PROSCIUTTO DI MODENA PDO:

COMPOSITION, NUTRITIONAL ASPECTS, SENSORY PROPERTIES, AND SHELF LIFE

MINISTERO DELL'AGRICOLTURA DELLA SOVRANITÀ ALIMENTARE E DELLE FORESTE

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CONSORZIO
DEL PROSCIUTTO
DI MODENA

The Consorzio Prosciutto di Modena was established voluntarily in 1969 and today brings together all the companies (10 ham factories) registered in the control system for the production and certification of Prosciutto di Modena PDO. The consortium's mission is to protect and safeguard, promote, enhance and spread knowledge of Prosciutto di Modena PDO.

The production area of Prosciutto di Modena PDO, as defined by the Production Specifications, does not exceed 900 meters above sea level and corresponds to the hilly belt and valleys around the Panaro river basin, extending from the foothills to include areas in the provinces of Bologna and Reggio Emilia.

All processing stages, from salting to complete curing, take place in this typical area, where environmental and human factors combine to make this excellence of Italian cured meats unique: the particular microclimate of the territory and the mastery of production techniques acquired and carefully handed down over the centuries. The overall curing period, required by the disciplinare di produzione, is at least 14 months; however, to make the most of the qualities and characteristics of the selected pork legs now used to produce Prosciutto di Modena PDO, most hams are cured for at least 18–20 months and often longer, before being placed on the market. Prosciutto di Modena PDO is made exclusively from pork legs (from pigs born and raised in 10 regions of central and northern Italy) and salt, in controlled proportions.

For more information about the product, please visit:

www.consorzioprosciuttomodena.it

The design and implementation of this study were carried out by the Stazione Sperimentale per l'Industria delle Conserve Alimentari (SSICA), with the aim of providing information on the nutritional value, sensory quality and shelf life of Prosciutto di Modena PDO.

PREFACE

The **Prosciutto di Modena PDO** has a centuries-old history and a deep, indissoluble bond with a territory that has always been dedicated to producing hams of excellence.

The Consorzio di Tutela has always focused on care and enhancement of the product, with the aim of maintaining in consumers the perception of superior quality that can be felt from the very first taste.
Consumers are increasingly attentive to what they bring to the table: they seek transparency, authenticity and clear information on ingredients, origin and nutritional values, while also showing interest in the identity of the product, its provenance, and the story that accompanies it.

To meet these expectations, the consortium has promoted a new scientific study to provide information on the nutritional value, sensory quality and shelf life of Prosciutto di Modena PDO, supporting its recognition and value in national and international markets. Several years have passed since the last analytical survey – carried out in 2011 – which defined the nutritional profile of Prosciutto di Modena PDO, analysing the product after fourteen months of curing.

Given the progress in farming techniques and production technologies, the Consorzio di Tutela has now deemed it appropriate to update the previous analyses, going into greater detail on quality, analytical aspects and shelf life.

Since Prosciutto di Modena PDO is usually available on the market with extended curing times, the study considered different curing periods (16, 20 and 24 months), with the aim of consolidating the scientific evidence that longer curing not only ensures a product with appropriate safety characteristics but also promotes the formation of bioavailable components with a positive impact on health, such as free amino acids and peptides released through proteolysis, which are easily assimilated by the human body. Furthermore, in order to provide consumers with more information and guarantees, it was also deemed necessary to further investigate the shelf life of Prosciutto di Modena PDO.
This focus pursued two objectives: first, to verify the quality, analytical and sensory parameters (panel test) of slices obtained from hams with three different curing times and stored at different temperatures, according to an accelerated shelf life study; second, to estimate the shelf life of vacuum-packed slices stored under refrigeration.

We are pleased to present, through this publication, the analytical results of the study, convinced that they represent a useful tool for both consumers and industry professionals. From our perspective, these results are not an end point, but rather an incentive to continue improving the product in nutritional and safety terms, in order to safeguard, also in the future, a product strongly linked to tradition and its territory.

Special thanks go to SSICA, whose research team worked on this project for over a year, and to Masaf, which has always supported the promotion and protection of Prosciutto di Modena PDO.

Giorgia VITALI President of the
Consorzio del Prosciutto di Modena PDO

INTRODUCTION

The purpose of this project is to investigate the nutritional properties of Prosciutto di Modena PDO, assess the shelf life of the ready-sliced and portioned ham, and support operational and communication strategies for producers and consumers. The project consists of two main phases:

- **Phase 1:** Study of the nutritional properties of Prosciutto di Modena PDO, focusing on extended processing times and developments in the nutritional profile;
- **Phase 2:** Study and prediction of the shelf life for vacuum-packed portions of Prosciutto di Modena PDO with different processing times.

For the purposes of the project, the Consorzio del Prosciutto di Modena manufacturers' group supplied 24 boned hams from 3 production sites with different processing times: 16, 20 and 24 months, as shown in the Figure 1.

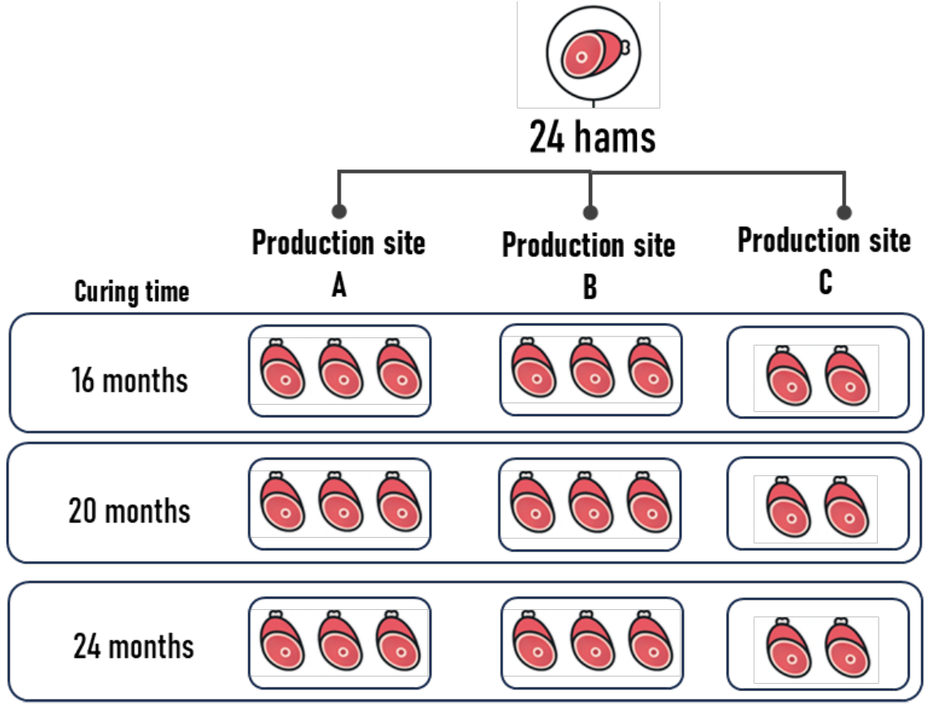

***Figure 1**. Prosciutto di Modena PDO samples used for the study*

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PHASE 1:

01. NUTRITIONAL PROPERTIES OF PROSCIUTTO DI MODENA PDO: EXTENDED PROCESSING TIMES AND DEVELOPMENTS IN THE NUTRITIONAL PROFILE

INTRODUCTION

Previous nutritional surveys (CREA 2011) have shown that Prosciutto di Modena PDO retains most of the main macro- and micro-nutrients naturally present in the meat. This project aims to expand the previous nutritional profile by analysing three processing times (16, 20 and 24 months) and widening the evaluation of micronutrients, such as minerals, water-soluble vitamins, free amino acids and fatty acids, in order to assess how they evolve during the processing time.

MATERIALS AND METHODS

SAMPLING

The study considered 18 of the 24 Prosciutto di Modena PDO supplied by three producers (identified as A, B, and C), aged 16, 20 and 24 months; two hams were chosen for each producer and processing time, as shown in Table 1, Annex 1. For each sample, two central adjacent slices of approximately 2 cm were taken; each slice included the semimembranosus, semitendinosus, biceps femoris and rectus muscles. One slice underwent basic analyses, while the second one was used to prepare three pool samples for each processing time, as shown in Figure 2.

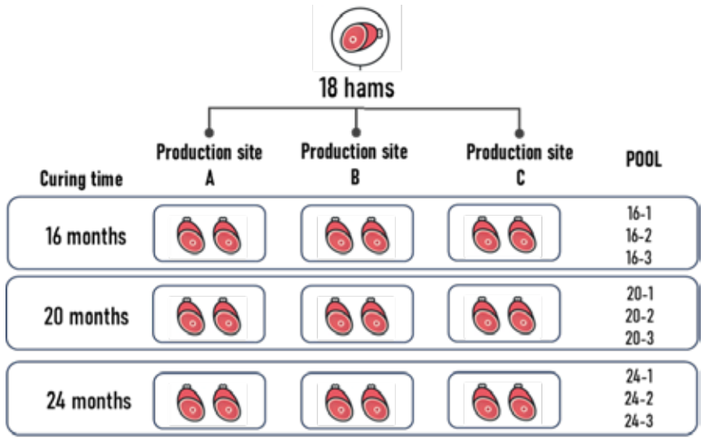

***Figure 2**: Sampling scheme for nutritional analysis*

BASIC ANALYSES

The proximate composition (moisture, protein, fat, ash) and main quality parameters such as salt, proteolysis index and nitrates were analysed for each ham (N=18), in the whole slice, i.e. trimmed as the product is commonly prepared for retail sale, as well for the pre-sliced and modified atmosphere packaged (MAP) product.

- **Moisture**: UNI ISO 1442:2010 method.
- **Protein**: UNI ISO 937:1991 method.
- **Free fat:** ISO 1444:1996 method.
- **Ash:** UNI 10590:1997 method.
- **Carbohydrates:** calculated by difference
- **NaCl (chlorides):** internal SSICA method LC/MP/N.6 2022 Rev.13.
- **Proteolysis index:** internal SSICA method LC/MP/N.19 (2012, Rev.11)
- **Nitrate ion:** internal method by ion chromatography SSICA MPCN.55 (2023 Rev.01)

ADVANCED ANALYSIS

Micronutrients analyses (mineral elements, B vitamins, free fatty acids, free amino acids) were carried out on 3 pool samples per processing time (N=9).

- **Heme iron**

Heme iron was determined using an in-house protocol (MPCN.8 1980 Rev.00) based on the Hornsey method, involving extraction in acidified acetone and subsequent spectrophotometric reading. Absorbance values were expressed as mg heme iron/100 g product, multiplying the heme value by a factor of 0.0882 (atomic weight ratio of iron/heme molecular weight).

- **Free amino acids**

The free amino acid composition was calculated by using UPLC-MS analysis in SIR (Single Ion Recording) acquisition mode. Analysis was duplicated (2 UPLC-MS injections) and quantification was carried out by external calibration for each amino acid, using Norvaline as internal standard. The results are expressed in mg /100 g of product.

- **Free fatty acids**

The fatty acid composition was calculated by gas chromatography (GC-FID). Total fat was extracted using the Folch method, followed by conversion of the fatty acids to methyl esters according to the UNI EN ISO 12966 method, using C19:0 fatty acid methyl ester as internal standard.
The results are expressed in % profile and in g /100 g of product.

- **B vitamins**

The B vitamin content (B1, B2, B3, B6) was calculated by chromatographic analysis, followed by spectrophotometric (HPLC-UV) or fluorimetric (HPLC-FLD) detection, depending on the chemical characteristics of the vitamins. The samples underwent acid hydrolysis, followed by enzymatic hydrolysis with three enzymes (taka-diastase, papain, acid phosphatase).

The combination of acid hydrolysis and multi-enzyme hydrolysis releases the vitamins in their free form for analysis. Vitamins B3 and B6 were analysed by HPLC-UV, while vitamins B1 and B2 were analysed by HPLC-FLD, as vitamin B2 is naturally fluorescent, while B1 was made fluorescent by thiochrome derivatisation.

Quantification was carried out by external calibration for each B-vitamin, in concentrations appropriate to the amount expected in the samples. The results are expressed in mg /100 g of product.

- **Mineral elements**

Mineral elements were analysed by using the ICP-MS technique; each element was quantified by external calibration with concentrations depending on the expected amount in the matrix. The results are expressed as macro- (mg/100 g product) and micro-elements (µg/100 g product).

DATA PRESENTATION

The results are shown in the tables as mean ± standard deviation of the individual samples and as the mean of the pool samples, grouped by processing time.

RESULTS

BASIC ANALYSIS

Proximate composition

Data obtained on 18 Prosciutto di Modena PDO samples, sub-grouped into three aging classes (16, 20 and 24 months), are shown in Table 1. The results reveal endogenous variability in the main compositional parameters, influenced by factors related to ham process, production plant and shape.
As expected, the moisture content is on average higher in the 16-month samples and tends to be lower in the 24-month samples, due to the loss of water during processing. By contrast, the protein content increases in the 24-month samples in relation to the higher dry matter concentration, due to moisture loss during the processing process. The fat content varies widely, as evidenced by the standard deviations associated with the mean values. The difference does not appear to be related to the processing time, but to individual factors such as the degree of marbling and the thickness of the cover fat in relation to the characteristics of the raw material.
The ash content, mainly attributable to the amount of salt absorbed during salting, is fairly constant between the ageing groups, while salt and ash show greater variability between individual hams.
The greatest variation between samples is not directly associated with the processing times, but rather with factors related to differences in fat, ham size, salt diffusion or the intrinsic characteristics of the hams analysed (Table 2, Annex 1).

