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ADVANCES IN FOOD AND NUTRITION RESEARCH

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CHAPTER SIX

Advances in Sheep and Goat Meat Products Research

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Contents

Abstract

The main goal of this chapter was to review the state of the art in the recent advances in sheep and goat meat products research. Research and innovation have been playing an important role in sheep and goat meat production and meat processing as well as food safety. Special emphasis will be placed on the imaging and spectroscopic methods for predicting body composition, carcass and meat quality. The physicochemical and sensory quality as well as food safety will be referenced to the new sheep and goat meat products. Finally, the future trends in sheep and goat meat products research will be pointed out.

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1. INTRODUCTION

The world population is expected to reach 8.6 billion in 2030 and 9.8 billion in 2050 (UN, 2017) and according to a recent report of the Food and Agriculture Organization of the United Nations (FAO) (2011) the meat consumption is projected to increase almost 73%. Trends in production and consumption levels per person, as well as patterns of consumption, are expected to grow substantially and particularly sheep and goat meat will be driven in developing countries where the protein supply is today above the minimum recommended level. Sheep and goat meat products have been growing interest and gaining popularity for several reasons and especially for their nutritional properties, traditional quality and physicochemical composition and sensory attributes. Sheep and goat meat are unique in flavor and palatability and particularly goat meat is leaner than other red meats and today has been preferred for meats with less fat. Furthermore, the consumption of sheep and goat meat is normally linked to certain ethnic groups and associated to some religious festivities. Some countries around the world with great tradition of sheep and goat meat consumption have the habit of eating some processed products of these meats as sheep and goat "mantas" (Oliveira et al., 2014; Teixeira, Pereira, & Rodrigues, 2011), the Spanish *cecina de castron* (Hierro, de la Hoza, Juan, & Ordóñez, 2004), the Italian *violoin di capra* (Fratianni, Sada, Orlando, & Nazzaro, 2008) or the Brazilian *charque* and *manta* (Madruga & Bressan, 2011). In southern Europe, particularly in Mediterranean countries, the meat consumption from younger animals as lamb and kid is very usual and appreciated and some of them are commercialized as quality brands with protected origin designation (PDO) or protected geographical indication (PGI).

In this context, there is no doubt that research and innovation will play a key role in advances in sheep and goat production, carcass evaluation and classification, in the control of processes and in the quality (physicochemical and sensory) of meat and meat products, as well as in the creation of new products and food safety. Recently some studies on the usage of sheep and goat meats to produce sausages, patties, pâtês have been reported (Leite et al., 2015; Teixeira, Fernandes, Pereira, Manuel, & Rodrigues, 2017). In terms of sheep and goat meat production systems, slaughter procedures, carcass evaluation and classification and body composition or meat quality, several new methodologies have recently been used like the use of ultrasounds (Silva, 2017; Teixeira, Joy, & Delfa, 2008), spectrophotometer methods (Prieto, Pawluczyk, Dugan, & Aalhus, 2017), hyperspectral imaging (Xu & Sun, 2017), the use of computed tomography (Bünger et al., 2011) or the use of computer vision (Ma et al., 2016). This chapter reviews the recent advances in sheep and goat meat products research. Special emphasis will be placed to the imaging and spectroscopic methods for predicting carcass and meat quality. The physicochemical and sensory quality as well as food safety will be referenced to the new sheep and goat meat products. Finally, the future trends in sheep and goat meat products research will be pointed out.

2. IMAGING AND SPECTROSCOPIC METHODS FOR PREDICTING MEAT QUALITY

In recent years, there have been important developments in non-invasive and non-destructive spectroscopic and image techniques to obtain objective data on carcass and meat quality of meat species. The following sections will present the most important advances of the use of these techniques in sheep and goat species.

