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A simple and portable method for on-line texture measurement of Italian "Speck Alto Adige"

Flavia Bianchi [a], Gerhard Gamper [a], Lidia Lozano [a,b], Nicoletta Simoncini [c], Roberta Virgili [c], Lukas Spada [d], Elena Venir [a,*]

[a] *Laimburg Research Centre, Ora (BZ), 39040, Auer, Italy*
[b] *IRTA Torre Marimon, 08140 Caldes de Montbui, Barcelona, Spain*
[c] *Stazione Sperimentale Conserve Alimentari, 43100 Parma, Italy*
[d] *Consorzio Tutela Speck Alto Adige, 39100 Bolzano, Italy*

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ABSTRACT

Texture is a relevant parameter for the assessment of cured ham's quality. In this study a rapid on-line instrumental technique for the measurement of the texture of pieces of cured smoked ham intended for sale as "Speck Alto Adige" PGI was developed. Speck samples were subjected to a compression test using a portable Shore A tester, and instrumental data were compared with conventional texture analyses (texture profile analysis and stress relaxation test) and with sensory evaluations. First, a hardness range in which a threshold value could be identified for the eligibility of 120 speck samples for the "Speck Alto Adige" PGI indication was established; afterwards, a Shore A hardness threshold value of 48 was defined based on measurements of more than 1000 samples. These findings may help manufacturers to determine the textural properties of Speck, based on a simple and rapid instrumental analysis.

1. Introduction

The "Speck Alto Adige" PGI is an Italian excellence typical of the South Tyrolean region. The characteristics of this cured smoked ham are widely regulated (*Disciplinare di produzione della Indicazione Geografica Protetta «Speck Alto Adige», «Südtiroler Markenspeck», «Südtiroler Speck»*, 2017). A number of 2.8 million ham hocks were produced in 2020 (Consorzio di Tutela Speck Alto Adige – Relazione Annuale, 2020). The production area comprises the territory of the Autonomous Province of Bolzano in South Tyrol. It is produced from boned pig thighs, trimmed using the traditional method with or without the rump, moderately salted and spiced with natural aromatic herbs, cold-smoked, dry-cured at a temperature not exceeding 20 °C, and aged at an ambient temperature of 10 °C to 15 °C with humidity between 60% and 90% (*Disciplinare di produzione della Indicazione Geografica Protetta «Speck Alto Adige», «Südtiroler Markenspeck», «Südtiroler Speck»*, 2017).

Numerous factors affect the characteristics of cured ham, including the quality of the meat before curing, processing techniques, and maturation conditions. Slaughter and pre-slaughter conditions influence the suitability of hams for processing: characteristics of a pig breed determine growth rate and quality of the meat (Čandek-Potokar & Škrlep, 2012), and a balanced diet in protein and micronutrients allows to achieve good meat qualities (Bosi & Russo, 2004). The animal diet was reported to affect the fatty acid composition of the adipose tissue of pigs (Smith & Smith, 2014), which is a relevant factor concerning fat oxidation stability and, therefore, sensory qualities, aromatic profile, and consistency of the meat (Bosi & Russo, 2004; Toldrá, 1998; Toldrá & Flores, 1998). The characteristics of the ham after processing and maturation are influenced by numerous factors including salt content, proteolytic potential, pH, temperature, moisture, quantity of fat, maturation time, and additives. Salt is an important stabilizer that confers the typical taste to cured ham (Čandek-Potokar & Škrlep, 2012). It helps to inhibit excessive proteolysis (Martín, Córdoba, Antequera, Timón, & Ventanas, 1998; Toldrá, 1998), which can lead to defects of texture and sensory properties (Arnau, Guerrero, & Sárraga, 1998; Čandek-Potokar & Škrlep, 2012; García-Garrido, Quiles-Zafra, Tapiador, & Luque De Castro, 2000; Parolari, Virgili, & Schivazappa, 1994). Parameters like pH, water content, and temperature affect texture and flavour of the final product by influencing the activity of enzymes (Arnau et al., 1998; Čandek-Potokar & Škrlep, 2012; Serra, Ruiz-Ramírez, Arnau, & Gou,

* Corresponding author.
E-mail address: elena.venir@laimburg.it (E. Venir).

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2005). The processing temperature, together with the content of salt, influence the composition of compounds released due to proteolysis (Martín et al., 1998).

Texture is a highly relevant quality parameter of cured ham that affects sensory characteristics (Serra et al., 2005), acceptability of the product by consumers (Arnau et al., 1998; Cilla, Martínez, Beltrán, & Roncalés, 2005), and their willingness to purchase (Cilla, Martínez, Beltrán, & Roncalés, 2006). Together with colour, taste, aroma, and flavour, texture is commonly examined in studies aimed at evaluating the sensory quality of cured ham (Arnau et al., 1998; Buscailhon, Berdague, Gandemer, Touraille, & Monin, 1994; Buscailhon, Touraille, Girard and Monin, 1995; Guerrero, Gou, Alonso, & Arnau, 1996; Ruiz, Ventanas, Cava, Timón, & García, 1998). As mentioned above, numerous factors influence the texture of cured ham, including genetic selection of the animals, pig production, processing, and maturation conditions (Virgili & Schivazappa, 2002).

Given the importance of texture in assessing the quality of cured ham, the present study focused on the development of a rapid on-line method to measure the hardness of pieces of Speck for sale under the trademark "Speck Alto Adige" PGI, using a portable instrument (portable Shore A tester).