Table 1. *Proximate composition (moisture, ash, protein, fat and carbohydrates), chlorides, heme-iron and nitrate ion for slices of Prosciutto di Modena PDO at different processing times. Data are reported as mean ± standard deviation.*

Parameters	Processing time (months)		
	16	20	24
Moisture %	48,3 ± 1,6	47,7 ± 2,8	47,0 ± 2,6
Protein %	26,4 ± 1,8	27,5 ± 1,8	27,6 ± 1,3
Free fat%	18,4 ± 3,5	18,2 ± 3,9	19,0 ± 4,1
Ash %	6,02 ± 0,73	5,99 ± 0,40	5,86 ± 0,52
Carbohydrates %	0,92 ± 0,44	0,59 ± 0,34	0,59 ± 0,34
Chlorides (NaCl) %	5,16 ± 0,70	5,08 ± 0,49	4,91 ± 0,45
Heme-iron (mg/100g)	0,46 ± 0,02	0,51 ± 0,07	0,45 ± 0,06
Nitrate (mg/kg)	<9*	<9	<9

**Below the limit of quantification (LOQ)*

NUTRITIONAL COMPOSITION OF THE DEFATTED SLICE

To meet the needs of consumers who manually remove fat from the slice, Table 2 was drawn up to show the data of the ham slice deprived of fat. The objective is to offer a flexible consultation tool that satisfies consumers who consume the product as it is, as well as those who remove some of the fat before eating.

To this end, a representative ham sample deprived of fat was prepared for each of the three processing times considered (16, 20 and 24 months). For these slices, the mean residual fat content after removing visible fat was experimentally verified to be:

- 7.56% in the 16-month sample,
- 8.09% in the 20-month sample,
- 6.47% in the 24-month sample.

These values were used as reference to recalculate the proximate composition of the individual samples. This allows to estimate the composition of the portion actually consumed once removable fat has been eliminated, while ensuring comparability with traditional nutritional tables.

The mean data are shown in Table 2, grouped by processing time.

Table 2. *Proximate composition (moisture, ash, protein, fat and carbohydrates) and chlorides of Prosciutto di Modena PDO at different processing times, referring to a defatted slice (g/100 g). Data are shown as the mean per processing time.*

Parameters	Processing time (months)		
	16	20	24
Moisture %	54,7	53,6	54,3
Protein %	29,9	30,9	31,8
Free fat%	7,56	8,09	6,47
Ash %	6,80	6,73	6,76
Carbohydrates %	1,07	0,66	0,62
Chlorides (NaCl) %	5,83	5,71	5,66

When the cover fat and fat from the central part of the slice are removed, the % fat content drops significantly (7.1-8.1%) compared to the whole slice, confirming that the lean part of the product has a moderate fat content, and it is almost constant in hams with different processing times.

As a result, the content of the other proximate composition parameters increases proportionally.

A higher amount of protein is observed in hams with extended processing time, due to the reduction in moisture.

The ash content, which is correlated to the quantity of salt in dry cured ham, remains constant across the increasing processing times

TOTAL IRON AND HEME IRON CONTENT

The results of the project have updated the nutritional profile of Prosciutto di Modena PDO, with particular focus to the total iron and heme iron content, thereby integrating data reported in CREA database (2011).

Collected data showed total iron values in the range of 0.81-1.07 mg/100 g (Table 7, Annex 1) and heme iron between 0.45 and 0.51 mg/100 g, approximately 40-50% of total iron (Table 3). These values are in line with data reported in literature on dry cured Italian hams, which show a mean total iron content ranging from 0.8 to 1.1 mg/100 g (Lucarini et al., 2013). Comparable results are also found for other ripened products, while lower values are seen in cooked cured meats (0.5-0.7 mg/100 g total iron and 0.2-0.3 mg/100 g heme iron) and in fish (0.3-0.6 mg/100 g total iron).

From a nutritional perspective, it is important to distinguish between total iron and heme iron. Heme iron has the highest bioavailability, with average absorption rate of 20-25%, and is only minimally affected by external dietary factors; in contrast, the absorption of non-heme iron, is lower and more variable (5-10%), and is strongly influenced by dietary promoter (e.g. vitamin C) or inhibitor (e.g. phytates, calcium).

As a result, Prosciutto di Modena PDO, with approximately 0.5 mg heme iron/100 g, provides an intermediate but significant contribution of bioavailable iron: lower than fresh beef (1.2-2.0 mg/100 g), but higher than poultry (0.2-0.4 mg/100 g), fish (0.1-0.3 mg/100 g) and cooked cured meats (0.2-0.3 mg/100 g). A 50 g portion provides about 10-15% of an adult's daily requirement of heme iron.

Finally, the long processing time of Prosciutto di Modena PDO, during which no nitrites are added, influences the fate of heme pigments: part of heme iron is gradually replaced by zinc with the formation of zinc-protoporphyrin IX (ZnPP), the main chromophore responsible for stabilising the typical red colour of the nitrite-free product. This phenomenon leads to a reduction of heme iron content in hams as the processing time progresses, with potentially positive impacts in terms of nutrition, as lower heme iron is associated with a reduction in the pro-oxidative and inflammatory processes described in the literature (B astide et al., 2015).

Table 3. *Comparison of total iron (mg/100 g) and heme iron (mg/100 g) content between the results of this study and literature data in fresh meat and processed meat products.*

Category	Total iron	Heme iron	% heme/ total iron	Source
Prosciutto di Modena PDO (16-24 months)	0,8-1,1	0,45–0,51	40–50%	SSICA data 2025
Dry-cured Italian hams	0,8–1,1	-	-	Lucarini et al., 2013
Dry-cured hams with added nitrite	1,0–1,2	0,4–0,6	40–60%	Bou et al., 2024
Cooked ham	0,5–0,7	0,2–0,3	35–45%	Lucarini et al., 2013, Lombardi Boccia 2002, Pretorius 2016, Archundia-Herrera, 2024
Fresh pork	0,4–1,5	0,4–0,8	58–88%	
Fresh beef	1,8–2,5	1,2–2,0	60–70%	
Poultry	0,4–0,8	0,2–0,4	≈50%	
Fish	0,3–0,6	0,1–0,3	30–40%	

FREE AMINO ACIDS

Table 4 shows the mean content of free amino acids for each processing time (16, 20 and 24 months); data for the individual pool samples are shown in Table 3, Annex 1.

Generally, there is an increase in the total amount of free amino acids as processing time progresses, in line with the natural rise in proteolysis that occurs during the process. Certain classes of amino acids contribute significantly to this increase, including essential (EAA) and branched (BCAA, i.e. valine, isoleucine, leucine) amino acids, which are nutritionally relevant and involved in metabolic cycles pertaining to the muscles, especially during physical exercise. Branched-chain amino acids, along with arginine, methionine, tryptophan and phenylalanine, are associated with the potential development of a bitter aftertaste. Nevertheless the 'umami' flavour, which is responsible for the savouriness and cured aroma that positively characterise cured ham, clearly predominates.

A number of hydrophilic amino acids contribute to this, including aspartic acid and glutamic acid, the content of which is particularly high and clearly increases as the processing process progresses. Other amino acids play a role in developing the sweet flavour of dry-cured ham, and they also increase during processing. They include glycine, threonine, proline, alanine and lysine, the latter two being particularly abundant. Some amino acids do not vary (glutamine, serine, threonine) or slightly decrease (histidine, asparagine) during processing. Glutamine and asparagine are oxidised to aspartic acid and glutamic acid by means of deamination reactions, increasing significantly over longer processing times. Glutamine also acts as a substrate for the formation of non-proteolytic amino acid derivatives (NPADs) such as γ-glutamyl peptides, which are key compounds in the development of the typical aroma and flavour of dry-cured ham.

Table 4. *Mean content of free amino acid (mg/100 g) in Prosciutto di Modena PDO at different processing times*

Amino acid (mg/100 g)	Processing time (months)		
	16	20	24
Histidine	193	171	151
Asparagine	40,2	39,6	34,3
Arginine	260	309	291
Glutamine	8,87	9,85	12,6
Taurine	64,1	69,2	68,7
Serine	196	225	198
Glycine	170	195	215
Aspartic acid	185	228	267
Citrulline	30,4	25,9	42,2
Glutamic acid	520	581	638
Threonine	173	203	210
Alanine	312	351	412
Proline	202	230	254
Ornithine	42,9	58,1	534
Lysine	489	530	590
Tyrosine	156	172	177
Methionine	107	123	135
Valine	268	299	340
Isoleucine	258	282	314
Leucine	376	412	459
Phenylalanine	183	208	238
Tryptophan	40,5	46,8	51,2
Essential amino acids	2087	2275	2490
Branched-chain amino acids	902	993	1113
Total amino acids	4273	4767	5153

Essential amino acids (Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan, and Valine)
BCAA= Branched-chain amino acids (Leucine, Isoleucine, and Valine)

FATTY ACID PROFILE

Table 5 shows the quantification of fatty acids as lipid profile (%) and concentration (g/100 g) of Prosciutto di Modena PDO at different processing times (16, 20 and 24 months); pool samples data are presented as a percentage distribution (%) and as concentration (g/100 g) in Tables 4 and 5 Annex 1 respectively.

The fatty acid profile consists of approximately 36% saturated, 50% monounsaturated and 13% polyunsaturated fatty acids.
The distribution of fatty acid classes is similar for all the processing times analysed.
The saturated fatty acids primarily include palmitic acid (C16:0, 23%), stearic acid (C18:0, 11%) and myristic acid (C14:0, 1.4%).

The unsaturated fatty acid profile comprises monounsaturated fatty acids, especially oleic acid (C18:1c, 46-47%) and, to a lesser extent, polyunsaturated fatty acids, including omega-3 and omega-6 fatty acids, the most abundant of which is linoleic acid (C18:2c, 10-11%), an essential fatty acid which humans cannot synthesise and which must therefore be taken with food. The ratio of omega-6 to omega-3 varies from 9.7 in the 16-month-old samples to 10.9 in the 20-month-old samples and 8.86 at 24 months, lower than with the other processing times. The omega-6/omega-3 ratio in the hams analysed are consistent with, or even lower than, those typically found in dry-cured hams coming from commercially-bred pigs; this fact is nutritionally relevant, as a reduction in the omega-6/omega-3 ratio is nutritionally desirable. The ratio of polyunsaturated to saturated fatty acids (PUFA/SFA) is significant in nutritional terms, and is comparable in the three processing times examined.

***Table 5**. Quantification of fatty acids expressed as percentage profile (%) and amount (g/100 g) in Prosciutto di Modena PDO at different processing times*

Fatty acid	Lipid profile (%)			Amount (g/100 g)		
	Processing time (months)			Processing time (months)		
	16	20	24	16	20	24
C10:0	0,10	0,12	0,11	0,02	0,02	0,02
C11:0	0,00	0,00	0,00	nd	nd	nd
C12:0	0,08	0,10	0,10	0,02	0,02	0,02
C13:0	0,00	0,00	0,00	nd	nd	nd
C14:0	1,39	1,46	1,39	0,29	0,27	0,28
C14:1	0,02	0,02	0,02	0,003	0,004	0,004
C15:0	0,03	0,03	0,03	0,01	0,01	0,01
C15:1	0,00	0,00	0,00	nd	nd	nd
C16:0	22,8	23,0	22,6	4,78	4,27	4,61
C16:1	2,85	2,91	2,79	0,60	0,54	0,57
C17:0	0,33	0,30	0,27	0,07	0,05	0,05
C17:1	0,26	0,19	0,22	0,05	0,04	0,04
C18:0	11,2	11,4	11,1	2,34	2,11	2,26
C18:1t	0,25	0,13	0,12	0,05	0,02	0,02
C18:1c	46,8	45,6	47,1	9,82	8,46	9,61
C18:2t	0,00	0,00	0,00	nd	nd	nd
C18:2c	9,4	10,7	10,0	2,09	1,99	2,04
C20:0	0,24	0,21	0,21	0,05	0,04	0,04
C18:3w6	0,03	0,03	0,03	0,01	0,00	0,01
C18:3w3	0,93	0,86	1,04	0,19	0,16	0,21
C20:1	0,88	0,88	0,84	0,18	0,16	0,17
C21:0	0,04	0,04	0,04	0,01	0,01	0,01
C20:2	0,48	0,52	0,57	0,10	0,10	0,12
C22:0	0,06	0,08	0,08	0,01	0,01	0,02
C20:3w6	0,12	0,14	0,13	0,03	0,03	0,03
C22:1	0,02	0,02	0,02	0,004	0,004	0,005
C20:3w3	0,08	0,08	0,10	0,02	0,01	0,02
C20:4	0,68	0,73	0,65	0,14	0,14	0,13
C22:2	0,00	0,00	0,00	nd	nd	nd
C23:0	0,00	0,01	0,00	nd	0,002	nd
C24:0	0,02	0,04	0,01	0,004	0,007	0,001
C20:5	0,01	0,01	0,00	0,001	0,002	0,000
C24:1	0,01	0,02	0,02	0,002	0,003	0,003
C22:4	0,21	0,24	0,25	0,04	0,04	0,05
C22:5	0,12	0,13	0,12	0,02	0,02	0,03
C22:6	0,05	0,05	0,05	0,01	0,01	0,01
Tot.	100	100	100	21,0	18,6	20,4
SFA	36,3	36,7	35,9	7,60	6,82	7,33
MUFA	51,1	49,3	51,1	10,7	9,24	10,4
PUFA	12,6	13,5	12,9	2,65	2,51	2,64
W6	11,5	12,4	11,6	2,41	2,30	2,37
W3	1,18	1,13	1,31	0,25	0,21	0,27
W6/W3	9,70	10,9	8,86	9,70	10,9	8,86
PUFA/SFA	0,35	0,37	0,36	0,35	0,37	0,36

c = Cis isomer fatty acids; t = Trans isomer fatty acids; SFA = Saturated Fatty Acids; MUFA = Monounsaturated Fatty Acids; PUFA = Polyunsaturated Fatty Acids; W6 = Omega-6 Fatty Acids; W3 = Omega-3 Fatty Acids; W6/W3 = Omega-6/Omega-3; ratio PUFA/SFA = Polyunsaturated Fatty Acids/Saturated Fatty Acids ratio

B VITAMINS

Table 6 shows the B vitamin content expressed in mg/100 g of Prosciutto di Modena PDO with different processing times (16, 20 and 24 months). Table 6, Appendix 1 shows the data for the pool samples.