2.1 Use of Real-Time Ultrasonography

The real-time ultrasonography (RTU) has become the most widespread technique for carcass composition and meat quality assessment on sheep and goat (Silva, 2017; Teixeira, 2008). For over 40 years, broad work has been carried out to obtain RTU information both in vivo or post-mortem about sheep and goat carcass traits to be used in breeding programs to improve carcass quality and also as a tool to monitoring carcass composition and meat quality of those two species (Hopkins, Stanley, & Ponnampalam, 2007; Leeds et al., 2008; Teixeira et al., 2008; Teixeira, Matos, Rodrigues, Delfa, & Cadavez, 2006). This section presents an overview of the RTU use for assessing carcass composition and meat quality in sheep and goat.

Along the years, the RTU technique has evolved continuously in both the equipment and the capability of image analysis and the ability to use and manage the generated information as a result of improvements in computer and ultrasound processing and image analysis capability (Whitsett, 2009). Furthermore, the ability for on-line image analysis and the decrease of equipment expenses (Li, 2010; Szabo, 2004) led to the extensive use of RTU in selection programs of carcass and meat traits for sheep and goat (Huisman, Brown, & Fogarty, 2016; McGregor, 2017; Tait, 2016).

The use of RTU needs accurate and precise ultrasound measurements. Usually, the studies conducted to evaluate the RTU in sheep and goat are orientated to two objectives. The first is the study of the correlation between RTU and the corresponding carcass measurements. The second is the use of RTU to predict carcass composition or meat quality traits. The next points will discuss both objectives.

The correlation between RTU and carcass measurements has been typically used as an indicator of accuracy in sheep and goat studies (Notter et al., 2014; Teixeira et al., 2008). Challenges are expected in comparing different works because of the diversity in the materials and methods. There are several factors which influence results (Silva, 2017). In this way, Table 1 includes information about species, breed, number of animals, equipment, frequency probe and reference point to help in the interpretation of the correlation values. In general, the works are focused on the 12–13th thoracic vertebrae and between the third and fourth lumbar vertebrae reference points to capture RTU images to do the measurements. The option for those anatomical points is supported in three major reasons: First, the thoracolumbar region is very easy to identify in a standing animal; second, this region has a simple anatomical feature, with a long muscle (*Longissimus thoracis* et *lumborum muscle*—LM) and the vertebrae apophyses, which help in a precise location of the reference points; third, and related to the other two reasons, the RTU images are straightforward interpretation which allows a high repeatability of the measurements (Glasbey, Abdalla, & Simm, 1996; Simm, 1987).

The correlations between RTU and the equivalent measurement in the carcass show significant values. Considering all correlations in Table 1, only 10 out of 81 are not significant ($P > 0.05$). The correlations observed for muscle measurements show a high variation, but in general, the LMA and LMD are more accurate than LMW. For LMA and LMD 15 out of 40 correlation coefficients are superior to 0.6, whereas for LMW that ratio is 8 out of 10. Also, the LMA and the LMD for goat and sheep show similar accuracy. The correlation variation observed for the LM measurements has different causes. For example, inadequate identification of the LM borders during RTU image analysis can influence the accuracy (Silva et al., 2006). The problem in distinguishing vertical interfaces such as the edges of the LM was also shown as a cause for the low correlation found with the LMW (McEwan, Clarke, Knowler, & Wheeler, 1989). As a consequence Hopkins et al. (1993) considered the LMW of little value as a trait to use sheep breeding programs.

Table 1 Correlations Between In Vivo Ultrasound Measurements and Corresponding Carcass Measurements in Sheep and Goat