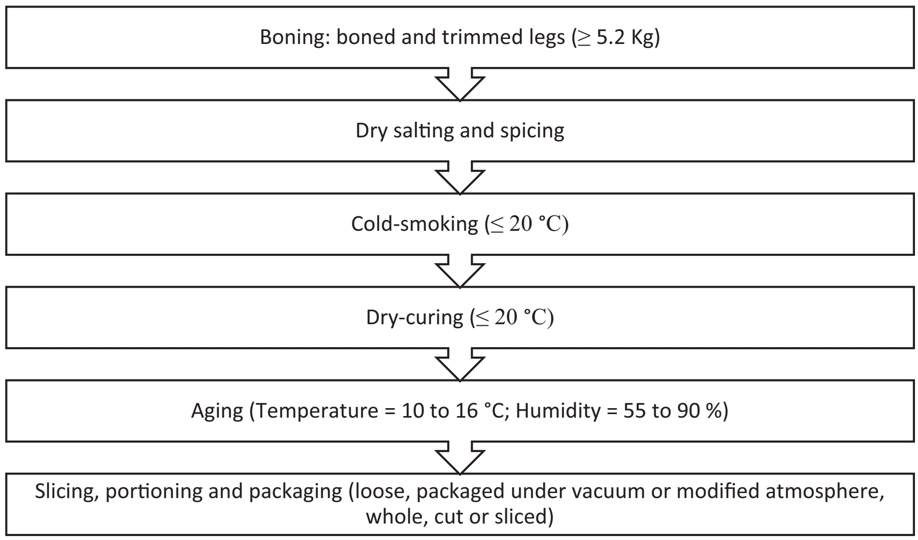
The first part of the experimental design aimed at establishing a hardness range in which a threshold value could be identified for the eligibility of samples under investigation for the production of "Speck Alto Adige" PGI pieces. For this purpose, instrumental data acquired were compared with those officially evaluated by a certified auditor (CA), who assessed the suitability of the speck pieces under examination for the PGI trademark. Additionally, a sensory evaluation was performed, and instrumental colour and physico-chemical parameters were measured. After establishing a threshold range of the instrumental hardness, the dataset was widened, including a larger number of producers and Speck samples intended for the "Speck Alto Adige" PGI trademark, aiming at evaluating their distribution in relationship to the threshold range identified, and to consequently define a threshold value.

The relevance of this study for Speck producers is to allow them through a simple instrumental analysis to determine the texture of pieces of Speck associated with the "Speck Alto Adige" PGI trademark.

2. Materials and methods

2.1. Speck

Speck, produced according to the product's specifications (*Disciplinare di produzione della Indicazione Geografica Protetta «Speck Alto Adige», «Südtiroler Markenspeck», «Südtiroler Speck»*, 2017; Official journal of the European Union, 2010), was provided by producers of the Consorzio Tutela Speck Alto Adige. The processing steps are summarized below:



The chemical, chemico-phyisical and microbiological requirements of the final product are:

- Total protein ≥20%
- Water/protein ≤2.0%
- Fat/protein ≤1.5%
- NaCl ≤5%
- $KNO_3 < 150$ mg·Kg^{-1}
- $NaNO_2 < 50$ mg·Kg^{-1}
- Mesophilic microorganisms count compliant with standard UNI ISO 4833 (2003): lactic acid bacteria within maximum concentration of $1{\cdot}10^8$ CFU·g^{-1}

For the experimental trials aimed at the determination of an instrumental hardness range (in which to identify a threshold value) for the suitability of speck pieces for the production of "Speck Alto Adige" PGI, samples, provided by producers who are members of the Consorzio Tutela Speck Alto Adige, belonged to two weight classes, according to the product specifications (*Disciplinare di produzione della Indicazione Geografica Protetta «Speck Alto Adige», «Südtiroler Markenspeck», «Südtiroler Speck»*, 2017): weight class 1 (3.4 to <4.3 kg) and weight class 2 (4.3 to <4.9 kg). Overall, 120 speck samples from five establishments were collected, including 19 samples (12 and 7 from weight class 1 and 2, respectively) considered as references, based on their optimal texture and colour characteristics judged by a CA and by producers.

Speck samples were vacuum-packed, transferred under refrigerated conditions to the laboratories, and stored under refrigeration for no longer than 15 days before analysis. Samples were collected at the minimum maturation, based on their weight class (20 weeks for weight class 1, 22 weeks for weight class 2), according to the product specifications. The 120 speck samples used for the first trials were further analyzed to determine their textural properties (measured with a dynamometer and a portable Shore hardness tester), sensory qualities, colour, and physico-chemical characteristics.

For the experimental trials aimed at evaluating the distribution of a higher number of speck samples, the hardness of 1088 samples provided by 10 manufacturers was measured using the portable device directly in the factories. All speck samples under examination were officially evaluated by the CA, who judged their quality according to the official evaluation protocol (Kontrollplan Südtiroler Speck G.G.A. Rev 2, 2021) and grouped them as follows: eligible (suitable for the "Speck Alto Adige" PGI), ineligible (unsuitable for the "Speck Alto Adige" PGI) and uncertain.

2.2. Sampling

Samples were cut along the major and minor axis, respectively. The cut was carried out in accordance with the production practices and under the supervision of a CA. This sampling procedure allowed to include in the cut section the biceps femoris muscle (BF).

2.3. Physico-chemical analyses

The following parameters were measured on the whole piece, using reference methods: water activity (a_w) (UNI 11302:2009) in the BF muscle, pH (ISO 2917:1999), moisture % (UNI ISO 1442:2010), protein % (UNI ISO 937:1991), free Fat % (ISO 1444:1996) and chlorides, expressed as NaCl % (LC/MP/N.62012 Rev.10).

2.4. Colour

Colour was measured through a portable reflectance spectrophotometer (Konica Minolta CM-700d; Osaka, Japan) on the muscle fractions of the cut surface and on the fat cover, immediately after cutting. The following conditions were used: illuminant D65, observer angle 10°, reading area ø = 8 mm for measurements on lean speck portion, and reading area ø = 3 mm for measurements on fat cover. The colour measurement was carried out in 8 points of the lean portion and in 4 points of the fat, on the same pieces used for the analysis of texture with the portable machine. Values of the three coordinates, L*, a* and b*, in the CIELAB colour space were acquired and their derived functions Chroma and Hue angle were calculated.

2.5. Texture analyses

Measurements were carried out on the 101 Speck samples and 19 references using a portable Shore A tester 1 kN Zwicki (ZwickRoell GmbH; Ulm, Germany) and a Texture Machine mod. 5565 (Instron; Norwood, MA, USA) equipped with a 100 N load cell and a compression device Ø = 50 mm.