***Table 6**. Mean content of B vitamins content expressed as mg/100g in Prosciutto di Modena PDO at different processing times.*

B vitamins (mg/100 g)	Processing time (months)		
	16	20	24
Thiamine (B1)	0.61	0.56	0.51
Riboflavin (B2)	0.25	0.27	0.25
Niacin (PP-B3) *	6.48	7.19	7.68
Pyridoxine (B6) **	1.10	1.24	1.30

** Sum of nicotinic acid and nicotinamide*
*** As pyridoxal*

Prosciutto di Modena PDO shows a high B-vitamin content, particularly vitamins PP and B6, which contribute significantly to the recommended daily allowance (RDA) for these vitamins (22% for PP and over 45% for B6, referring to a 50 g portion of ham). Thiamine (23%) also contributes significantly to the RDA per 50 g serving of ham. During the ageing process, there was a slight increase in the amounts of the B-vitamins, due to the reduction in moisture which leads to an increase in the concentration of nutrients; conversely, thiamine showed a slight decrease.

MINERAL ELEMENTS

Table 7 shows the mineral content expressed in mg /100 g (macro-elements) and µg/100 g (micro-elements) of Prosciutto di Modena PDO at different processing times (16, 20 and 24 months). Table 7, Annex 1 shows the mineral content of pool samples.

***Table 7**. Mean content of macro-elements (mg/100 g) and micro-elements (µg/100 g) of Prosciutto di Modena PDO at different processing times.*

Mineral elements		Processing time (months)		
		16	20	24
Calcium	mg/100g	15,7	15,2	15,6
Phosphorus		193	200	226
Magnesium		27,6	28,5	31,7
Potassium		431	497	521
Sodium		1701	1774	1612
Iron		0,97	0,89	0,91
Zinc		4,41	4,46	4,49
Copper		0,05	0,06	0,06
Manganese		0,03	0,01	0,01
Selenium	µg/100g	11,8	12,1	12,3

Prosciutto di Modena PDO is an important source of minerals, especially iron, phosphorus, zinc and potassium, in highly biovailable form. The results obtained are in agreement with the mineral values reported in CREA tables (2011). Some elements, such as phosphorus, magnesium, potassium and zinc, show a slight increase over the process: the overall stability of minerals over processing times indicates that the prolonged ageing does not compromise the availability of these nutrients, confirming the role of dry-cured ham as a food with high nutritional value, according to literature (Ventanas et al., 2010; Jiménez-Colmenero et al., 2020). A 50 g portion of Prosciutto di Modena PDO provides more than 15% of an adult's daily requirement of minerals such as phosphorus and zinc, contributing significantly to the overall nutritional balance.

CONCLUSIONS

The overall analyses carried out allowed to update and extend the nutritional profile of Prosciutto di Modena PDO, monitoring its evolution throughout the process.

The gradual loss of moisture leads to an increase in protein concentration, while fat and salt content are mainly determined by the individual characteristics of dry cured hams.

Prosciutto di Modena PDO is a significant source of heme iron, the most bioavailable form, and B vitamins, particularly B6 and niacin.

The free amino acid profile evolves during the ageing process, with increases in specific amino acids classes, leading to improvements in nutritional (essential and branched-chain amino acids availability) and sensory quality like umami and sweet notes.

The content and composition of free fatty acids maintain a nutritionally balanced profile and remain largely stable during the ageing process, except for the omega-6/omega-3 ratio, which decreases slightly as ageing time progresses, a beneficial factor from a nutritional perspective.

The product also provides essential minerals such as iron, zinc, phosphorus, potassium and magnesium, whose nutritional availability remains substantially unchanged throughout processing time.

Overall, the data indicate that even after a prolonged processing, Prosciutto di Modena PDO retains its nutritional profile, characterised by high biological value proteins, bioavailable heme iron, B vitamins and essential minerals, along with compounds resulting from the protracted processing time.

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FASE 2:

02. REFRIGERATED AND ACCELERATED SHELF LIFE OF PRE-PORTIONED AND VACUUM PACKED PROSCIUTTO DI MODENA PDO

INTRODUCTION

The shelf life of a food product is defined as the period during which the producer guarantees that the product maintains microbiological safety and acceptable quality for consumption. Although Prosciutto di Modena PDO is safe throughout its shelf life, after it has been opened and portioned, may undergo quality changes due to the product's characteristics, packaging and storage conditions.

Sliced, pre-portioned and vacuum packed dry-cured ham can reach an extended refrigerated shelf life of several months.

To investigate the effect of storage temperature, accelerated shelf life tests (ASLT) can be carried out. A minimum of three increasing temperatures is used to accelerate the quality degradation processes due to this stress factor and monitor changes in relevant quality indicators.

In this study, the parameters assessed during the accelerated shelf life of Prosciutto di Modena PDO included pH, water activity, proteolysis, lipid oxidation, CIE L*, a*, b* colour indices and derived parameters, as well as descriptive sensory analysis by panel test (ISO 16779: 2015).

The resulting data were analysed using the Arrhenius equation to relate the rate of quality degradation with the storage temperatures and to extrapolate the corresponding shelf life.

MATERIALS AND METHODS

SAMPLING

Twenty-four Prosciutto di Modena PDO boned hams were supplied by three producers (identified as A, B, and C) at 16, 20 and 24 months' ageing times (Figure 1, Phase 1). For each ham, 6 vacuum-packed portions (Tr1 - Tr6) were obtained for the ASLT treatments, plus 2 spare portions (Trx and Try), as shown in the diagram in Figure 1:

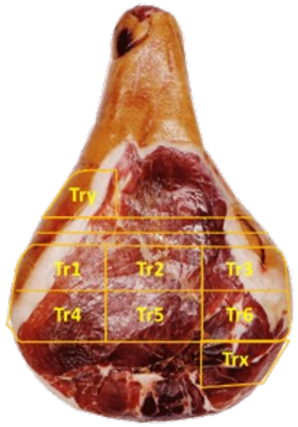

Figure 1. *Distribution of portions for ASLT testing.*

STORAGE CONDITIONS

The test was carried out over a 12-month period (September 2024 - September 2025). Four storage temperatures were considered for the shelf life tests: 4 °C, the reference refrigerated storage temperature, and three higher temperatures (10, 20 and 30 °C) for the ASLT tests, with five sampling deadlines for each temperature. At each deadline and temperature condition, 2 vacuum-packed portions of ham were analysed for each processing time, based on the following protocol:

- 4 °C: Sampling days → start of shelf life, 120, 210, 300, 360
- 10 °C: Sampling days → 60, 120, 180, 210, 240
- 20 °C: Sampling days → 30, 60, 90, 120, 150
- 30 °C: Sampling days → 14, 22, 29, 36, 44

The schedule of ASLT deadlines and sampling times is shown in Figure 2.

At each sampling time, six vacuum-packed portions of Prosciutto di Modena PDO were analysed, for a total of 120 samples.

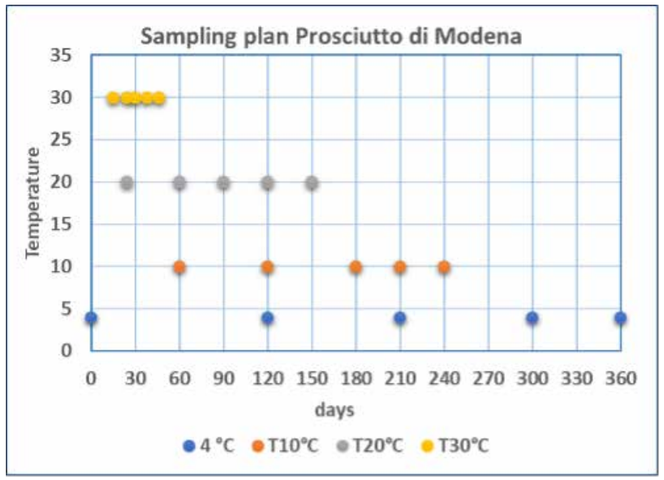

Figure 2. *ASLT deadlines and sampling times.*

MICROBIOLOGICAL ANALYSIS

The following microbiological analyses were performed on the vacuum-packed portions stored at 4 °C (control temperature): Colony count at 30 °C (CMA) (ISO 4833-1:2013), Mesophilic lactic bacteria count (LAB) (ISO 15214:1998), Micrococci and Staphylococci count (LM MP No. 15 REV.12000), Enterobacteriaceae count (UNI EN ISO 21528-2:2017/EC-1:2018), Coagulase-positive Staphylococci (S. aureus and other species) count (UNI EN ISO 6888-2:2021), Yeast and Mould counts (LM/MP/N. 8 Rev. 1 2000). Listeria monocytogenes test (ISO 11290-1:2017), Listeria monocytogenes count (ISO 11290-2:2017), Salmonella test (UNI EN ISO 6579-1:2020). Analyses for the main components of typical microbiota were carried out at shelf life deadlines (3, 120, 210, 300 and 360 days); Enterobacteriaceae counts and the L. monocytogenes and Salmonella spp. testing were performed at the start and end of shelf life.

CHEMICAL AND CHEMOPHYSICAL ANALYSIS

The chemical and chemical-physical indicators are as follows:

- **pH of the muscle fraction**

The pH was measured using a pH meter (3110, WTW) with an infusion electrode (XS sensors), after calibration with standard buffer solutions (pH 4.01 and 7.00). The pH was measured in triplicate for each portion.

- **Water activity (a_w) of the muscle fraction**

A representative sample of the lean ham fraction was placed in a capsule inside the instrument's measuring chamber (LabMaster, Novasina), previously calibrated. After reaching equilibrium at 20 °C, the a_w value was recorded. The analysis was carried out in duplicate.

- **Lipid oxidation index (TBARs test) on a slice including 1 cm cover fat**

The TBARs method is based on the reaction between oxidation products generated in meat (mainly malondialdehyde) and thiobarbituric acid (TBA) which at high temperature causes the formation of a compound that can be measured using a spectrophotometer (V-730, Jasco) at a wavelength of 532 nm. The analysis was carried out in duplicate.

- **Proteolysis index in 5 % trichloroacetic acid (TCA)**

The proteolysis index was calculated to assess the degree of protein fragmentation. Ham sample is homogenised with a 5% TCA solution to solubilise the products of proteolysis (peptides and free amino acids), then filtered to remove protein nitrogen; soluble nitrogen is quantified using the Kjeldahl method, then compared to total nitrogen to calculate the proteolysis index (%). The analysis was carried out in duplicate.

- **CIE L*, a*, b* colourimetric indices and derived parameters Chroma (C*), Hue and ΔE_{00} in muscle fraction and cover fat**

The L* index indicates the brightness of the sample, varying between 0 (black) and 100 (white); a* is the red index; b* is the yellow index, Chroma (C*) measures colour saturation or intensity; Hue refers to the colour tone. Measurements were obtained with a spectrocolorimeter (CM 700d, Konica-Minolta). For each sample, 5 readings were taken in the muscle fraction and 5 readings in the cover fat:

- on the outer slice exposed to the packaging;
- on a slice underneath, after removing the cover slice.

The CIE indices L*, a*, b* and derived parameters C* and Hue are calculated as means of the 5 readings in the slices for each fraction (lean and fat).

The ΔE_{00} index quantifies the perceived difference between two colours in the CIE L*, a*, b* colour space, represented by a numerical value indicating how two products appear different to the human eye. The calculation formula [1] takes into account differences in brightness, saturation and hue (ΔL*, ΔC*, ΔH) and the K and S parameters, intended as weight and correction factors for each index.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L^*}{K_L S_L}\right)^2 + \left(\frac{\Delta C^*}{K_C S_C}\right)^2 + \left(\frac{\Delta H^*}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C^*}{K_C S_C}\right)\left(\frac{\Delta H^*}{K_H S_H}\right)} \quad [1]$$

Generally, in the case of food products, values above 3.0 indicate clearly visible differences. In this study, ΔE_{00} was calculated by comparing measurements taken from the surface of the slice exposed to packaging with those taken from the slice immediately after cutting the first slice.

SENSORY ANALYSIS (PANEL TEST)

Descriptive sensory analysis (panel test) was performed according to ISO 16779: 2015 . A group of judges (panelists) was selected based on their experience of evaluating processed meats and willingness to participate. The panelists were given initial training to anchor the quantitative evaluations of the sensory descriptors for the hams being studied. Sensory sessions took place in a room compliant with the ISO standard (adequate lighting, controlled temperature, absence of interfering odours). The sensory descriptors (appearance, texture, aroma) were defined; panelists expressed their ratings on a numerical scale 0-9, where 9 represents the maximum perception intensity of the descriptor and 0 the absence of perception.

Sensory descriptors

The following descriptors are used for the portions of dry-cured ham:

- **Appearance**
  - Intensity of red colour
  - Intensity of brown colour
  - Presence of dry, dark borders
  - Presence of white grains
  - Presence of white film
  - Intensity of yellowness/greyness of cover fat
  - Intensity of pinkness of cover fat
  - Oilyness of cover fat
- **Texture**
  - Hardness of the lean fraction
  - Hardness of the cover fat
  - Adhesiveness of the lean fraction
- **Aroma**
  - Fully matured odour
  - Rancid odour
  - Foreign odour

The scores given to portions at established sampling deadlines were acquired using Biosystemes' Fizz software (V. 2.51). di Biosystemes (V. 2.51).

ISO 16779: 2015: Sensory analysis — Assessment (determination and verification) of the shelf life of foodstuffs.

STATISTICAL ANALYSIS

Chemical, chemophysical and sensory data of samples stored at 4 °C and analysed at the start of shelf life, and after 120, 210, 300 and 360 days were processed with a generalised linear model (GLM) using the statistical package IBM SPSS, version 29 (SPSS Inc., Chicago, IL, USA). In the model, storage and processing times (in months) were considered as fixed factors. Significant differences between the groups were assessed using the Bonferroni t-test, applying a 5% confidence level ($P < 0.05$).