						Muscle Measurements						
Specie	**Breed**	***n***	**Equipment**	**MHz**	**Reference Point**	**LMA**	**LMD**	**LMW**	**SF**	**GR**	**ST**	**Reference**
Sheep	Barki	15	PieMedical100	8	12/13TV	0.06^{ns};0.83	−0.18^{ns};0.67	0.21^{ns};0.42	0.34;0.62			Agamy, Moneim, Alla, Mageed, and Ashmawi (2015)
	Aragonesa	14	Toshiba SAL-32B	5	3/4VL			0.22^{ns}	0.73;0.87			Delfa, Teixeira, Blasco, and Rocher-Colomber (1991)
	Suffolk	163	Aloka 500	3.5	12/13TV;WT	0.66			0.78	0.73		Emenheiser, Greiner, Lewis, and Notter (2010)
	Mixed breeds	124	Vet 180 Plus	5	12/13TV;1/2LV	0.72;0.78	0.61*;0.88	0.69;0.70	0.32;0.60			Esquivelzeta, Casellas, Fina, and Piedra (2012)
	3 genotypes	60	Toshiba SAL-32B	5	12/13TV	0.88	0.56		0.74			Fernández, Gallego, and Quintanilla (1997)
	Manchego	10	Toshiba SAL-32B	5	12/13TV;3/4LV		0.13^{ns};0.76	0.40^{ns};0.83	−0.06^{ns};0.92			Fernández, Garcia, Vergara, and Gallego (1998)
	6 genotypes	36	Mindray DP-6900	5	12/13TV		0.76		0.82			Grill, Ringdorfer, Baumung, and Fuerst-waltl (2015)
	Rambouillet × Finn	30	Technicare 210		12/13TV	0.80						Hamby, Stouffer, and Smith (1986)

Continued

Table 1 Correlations Between In Vivo Ultrasound Measurements and Corresponding Carcass Measurements in Sheep and Goat—cont'd

						Muscle Measurements						
Specie	**Breed**	***n***	**Equipment**	**MHz**	**Reference Point**	**LMA**	**LMD**	**LMW**	**SF**	**GR**	**ST**	**Reference**
	5 genotypes	147	Honda HS-1201	5	12/13TV		0.55		0.67			Hopkins et al. (2007)
		58	Aloka 500	3.5	12TV;GR	0.42	0.36	-0.15^{ns}	0.17^{ns}	0.60		Hopkins, Pirlot, Roberts, and Beattie (1993)
	F1 wether lambs	168	Aloka 500	3.5	12/13TV	0.75	0.71		0.81			Leeds et al. (2008)
	Omani	19	Microimager	7.5	6TV;12TV;2LV		0.27*;0.48					Mahgoub (1998)
	Mixed breeds	512	Aloka 500	3.5	12/13TV	0.65			0.69			Notter et al. (2014)
	Awassi	13	Dynamic	7.5	12/13TV	0.87;0.89	0.58*;0.60	-0.17^{ns};0.48	0.79;0.82			Orman et al. (2008)
	Awassi	30	Dynamic	7.5	12/13TV	0.88	0.77	0.58	0.93			Orman, Caliskan, and Dikmen (2010)
		99;147	Toshiba SAL-22A	5	GR;BWT					0.87		Ramsey, Kirton, Hogg, and Dobbie (1991)
	Tensina	114	Aloka 900	7	10/11TV;12/13TV 1/2LV;3/4LV		0.42*;0.59	0.16^{ns};0.37	0.70;0.74			Ripoll, Joy, and Sanz (2010)
	Akkaraman	40	PieMedical100	8	12/13TV	0.82	0.60		0.77			Sahin, Yardimci, Cetingul, Bayram, and Sengor (2008)
		15	Aloka 500	5	12/13TV	0.89			0.93			Stouffer (1991)
	Churra Bragançana	67	Aloka 500	5;7.5	12/13TV;3/4LV				0.31;0.42			Teixeira et al. (2006)

	2 genotypes	96	Ultrscan 50	3.5	12/13TV; GR;3/4LV		0.34*;0.42		0.78;0.82	0.83		Thériault, Pomar, and Castonguay (2009)
		162	Technicare 210		13TV	0.58			0.42;0.63			Turlington (1989)
	Torki	99	PieMedical100	8	12/13TV	0.80	0.77	0.54	0.70			Vardanjani, Ashtiani, Pakdel, and Moradi (2014)
		89	Dynamic	3.5	12TV	0.76	0.79					Ward, Purchas, and Abdullah (1992)
Goat	Boer	77	Aloka 500	5	12/13TV		0.51		-0.09^{ns}			Carr, Waldron, and Willinghan (2002)
	Spanish	40	Aloka 500	5	12/13TV	0.75	0.71	0.52	0.49			Mesta et al., 2016
	Alpine	25	Keikei CS-3000	3.5	12/13TV	0.47;0.64	0.23*;0.62					Stanford, Clark, and Jones (1995)
	Blanca Celtiberica	56	Toshiba SAL-32B	5	1/2LV		0.81		0.69		0.94	Teixeira et al. (2008)
	Blanca Celtiberica	56	Toshiba SAL-32B	5	3/4LV		0.84		0.70			Teixeira et al. (2008)
	Blanca Celtiberica	56	Toshiba SAL-32B	5	5/6LV		0.47		0.74			Teixeira et al. (2008)