A 15 mm thick piece (portion A) was cut from the BF muscle, 3 or 4 (depending on the size of the muscle) cylindrical samples were taken with a core drill (h = 15 mm; Ø = 16 mm) and subjected to two tests commonly used for meat products, namely Texture Profile Analysis (TPA) and Stress-Relaxation (SR) (Benedini, Parolari, Toscani, & Virgili, 2012; Morales, Guerrero, Serra, & Gou, 2007; Morales, Serra, Guerrero, & Gou, 2007). To reproduce common sensory compression patterns, the compression was applied both perpendicular and parallel to the direction of the muscle fibres. The textural parameters determined were: hardness (N), adhesiveness (mJ), cohesiveness, and springiness, with the TPA test and maximum compression force (N) and decaying force recorded after 2, 10, and 90 s of compression, with the SR test. Measurements were carried out at 15 °C.

The portable Shore A tester was used for the assessment of the texture of a piece (portion B) immediately close to the portion A, in the direction parallel to the fibres of the muscle. This instrument provides a value of hardness on a Shore A scale, after 15 s of compression. Measurements were performed at least in triplicate on each piece at a temperature of 15 °C. On 12 speck samples hardness values measured with the portable device were determined at three different temperatures (10 °C – 15 °C – 20 °C).

2.6. Sensory analyses

In each tasting session, 8 samples (pieces) were evaluated and presented to the tasters in a balanced order (Macfie, Bratchell, Greenhoff, & Vallis, 1989), choosing, if possible, samples belonging to different sizes and production plants. One half of each ham was assessed by the CA to judge its eligibility for production of pieces of "Speck Alto Adige" PGI based on texture and colour. The other half of each ham was submitted to the assessment by a panel of 8 assessors trained in the evaluation of cured meat products. The CA used the same evaluation form as the panelists each attribute was evaluated on a 0–9 intensity scale, where the extremes of the scale corresponded to the absence and maximum perception of the descriptor, respectively. The sensory attributes are summarized in Table 1. All samples were evaluated at a temperature of 15 °C.

2.7. Data analysis

Statistical analysis and data visualization were performed in SPSS

Table 1
Evaluation form used for sensory analyses.

Evaluation of the lean portion	Red colour intensity
	Yellow/brown colour intensity
	Non-uniformity of the colour
	Light horizontal band
	Iridescence
	Dry and dark edges
	Marbling
Evaluation of the fat portion	Yellow/Grey colour intensity
	Pinkish colour
	Oiliness
Texture	Texture of the ham
	Stickiness (of the lean portion)
	Soft fat

Table 2
Values (mean ± SD) of the physico-chemical parameters and colour attributes. Results are reported based on the weight class (1 and 2).

Parameter	Weight class 1	Weight class 2
	(n = 49)	(n = 71)
Maturation (weeks)	21.92 ± 1.88	22.66 ± 1.98
Weight loss (%)	40.61 ± 1.93	38.37 ± 2.37
Weight ham (Kg)	3.96 ± 0.24	4.69 ± 0.29
Water activity (a_w)	0.91 ± 0.01	0.92 ± 0.01
pH	5.85 ± 0.09	5.87 ± 0.08
Moisture (g/100 g)	41.85 ± 2.95	42.37 ± 3.63
Chlorides (g/100 g)	4.81 ± 0.73	4.26 ± 0.79
Chlorides/Moisture	0.12 ± 0.02	0.10 ± 0.02
Fat (g/100 g)	21.89 ± 4.79	23.04 ± 4.99
Proteins (g/100 g)	29.88 ± 2.30	28.29 ± 2.05
Fat/Proteins	0.75 ± 0.22	0.83 ± 0.23
Moisture/Proteins	1.41 ± 0.11	1.50 ± 0.14
L*	40.87 ± 3.09	39.92 ± 2.85
a*	8.40 ± 1.19	8.69 ± 1.10
b*	8.59 ± 1.04	8.49 ± 1.18
Chroma	12.14 ± 1.24	12.25 ± 1.25
Hue	45.67 ± 4.58	44.30 ± 4.79
a*/b*	1.02 ± 0.16	1.06 ± 0.18

IBM Statistics software (Version 27, Chicago, IL) and Microsoft Excel (Microsoft Office 2016, Redmond, WA).

Concerning the dataset of 120 samples, correlations between instrumental data and sensory scores were evaluated based on the Pearson's correlation coefficients (r), corresponding significant levels ($p < 0.01$), and on coefficients of determination (r^2). An analysis of variance (One-Way ANOVA) with Tukey HSD post-hoc test for pairwise comparisons was performed to assess which sensory parameters allowed to discriminate between eligible, ineligible, and uncertain samples. For each variable under examination, the non-parametric Kruskal-Wallis test with Dunn-Bonferroni for pairwise comparisons was applied whenever the assumptions of normal distribution (verified through the Shapiro-Wilk test) and equality of variances (verified through the Levene's test) required to apply parametric tests were not assessed. An Independent-Samples Mann-Whitney *U* Test was performed to evaluate statistical differences ($p < 0.05$) between weight classes.

A One-Way ANOVA was performed to evaluate the effect of three different temperatures (10, 15, and 20 °C) on the hardness measurements with the portable device.

3. Results and discussion

3.1. Physico-chemical properties and colour of 120 speck samples

Samples were characterized for colour and physico-chemical properties.

Physico-chemical properties including pH, salt concentration, and water content affect the enzymatic activity during maturation and, in turn, the texture, flavour, and organoleptic characteristic of the product (Čandek-Potokar & Škrlep, 2012; Virgili & Schivazappa, 2002). Colour is of great relevance for the acceptability of dry-cured ham by consumers (Cilla et al., 2005; García-Esteban, Ansorena, Gimeno, & Astiasarán, 2003). Together with texture it represents a key factor for the sensory quality of smoked ham (Kostyra, Wasiak-Zys, Rambuszek, & Waszkiewicz-Robak, 2016).

A summary of the values of the physico-chemical parameters and colour attributes measured is reported in Table 2.

Values of maturation and weight loss always met the minimum requirements recommended in the product specifications. Long maturation time was found to positively correlate with aromatic, texture, and taste characteristics of dry-cured hams (Benedini et al., 2012; Cilla et al., 2005; Ruiz et al., 1998). The mean weight loss exceeds the required 35% minimum in all samples. Values of the chloride content, expressed as sodium chloride, of moisture-proteins, and fat-proteins ratios meet the minimum requirements indicated in the specifications, albeit with high variability. Speck samples belonging to the weight class 2 showed higher values of water activity compared to those of weight class 1. The values of the three coordinates L*, a*, b*, of the derivate parameters Chroma, Hue, and a* to b* ratio were reported (Table 2). The instrumental data concerning the colour parameters did not show relevant differences ($p <$ 0.05) between the two weight classes.

