0.8 and 0.9 (Badui, 2006). The protein in all fuets considered showed a high correlation ($r^2 = 0.95$) with $a_{w,}$ which could be due to the water-holding capacity in the fuet. Also, the protein had an inverse behaviour with respect to the fat (%) ($r^2 = -0.91$) and Sodium (Na^+) quantities ($r^2 = -0.91$). It is highlighting the correlations between energy value with protein ($r^2 = -0.80$) and fat ($r^2 = 0.98$) that demonstrated in a clearly the significan influences of fat over the nutritional composition of the fuet.

3.3. Sensory characterization

3.3.1. Quantitative descriptive analysis (QDA)

Fig. 2 shows the general sensory profile of both rabbit and commercial fuets. No differences were observed between replicates and the interaction was not significant. Among the rabbit fuets, differences in succulence were the only ones observed ($p < 0.05$), those that incorporated konjac gum in their formulation resulted in less succulent than each other, which could indicate some effect over the organoleptic properties of fuets when this gum is used as a fat substitute.

Comparing the rabbit fuets with the commercial pork-based fuets (Fig. 2 B), the rabbit fuets presented a greater homogeneity of the dough, possibly due to a higher degree of mincing, and a greater intensity of spiciness, which could be related to the incorporated pepper. In contrast, the rabbit fuets were less firm, possibly related to the higher moisture content and less succulent, as the fat content of the commercial fuets was higher (BEDCA, 2022). On a favourable note, the rabbit fuets were considered less salty than the commercial pork fuets. These characteristics were maintained in the chicken fuet (Fig. 2 A). However, the pork and turkey fuet (Fig. 2 C) were perceived to have greater differences, being characterized by a much greater succulence and less characteristic flavour than the rabbit fuet, which could be due to the softness of the turkey meat and the addition of pork fat (Mora-Gallego et al., 2016).

3.3.2. Sensory texture profile

Fig. 3 shows three differential semantic graphs for the texture attributes evaluated in the different fuets. No differences were observed between replicates and the interaction was also non-significant. Fig. 3 B shows the final rabbit fuets versus the three commercial pork fuets. It

Table 2
Proximal composition and physicochemical parameters for studied fuets. Different letters in the same row denote significant ($P < 0.05$) differences between products for a given parameter.

	Rabbit fuet		Commercial fuet					Reference (BEDCA, 2022)
	F4	F5	P1	P2	P3	P4	P5	Typical Fuet
Moisture (%)	32.60^e	32.63^e	29.05^d	25.41^c	33.83^f	18.12^a	22.82^b	32.90
Protein (%)	47.41^f	45.54^e	30.22^d	30.51^d	21.21^a	29.22^c	26.27^b	19.50
Fat (%)	12.32^a	16.78^b	32.21^c	36.26^d	37.27^e	44.28^g	43.27^f	42.00
Salt (NaCl %)	3.14^a	3.05^a	5.23^b	5.05^b	4.90^b	5.28^b	4.87^b	3.50
Na+ (g)	1.38^a	1.37^a	2.26^b	2.15^{ab}	2.10^{ab}	2.27^b	2.00^{ab}	1.40
Energy value (kcal/100g)	301.12^a	332.91^b	411.29^c	448.46^d	420.25^c	515.26^f	494.22^e	456.00
pH	6.04^d	5.89^d	5.72^c	5.50^b	5.70^c	5.04^a	4.93^a	5.55
a_w	0.895^d	0.906^e	0.741^c	0.745^c	0.675^b	0.674^b	0.632^a	<0.92

*Results are averages of 3 replicates.

Image 1. Visual comparison of commercial fuets (P1–P5) with developed rabbit fuets (F4 & F5).