Abbreviations: LW, live weight; LMA, longissimus thoracis et lumborum muscle area; LMD, longissimus thoracis et lumborum muscle depth; LMW, longissimus thoracis et lumborum muscle width; SF, subcutaneous fat depth; GR, total depth of soft tissues over the 12th rib 11 cm from the dorsal midline; ST, fat thickness measurement in sternum region; BWT, measurement of body wall thickness between the 12th and 13th ribs 12 cm from the dorsal midline; WT, body wall thickness between the 12th and 13th ribs including the lateral edge of the LM but not the spine; TV, thoracic vertebra; LV, lumbar vertebra. All correlation coefficients values are significant to $P<0.01$ unless noted otherwise; $^{*}P<0.05$; $^{ns}P>0.05$.

The correlation values for the SF show a considerable variation (r between −0.09, $P>0.05$ to 0.93, $P<0.01$). In spite of this substantial variation, the majority of the studies present values above 0.6. The GR and ST measurements show values of correlation that are comparable to the highest values reported for SF. The GR measurement is a well-known measurement included in the carcass grading systems (Hopkins, 1994; Jones, Robertson, Price, & Coupland, 1996; Kirton & Johnson, 1979). The GR can also be of attention for in vivo studies for selection decisions made in young lambs as this measurement shows a higher dimension than the SF measurement. The reduced depth observed with the SF measurement was reported by Hopkins et al. (1993) as an explanation of the low accuracy when compared with the GR ($r=0.17$; $P>0.05$ vs $r=0.60$; $P<0.01$, respectively). In goat, the reduced SF depth is also a problem since this species has less amount of that fat depot (Teixeira et al., 2008). One way to overcome this constraint is the use of a high-frequency probe (for example, 7.5 MHz). Higher frequency probes have a higher resolution at the surface (Silva et al., 2006). Currently, the RTU equipment works with multi-frequency probes which can be very helpful to set the probe with the SF depth. Conscious of this problem Ripoll et al. (2010) operated a high frequency (8–10 MHz) for SF measurements and a 7 MHz frequency for LMD.The prediction of body and carcass composition in meat species was reviewed in the past (Houghton & Turlington, 1992; Simm, 1987). However, little attention was directed to the goat and sheep species. Therefore, this section presents an overview of the prediction of body and carcass composition of goat and sheep using RTU measurements. The prediction models are typically obtained by multiple linear regression using RTU measurements along with live animal weight. The accuracy and the precision of the models are achieved by the using the coefficient of determination (R^2) which indicates accuracy and the residual mean square errors (RMSE), respectively, to assess the model fit (Hopkins, Ponnampalam, & Warner, 2008).

The coefficients of determination (R^2) and residual mean square errors (RMSE) values for the prediction of goat and sheep carcass or body fat, from multiple regressions with LW and RTU measurements, are presented in Table 2.

The LW was normally introduced in the body and carcass prediction models. Usually this variable is the most powerful predictor of carcass composition (Kempster et al., 1982; Silva et al., 2006). In general, the models using LW and RTU measurements accurately explain the variation of the fat components of goat and sheep (R^2 between 0.36 and 0.98). Most of

Table 2 Coefficients of Determination (R^2) and Residual Mean Square Errors (RSME) for the Prediction of Goat and Sheep Carcass or Body Fat, From Multiple Regressions With LW and RTU Measurements