3.2. Instrumental texture of 120 speck samples

As mentioned above, texture is together with colour the main parameter affecting the sensory acceptability of smoked ham (Kostyra et al., 2016). Previous studies demonstrated a good agreement between sensory evaluation of texture by trained assessors and instrumental measures, indicating the possibility to reliably characterize dry-cured hams through instrumental devices (Laureati et al., 2014). In the present work, two instrumental procedures for the measurement of the texture were performed, and data were compared with sensory scores assigned to texture attributes.

Texture profile analysis is frequently used for the measurement of textural properties of cured ham (Andronikov, Gašperlin, Polak, & Žlender, 2013; Benedini et al., 2012; Marjeta Čandek-Potokar et al., 2020; *L.* Guerrero, Gou, & Arnau, 1999; Harkouss et al., 2015; Morales, Guerrero, et al., 2007; Morales, Serra, et al., 2007; Ruiz-Ramírez, Arnau, Serra, & Gou, 2005; Serra et al., 2005). Stress relaxation, commonly used for the evaluation of texture in food, was previously reported also for cured ham applications (Benedini et al., 2012; Costa-Corredor, Serra, Arnau, & Gou, 2009; Morales, Arnau, Serra, Guerrero, & Gou, 2008; Morales, Guerrero, et al., 2007; Morales, Serra, et al., 2007). Beside these two broadly utilized tests, non-destructive techniques were reported to assess the texture of dry-cured ham in the literature (Pérez-Santaescolástica et al., 2019), including ultrasounds (Contreras et al., 2020), visible and near infrared spectroscopy (García-Rey, García-Olmo, De Pedro, Quiles-Zafra, & Luque De Castro, 2005), which were used to evaluate/predict the pastiness of dry-cured ham, and multi energy X-ray sensors, the feasibility of which was assessed for the detection of changes in dry-cured ham slices after proteolysis (Fulladosa et al., 2018).

Table 3
Values (mean ± SD) of the hardness measured with the portable device (Shore A) and of the texture parameters measured parallel to the muscle fibres through the Texture Profile Analysis (TPA) and the Stress-Relaxation analysis (SR). Results are reported dividing the dataset based on the weight class (1 and 2).

Parameter	Weight class 1	Weight class 2
	(*n* = 49)	(n = 71)
TPA – Hardness [N]	21.1 ± 6.17	15.07 ± 5.34
TPA – Adhesiveness [mJ]	1.48 ± 0.27	1.45 ± 0.32
TPA – Springiness [mm]	0.73 ± 0.04	0.72 ± 0.04
TPA – Cohesiveness	0.51 ± 0.03	0.50 ± 0.04
SR – Maximum compression force [N]	11.21 ± 3.61	7.52 ± 3.27
SR – Decay after 2 s [N]	7.22 ± 2.36	4.81 ± 2.25
SR – Decay after 10 s [N]	5.66 ± 1.89	3.74 ± 1.81
SR – Decay after 90 s [N]	3.76 ± 1.36	2.43 ± 1.27
Hardness [Shore A]	54.47 ± 8.16	44.79 ± 10.13

Table 4
Pearson's correlation coefficients (r) and significant levels (** = $p < 0.01$; ns = not significant) resulting from the comparison of the hardness expressed in a Shore A scale measured with the portable instrument and instrumental results of the Texture Profile Analysis (TPA) and Stress-Relaxation (SR), measured on the 120 speck samples parallel to the muscle fibres.

	Hardness [Shore A]
Parameter	**r**
Hardness [N][a]	0.855**
Adhesiveness [mJ][a]	ns
Springiness [mm][a]	ns
Cohesiveness[a]	0.455**
Maximum compression force [N][b]	0.891**
Decay 2s[b]	0.895**
Decay 10s[b]	0.897**
Decay 90s[b]	0.893**

[a]TPA test; [b]SR test.

Because of their extensively documented use for measuring the textural properties of dry-cured ham, including hardness, in this study TPA and SR were taken as a reference for comparison with the results of Shore A hardness obtained with the portable Shore A tester. Though the compression was applied both perpendicular and parallel to the direction of the muscle fibres, only results of the TPA and SR tests performed parallel to the fibres are reported, together with the data acquired with the portable device (Table 3).

The results of TPA test showed that samples belonging to weight class 1 had statistically higher ($p < 0.05$) hardness, maximum compression force, and decay of force values compared to those of weight class 2. In agreement with the TPA test, samples belonging to weight class 1 have on average statistically higher ($p < 0.05$) hardness measured with the portable device compared to those belonging to weight class two.

Potential correlations between values of hardness measured with the portable instrument and all parameters acquired with the texture