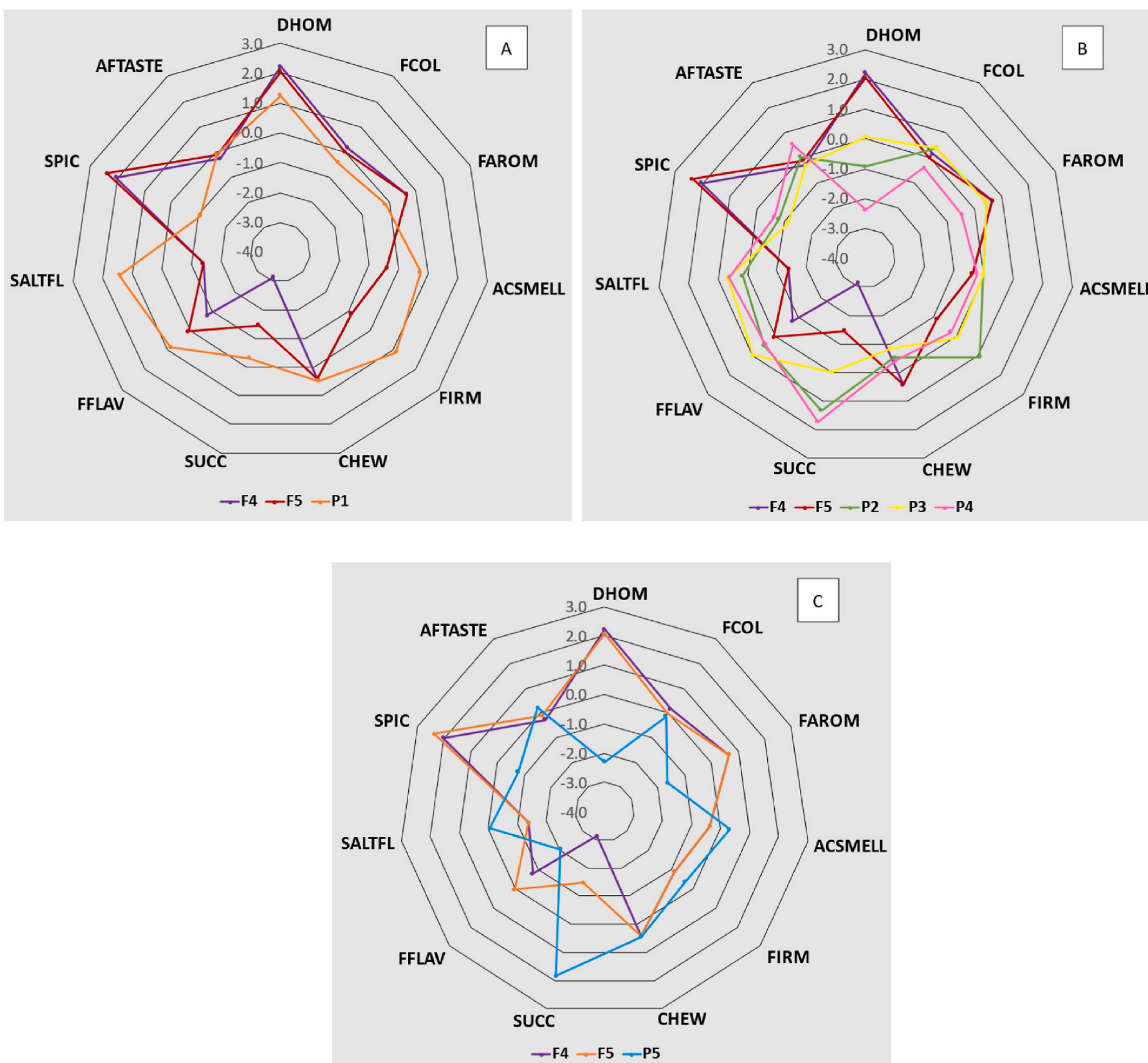

Fig. 2. General sensory profile of rabbit and commercial fuets. A: F4 & F5 (rabbit) compared to P1 (chicken); B: F4 & F5 (rabbit) compared to P2, P3 & P4 (pork); C: F4 & F5 (rabbit) compared to P5 (pork & turkey). DHOM: dough homogeneity, FCOL: fuet colour, FAROM: fuet aroma, ACSMELL: acid smell, FIRM: firmness, CHEW: chewiness, SUCC: succulence, FFLAV: fuet flavour, SALTFL: salty flavour, SPIC: spicy sensation, AFTASTE: aftertaste. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