Kinetic model of the ASLT: Arrhenius' law

The calculation of shelf life using ASLT is performed by accelerating qualitative degradation processes of the product under controlled stress conditions (Galanakis, 2019). In this study, temperature was chosen as the main stress factor, as it directly influences chemical, physical and microbiological processes, affecting the quality changes of meat products (Ntzimani, et al. 2025).

The relationship between temperature and the degradation rate of the monitored quality parameters was modelled using the Arrhenius equation[2]:

K=Ae^(-Ea/RT) [2]

where:

K = reaction rate constant (related to product deterioration)

A = constant (frequency of molecular collisions)

Ea = activation energy (kJ/mol) (variable depending on parameter considered)

R = universal gas constant (8.314 J/mol·K)

T = absolute temperature (°K)

The Arrhenius equation can be turned into a linear in the following steps:

$$\ln k = \ln\left(Ae^{-\frac{Ea}{RT}}\right)$$

$$\ln k = \ln A + \ln e^{-\frac{Ea}{RT}}$$

$$\ln k = \ln A - \frac{Ea}{RT}$$

$$\ln k = -\left(\frac{Ea}{R}\right)\left(\frac{1}{T}\right) + \ln A$$

This transformation yields a linear relationship (y= mx + q) between ln k and 1/T where:

- the slope of the line (m) corresponds to -Ea/R
- the intercept (q) corresponds to ln A.

The kinetics of the observed changes in the parameters and descriptors of interest are studied for linearity (linear if $R^2 > 0.7$). Only linear relationships were considered in the Arrhenius model for shelf life prediction.

ACCEPTANCE CRITERIA

In order to estimate shelf life, the acceptance limit of the monitored analytical parameters was defined, as no pre-existing values were available for Prosciutto di Modena PDO. The criterion defines the end of shelf life when the measured variation in the parameter reaches 40% of the variation range from the initial values.

When the variation of the quality parameter exceeds the established acceptance limit, it is possible to estimate the shelf life of the ham at the established temperature.

RESULTS

Analyses of vacuum-packed portions of Prosciutto di Modena PDO allowed to assess the evolution of the product when stored at the established temperatures.

SHELF LIFE TREND FOR HAM PORTIONS AT 4 °C

Chemophysical analyses and sensory evaluations were carried out at 4 °C, considered as the reference storage condition.

Microbiological parameters

Table 1 shows the results of microbiological analyses performed at the start of shelf life and after 120, 210, 300 and 360 days on portions of Prosciutto di Modena PDO stored at 4 °C.

Each value corresponds to the mean ± standard deviation of 9 samples analysed, which were representative of the three production site, the different processing times and the different portions of ham used.

Microbiological data were processed together, since there were no differences attributable to an individual production site or processing time.

Table 1. *Results of microbiological analyses performed during the shelf life of vacuum-packed, boned Prosciutto di Modena PDO portions stored at 4 °C.*

Time (days)	Microbiological analysis (Log cfu/g)			
	Colony count at 30°	Count: Micrococci and Staphylococci	Count: Mesophilic lactic acid bacteria	Count: Yeasts
Start of shelf life	5,20 ± 1,11	3,41 ± 0,45	1,49 ± 0,48	2,64 ± 0,67
120	4,91 ± 1,28	3,46 ± 0,61	1,06 ± 0,64	3,33 ± 0,54
210	5,45 ± 1,02	3,95 ± 1,29	1,19 ± 0,78	3,24 ± 0,47
300	5,67 ± 1,50	3,26 ± 1,38	0,98 ± 0,40	3,23 ± 0,43
360	4,96 ± 1,17	3,20 ± 0,74	0,91 ± 0,52	3,61 ± 0,36

Data obtained at the start of shelf life show a degree of variability between the different hams. The colony count data ranged from a minimum of 4.00 Log cfu/g to a maximum of 7.56 Log cfu/g (data not shown in the table). The main components of the microbiota in all samples were bacteria belonging to the genera *Tetragenococcus*, *Micrococcus Staphylococcus* and, to a lesser extent, Yeasts (2.64±0.67 Log uc/g). Mould counts were below the analytical limit (<100 cfu/g) in all samples. Mesophilic lactic acid bacteria were found in all samples at levels between 1.00 Log cfu/g and 2.11 Log cfu/g.

Enterobacteriaceae and coagulase-positive Staphylococci counts (S. *aureus* and other species) were below the limit of detection (<10 cfu/g) in all samples. *Salmonella* was not detected in all hams (9 out of 9 tested), while L. *monocytogenes* was detected in two hams (both taken from hams from the same producer). After the detection of Listeria, quantitative analysis was also carried out on the same samples to determine the pathogen, which was found to be below the analytical limit (<10 cfu/g) in both ham portions.

During storage at 4 °C, the microbiological parameters of the ham portions remained, on average, at the initial levels, confirming the variability in microbial load observed during the initial characterisation across all sampling deadlines. The composition of the microbiota did not change during the storage period. At all sampling deadlines, the main component of the colony count was bacteria belonging to the genus *Tetragenococcus*, followed by bacteria belonging to the genera *Micrococcus Staphylococcus* and, to a lesser extent, Yeasts.

Mould (<100 cfu/g) was not detected at any sampling deadline or in any ham.

Since two samples tested positive for L. monocytogenes at the start of shelf life, the pathogen test was repeated at all subsequent sampling deadlines and for all samples from the same producer. L. monocytogenes was only found in one sample analysed at 120 days (<10 cfu/g) and was not detected in any of the samples analysed thereafter.

At the end of shelf life (360 days), the same tests performed at the start of shelf life were repeated on all samples. Enterobacteriaceae and coagulase-positive Staphylococci (S. aureus and other species) counts were below the analytical limit of detection (<10 cfu/g) in all hams.

Salmonella and L. monocytogenes were not detected in all samples.

CHEMOPHYSICAL AND SENSORY PARAMETERS

The shelf life of Prosciutto di Modena PDO stored at 4 °C was assessed up to 360 days using chemophysical parameters and sensory descriptors, with samples taken at the start of shelf life and after 120, 210 and 300 days. The data obtained were analysed using a generalised linear model (GLM), taking into account storage time and processing time as main factors.

Table 2 shows the chemophysical and sensory parameters with statistically significant ($P < 0.05$) differences between processing times; Table 1A, Annex 2 shows the results of the comparison of all determined parameters.

***Table 2**. Estimated marginal means of parameters showing significant differences between processing times ($P < 0.05$). Different letters along the rows correspond to significantly different means in multiple pairwise tests (Bonferroni t-test, $P < 0.05$).*

Parameters	Processing time (months)			*P-value*
	16	20	24	
Proteolysis index	26,0 ^{b}	30,3 ^{a}	30,6 ^{a}	0,001
a^*_{lean}	8,83 ^{b}	9,49 ^{a,b}	10,06 ^{a}	0,007
C^*_{lean}	11,91 ^{b}	12,85 ^{a,b}	13,69 ^{a}	0,010
White film $_{lean}$	4,14 ^{b}	5,82 ^{a}	5,40 ^{a,b}	0,009
White grains $_{lean}$	0,13 ^{b}	0,21 ^{a,b}	0,33 ^{a}	0,046
Yellow colour $_{fat}$	2,50 ^{b}	3,18 ^{a}	3,60 ^{a}	0,034

The proteolysis index was significantly higher in 20- and 24-month-cured hams than in 16-month-cured hams, in line with Benedini et al., 2012. The colorimetric indices of the lean fraction of the inner slice, after removing the slice exposed to the packaging, showed an increase in a* and C*, indicating a more intense red component in the longer-processed hams. This difference did not emerge from the sensory analysis (Table 1A, Annex 2), during which the surface exposed to packaging was evaluated.

Among the sensory descriptors, the presence of a white film and white grains on the cut surface of the ham are related to proteolysis; they are more evident in hams that have been processed for longer periods than hams processed for 16 months. The yellow/grey colour of the cover fat was higher in the longer-processed hams (20 and 24 months), indicating a progression of oxidative phenomena in the lipids over time.

Table 3 shows the chemophysical and sensory parameters with significant differences ($P < 0.05$) or a tendency to significance ($P < 0.10$) as a function of storage time; the results of all measured parameters are given in Table 1A, Annex 2.

As regards the colorimetric indices, in the lean fraction the L* index (lightness) already increases at 120 days due to the formation of a surface white film , while a decreasing trend is observed in the red a* and brightness C* indices. In the cover fat, the L* index decreases after 300 days, indicating a less light and bright colour; conversely, the a* index increases after 120 days, likely due to the migration of the pink pigments from the muscle fraction into the fat.

Among the sensory descriptors, the intensity of the red colour decreased significantly at 210 days, and the intensity of the brown colour increased at the same time. The white film increased significantly at 120 days, although it was already seen at the start of shelf life. The yellow-grey colour of the cover fat increased significantly at 210 days; the pink colour of the fat increased at 120 and 210 days, but decreased at 300 and 360 days. A significant decrease in the hardness of the cover fat was detected at 120 days, although it stabilised at later sampling times.

In olfactory terms, the perception of the fully matured odour decreased significantly at 120 days, with a further significant decrease at 300 days. The rancid odour increased significantly at 120 days, while the onset of the off odour increased at 210 days, though remaining at very low levels of perception.

In general, significant variations in the colorimetric indices were already detected at 120 days, as data obtained with a spectrocolorimeter can measure small variations; as regards the sensory descriptors, which depend on the average response of the sensory panel, most of them do not vary before 210 days.

Table 3. *Estimated marginal means of chemophysical and sensory parameters measured during the shelf life of vacuum-packed Prosciutto di Modena PDO portions stored at 4 °C, for which significant variations were found during shelf life (P < 0.05). Different letters along the rows correspond to significantly different means in multiple pairwise tests (Bonferroni t-test, P < 0.05).*

Parameters	Storage time (days)					Sign. P
	Start of shelf life	120	210	300	360	
Colorimetric indices						
L^*_{lean}	37,8 ^{b}	43,7 ^{a}	41,5 $^{a, b}$	44,1 ^{a}	43,4 ^{a}	0,014
a^*_{lean}	10,2	9,38	9,20	9,64	8,88	0,069
C^*_{lean}	14,1	12,9	12,5	12,6	12,0	0,064
L^*_{fat}	75,7 $^{a, b}$	76,5 ^{a}	75,2 $^{a, b}$	74,32 ^{b}	74,39 ^{b}	0,038
a^*_{fat}	0.28 ^{c}	2.13 $^{a, b}$	1.20 $^{b, c}$	2.41 ^{a}	2.02 $^{a, b}$	0.004
Sensory descriptors						
Intensity of red $_{lean}$	7,38 ^{a}	6,55 $^{a, b}$	5,98 $^{b, c}$	5,47 ^{c}	5,14 ^{c}	<0,001
Intensity of brown $_{lean}$	2,50 ^{c}	3,25 $^{b, c}$	3,65 $^{a, b}$	3,99 $^{a, b}$	4,37 ^{a}	0,003
White grains $_{lean}$	0,02 ^{b}	0,08 ^{b}	0,16 ^{b}	0,59 ^{a}	0,26 ^{b}	0,001
White film $_{lean}$	2,30 ^{b}	5,13 ^{a}	5,22 ^{a}	6,78 ^{a}	6,16 ^{a}	<0,001
Yellow/grey colour $_{fat}$	2,20 ^{b}	2,10 ^{b}	3,31 ^{a}	3,99 ^{a}	3,86 ^{a}	0,008
Pink colour $_{fat}$	2,34 ^{b}	3,29 ^{a}	3,31 ^{a}	2,21 ^{b}	2,23 ^{b}	0,019
Hardness $_{fat}$	5,05 ^{a}	2,96 ^{b}	3,68 ^{b}	3,70 ^{b}	3,93 ^{b}	0,029
Fully matured odour	6,67 ^{a}	5,58 ^{b}	5,47 ^{b}	5,18 $^{b, c}$	4,72 ^{c}	<0,001
Rancid odour	1,03 ^{b}	3,08 ^{a}	3,40 ^{a}	3,22 ^{a}	3,44 ^{a}	0,021
Off odour	0,23 ^{c}	0,55 $^{b, c}$	0,95 $^{a, b}$	0,66 $^{b, c}$	1,23 ^{a}	0,009

ACCELERATED SHELF LIFE APPLIED TO PROSCIUTTO DI MODENA PDO

Chemophysical analyses and sensory evaluations were carried out at 10, 20, 30 °C for accelerated shelf life by applying the Arrhenius equation. The accelerated shelf life model and multi-temperature shelf life predictions were calculated for the parameters showing a linear trend as a function of time with $R^2 > 0.7$ at the three temperatures, i.e. the chemophysical parameters: pH, colorimetric indices Hue of lean, b* of fat, C* of fat, ΔE_{00} of fat, and the sensory descriptors: intensity of red colour, white film, fully matured odour, rancid odour, off odour.

Table 4 shows the results of the accelerated shelf life study and the shelf life prediction at 12, 18 and 25 °C. The values recorded at the beginning of the shelf life, the extreme value observed and the limit value established for each parameter as an acceptability threshold are reported. The application of the Arrhenius equation enabled to calculate the activation energy, representing the sensitivity of the parameter to increasing temperature.

The kinetics of variation for each parameter during the shelf life tests under different conditions (temperature, sampling days) are shown in Tables 2-31, Annex 2.

CHEMOPHYSICAL PARAMETERS

The pH was stable at 4 °C up to 360 days, while at 10 °C or higher temperature a decrease was found (Table 2, Annex 2) as a result of acidification processes, with an increase in 'off odour'; the acceptance limit for the pH (40% reduction in the variation range from the start of shelf life) is 5.62. The estimated shelf life at 25 °C is 37 days.