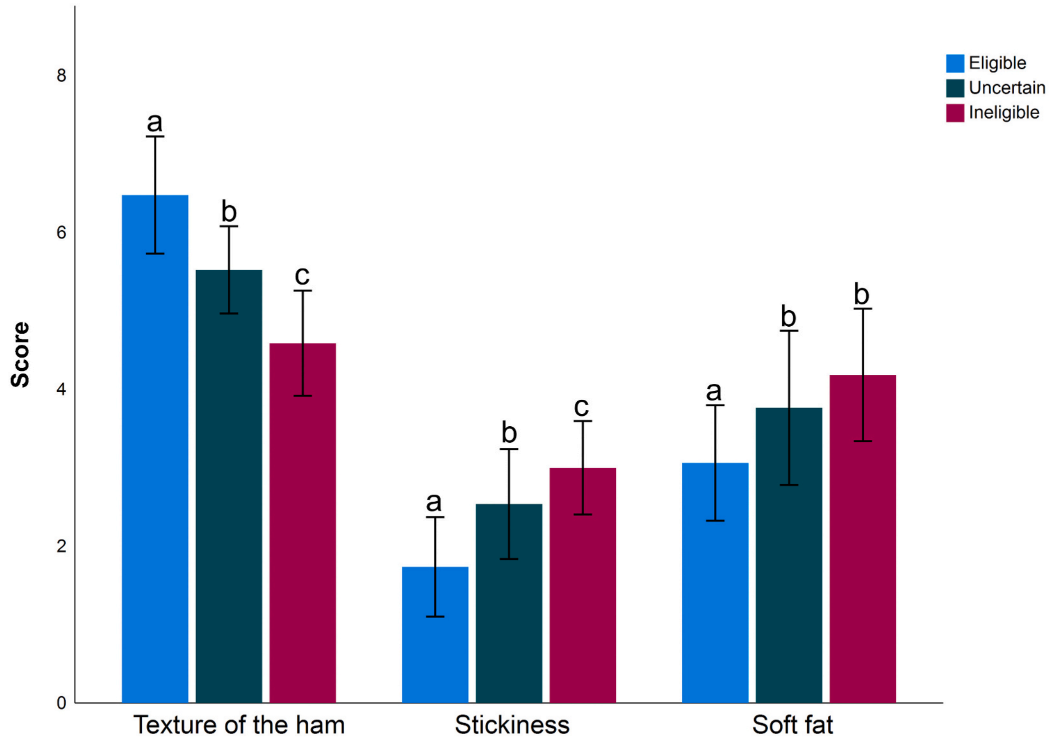


Fig. 1. Scores (mean ± SD) of the sensory descriptors (0–9 scale) of texture assigned to speck samples divided in three groups (eligible, uncertain, ineligible for the "Speck Alto Adige" PGI trademark) defined by the CA. Statistical differences ($p < 0.05$) between groups resulting from pairwise comparisons are displayed using different letters.

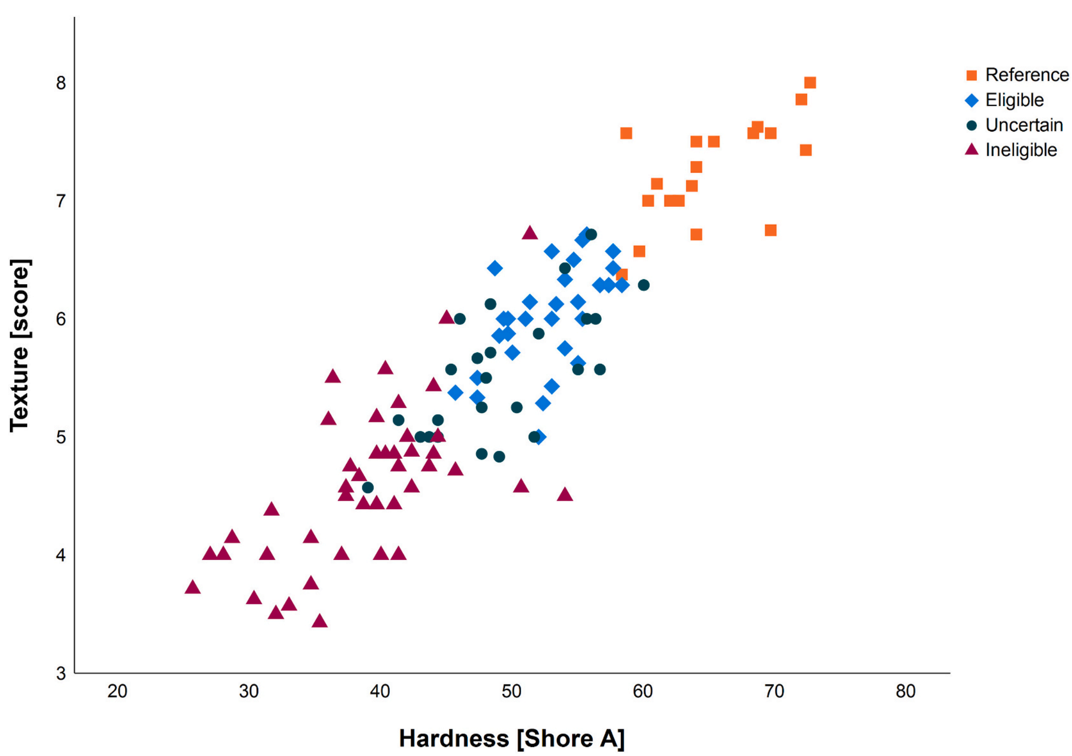


Fig. 2. Linear regression between the instrumental Shore A hardness and the sensory score (0–9 scale) of "Texture of the ham" assessed by the panel ($r^2 = 0.82$). The different colours and symbols differentiate speck samples according to the CA's suitability judgement for the "Speck Alto Adige" PGI trademark: eligible (blue), uncertain (green), and ineligible (purple). Reference samples are marked in orange and were all assessed as eligible. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