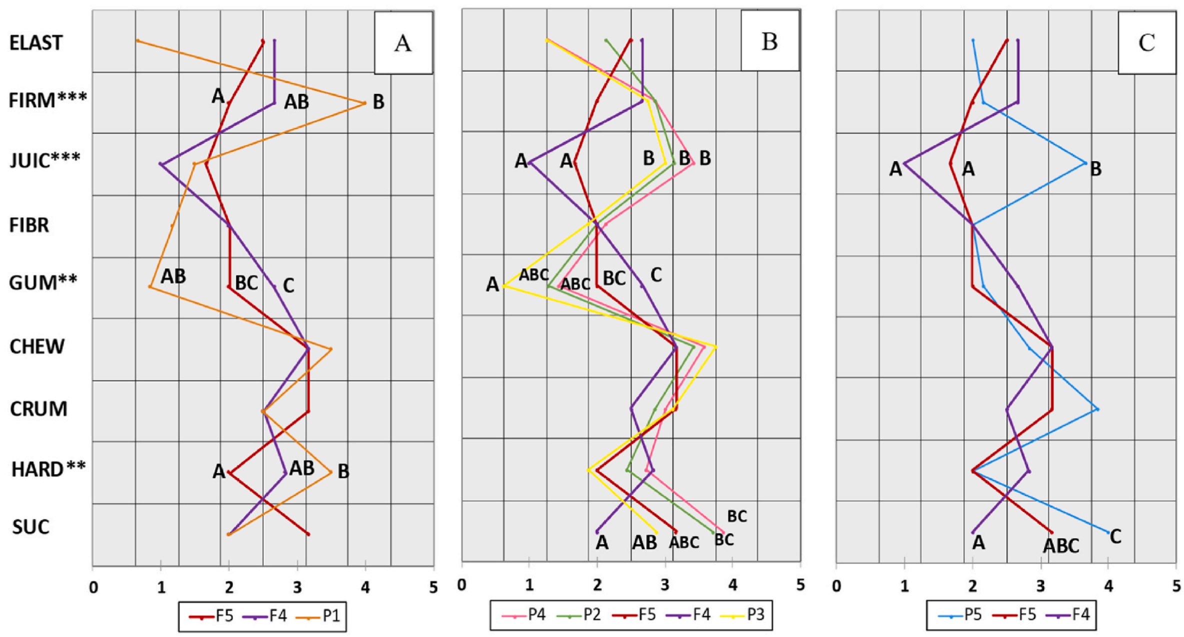

Fig. 3. sensory texture profile of rabbit and commercial fuets. A: F4 & F5 (rabbit) compared to P1 (chicken); B: F4 & F5 (rabbit) compared to P2, P3 & P4 (pork); C: F4 & F5 (rabbit) compared to P5 (pork & turkey). ELAST: elasticity, FIRM: firmness, JUIC: juiciness, FIBR: fibrosity, GUM: gumminess, CHEW: chewiness, CRUM: crumbliness, HARD: hardness, SUC: succulence. Different letters denote statistically significant differences between products for the same attribute: *** ($p < 0.001$), **($p < 0.01$).

can be deduced that statistically significant differences ($p < 0.05$) between the pork and rabbit products were found for juiciness. However, although non-significant, differences were also found in gumminess and succulence. In general, the rabbit fuets were gummier and less succulent. This would be related to the fat content of the pork fuets as well as to the presence of konjac gum in the F4 formulation.

Fig. 3 A shows the texture attributes for the product made with rabbit meat versus the commercial chicken fuets. In this case, the differences