Water activity (a_w) is a key parameter for microbiological safety. In Prosciutto di Modena PDO portions analysed, a_w ranged between 0.880-0.901, regardless of temperature and storage time (Table 3, Annex 2).

The TBARs index is expressed as malondialdehyde (MDA), a secondary product of polyunsaturated fatty acid peroxidation. During storage of the ham portions at the applied temperatures, TBARs values (0.60-1.03 mg MDA/kg) did not exhibit a linear trend (Table 4, Annex 2). A non-linear increasing trend with storage time was found for the proteolysis index, preventing the application of the Arrhenius model (Table 5, Annex 2).

COLORIMETRIC INDICES

Muscle part

An increase in L* was seen over time (Table 6, Annex 2), attributable to the formation of the characteristic white surface film, with a more pronounced effect in samples stored at 4 °C for extended periods. The a* index decreased during shelf life at 4 and 10 °C, while the b* index showed a clear increase at 20 °C (Tables 7 and 8, Annex 2). The C* index, derived from a* and b*, does not have a linear trend but shows a tendency to increase in hams stored at higher temperatures (Table 9, Annex 2).

The Hue index showed a linear increase (Table 10 Appendix 2): at the start of shelf life, the samples had lower values for the red nuance, but with increasing times and temperatures, the values increased towards more yellowish or brownish hues.

The acceptance limit is Hue = 50.5, and the predicted shelf life at 25 °C is 44 days. The Hue index from previous studies was found to be a reliable indicator of the colour quality of dry-cured ham, as perceived in sensory testing.

Cover fat

The same colorimetric indices were measured in the cover fat (Tables 11-15, Annex 2). The colorimetric indices b* and C* showed a linear correlation with storage time, with b* reaching its highest values at 150 days' storage at 20 °C. Low b* values indicate bright white fat, increasing values indicate oxidation and yellow colour development. The C* index is mainly influenced by b* since the a* values for the fat are very low (Tables 13 and 14, Annex 2). The acceptance limit is 15.2 for b* and 15.0 for C*, and the estimated shelf life at 25 °C is 40 and 39 days respectively.

Difference in colour ΔE_{00}

In the lean fraction, the parameter ΔE_{00} - presumably due to the white film already present at the start of shelf life - did not show a linear trend (Table 16, Annex 2). In the cover fat, the differences in colour ΔE_{00} are mainly due to the increase in the colorimetric index b*, caused by oxidation. ΔE_{00} remains low, particularly at 4 °C (Table 17, Annex 2). Taking ΔE_{00} = 2.95 as the limit value, the estimated shelf life at 25 °C is 39 days.

For some colorimetric indices, differences were already detected at 4 °C after 120 days of shelf life; shelf life predictions at 12 °C for the colorimetric indices of lean part and cover fat suggest that the acceptance limit is reached between 80 and 100 days, with a perceived difference in cover fat colour ΔE_{00} after approximately 5 months' shelf life.

SENSORY PARAMETERS

Muscle part

As regards the lean part, red and brown colour intensity descriptors are considered (Tables 18 and 19, Annex 2); they are influenced by muscle pigments, in particular heme and zinc-protoporphyrin, which are responsible for the typical colour of ham processed without adding nitrates or nitrites. For the sensory descriptors 'Intensity of red colour' and 'White film', shelf life at 4 °C and the predictions obtained from the accelerated shelf life showed compatible trends.

Intensity of red colour. Given the acceptance limit, the predicted shelf life at 25 °C is 58 days. At 4 °C it decreases significantly at 210 days; at 12 °C the acceptance limit is 146 days.

Intensity of brown colour. The descriptor did not show a linear trend under tested temperature conditions, so the shelf life could not be predicted.

Presence of dry, dark borders. This phenomenon is found typically in dry-cured ham, mainly due to surface dehydration; the borders of the ham portions dry out significantly (Table 20, Annex 2).

The appearance of white grains and white film (Tables 21 and 22, Annex 2) depends on natural phenomena related to changes in moisture and in solubility of solutes in dry cured ham. The white film appears as a thin, whitish surface layer caused by precipitation of some products of proteolysis, such as amino acids and peptides due to decreased solubility; this can be attributed to changes in the ham surface composition, resulting from the surface drying and fat melting during slice cutting, and is influenced by temperature and storage time.

White patina. Given the acceptance limit, the estimated shelf life at 25 °C is 35 days; at 4 °C it increases significantly at 120 days, at 12 °C the acceptance limit is 117 days.

Cover fat

The appearance of the fat was evaluated for the intensity of its yellow and pink colour, as well as its greasiness (Tables 23-25, Annex 2).

The yellow/grey colour is mainly attributable to lipid oxidation, while the pink colour derives from the moving of a muscle pigment fraction, particularly zinc-protoporphyrin, into the fat during ham processing. The oiliness descriptor is also related to lipid oxidation; it depends on the degree of unsaturation of the fatty acids. These descriptors did not show a linear trend and no predictions of shelf life could therefore be made.

Texture

The texture of the ham portion was assessed separately for lean and for fat (Tables 25 – 27). The hardness and adhesiveness of the lean part remained almost constant over time and at different storage temperatures (Tables 25 and 26, Annex 2). A slight reduction in hardness was observed for the cover fat. The performance of these descriptors during accelerated shelf life did not allow for predictive models to be applied (Table 27, Annex 2).

Aroma

The aroma of the ham portion was assessed by considering the sensory parameters 'Cured odour', 'Rancid odour' and 'Off odour'.

The fully matured odour is regarded as a marker of quality which should persist throughout the ham's shelf life. In dry-cured ham, the aroma is characterised by sweet and slightly nutty notes due to the presence of specific molecules (volatile compounds). If the product undergoes oxidative and enzymatic changes and the volatile compounds associated with the fully matured odour decrease, and rancid or off odours may develop. For the sensory descriptors 'Fully matured odour', 'Rancid odour' and 'Off odour', shelf life at 4 °C and the predictions obtained from the accelerated shelf life showed comparable trends.

Fully matured odour. A gradual decrease over time was observed at assayed storage temperatures (Table 29, Annex 2). The estimated shelf life at 25 °C is 37 days; at 4 °C it falls significantly after 120 days, and further after 360 days; at 12 °C the acceptance limit is 90 days.

Rancid odour. The intensity of perception is influenced by storage temperature, exposure to light and length of storage, with a gradual increase over time at all applied storage temperatures (Table 30, Annex 2). The predicted shelf life at 25 °C is 39 days; at 4 °C it increases significantly after 120 days, then remains constant; at 12 °C the acceptance limit is 90 days.

Off odour. The Off odour may appear due to oxidative phenomena, acidification and/or microbial contamination that alter the natural flavour profile (Table 31, Annex 2). The estimated shelf life at 25 °C is 45 days; at 4 °C it is bearly perceptable but increases significantly after 210 days; at 12 °C the acceptance limit is 99 days.

__Table 4__. Shelf life (SL) predictions expressed in days, at 12, 18 and 25 °C, obtained by ASLT.

Parameters	Start of shelf life	Extreme value	Limit value	Ea*	$SL_{12°C}$	$SL_{18°C}$	$SL_{25°C}$
pH	5,74	5,45	5,62	83,2	172	83	37
Hue_{lean}	41,92	63,41	50,51	33,9	80	61	44
b^*_{fat}	11,16	21,14	15,15	51,5	103	66	40
C^*_{fat}	11,20	21,24	15,00	52,4	103	65	39
ΔE_{fat}	1,54	5,30	2,95	71,7	148	79	39
Intensity of red_{lean}	7,40	5,16	6,61	49,7	146	95	58
White $film_{lean}$	2,24	6,20	4,05	65,8	117	66	35
Fully matured odour	6,64	4,62	5,83	47,9	90	59	37
Rancid odour	1,03	4,76	2,52	45,3	90	60	39
Off odour	0,20	3,22	1,44	43,0	99	68	45

** Ea: energia di attivazione (kJ/mol)*

CONCLUSIONS

This study of Prosciutto di Modena PDO was carried out on dry cured hams with different processing times (16, 20 and 24 months) and production site (three producers) to ensure the representativeness of the product used. Extended processing times showed a concomitant increase in the proteolysis index and the formation of a surface white film in packaged slices, and at the same time led to an increase in the redness and brightness of the colour of the muscle fraction (fresh cut).

As regards the otucomes of the shelf life tests performed, some chemophysical and sensory parameters of product quality, showed a linear kinetics of variation over time when subjected to the stress factor 'temperature' (10, 20 and 30 °C) during storage.

The pH, the colorimetric indices Hue (red nuance) of the lean meat and b*(yellow index), C* (brightness) and ΔE_{00} (colour difference) of cover fat were useful analytical parameters for estimating shelf life using the Arrhenius model of accelerated shelf life.

To avoid acidification and a drop in pH, ham should not be stored at room temperature (25 °C) for more than 30-40 days. Similarly, to avoid a reduction in the red hue of the lean fraction, a change in colour and an increase in the yellow hue of the cover fat, the product should not be stored at room temperature (25 °C) for more than 30-40 days.

Predictive shelf life models were obtained for the sensory descriptors 'Intensity of red colour (lean)', 'White film', 'Fully matured odour', 'Rancid odour' and 'Off odour', which include the main characteristics perceived by consumers of sliced ham during storage. Except for the descriptor 'Intensity of red colour (lean)', for which the panel test indicates an acceptance limit at room temperature of approximately 2 months, the results from sensory analysis are in agreement with analytical parameters ,
corresponding to a shelf life of 30-40 days.

The quality attributes for vacuum-packed ham portion indicated that the shelf life remains acceptable for up to approximately 60 days at 18 °C, and up to 100 days at 12 °C.

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ANNEX 1. NUTRITION

Table 1. *Prosciutto di Modena PDO boned hams selected for nutritional analysis, identified by curing time, production site and lot number as indicated in the label.*

Processing time (months)	Production site	Lot number	Label	Deboned weight (Kg)	SSICA Code
16	A	24360229	16 months	8,058	229_A
16		24360082	2317A02	8,846	082_A
16	B	P23 V/2023	P23 V/2023	8,406	P23_A
16		P23 V/2023	P23 V/2023	9,334	P23_B
16	C	L320 V '23	L320 V '23	9,032	320_A
16		L320 V '23	L320 V '23	10,421	320_B
20	A	24360230	20 months	8,826	230_A
20		24360084	2304A01	7,039	084_A
20	B	P75 XII/2022	P75/22	8,519	PT75_A
20		P75 XII/2022	P75/22	8,692	PT75_B
20	C	L303 I '23	L303 I '23	8,350	303_A
20		L303 I '23	L303 I '23	8,075	303_B
24	A	24360228	24 months	8,348	228_A
24		24360085	2239A02	7,354	085_A
24	B	P53 IX/2022	P53/22	8,010	P53_A
24		P53 IX/2022	P53/22	7,620	P53_C
24	C	L238 IX '22	L238 IX '22	8,730	238_A
24		L238 IX '22	L238 IX '22	7,460	238_B

Table 2. *Proximate composition (moisture, ash, protein, lipids and carbohydrates), nitrate and heme-iron content of Prosciutto di Modena PDO, referred to whole slices (g/100 g).*

SSICA Code	Processing time (months)	Moisture (g/100g)	Ash (g/100g)	Protein (g/100g)	Free fat (g/100g)	Chlorides (g NaCl/ 100g	Nitrate* (mg/kg)	Heme-iron (mg/100g)
229_A	16	50,1	6,30	28,3	14,8	4,90	<9	0,47
082_A	16	46,6	5,75	26,2	18,4	4,98	<9	0,45
P23_A	16	47,2	5,70	24,7	21,4	4,87	<9	0,46
P23_B	16	46,5	4,94	23,6	21,6	4,41	<9	0,45
320_A	16	49,2	7,35	29,4	14,7	6,45	<9	0,49
320_B	16	51,6	6,31	26,8	16,5	5,34	<9	0,42
Mean 16 months		**48,5**	**6,06**	**26,5**	**17,9**	**5,16**	**<9**	**0,46**
230_A	20	48,5	5,31	25,3	19,8	4,33	<9	0,48
084_A	20	46,7	6,16	29,2	17,5	5,15	<9	0,57
PT75_A	20	44,8	6,16	25,5	24,4	5,50	<9	0,38
PT75_B	20	51,5	6,39	28,0	13,2	5,52	<9	0,58
303_A	20	50,2	6,29	29,1	15,3	5,35	<9	0,53
303_B	20	44,7	5,64	27,6	20,4	4,65	<9	0,53
Mean 16 months		**47,7**	**5,99**	**27,4**	**18,4**	**5,08**	**<9**	**0,51**
228_A	24	47,1	5,53	27,4	18,5	4,78	<9	0,37
085_A	24	45,1	6,04	26,5	23,6	5,04	<9	0,44
P53_A	24	50,2	6,22	30,6	13,5	5,30	<9	0,45
P53_C	24	49,9	6,15	29,8	14,3	5,27	<9	0,50
238_A	24	45,3	6,03	27,7	19,7	4,97	<9	0,55
238_B	24	42,5	4,94	27,4	23,6	4,08	<9	0,41
Mean 16 months		**46,7**	**5,82**	**28,2**	**18,9**	**4,91**	**<9**	**0,45**

** Below the limit of quantification (LOQ=9 mg/kg)*

Table 3. *Mean free amino acids content (mg/100 g) in pool samples of Prosciutto di Modena PDO.*