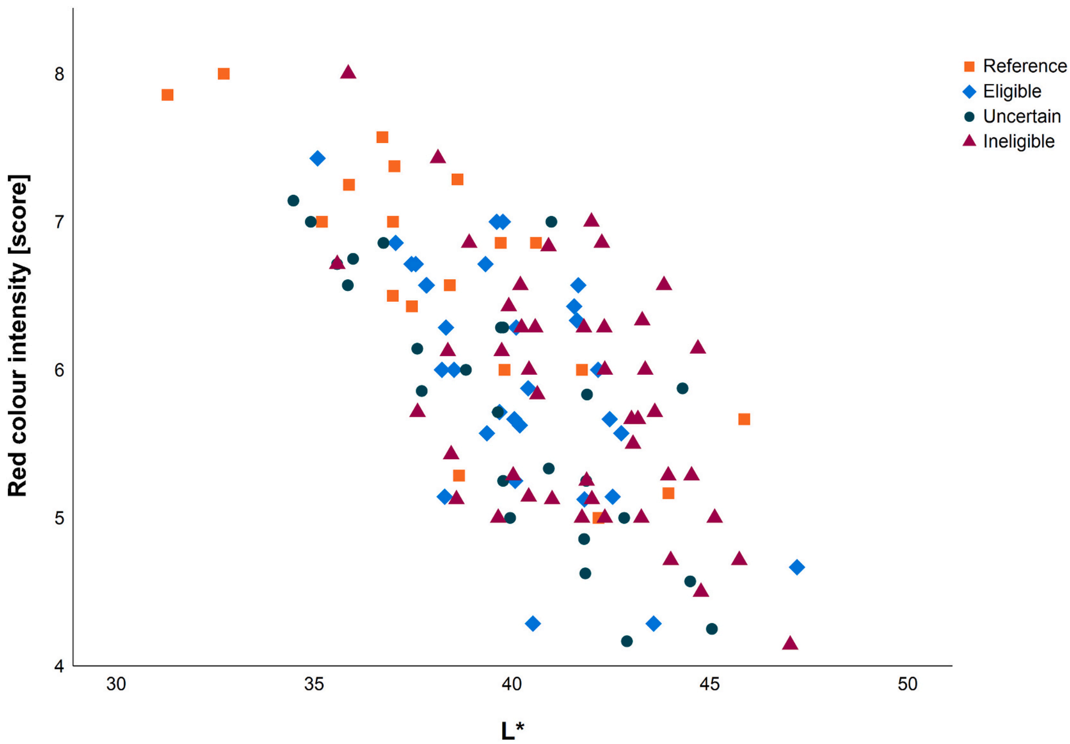


Fig. 3. Linear regression between the colorimetric coordinate L* and the sensory score (0–9 scale) of "Red colour intensity" assessed by the panel ($r^2 = 0.47$). The different colours and symbols differentiate speck samples according to the CA's suitability judgement for the "Speck Alto Adige" PGI trademark: eligible (blue), uncertain (green), and ineligible (purple). Reference samples are marked in orange and were all assessed as eligible. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

machine parallel to the muscle fibres were investigated, and Person's correlation coefficients (r), with corresponding significant levels, were obtained (Table 4).

As expected, hardness measured with the texture machine and with the portable device (both applied parallel to the fibres) exhibited a good correlation ($r = 0.855$), indicating that the two measurement systems provide similar results. Values of hardness measured with the portable instrument better correlated with the results of the SR test, with regard to maximum compression force, decay after 2 s, 10 s, and 90 s. Is should be noted that Shore A hardness values were taken after 15 s of loading force, this timepoint was determined through preliminary tests and considered compatible with processing operation time.

Since TPA and SR tests require the use of non-portable machinery, as well as the need for staff specialized in their use, the good correlation between measurements performed with the Texture Machine and those obtained with the portable Shore A tester represent an intriguing result and an innovation concerning texture assessment of cured ham.

3.3. Sensory evaluation of 120 speck samples

Speck hams were evaluated by the CA, who judged their quality and grouped them as follows, based on the suitability of their characteristics for the "Speck Alto Adige" PGI indication: i) eligible ($n = 50$), ii) uncertain ($n = 25$), and iii) ineligible ($n = 45$) samples.

The sensory evaluation of Speck samples was performed by trained assessors. Besides providing a detailed sensory description of the samples under examination, the aim of this evaluation was to determine which sensory parameters mainly accounted for the eligibility of samples to the production of "Speck Alto Adige" PGI.

Results of the statistical analyses revealed that the sensory parameters that mostly affected the differentiation between groups were those related to the texture, while colour attributes did not allow to distinguish samples belonging to the three abovementioned groups.

The most significant differences among groups were found concerning the sensory attributes texture of the piece, stickiness of the lean portion, and soft fat, that showed higher scores of the texture for eligible samples compared to ineligible and uncertain ones, and lower scores of stickiness of the lean portion and soft fat for eligible samples compared to ineligible and uncertain ones (Fig. 1). Though significant differences among groups ($p < 0.05$) were found concerning some other sensory parameters regarding the visual aspect, the pairwise comparisons revealed that these parameters did not allow to distinguish between eligible and ineligible or uncertain samples (data not shown).

3.4. Correlation between instrumental data and sensory attributes

The results shown so far already highlighted a correlation between texture parameters measured with the texture machine and those detected with the portable one.

In this section, the correlation between instrumental data obtained with the portable device and the score of the sensory descriptor "Texture of the ham" assigned by the panelists was investigated. The determination coefficient found of 0.82 confirms the relationship between instrumental hardness and sensory perception of the texture, as previously suggested using a Texture Analyzer (Laureati et al., 2014).

Fig. 2 shows the linear regression between the instrumental Shore A hardness and the sensory score of the texture of the ham, using different colours for samples according to the suitability judgement assessed by the CA. Samples with lower hardness, also judged by the sensory panel as softer, were considered ineligible by the CA. On the contrary, samples with higher instrumental hardness and scores of the sensory attribute of texture fell into the group of eligible ones. The group of uncertain samples showed intermediate textural characteristics. Finally, the reference samples were distributed at higher hardness, confirming the importance of the texture for the suitability to produce Speck IGP pieces.