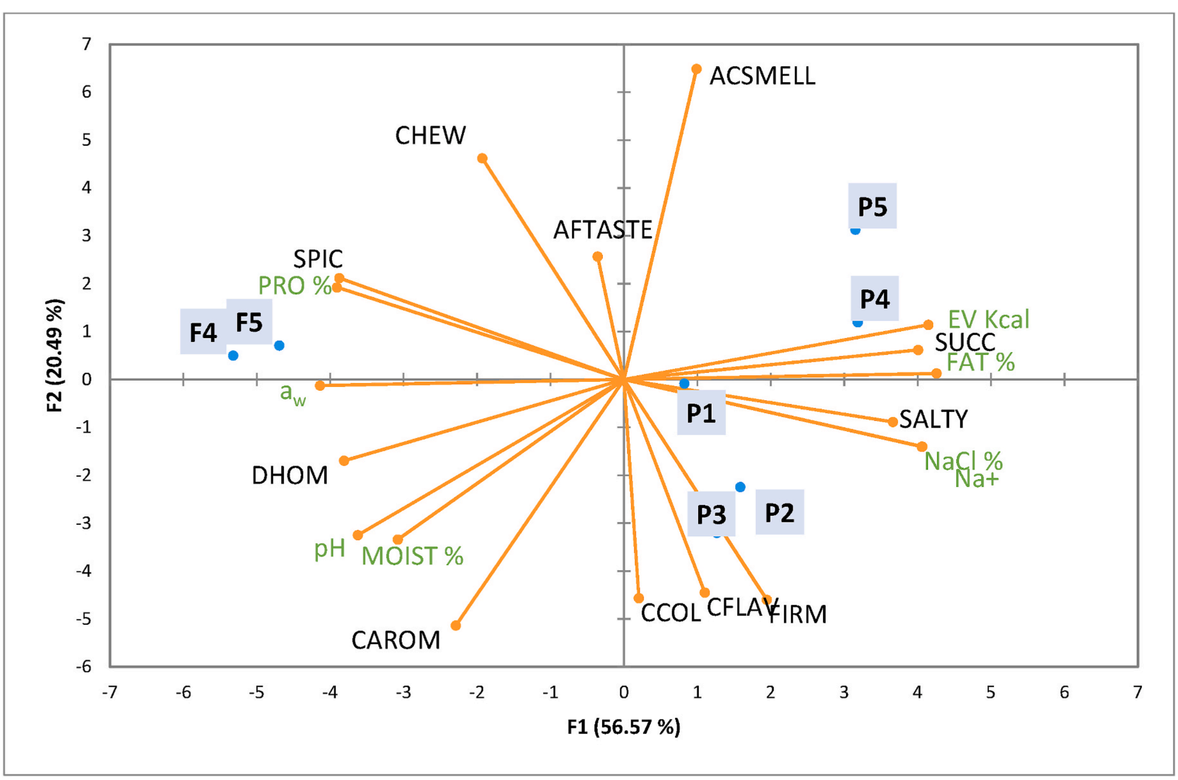

Fig. 4. Principal component analysis of the proximal, physico-chemical parameters and sensory attributes of the experimental (F4 and F5) and commercial fuets studied (P1–P5). DHOM: dough homogeneity; FAROM: fuet aroma; FCOL: fuet colour; FFLAV: fuet flavour; FIRM: firmness; SALTFL: salty flavour; ACSMELL: acid smell; SUCC: succulence; AFTASTE: aftertaste; CHEW: chewiness; SPIC: spicy; EV: energetic value; PRO%: protein; moist%: moisture. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

($p < 0.05$) were found in the firmness and hardness attributes between the rabbit fuet containing fat (F5) and the chicken fuet, being greater in this one, and in the gumminess attribute between the product from rabbit (F4) and the chicken fuet probably due to konjac gum addition.

In the right graph (Fig. 3 C), where the product developed have been represented against the mixed pork and turkey fuet, differences could be observed ($p < 0.05$) in juiciness between the two rabbit fuets and the mixed one, and in succulence between the rabbit fuets with gum (F4) and the mixed one. These results contrast with the ones obtained by Osburn and Keeton (1994) in fresh pork sausage where an increase of konjac gum produced a decrease in textural attribute scores and tended to lessen the force necessary to shear. Atashkar et al. (2018) found that when adding konjac gum 1% hardness decreased significantly, also in fresh sausage. Osburn and Keeton (2004) reported that low-fat sausages with konjac gel slightly reduced sensory panel values. However, Jiménez-Colmenero et al. (2012) showed in a documental review that, according to instrumental hardness measurements, when the fat content decreases (and konjac gel levels increase) a rise in firmness and harness occurred. This behaviour was like rabbit fuet. This could be related to the water content. In Frankfurt sausages, the konjac gum absorbs the water, modifying the texture and making it softer. However, in fuet, the low percentage of water makes it impossible for this to happen.

3.4. Overall assessment

The PCA collected the data's dispersion in 77.06% of the variability in the study (Fig. 4). There was a large separation between rabbit fuets and all commercial fuets, as they were positioned opposite each other in the first component (F1) of the graph, representing almost 60% of data variability. The rabbit fuets stood out for having a high protein content, while the fat content, and therefore the energy value provided, was lower than in commercial fuets. In addition, this lower fat content also made them less succulent than the other fuets, although more homogeneous, which may be positive. However, the rabbit fuets were quite far away from the characteristic flavour, which could be due to the spicy taste associated with them, being its major shortcoming. The salt content was found just opposite F4 and F5, which makes them a healthier product. This fact and the higher moisture of rabbit fuets made them the ones with the highest a_w. Furthermore, pH was found to be higher in F4 and F5 due to their maturation was fallow a traditional process with natural acidification in contrast with commercial fuets where starters were added in the manufactory. This would also explain the acid smell of commercial fuets. Another result provided by this graph is that the use of Konjac gum as a fat substitute in ''F4'' worked to replace the low-fat present in the rabbit fuet ''F5'' as both products were evaluated similarly. However, it was not sufficient to achieve the succulence characteristic of pork fuets. As can be seen, the variation on F2, which represents 20%, is due mostly to sensory characteristics. The rabbit fuets were characterized by a spicy taste, slightly sour smell, and succulence, lower than in commercial fuets.