AA	Processing time (16 months)				Processing time (20 months)				Processing time (24 months)			
	16 A	16 B	16 C	Mean	20 A	20 B	20 C	Mean	24 A	24 B	24 C	Mean
	mg/100 g				mg/100 g				mg/100 g			
His	197	185	199	193	170	163	178	171	142	166	146	151
Asn	40,8	35,9	43,8	40,2	37,6	35,1	46,1	39,6	36,6	33,1	33,3	34,3
Arg	255	264	261	260	322	310	296	309	289	308	277	291
Gln	7,66	9,13	9,83	8,87	8,03	11,8	9,75	9,85	13,4	12,2	12,2	12,6
Tau	71,4	52,0	68,9	64,1	70,4	61,7	75,5	69,2	66,4	69,4	70,3	68,7
Ser	192	197	198	196	225	228	220	225	194	197	203	198
Gly	170	165	173	170	196	196	193	195	214	218	213	215
Asp	182	175	198	185	246	202	234	228	260	275	265	267
Citr	28,5	41,8	21,0	30,4	13,2	35,9	28,6	25,9	47,1	38,2	41,5	42,2
Glu	496	537	527	520	554	595	595	581	640	622	652	638
Thr	173	170	175	173	206	204	199	203	210	209	212	210
Ala	303	317	316	312	324	360	368	351	415	420	401	412
Pro	198	206	202	202	226	235	227	230	254	256	253	254
Orn	40,1	42,0	46,7	42,9	62,6	63,2	48,5	58,1	56,2	47,7	56,3	534
Lys	472	499	495	489	473	542	574	530	591	581	598	590
Tyr	154	159	155	156	183	176	155	172	163	186	183	177
Met	109	105	108	107	130	125	114	123	138	133	135	135
Val	262	274	269	268	293	309	295	299	342	337	341	340
Ile	256	261	257	258	276	291	279	282	318	310	315	314
Leu	374	382	373	376	405	425	405	412	465	454	458	459
Phe	190	176	182	183	223	214	189	208	242	240	232	238
Trp	40,7	41,4	39,3	40,5	44,7	47,2	48,6	46,8	50,7	53,6	49,2	51,2
EEA	2073	2092	2097	2087	2222	2321	2282	2275	2499	2483	2487	2490
BCAA	892	916	899	902	975	1025	979	993	1126	1100	1114	1113
Tot.	4211	4292	4317	4273	4689	4832	4779	4767	5147	5165	5148	5153

EEA = Essential amino acids
BCAA= Branched-chain amino acids

Table 4. *Fatty acid profile (%) in pool samples of Prosciutto di Modena PDO.*

Fatty acid	Processing time (16 months)				Processing time (20 months)				Processing time (24 months)			
	16 A	16 B	16 C	Mean	20 A	20 B	20 C	Mean	24 A	24 B	24 C	Mean
	%				%				%			
C10:0	0,10	0,10	0,11	0,10	0,12	0,12	0,12	0,12	0,11	0,11	0,11	0,11
C11:0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C12:0	0,09	0,04	0,09	0,08	0,10	0,10	0,10	0,10	0,10	0,10	0,09	0,10
C13:0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C14:0	1,34	1,36	1,47	1,39	1,45	1,45	1,48	1,46	1,41	1,38	1,38	1,39
C14:1	0,02	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
C15:0	0,03	0,01	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
C15:1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C16:0	22,6	22,7	23,1	22,8	22,9	23,0	23,1	23,0	22,7	22,5	22,7	22,6
C16:1	2,70	2,99	2,85	2,85	2,86	2,96	2,92	2,91	2,78	2,74	2,85	2,79
C17:0	0,31	0,28	0,38	0,33	0,31	0,30	0,28	0,30	0,27	0,27	0,27	0,27
C17:1	0,26	0,26	0,26	0,26	0,14	0,22	0,21	0,19	0,20	0,22	0,23	0,22
C18:0	11,0	11,3	11,3	11,2	11,3	11,3	11,4	11,4	11,1	11,0	11,2	11,1
C18:1t	0,17	0,21	0,37	0,25	0,14	0,12	0,12	0,13	0,12	0,12	0,13	0,12
C18:1c	47,4	47,3	45,7	46,8	45,7	46,0	45,0	45,6	46,8	47,3	47,2	47,1
C18:2t	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00
C18:2c	10,4	9,57	9,89	9,4	10,7	10,6	11,0	10,7	10,2	10,0	9,74	10,0
C20:0	0,24	0,23	0,25	0,24	0,22	0,20	0,20	0,21	0,23	0,20	0,22	0,21
C18:3w6	0,02	0,02	0,05	0,03	0,04	0,00	0,04	0,03	0,02	0,03	0,04	0,03
C18:3w3	0,93	0,90	0,96	0,93	0,87	0,87	0,85	0,86	1,03	1,03	1,05	1,04
C20:1	0,86	0,77	1,01	0,88	0,91	0,87	0,86	0,88	0,90	0,79	0,84	0,84
C21:0	0,05	0,02	0,05	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,05	0,04
C20:2	0,37	0,52	0,54	0,48	0,53	0,50	0,53	0,52	0,59	0,57	0,57	0,57
C22:0	0,06	0,04	0,07	0,06	0,07	0,07	0,09	0,08	0,08	0,08	0,08	0,08
C20:3w6	0,12	0,12	0,13	0,12	0,15	0,12	0,15	0,14	0,13	0,14	0,13	0,13
C22:1	0,03	0,00	0,02	0,02	0,02	0,03	0,01	0,02	0,02	0,02	0,02	0,02
C20:3w3	0,08	0,06	0,09	0,08	0,08	0,08	0,08	0,08	0,11	0,09	0,10	0,10
C20:4	0,58	0,70	0,75	0,68	0,74	0,68	0,77	0,73	0,62	0,69	0,64	0,65
C22:2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C23:0	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,00	0,01	0,00	0,00
C24:0	0,00	0,02	0,04	0,02	0,05	0,03	0,04	0,04	0,00	0,02	0,00	0,01
C20:5	0,00	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,00	0,00	0,00	0,00
C24:1	0,00	0,01	0,02	0,01	0,02	0,01	0,02	0,02	0,02	0,02	0,02	0,02
C22:4	0,20	0,22	0,23	0,21	0,24	0,22	0,25	0,24	0,25	0,26	0,24	0,25
C22:5	0,11	0,11	0,13	0,12	0,12	0,12	0,14	0,13	0,12	0,13	0,12	0,12
C22:6	0,05	0,05	0,07	0,05	0,05	0,06	0,06	0,05	0,05	0,06	0,03	0,05
Tot.	100	100	100	100	100	100	100	100	100	100	100	100
SFA	35,7	36,1	37,0	36,3	36,7	36,6	37,0	36,7	36,0	35,8	36,0	35,9
MUFA	51,5	51,6	50,2	51,1	49,8	50,2	49,2	49,3	50,9	51,2	51,3	51,1
PUFA	12,8	12,3	12,8	12,6	13,5	13,2	13,9	13,5	13,2	13,0	12,7	12,9
W6	11,7	11,1	11,6	11,5	12,4	12,1	12,7	12,4	11,8	11,7	11,4	11,6
W3	1,16	1,13	1,25	1,18	1,13	1,13	1,14	1,13	1,32	1,31	1,31	1,31
W6/W3	10,0	9,86	9,24	9,70	10,9	10,7	11,1	10,9	9,00	8,91	8,68	8,86
PUFA/SFA	0,36	0,34	0,35	0,35	0,37	0,36	0,37	0,37	0,36	0,35	0,36	0,36

c = Cis isomer fatty acids; t = Trans isomer fatty acids; SFA = Saturated Fatty Acids; MUFA = Monounsaturated Fatty Acids; PUFA = Polyunsaturated Fatty Acids; W6 = Omega-6 Fatty Acids; W3 = Omega-3 Fatty Acids; W6/W3 = Omega-6/Omega-3 ratio PUFA/SFA = Polyunsaturated Fatty Acids/Saturated Fatty Acids ratio

Table 5. *Fatty acids amount (g/100g) in pool samples of Prosciutto di Modena PDO.*

Fatty acid	Processing time (16 months)				Processing time (20 months)				Processing time (24 months)			
	16 A	16 B	16 C	Mean	20 A	20 B	20 C	Mean	24 A	24 B	24 C	Mean
	(g/100g)				(g/100g)				(g/100g)			
C10:0	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
C11:0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C12:0	0,02	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
C13:0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C14:0	0,32	0,27	0,29	0,29	0,27	0,28	0,26	0,27	0,30	0,26	0,29	0,28
C14:1	0,004	0,002	0,004	0,003	0,004	0,004	0,004	0,004	0,004	0,004	0,004	0,004
C15:0	0,01	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
C15:1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C16:0	5,35	4,48	4,50	4,78	4,35	4,38	4,09	4,27	4,81	4,31	4,70	4,61
C16:1	0,64	0,59	0,55	0,60	0,54	0,57	0,52	0,54	0,59	0,53	0,59	0,57
C17:0	0,07	0,06	0,07	0,07	0,06	0,06	0,05	0,05	0,06	0,05	0,06	0,05
C17:1	0,06	0,05	0,05	0,05	0,03	0,04	0,04	0,04	0,04	0,04	0,05	0,04
C18:0	2,60	2,23	2,20	2,34	2,15	2,15	2,02	2,11	2,35	2,12	2,32	2,26
C18:1t	0,04	0,04	0,07	0,05	0,03	0,02	0,02	0,02	0,03	0,02	0,03	0,02
C18:1c	11,3	9,33	8,88	9,82	8,66	8,77	7,96	8,46	9,95	9,07	9,80	9,61
C18:2t	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C18:2c	2,46	1,89	1,92	2,09	2,03	2,01	1,94	1,99	2,17	1,92	2,02	2,04
C20:0	0,06	0,04	0,05	0,05	0,04	0,04	0,04	0,04	0,05	0,04	0,05	0,04
C18:3w6	0,00	0,00	0,01	0,01	0,01	0,00	0,01	0,00	0,00	0,01	0,01	0,01
C18:3w3	0,22	0,18	0,19	0,19	0,16	0,17	0,15	0,16	0,22	0,20	0,22	0,21
C20:1	0,20	0,15	0,20	0,18	0,17	0,17	0,15	0,16	0,19	0,15	0,17	0,17
C21:0	0,01	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
C20:2	0,09	0,10	0,11	0,10	0,10	0,10	0,09	0,10	0,13	0,11	0,12	0,12
C22:0	0,02	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,02	0,02	0,02	0,02
C20:3w6	0,03	0,02	0,03	0,03	0,03	0,02	0,03	0,03	0,03	0,03	0,03	0,03
C22:1	0,008	0,000	0,004	0,004	0,003	0,005	0,003	0,004	0,005	0,004	0,005	0,005
C20:3w3	0,02	0,01	0,02	0,02	0,02	0,01	0,01	0,01	0,02	0,02	0,02	0,02
C20:4	0,14	0,14	0,15	0,14	0,14	0,13	0,14	0,14	0,13	0,13	0,13	0,13
C22:2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C23:0	nd	nd	nd	nd	0,001	0,002	0,003	0,002	nd	nd	nd	nd
C24:0	0,000	0,003	0,008	0,004	0,009	0,006	0,006	0,007	0,000	0,004	0,000	0,001
C20:5	0,000	0,002	0,002	0,001	0,002	0,002	0,003	0,002	0,000	0,001	0,000	0,000
C24:1	0,000	0,002	0,004	0,002	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003
C22:4	0,05	0,04	0,04	0,04	0,05	0,04	0,04	0,04	0,05	0,05	0,05	0,05
C22:5	0,03	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,02	0,03	0,03
C22:6	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Tot.	23,7	19,7	19,5	21,0	19,0	19,1	17,7	18,6	21,3	19,2	20,8	20,4
SFA	8,48	7,12	7,19	7,60	6,96	6,98	6,53	6,82	7,64	6,86	7,48	7,33
MUFA	12,2	10,2	9,77	10,7	9,44	9,58	8,70	9,24	10,8	9,83	10,7	10,4
PUFA	3,04	2,42	2,50	2,65	2,57	2,52	2,45	2,51	2,80	2,49	2,63	2,64
W6	2,77	2,20	2,25	2,41	2,35	2,30	2,25	2,30	2,52	2,24	2,36	2,37
W3	0,28	0,22	0,24	0,25	0,22	0,22	0,20	0,21	0,28	0,25	0,27	0,27
W6/W3	10,0	9,86	9,24	9,70	10,9	10,7	11,1	10,9	9,00	8,91	8,68	8,86
PUFA/SFA	0,36	0,34	0,35	0,35	0,37	0,36	0,37	0,37	0,37	0,36	0,35	0,36

c = Cis isomer fatty acids; t = Trans isomer fatty acids; SFA = Saturated Fatty Acids; MUFA = Monounsaturated Fatty Acids; PUFA = Polyunsaturated Fatty Acids; W6 = Omega-6 Fatty Acids; W3 = Omega-3 Fatty Acids; W6/W3 = Omega-6/Omega-3 ratio PUFA/SFA = Polyunsaturated Fatty Acids/Saturated Fatty Acids ratio

Table 6. *B-vitamin content (mg/100g) in pool samples of Prosciutto di Modena PDO.*

B vitamins	Processing time (16 months)				Processing time (20 months)				Processing time (24 months)			
	16 A	16 B	16 C	Mean	20 A	20 B	20 C	Mean	24 A	24 B	24 C	Mean
	(mg/100 g)				(mg/100 g)				(mg/100 g)			
Thiamine (B1)	0,59	0,56	0,66	0,61	0,58	0,56	0,53	0,56	0,49	0,47	0,56	0,51
Riboflavin (B2)	0,28	0,28	0,19	0,25	0,34	0,25	0,22	0,27	0,19	0,25	0,31	0,25
Niacin (PP-B3) *	5,96	7,54	5,94	6,48	7,03	6,69	7,03	7,19	7,41	7,71	7,92	7,68
Pyridoxine (B6) **	1,10	1,06	1,14	1,10	1,05	1,33	1,32	1,24	1,43	1,30	1,17	1,30

** Sum of nicotinic acid and nicotinamide*
*** As pyridoxal*

Table 7. Mineral content (mg/100g or µg/100g) in pool samples of Prosciutto di Modena PDO.