A lower correlation than that observed between hardness and the

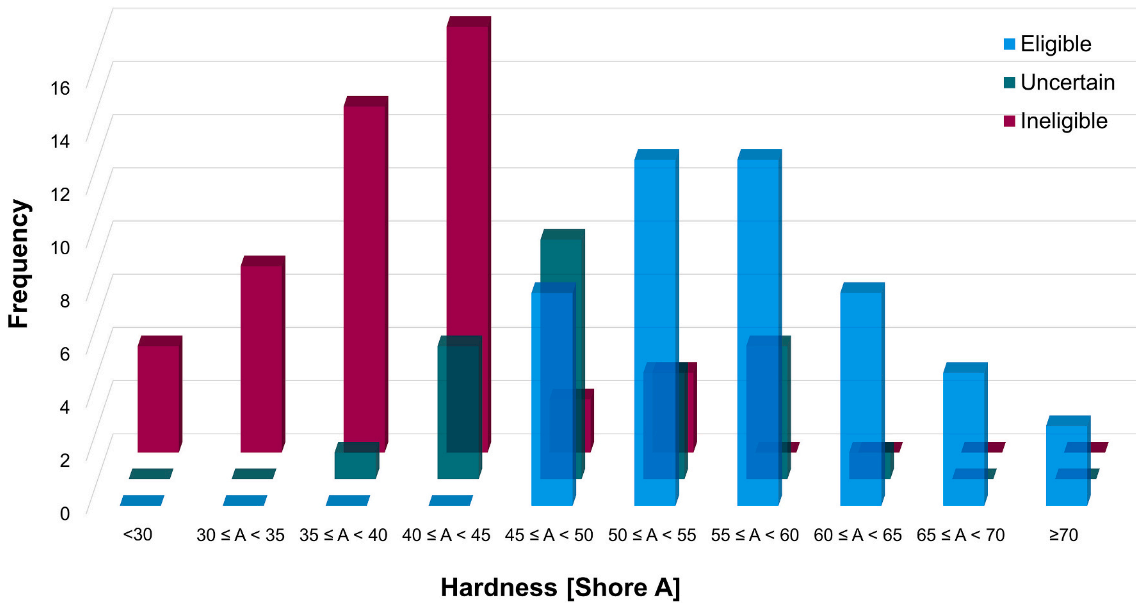


Fig. 4. Frequency distribution of the Speck samples in the 5-units interval classes of instrumental Shore A hardness defined. Samples are grouped according to the CA's suitability judgement for the "Speck Alto Adige" PGI trademark as eligible, uncertain, and ineligible.

Table 5
Mean scores (0–9 scale) of "Texture of the ham" assigned by the sensory panel to eligible, uncertain, and ineligible Speck samples. Results are shown in relationship to corresponding hardness values, divided in 5-unit intervals. The shaded area delimits the hardness range within which there is an overlap between the three groups.

Hardness [Shore A]	Eligible	Uncertain	Ineligible
Nr. Samples	*50*	*25*	*45*
<30			3.96
30 ≤ A < 35			3.81
35 ≤ A < 40		4.57	4.44
40 ≤ A < 45		5.06	4.81
45 ≤ A < 50	**5.75**	**5.50**	**5.36**
50 ≤ A < 55	**5.87**	**5.64**	**5.26**
55 ≤ A < 60	6.42	5.97	
60 ≤ A < 65	7.04	6.29	
65 ≤ A < 70	7.57		
≥70	7.52		

sensory attribute texture of the ham was found concerning instrumental colorimetric parameters (L^*, a^*, b^*, Hue, and a^*/b^*) and colour sensory descriptors of the lean portion reported in Table 1 (data not shown), with the highest coefficient of determination of 0.47 between L^* and the sensory score for "Red colour intensity" (Fig. 3).

The greater dispersion of the instrumental data and sensory evaluations regarding the colorimetric characteristics of the samples under investigation compared to the texture evaluations, makes the colour parameters (detected in the conditions used for the present experimentation) inappropriate for predicting the suitability of a sample for the production of pieces for sale under the "Speck Alto Adige" PGI trademark.

3.5. Threshold range of Shore A hardness for speck pieces suitable for sale under the "Speck Alto Adige" PGI trademark

A threshold range of hardness measured with the portable instrument for the suitability of Speck samples to produce pieces for sale under the PGI trademark was established.

Based on the measured hardness values, 5-unit interval classes of Shore A hardness values ranging from <30 to ≥70 were defined, and the frequency distribution of eligible, ineligible, uncertain and reference samples in each class was calculated and displayed in Fig. 4.

Samples judged as eligible had a minimum hardness value of 46 with a mean value of 57, while speck judged as ineligible for the Alto Adige PGI trademark had values not exceeding 54 in all cases, with a mean value of 39 and a minimum of 26. Concerning uncertain samples, a mean value of 49 and a minimum of 39 were observed. An overlap of eligible, ineligible, and uncertain samples in the hardness range between 45 and 55 was observed (Fig. 4).

Cross matching the instrumental and sensory data, it resulted that hardness values ranging from 45 to 55 corresponded to very similar judgements of "Texture of the ham" between the groups (Table 5). In this range, the assigned score of texture of the piece is more than halfway on a descriptor intensity scale from 0 to 9. Below this range (Shore A < 45), samples also received lower scores by the sensory panel