3.5. Consumer preference study

Regarding the consumers' preferences, the findings for the different types of meat and the different kinds of sausages revealed that they were liked by a very high percentage of the consumers surveyed (Fig. 5). Pork and chicken are liked by 100% of the participants. Rabbit meat, on the other hand, is the least liked with 80%. In relation to cured meats, consumers indicated that they most liked fuet and black pudding with 95% in both cases, with *salchichón* coming last with 80%.

On the other hand, the Hierarchical Agglomerative Analysis carried out considering only the consumers' liking for each product evaluated, classified them into three clusters: I (n = 29), who preferred P2 and P4; II (n = 26), who liked the most P3 and P4 and III (n = 10), who opted for F5. These clusters found together with the other data from QDA were used to elaborate the External Preference Map (Fig. 6).

A large proportion of consumers of cluster II had a greater preference for pork fuets (P2 and P3), followed by chicken fuet P1, where the same cluster dominated, but in the range of 60–80%. The traditional and mixed (turkey/pork) fuet, P4 and P5 were in the same area, but with a significant contribution from cluster III. Finally, F4 and F5, the developed rabbit fuets, were located in the cold area, between 20 and 40%, within the representative cluster III, the smallest cluster. This cluster could have a certain predilection for the descriptors that characterize rabbit fuet, such as the spicy flavour. These may have two reasons: first, as could be seen, the lowest preferences were always associated with the substitution of pork for other types of meat in the fuets evaluated, especially the ones made with rabbit. Second, as some authors claim (Astiasarán and Ansorena, 2015) the sensory analysis of products containing kojac gum as a fat replacer resulted in some sensory limitations. However, F4 and F5 were similarly evaluated, so konjac gum seems not to be responsible for its low preference.

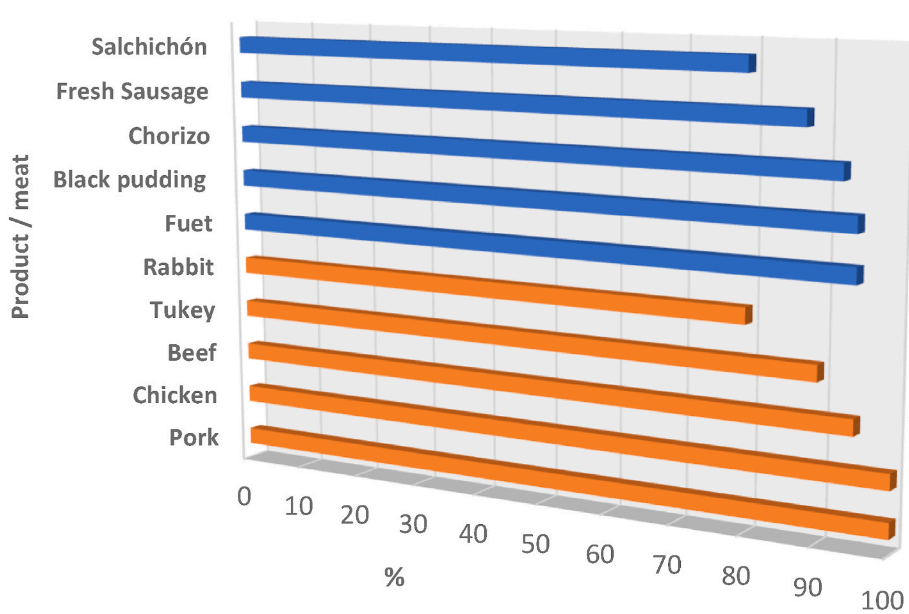

Fig. 5. Percentage of consumers who like different meats and meat products.