Mineral elements	Curing time (16 M)				Curing time (20 M)				Curing time (24 M)			
	16 A	16 B	16 C	Mean	20 A	20 B	20 C	Mean	24 A	24 B	24 C	Mean
Ca (mg/100g)	11,7	15,1	20,4	15,7	16,6	14,3	14,6	15,2	17,0	15,5	14,2	15,6
P (mg/100g)	171	200	207	193	178	210	213	200	231	226	219	226
Mg (mg/100g)	24,8	27,8	30,2	27,6	24,5	29,7	31,2	28,5	32,1	32,1	30,8	31,7
K (mg/100g)	385	454	454	431	532	481	477	497	526	529	507	521
Na (mg/100g)	1715	1585	1804	1701	1900	1655	1766	1774	1536	1711	1590	1612
Fe (mg/100g)	0,83	1,01	1,07	0,97	0,81	0,91	0,96	0,89	0,87	1,02	0,83	0,91
Zn (mg/100g)	4,03	4,49	4,72	4,41	4,25	4,64	4,50	4,46	4,64	4,52	4,31	4,49
Cu (mg/100g)	0,05	0,05	0,06	0,05	0,06	0,05	0,06	0,06	0,05	0,06	0,06	0,06
Mn (mg/100g)	0,01	0,01	0,08	0,03	0,03	0,01	0,01	0,01	0,01	0,02	0,01	0,01
Se (µg/100g)	9,95	13,2	12,1	11,8	10,8	13,0	12,5	12,1	13,5	12,8	10,6	12,3

ANNEX 2. SHELF LIFE

Table 1A. *Estimated marginal means of chemical-physical and sensory parameters measured in Prosciutto di Modena PDO with three processing times (16, 20, 24 months) and the significance of differences (P < 0.05). Different letters along the rows correspond to significantly different means in multiple pairwise tests (Bonferroni t-test, P < 0.05). n.s.: not significant*

Parameters	Processing time (months)			*P-value*
	16	20	24	
Chemophysical parameters				
pH	5,72	5,72	5,70	n.s.
a_w	0,90	0,90	0,89	n.s.
TBARs (MDA mg/Kg)	1,00	0,76	0,73	n.s.
Proteolysis index (%)	26,0	30,3	30,6	0,001
L^*_{lean}	42,1	42,6	41,6	n.s.
a^*_{lean}	8,83	9,49	10,1	0,007
C^*_{lean}	11,9	12,9	13,7	0,010
Hue_{lean}	42,1	41,7	42,3	n.s.
L^*_{fat}	75,6	75,3	74,8	n.s.
a^*_{fat}	1,50	1,50	1,83	n.s.
b^*_{fat}	11,8	12,1	12,5	n.s.
C^*_{fat}	11,9	12,3	12,7	n.s.
Hue_{fat}	83,2	83,5	81,9	n.s.
Sensory descriptors				
$Red\ colour_{lean}$	6,39	5,97	5,95	n.s.
$Brown\ colour_{lean}$	3,61	3,30	3,75	n.s.
$Dry,\ dark\ borders_{lean}$	2,17	2,44	1,96	n.s.
$White\ grains_{lean}$	0,13	0,21	0,33	0,046
$White\ film_{lean}$	4,14	5,82	5,40	0,009
$Yellow\ colour_{fat}$	2,50	3,18	3,60	0,034
$Pink\ colour_{fat}$	2,78	2,65	2,59	n.s.
$Oilyness_{fat}$	4,65	4,91	4,69	n.s.
$Hardness_{lean}$	5,18	4,93	5,15	n.s.
$Hardness_{fat}$	4,08	3,77	3,74	n.s.
$Adhesiveness_{lean}$	2,86	2,50	2,60	n.s.
Fully matured odour	5,31	5,63	5,64	n.s.
Rancid odour	2,89	2,88	2,74	n.s.
Off-odour	0,61	0,71	0,84	n.s.

Table 1B. *Estimated marginal means of chemophysical and sensory parameters measured in vacuum-packed portions of Prosciutto di Modena PDO at the beginning of shelf life and after 120, 210, 300 and 360 days of storage at 4 °C. Significance of the comparison is reported at P < 0.05. Different letters within rows correspond to significantly different means in multiple pairwise tests (Bonferroni t-test, P < 0.05).*

Parameters	Processing time (days)					
	Start of shelf life	120	210	300	360	*P-value*
Chemophysical parameters						
pH	5,74	5,65	5,71	5,72	5,73	n.s.
a_w	0,893	0,901	0,886	0,894	0,890	n.s.
TBARs (MDA mg/Kg)	0,60	1,02	1,00	0,83	0,71	n.s.
Proteolysis index (%)	28,3	30,4	28,3	29,9	28,0	n.s.
L^*_{lean}	37,8 ^{b}	43,7 ^{a}	41,5 $^{a, b}$	44,1 ^{a}	43,4 ^{a}	0,014
a^*_{lean}	10,2	9,38	9,20	9,64	8,88	0,069
b^*_{lean}	9,63	8,81	8,47	8,14	7,98	n.s.
C^*_{lean}	14,1	12,9	12,5	12,6	12,0	0,064
Hue_{lean}	43,4	43,1	42,6	39,5	41,5	n.s.
Sensory descriptors						
$Red\ colour_{lean}$	7,38 ^{a}	6,55 $^{a, b}$	5,98 $^{b, c}$	5,47 ^{c}	5,14 ^{c}	<0,001
$Brown\ colour_{lean}$	2,50 ^{c}	3,25 $^{b, c}$	3,65 $^{a, b}$	3,99 $^{a, b}$	4,37 ^{a}	0,003
$Dry, dark\ borders_{lean}$	2,30	2,20	2,73	2,27	1,45	n.s.
$White\ grains_{lean}$	0,02 ^{b}	0,08 ^{b}	0,16 ^{b}	0,59 ^{a}	0,26 ^{b}	0,001
$White\ film_{lean}$	2,30 ^{b}	5,13 ^{a}	5,22 ^{a}	6,78 ^{a}	6,16 ^{a}	<0,001
$Yellow\ colour_{fat}$	2,20 ^{b}	2,10 ^{b}	3,31 ^{a}	3,99 ^{a}	3,86 ^{a}	0,008
$Pink\ colour_{fat}$	2,34 ^{b}	3,29 ^{a}	3,31 ^{a}	2,21 ^{b}	2,23 ^{b}	0,019
$Oilyness_{fat}$	4,50	4,41	5,26	5,03	4,56	n.s.
$Hardness_{lean}$	5,83	3,96	5,30	5,09	5,25	n.s.
$Hardness_{fat}$	5,05 ^{a}	2,96 ^{b}	3,68 ^{b}	3,70 ^{b}	3,93 ^{b}	0,029
$Adhesiveness_{lean}$						
Fully matured odour	6,67 ^{a}	5,58 ^{b}	5,47 ^{b}	5,18 $^{b, c}$	4,72 ^{c}	<0,001
Rancid odour	1,03 ^{b}	3,08 ^{a}	3,40 ^{a}	3,22 ^{a}	3,44 ^{a}	0,021
Off-odour	0,23 $_{c}$	0,55 $^{b, c}$	0,95 $^{a, b}$	0,66 $^{b, c}$	1,23 ^{a}	0,009

**n.s.: not significant*

Table 2*. Mean pH values of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

pH	4 °C	10 °C	20 °C	30 °C
Start of shelf life	5,74			
	5,74 $_{3}$	5,64 $_{60}$	5,72 $_{30}$	5,69 $_{14}$
	5,65 $_{120}$	5,65 $_{120}$	5,54 $_{60}$	5,56 $_{22}$
	5,71 $_{210}$	5,70 $_{180}$	5,46 $_{90}$	5,58 $_{29}$
	5,72 $_{300}$	5,54 $_{210}$	5,60 $_{120}$	5,54 $_{36}$
	5,73 $_{360}$	5,57 $_{240}$	5,56 $_{150}$	5,45 $_{44}$
R^2	/	/	/	0,913

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 3. *Mean water activity values of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

a_w	4 °C	10 °C	20 °C	30 °C
Start of shelf life	0,893			
	0,893 $_{3}$	0,893 $_{60}$	0,896 $_{30}$	0,898 $_{14}$
	0,901 $_{120}$	0,898 $_{120}$	0,887 $_{60}$	0,892 $_{22}$
	0,886 $_{210}$	0,890 $_{180}$	0,901 $_{90}$	0,886 $_{29}$
	0,894 $_{300}$	0,883 $_{210}$	0,894 $_{120}$	0,882 $_{36}$
	0,890 $_{360}$	0,884 $_{240}$	0,878 $_{150}$	0,880 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 4. *Mean TBARs values (mg MDA/Kg) values of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

TBARs test	4 °C	10 °C	20 °C	30 °C
Start of shelf life	0,60			
	0,60 $_{3}$	0,86 $_{60}$	0,74 $_{30}$	0,81 $_{14}$
	1,03 $_{120}$	0,86 $_{120}$	0,65 $_{60}$	0,81 $_{22}$
	1,00 $_{210}$	0,74 $_{180}$	0,87 $_{90}$	0,77 $_{29}$
	0,83 $_{300}$	0,88 $_{210}$	0,68 $_{120}$	0,78 $_{36}$
	0,71 $_{360}$	0,97 $_{240}$	0,76 $_{150}$	0,68 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R2 <0.7

Table 5. *Mean proteolysis index values (%) values of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Indice di proteolisi	4 °C	10 °C	20 °C	30 °C
Start of shelf life	28,3			
	28,3 $_{3}$	31,0 $_{60}$	30,1 $_{30}$	30,2 $_{14}$
	30,4 $_{120}$	30,4 $_{120}$	29,0 $_{60}$	30,4 $_{22}$
	28,3 $_{210}$	27,2 $_{180}$	30,0 $_{90}$	31,3 $_{29}$
	33,6 $_{300}$	28,2 $_{210}$	33,1 $_{120}$	31,7 $_{36}$
	28,0 $_{360}$	31,1 $_{240}$	32,2 $_{150}$	31,5 $_{44}$
R^2	/	/	0,739	0,879

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R2 <0.7

Table 6. *Mean L* values measured in the lean fraction of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

L^*_{lean}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	39,9			
	39,9 $_{3}$	48,7 $_{60}$	45,0 $_{30}$	45,8 $_{14}$
	47,4 $_{120}$	50,1 $_{120}$	45,9 $_{60}$	45,6 $_{22}$
	47,2 $_{210}$	47,1 $_{180}$	50,4 $_{90}$	46,8 $_{29}$
	47,7 $_{300}$	50,2 $_{210}$	51,9 $_{120}$	47,8 $_{36}$
	51,5 $_{360}$	51,0 $_{240}$	47,5 $_{150}$	49,1 $_{44}$
R^2	0,816	/	/	0,884

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R2 <0.7

Table 7. *Mean a* values measured in the lean fraction of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

a^*_{lean}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	8,03			
	$8,03_{3}$	$5,37_{60}$	$7,45_{30}$	$7,67_{14}$
	$6,82_{120}$	$6,17_{120}$	$5,89_{60}$	$7,17_{22}$
	$5,56_{210}$	$5,47_{180}$	$7,06_{90}$	$8,27_{29}$
	$6,51_{300}$	$4,65_{210}$	$5,45_{120}$	$6,33_{36}$
	$3,77_{360}$	$4,05_{240}$	$7,40_{150}$	$7,54_{44}$
R^2	0,732	0,761	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R2 <0.7

Table 8. *Mean b* values measured in the lean fraction of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

b^*_{lean}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	7,31			
	$7,31_{3}$	$5,58_{60}$	$8,18_{30}$	$8,42_{14}$
	$7,39_{120}$	$7,69_{120}$	$6,38_{60}$	$8,33_{22}$
	$7,17_{210}$	$8,77_{180}$	$10,47_{90}$	$9,23_{29}$
	$7,26_{300}$	$9,12_{210}$	$9,07_{120}$	$8,31_{36}$
	$6,18_{360}$	$7,90_{240}$	$11,21_{150}$	$8,53_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 9. *Mean C* values measured in the lean fraction of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

C^*_{lean}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	10,9			
	$10,9_{3}$	$7,76_{60}$	$11,1_{30}$	$11,5_{14}$
	$10,1_{120}$	$9,94_{120}$	$8,70_{60}$	$11,0_{22}$
	$9,10_{210}$	$10,4_{180}$	$12,7_{90}$	$12,4_{29}$
	$9,88_{300}$	$10,4_{210}$	$10,7_{120}$	$10,5_{36}$
	$7,27_{360}$	$8,95_{240}$	$13,5_{150}$	$11,4_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R2 <0.7

Table 10. *Mean Hue values measured in the lean fraction of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C..*

Hue_{lean}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	41,9			
	$41,9_{3}$	$45,3_{60}$	$47,4_{30}$	$47,1_{14}$
	$48,2_{120}$	$52,5_{120}$	$47,3_{60}$	$49,0_{22}$
	$51,9_{210}$	$57,8_{180}$	$58,6_{90}$	$48,1_{29}$
	$50,4_{300}$	$62,8_{210}$	$59,2_{120}$	$52,0_{36}$
	$58,9_{360}$	$63,4_{240}$	$57,1_{150}$	$48,5_{44}$
R^2	0,849	0,985	0,895	0,902

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 11. *Mean L* values measured in the cover fat of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

L^*_{fat}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	76,3			
	$76,3_{3}$	$74,9_{60}$	$76,6_{30}$	$68,6_{14}$
	$76,1_{120}$	$76,7_{120}$	$74,3_{60}$	$73,4_{22}$
	$75,3_{210}$	$76,2_{180}$	$78,2_{90}$	$73,2_{29}$
	$74,1_{300}$	$75,5_{210}$	$76,4_{120}$	$72,1_{36}$
	$74,5_{360}$	$74,6_{240}$	$75,6_{150}$	$69,9_{44}$
R^2	0,868	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 12. *Mean a* values measured in the cover fat of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

a^*_{fat}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	0,14			
	$0,14_{3}$	$0,91_{60}$	$1,20_{30}$	$0,96_{14}$
	$1,47_{120}$	$1,51_{120}$	$1,73_{60}$	$1,72_{22}$
	$0,89_{210}$	$1,89_{180}$	$1,48_{90}$	$1,30_{29}$
	$1,65_{300}$	$1,89_{210}$	$2,15_{120}$	$1,74_{36}$
	$1,45_{360}$	$1,73_{240}$	$1,79_{150}$	$3,19_{44}$
R^2	/	0,866	/	0,844