Specie	*n*	Breed	LW	Device	MHz	Dependent Variable	Independent Variables		R^2	RSME	Reference
							LW	RTU			
Goat	10	Blanca Celtiberica	22	Toshiba SAL-32B	5	BF (g)	●	4	0.98	0.04	Delfa, Teixeira, González, Torrano, and Valderrábano (1999)
Sheep	31	2 genotypes		Aloka 500	7.5	ChemBF (g/kg)	●	2	0.83	19.4	Silva, Gomes, Dias-da-Silva, Gil, and Azevedo (2005)
Sheep	31	2 genotypes		Aloka 500	7.5	ChemBF (kg)	●	2	0.95	0.6	Silva et al. (2005)
Sheep	15	Romney		Aloka	3	ChemCF (%)	●	1	0.52	2.9	McEwan et al. (1989)
Sheep				Toshiba SAL-22A	5	ChemCF (%)	●	1	0.66	2.44	Ramsey et al. (1991)
Goat		Blanca Celtiberica	22	Toshiba SAL-32B	5	CF (g)	●	2	0.92	0.22	Delfa (2004)
Goat	38	BoerxWhite	25	Pie Medical 100LC	8	CF (kg)	●	4	0.92	0.21	Stanisz, Gut, and Ślósarz (2004)
Sheep				Aloka 900	7;10	CF	●	1	0.51		Ripoll, Joy, Alvarez-Rodriguez, Sanz, and Teixeira (2009)
Sheep	67	Churra Bragançana	36	Aloka 500	5;7.5	CF	●	1	0.88		Teixeira et al. (2006)
Sheep	147	5 genotypes		Honda HS-1201	5	CF (%)	●	1	0.48	2.85	Hopkins et al. (2007)
Sheep	147			Toshiba Sal-22A	5	CF (%)	●	1	0.66	2.4	Ramsey et al. (1991)

Continued

Table 2 Coefficients of Determination (R^2) and Residual Mean Square Errors (RSME) for the Prediction of Goat and Sheep Carcass or Body Fat, From Multiple Regressions With LW and RTU Measurements—cont'd

Specie	*n*	Breed	LW	Device	MHz	Dependent Variable	Independent Variables LW	RTU	R^2	RSME	Reference
Sheep	45	3 genotypes		Pie Medical Falco 100	8	CF (kg)	●		0.39		Agamy et al. (2015)
Sheep	14	Noire de Thibar		Falco Vet	3.5	CF (kg)	●	4	0.90	0.151	Hajji, Atti, and Hamouda (2015)
Sheep	40	Akkaraman	42	Pie Medical Falco 100	8	CF (kg)	●	1	0.84	0.24	Sahin et al. (2008)
Goat	20	Serrana		Aloka 500	7,5	CIF (g)	●	2	0.95	23.6	Cadavez, Rodrigues, and Teixeira (2007)
Sheep	114	Tensina	22	Aloka 900	7;10	CIF	●	2	0.84		Ripoll et al. (2010)
Sheep	67	Churra Bragançana	36	Aloka 500	5;7.5	CIF	●	1	0.84		Teixeira et al. (2006)
Sheep	67	Churra Bragançana	36	Aloka 500	5;7.5	CIF	●	1	0.85		Teixeira et al. (2006)
Sheep	46			Aloka 500		CIF (g/kg)	●	1	0.68	8.3	Silva et al. (2006)
Sheep	46			Aloka 500		CIF (kg)	●	1	0.92	0.3	Silva et al. (2006)
Goat	56	Blanca Celtiberica		Toshiba SAL-32B	5	CSF (g)	●	2	0.91	0.32	Teixeira et al. (2008)
Sheep	114	Tensina	22	Aloka 900	7;10	CSF (g)	●	2	0.75	214.9	Ripoll et al. (2010)

Sheep	254	Several breeds	39–47	Danscanner	2.2	CSF (g/kg)	●	1		28.6	Kempster, Arnall, Alliston, and Barker (1982)
Sheep	46			Aloka 500		CSF (g/kg)	●	2	0.89	8.0	Silva et al. (2006)
Sheep	67	Churra Bragançana	36	Aloka 500	5;7.5	KPF	●	1	0.66		Teixeira et al. (2006)
Goat	56	Blanca Celtiberica		Toshiba SAL-32B	5	OF (g)	●	2	0.91	686B207	Teixeira et al. (2008)
Goat	10	Blanca Celtiberica	22	Toshiba SAL-32B	5	CSF + Internal fat (g)		5	0.98	58	Delfa et al. (1999)