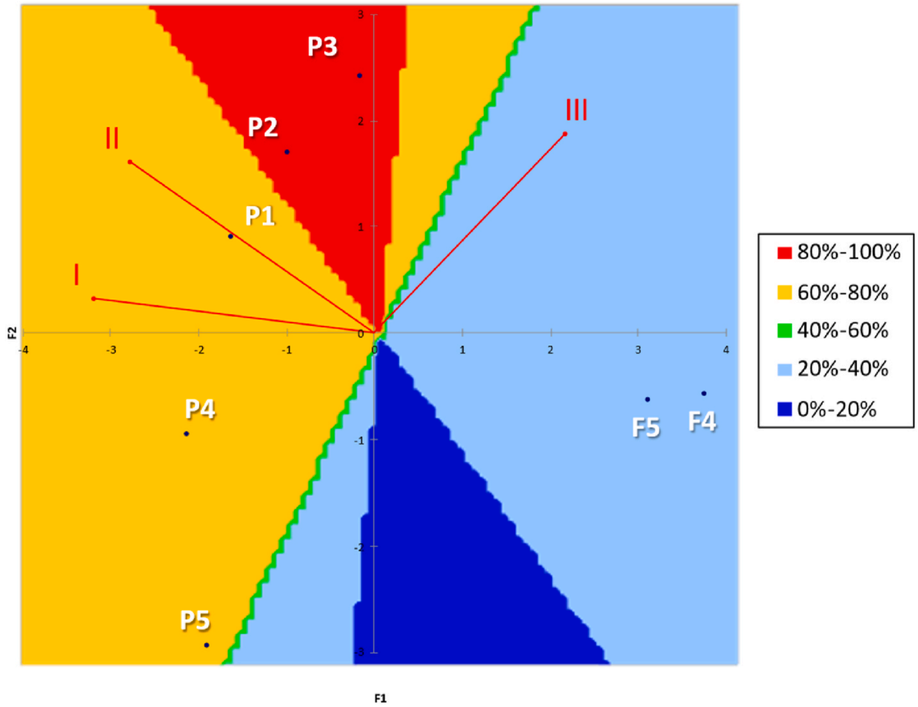

Fig. 6. External preference map for commercial products and developed rabbit fuets.

4. Conclusion

In this study, a fuet was developed from rabbit meat and its low-fat version by substituting it with konjac gum. It could be concluded that the rabbit fuet had a higher protein content and lower fat and salt content than commercial fuets. The lower fat content was achieved because of the use of rabbit meat and the non-addition of pork fat. In addition, in F4 a further reduction was achieved by replacing predominantly fatty tissue with konjac gum. This konjac gum does not seem to have a positive or negative effect on this cured product, although its presence in F4 could have made it possible to obtain similar sensory characteristics to F5 despite having 4.36% less fat. It could be concluded that to obtain better acceptability, the formulations should be readjusted, mainly by increasing the fat content or by incorporating another natural substitute of animal fat, for example, oleo gels from vegetables, also decreasing the pepper content, as it masks the characteristic flavour of fuet.

Implications for gastronomy

Rabbit has been consumed since 1100 BCE in some Mediterranean countries, especially in the Iberian Peninsula from which its name derives (Hispania, in Latin Land of Rabbits). The most common way of eating it has been fresh or defrosted meat. Currently, several meat products from this kind of meat are available on the Spanish market, for example, sausages and burgers. However, in Spain a typical and traditional fermented sausage named fuet and made generally with pork meat and fat, minced, and subjected to a salting process is consumed. This product is a hallmark and a gastronomic heritage despite their nutritional weaknesses, due to its high amounts of fat (≥30%) and salt (≈3%), and so far, none are known made from rabbit meat. Due to the above, it could be an interesting option to improve the eating habits of people through the development of alternative options that consider another typical Mediterranean ingredient as rabbit meat. From a sensory point of view, is a big challenge and we must be able to offer a new product made with an alternative source of meat, providing higher protein amount, a lower fat content and a significant reduction of salt content than commercial fuets but keeping the organoleptic properties that give the identity to this product. We propose to enrich the gastronomic Spanish heritage by offering an alternative fuet that continues being delicious and representative of Iberian Culture, but much healthier for the consumer.

CRediT authorship contribution statement

Adrián Honrado: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing. **Carmen Lahoz:** Data curation, Investigation, Methodology, Software. **Juan B. Calanche:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – review & editing. **José A. Beltrán:** Data curation, Formal analysis, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing, All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors of this manuscript certify that there are no financial or personal relationships with other individuals or organisations that could inappropriately influence this work.

Data availability

Data will be made available on request.

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