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 13. *Mean b* values measured in the cover fat of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

b^*_{fat}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	11,2			
	$11,2_{3}$	$11,5_{60}$	$13,0_{30}$	$12,9_{14}$
	$13,4_{120}$	$14,9_{120}$	$15,4_{60}$	$13,9_{22}$
	$13,7_{210}$	$16,7_{180}$	$16,4_{90}$	$15,0_{29}$
	$13,5_{300}$	$17,2_{210}$	$19,9_{120}$	$15,9_{36}$
	$15,3_{360}$	$18,9_{240}$	$21,1_{150}$	$17,6_{44}$
R^2	0,811	0,961	0,986	0,991

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 14. *Mean C* values measured in the cover fat of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

C^*_{fat}	4 °C	10 °C	20 °C	30 °C
Start of shelf life	11,2			
	$11,2_{3}$	$11,5_{60}$	$13,1_{30}$	$12,9_{14}$
	$13,5_{120}$	$15,0_{120}$	$15,5_{60}$	$14,1_{22}$
	$13,7_{210}$	$16,8_{180}$	$16,5_{90}$	$15,0_{29}$
	$13,6_{300}$	$17,4_{210}$	$20,0_{120}$	$16,1_{36}$
	$15,4_{360}$	$19,0_{240}$	$21,2_{150}$	$17,9_{44}$
R^2	0,812	0,962	0,985	0,988

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 15. *Mean Hue values measured in the cover fat of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Hue $_{fat}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	89,7			
	89,7 $_{3}$	85,6 $_{60}$	85,2 $_{30}$	85,9 $_{14}$
	84,4 $_{120}$	84,5 $_{120}$	83,9 $_{60}$	83,6 $_{22}$
	86,5 $_{210}$	83,8 $_{180}$	85,2 $_{90}$	85,1 $_{29}$
	83,07 $_{300}$	84,0 $_{210}$	84,3 $_{120}$	84,4 $_{36}$
	84,65 $_{360}$	84,8 $_{240}$	85,3 $_{150}$	79,6 $_{44}$
R^2	/	/	/	0,737

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 16. *Mean ΔE_{00} values measured in the lean fraction of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

$\Delta E_{00\ lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	3,22			
	3,22 $_{3}$	5,62 $_{60}$	5,97 $_{30}$	5,38 $_{14}$
	4,37 $_{120}$	7,88 $_{120}$	7,02 $_{60}$	7,01 $_{22}$
	6,59 $_{210}$	8,17 $_{180}$	7,49 $_{90}$	5,56 $_{29}$
	7,34 $_{300}$	9,07 $_{210}$	10,0 $_{120}$	7,11 $_{36}$
	7,11 $_{360}$	10,4 $_{240}$	8,69 $_{150}$	5,75 $_{44}$
R^2	0,912	0,956	0,829	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 17*. Mean ΔE_{00} values measured in the cover fat of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

$\Delta E_{00\ fat}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	1,38			
	1,38 $_{3}$	1,61 $_{60}$	1,52 $_{30}$	2,10 $_{14}$
	1,50 $_{120}$	2,08 $_{120}$	2,50 $_{60}$	2,29 $_{22}$
	1,76 $_{210}$	2,47, $_{180}$	3,19 $_{90}$	2,63 $_{29}$
	1,97 $_{300}$	3,21 $_{210}$	3,73 $_{120}$	3,31 $_{36}$
	2,09 $_{360}$	2,79 $_{240}$	5,30 $_{150}$	3,76 $_{44}$
R^2	0,976	0,846	0,967	0,955

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 18*. Mean values of "Red colour of the lean fraction" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Red colour $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	7,40			
	7,40 $_{3}$	6,33 $_{60}$	6,62 $_{30}$	6,59 $_{14}$
	6,52 $_{120}$	6,26 $_{120}$	6,70 $_{60}$	6,31 $_{22}$
	5,94 $_{210}$	5,88, $_{180}$	6,12 $_{90}$	6,33 $_{29}$
	5,42 $_{300}$	5,82 $_{210}$	6,25 $_{120}$	6,32 $_{36}$
	5,16 $_{360}$	5,73 $_{240}$	6,09 $_{150}$	6,18 $_{44}$
R^2	0,933	0,857	0,788	0,789

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 19. *Mean values of "Brown colour of the lean fraction" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Brown colour $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	2,51			
	2,51 $_{3}$	3,71 $_{60}$	2,40 $_{30}$	2,87 $_{14}$
	3,21 $_{120}$	3,48 $_{120}$	3,40 $_{60}$	3,51 $_{22}$
	3,67 $_{210}$	4,86 $_{180}$	4,07 $_{90}$	2,94 $_{29}$
	3,94 $_{300}$	3,69 $_{210}$	3,88 $_{120}$	2,88 $_{36}$
	4,33 $_{360}$	3,35 $_{240}$	4,57 $_{150}$	2,83 $_{44}$
R^2	0,989	/	0,890	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 20. *Mean values of" Dry, dark boarders" score of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Presence of dry, dark boarders $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	2,29			
	2,29 $_{3}$	2,71 $_{60}$	2,22 $_{30}$	1,84 $_{14}$
	2,09 $_{120}$	1,75 $_{120}$	2,42 $_{60}$	3,56 $_{22}$
	2,71 $_{210}$	3,21 $_{180}$	2,32 $_{90}$	3,46 $_{29}$
	2,26 $_{300}$	2,02 $_{210}$	2,52 $_{120}$	3,08 $_{36}$
	2,11 $_{360}$	2,83 $_{240}$	3,83 $_{150}$	2,19 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 21. *Mean values of "White grains in the lean fraction" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

White grains $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	0,02			
	0,02 $_{3}$	0,50 $_{60}$	0,07 $_{30}$	0,00 $_{14}$
	0,08 $_{120}$	0,19 $_{120}$	0,61 $_{60}$	0,16 $_{22}$
	0,16 $_{210}$	0,66 $_{180}$	0,23 $_{90}$	0,24 $_{29}$
	0,62 $_{300}$	0,43 $_{210}$	0,59 $_{120}$	0,28 $_{36}$
	0,21 $_{360}$	0,51 $_{240}$	1,62 $_{150}$	0,82 $_{44}$
R^2	/	/	/	0,799

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 22. *Mean values of "White film" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

White film $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	2,24			
	2,24 $_{3}$	5,15 $_{60}$	3,73 $_{30}$	4,59 $_{14}$
	5,09 $_{120}$	5,59 $_{120}$	5,33 $_{60}$	5,14 $_{22}$
	5,18 $_{210}$	5,47, $_{180}$	5,86 $_{90}$	4,64 $_{29}$
	6,76 $_{300}$	5,61 $_{210}$	6,07 $_{120}$	5,46 $_{36}$
	6,14 $_{360}$	6,20 $_{240}$	4,96 $_{150}$	4,80 $_{44}$
R^2	0,832	0,70	0,904	0,792

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 23. *Mean values of "Yellow colour of the cover fat" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Yellow colour $_{fat}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	2,21			
	2,21 $_{3}$	2,35 $_{60}$	1,58 $_{30}$	4,15 $_{14}$
	2,15 $_{120}$	2,76 $_{120}$	2,37 $_{60}$	2,00 $_{22}$
	3,30 $_{210}$	2,99 $_{180}$	3,45 $_{90}$	3,20 $_{29}$
	3,92 $_{300}$	3,39 $_{210}$	4,05 $_{120}$	4,05 $_{36}$
	3,86 $_{360}$	4,58 $_{240}$	5,21 $_{150}$	3,73 $_{44}$
R^2	0,862	0,784	0,866	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 24. *Mean value of "Pink colour of the cover fat" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Pink colour $_{fat}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	2,34			
	2,34 $_{3}$	3,59 $_{60}$	3,04 $_{30}$	2,87 $_{14}$
	3,31 $_{120}$	3,39 $_{120}$	2,59 $_{60}$	3,83 $_{22}$
	3,28 $_{210}$	2,78 $_{180}$	2,87 $_{90}$	3,11 $_{29}$
	2,21 $_{300}$	3,13 $_{210}$	2,19 $_{120}$	3,22 $_{36}$
	2,21 $_{360}$	2,18 $_{240}$	1,10 $_{150}$	3,66 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 25. *Mean values of "Oiliness of the cover fat" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Oiliness $_{fat}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	4,43			
	4,43 $_{3}$	3,42 $_{60}$	4,16 $_{30}$	5,88 $_{14}$
	4,25 $_{120}$	4,37 $_{120}$	4,46 $_{60}$	4,59 $_{22}$
	5,25 $_{210}$	4,56 $_{180}$	5,57 $_{90}$	5,29 $_{29}$
	5,02 $_{300}$	4,39 $_{210}$	5,10 $_{120}$	5,14 $_{36}$
	4,57 $_{360}$	5,04 $_{240}$	6,06 $_{150}$	4,29 $_{44}$
R^2	/	/	0,752	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 26. *Mean values of "Hardness of the lean fraction" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Hardness $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	5,86			
	5,86 $_{3}$	5,05 $_{60}$	5,29 $_{30}$	5,13 $_{14}$
	3,98 $_{120}$	4,82 $_{120}$	5,84 $_{60}$	6,08 $_{22}$
	5,27 $_{210}$	5,90 $_{180}$	5,31 $_{90}$	6,12 $_{29}$
	5,12 $_{300}$	5,95 $_{210}$	5,04 $_{120}$	6,05 $_{36}$
	5,26 $_{360}$	5,55 $_{240}$	6,28 $_{150}$	6,13 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 27. *Mean values of "Adhesiveness of the lean fraction" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Adhesiveness $_{lean}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	2,20			
	2,20 $_{3}$	2,29 $_{60}$	1,89 $_{30}$	1,83 $_{14}$
	3,34 $_{120}$	2,16 $_{120}$	2,04 $_{60}$	2,56 $_{22}$
	3,41 $_{210}$	1,86 $_{180}$	3,16 $_{90}$	3,13 $_{29}$
	2,33 $_{300}$	2,33 $_{210}$	3,13 $_{120}$	1,87 $_{36}$
	1,90 $_{360}$	2,54 $_{240}$	2,11 $_{150}$	2,01 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 28. *Mean value of "Hardness of the cover fat" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Hardness $_{fat}$	4 °C	10 °C	20 °C	30 °C
Start of shelf life	5,05			
	5,05 $_{0}$	4,57 $_{60}$	4,56 $_{30}$	3,66 $_{14}$
	2,96 $_{120}$	4,04 $_{120}$	4,10 $_{60}$	4,65 $_{22}$
	3,67 $_{210}$	4,38 $_{180}$	4,77 $_{90}$	4,20 $_{29}$
	3,71 $_{300}$	4,56 $_{210}$	4,44 $_{120}$	4,81 $_{36}$
	3,88 $_{360}$	3,71 $_{240}$	3,86 $_{150}$	3,98 $_{44}$
R^2	/	/	/	/

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 29. *Mean values of "Fully-matured odour" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Fully-matured odour	4 °C	10 °C	20 °C	30 °C
Start of shelf life	6,64			
	6,64 $_{3}$	5,70 $_{60}$	6,00 $_{30}$	5,29 $_{14}$
	5,55 $_{120}$	5,06 $_{120}$	5,72 $_{60}$	5,77 $_{22}$
	5,47 $_{210}$	4,98, $_{180}$	5,29 $_{90}$	5,33 $_{29}$
	5,15 $_{300}$	4,74 $_{210}$	4,73 $_{120}$	5,87 $_{36}$
	4,73 $_{360}$	4,62 $_{240}$	4,76 $_{150}$	5,15 $_{44}$
R^2	0,919	0,910	0,956	0,770

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 30*. Mean values of "Rancid odour" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Rancid odour	4 °C	10 °C	20 °C	30 °C
Start of shelf life	1,03			
	1,03 $_{3}$	2,17 $_{60}$	1,39 $_{30}$	4,17 $_{14}$
	3,12 $_{120}$	3,46 $_{120}$	2,14 $_{60}$	2,00 $_{22}$
	3,39 $_{210}$	4,33, $_{180}$	3,93 $_{90}$	3,34 $_{29}$
	3,26 $_{300}$	3,78 $_{210}$	3,83 $_{120}$	2,83 $_{36}$
	3,43 $_{360}$	4,44 $_{240}$	4,76 $_{150}$	3,28 $_{44}$
R^2	0,675	0,939	0,939	0,838

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

Table 31. *Mean values of "Off-odour" scores of Prosciutto di Modena PDO stored at different temperatures at the beginning of shelf life and after established storage time until 44 days at 30 °C, 150 days at 20 °C, 240 days at 10 °C and 360 days at 4 °C.*

Off-odour	4 °C	10 °C	20 °C	30 °C
Start of shelf life	0,20			
	0,20 $_{3}$	0,86 $_{60}$	0,62 $_{30}$	1,89 $_{14}$
	0,56 $_{120}$	1,58 $_{120}$	1,21 $_{60}$	1,15 $_{22}$
	0,95 $_{210}$	2,01 $_{180}$	1,22 $_{90}$	2,02 $_{29}$
	0,67 $_{300}$	2,24 $_{210}$	3,30 $_{120}$	0,79 $_{36}$
	1,25 $_{360}$	3,22 $_{240}$	2,43 $_{150}$	2,04 $_{44}$
R^2	0,764	0,956	0,782	0,714

In subscript, the deadlines (days) when analysis was carried out
/: non-linear R^2 <0.7

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