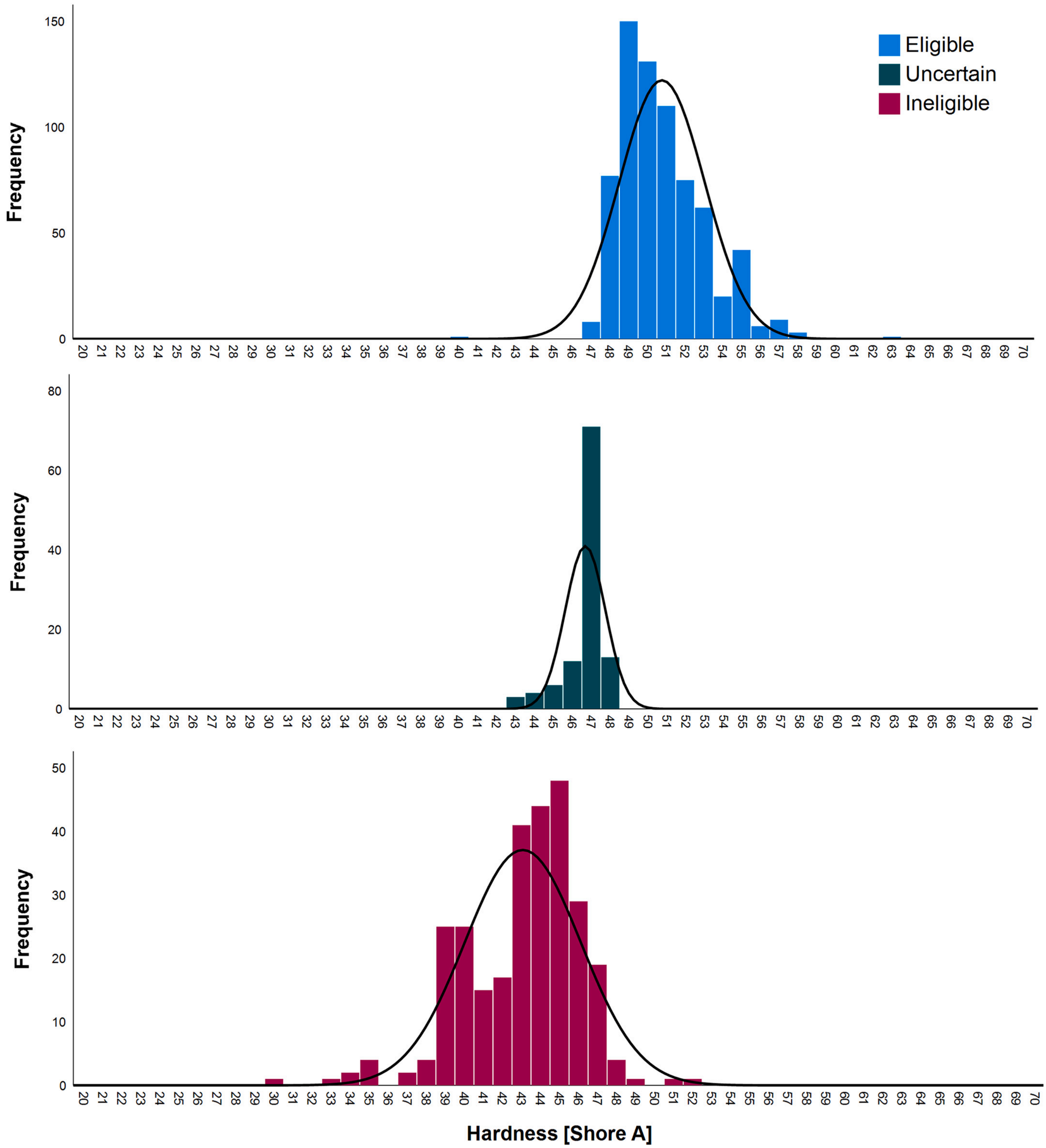


Fig. 5. Frequency distribution of hardness expressed in a Shore A scale for the samples ($n = 1088$), grouped according to the CA suitability judgement for the "Speck Alto Adige" PGI trademark as (A) eligible ($n = 695$), (B) uncertain ($n = 109$), and (C) ineligible ($n = 284$).

and were judged as ineligible or uncertain.

Taking into account the frequency distribution of samples based on their hardness (Fig. 4), the sensory scores assigned by the panel (Table 5), and the suitability judgement of the CA, it can be assumed that a threshold value for the discrimination of unsuitable and suitable samples for "Speck Alto Adige" PGI indication should be within the range of hardness between 45 and 55. All suitable and reference samples exhibited a hardness value higher than 45, nevertheless more data were needed in order to provide a precise threshold value rather than a range. For this reason, the spectrum of data was widened, only regarding Shore A hardness analysis and the related audit opinion, and more than 1000 samples were evaluated for hardness values in reference to suitable, unsuitable and uncertain samples.

As the further measurements on the dataset of more than 1000 samples were carried out directly in the factory, the effect of possible temperature fluctuations at the time of the evaluations was assessed by measuring hardness at three temperatures (10 °C – 15 °C – 20 °C) on 12 speck samples. Data indicated that temperature did not affect the hardness measurements with the portable device, resulting in a not statistically significant difference ($p < 0.05$) between the measurements taken at 10, 15 and 20 °C.

3.6. Identification of a threshold hardness value based on the distribution of 1088 speck samples

The distribution of hardness values into the wider dataset gave slightly different results regarding the proportion of samples whose hardness values overlapped, but they agree with the previous 120 samples for the overlapping range of Shore A hardness between 45 and 55.

The overall mean value of the entire dataset was 48.35 ± 4.14, with a minimum hardness value of 30.00 and a maximum of 63.00. The mean Shore A hardness values for the samples classified as eligible, uncertain, and ineligible were 50.77 ± 2.27, 46.68 ± 1.06, and 43.07 ± 3.06, respectively.

Based on the frequency distribution of samples divided into eligible, uncertain, and ineligible (Fig. 5), it was observed that those judged as eligible had hardness values ≥45, while speck samples judged as ineligible have most of the values <45.

Within the range between 45 and 55 (Shore A), each value was examined as a potential threshold. The value of 48 was found to be the most effective threshold in discriminating eligible from ineligible samples: 98.7% of eligible samples had a hardness value ≥48, whereas 97.5% of ineligible and 88% of uncertain samples were below 48. Therefore, the value of 48 was proposed as acceptability threshold.

4. Conclusions

In the present study, physico-chemical properties, colorimetric parameters, sensory attributes, and texture characteristics of Speck samples for sale as "Speck Alto Adige" PGI pieces were determined. All samples were officially evaluated by a CA, who assessed their eligibility to produce pieces for sale under the "Speck Alto Adige" PGI trademark.

The first experimental part aimed at establishing whether texture measurements performed with a portable Shore hardness tester were comparable to those obtained with a standard instrumental analysis and with sensory evaluations. For this purpose, 120 samples were investigated, and a good agreement between instrumental data obtained with the standard procedure with those acquired with the portable device was found. A high correlation between hardness values measured with the portable device and sensory scores concerning the texture of the ham was observed.

Cross-referencing this result with the evaluation by the CA, it was confirmed that textural qualities of Speck highly affected the judgement of eligibility of samples for "Speck Alto Adige" PGI indication, suggesting that a simple, on-line, and reliable instrumental method to assess the texture of Speck could be helpful for manufacturers.

An overlap of eligible, uncertain, and ineligible samples was found at a Shore A hardness range between 45 and 55, suggesting that a threshold value for discriminating between eligible and ineligible samples should be found within this range.

A more specific threshold was derived after considering a dataset of 1088 samples: a value of Shore A hardness of 48 enabled to confirm the acceptability of samples judged as eligible by the CAs in 98.7% of cases, while ineligible and uncertain samples were correctly identified in 97.5% and 88.1% of the cases, respectively.

The portable Shore A tester used in the present study proved to be functional for this scope and could be directly used by producers under plant conditions.

CRediT authorship contribution statement

Flavia Bianchi: Investigation, Data curation, Visualization, Software, Writing – original draft. **Gerhard Gamper:** Formal analysis, Investigation, Data curation, Writing – review & editing. **Lidia Lozano:** Formal analysis, Investigation, Data curation, Writing – review & editing. **Nicoletta Simoncini:** Formal analysis, Investigation, Data curation, Writing – review & editing. **Roberta Virgili:** Formal analysis, Investigation, Data curation, Writing – review & editing. **Lukas Spada:** Formal analysis, Investigation, Writing – review & editing. **Elena Venir:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

none.

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