Abbreviations: LW, live weight; CF, carcass fat; CSF, carcass subcutaneous fat; CIF, carcass intermuscular fat; ChemCF, chemical carcass fat; ChemBF, chemical body fat; BF, body fat; KPF, kidney and pelvic fat; OF, omental fat; R^2, coefficient or determination; RSD, residual standard deviation.

the models include in addition to the LW one or two RTU measurements, and only one model contains only RTU measurements (Delfa et al., 1999). All studies show that RTU measurements allow accurate prediction of carcass fat tissues ($R^2 > 0.8$ in 13 out of 19 models) as well as chemical fat (R^2 from 0.52 to 0.95). In goats and sheep, a good prediction of internal fat depots was observed when using RTU (Delfa et al., 1999; Teixeira et al., 2008, 2006). These results are very relevant when monitoring the body fat reserves along the productive cycle of these species.

The coefficient of determination (R^2) and residual mean square errors (RSME) for the prediction models of the goat and sheep protein and muscle carcass from multiple regressions with LW and RTU measurements are presented in Table 3.

The results for protein and muscle are in line with those previously discussed for fat components. In general, a very good prediction ability of the models was observed with LW and RTU measurements explaining well the muscle and protein variations (R^2 between 0.32 and 0.97). It is not possible to discriminate between species regarding the accuracy and precision. In general, the higher R^2 values are related to the amount of protein ($R^2 = 0.97$) or muscle ($R^2 > 0.8$ in 11 out of 14 models), rather than for the percentage or proportion of protein and muscle (R^2 from 0.46 to 0.87).

As was previously discussed for fat prediction, the LW usually explains the most significant part of the variation of protein and muscle. For example, Teixeira et al. (2006) reported that LW accounted for 96% of the muscle weight variation, whereas for the amount of protein the LW explains 97% (Silva et al., 2005). One aspect to note is that despite the LW value, the RTU measurements are relevant to the model accuracy.

2.2 Use of Computed Tomography

Despite its complexity and cost, the computed tomography (CT) has been recognized useful in animal science since the beginning. However, only in the last 10 years CT have gained importance for the knowledge of body and carcass composition and meat quality, especially in pigs and sheep. (Bünger et al., 2011; Kongsro, 2014; Scholz, Bünger, Kongsro, Baulain, & Mitchell, 2015). Much of this knowledge increase with projects such as Farm Animal Imaging—FAIM (Bunger et al., 2015).

For sheep, as well for other meat species, the dissection of an animal into its components represents the most accurate method of measuring carcass composition. However, this method is invasive, destructive, time-consuming, and

Table 3 Coefficients of Determination (R^2) and Residual Mean Square Errors (RSME) for the Prediction of Goat and Sheep Protein and Muscle Carcass, From Multiple Regressions With LW and RTU Measurements

Specie	*n*	Breed	LW	Device	MHz	Dependent Variable	Independent Variables		R^2	RSME	Reference
							LW	RTU			
Sheep	99			Toshiba Sal-22A	5	Protein (%)	●	1	0.51	0.87	Ramsey et al. (1991)
Sheep	31	2 genotypes		Aloka 500	7.5	Protein (g/kg)	●	1	0.54	5.35	Silva et al. (2005)
Sheep	31	2 genotypes		Aloka 500	7.5	Protein (kg)	●		0.97	0.18	Silva et al. (2005)
Goat	20	Serrana		Aloka 500	7,5	Musculo (g)	●	2	0.97	129.8	Cadavez et al. (2007)
Goat	56	Blanca Celtiberica		Toshiba SAL-32B	5	Musculo (g)	●	2	0.90	533	Teixeira et al. (2008)
Goat	38	BoerxWhite	25	Pie Medical 100LC	8	Musculo (kg)	●	4	0.85	1.81	Stanisz et al. (2004)
Sheep	114	Tensina	22	Aloka 900	7;10	Muscle	●	1	0.96	154.2	Ripoll et al. (2010)
Sheep	147	5 genotypes		Honda HS-1201	5	Muscle (%)	●	1	0.46	2.71	Hopkins et al. (2007)
Sheep				Aloka 900	7;10	Muscle (g)	●	1	0.59	144.46	Ripoll et al. (2009)
Sheep	67	Churra Bragançana	36	Aloka 500	5;7.5	Muscle (g)	●	1	0.96	214.6	Teixeira et al. (2006)
Sheep	46			Aloka 500	7.5	Muscle (g/kg)	●	2	0.87	12.7	Silva et al. (2006)
Sheep	45	3 genotypes		100 LC, Pie Medical	8	Muscle (kg)	●	1	0.82		Agamy et al. (2015)
Sheep	14	Noire de Thibar		Falco Vet	3.5	Muscle (kg)	●	3	0.88	0.238	Hajji et al. (2015)
Sheep	147	5 genotypes		Honda HS-1201	5	Muscle (kg)	●	1	0.86	1.62	Hopkins et al. (2007)
Sheep	40	Akkaraman	42	Pie Medical 100LC	8	Muscle (kg)	●	1	0.80	0.63	Sahin et al. (2008)
Sheep	46			Aloka 500	7.5	Muscle (kg)	●	2	0.99	0.48	Silva et al. (2006)
Sheep	162			Technicare 210		Muscle (kg)	●	1	0.89		Turlington (1989)
Sheep	76	Coopworth		Aloka 210	5	Muscle (kg)		1	0.32	0.723	Young and Deaker (1994)

Abbreviations: LW, live weight; R^2, coefficient or determination; RSD, residual standard deviation.

costly. Moreover, as this method needs the animal slaughter and carcass destruction it is inadequate for genetic selection programs (Bünger et al., 2011). For genetic purposes, Simm (1987) estimated that CT would improve by 50% the rates of response to the selection, due to a more accurate measurement of tissue dimensions when compared with ultrasound measurements. The CT has been successfully applied for the selection of breeders in breeding programs, such as those practiced in the UK sheep industry (Bunger et al., 2015; Bünger et al., 2011). In these programs, a two-stage approach is used in which a first stage supported by real-time ultrasound (RTU) is used for all potential candidates followed by CT scans in 10–15% of the animals that were identified as the best by RTU (Bünger, Moore, McLean, Kongsro, & Lambe, 2014). In New Zealand Jopson, Newman, and McEwan (2009) reported that economic returns were maximized when all lambs were ultrasonically scanned, and the best 13% were CT scanned. Although the expenses evolved in selection programs based on CT traits measurements are relatively high, the cost of these measurements needs to be considered in relation to its benefits (Bünger et al., 2014). The measure of spine traits in vivo, such as spine length and vertebrae number, is other CT use for sheep meat production. Several reports show that CT method is a non-invasive feasible approach to take information about spine and vertebrae length measurements traits which will be included in breeding programs aimed the loin yield increase (Donaldson, Lambe, Maltin, Knott, & Bunger, 2013; Donaldson, Lambe, Maltin, Knott, & Bünger, 2014).

The creation of a database with images, which allows permanent access to information related to the composition of animals, is also an important attribute of CT (Bünger et al., 2014; Scholz et al., 2015). In addition to the work related to selection, CT can also be used successfully in longitudinal studies. In fact, CT is a non-invasive tool, suitable for in vivo work to model protein and fat deposition during growth, providing valuable information to optimize sheep breeding, nutrition, feed efficiency and whole production systems (Bünger et al., 2014; Lambe et al., 2012). Also, CT can be used to modeling optimal slaughter times and weights, and therefore to produce final products which better meet industry and consumer demands (Bünger et al., 2014).

Table 4 summarizes the use of CT for prediction of carcass composition of sheep and goat in sheep and goat species. Most CT studies with sheep species are related to carcass composition and have been made in vivo (e.g., Rosenblatt et al., 2017) or with carcasses (e.g., Kongsro et al., 2008). For goat species little information is available. The only work with goat examines the carcass composition of light carcasses of goat kid (Silva et al., 2015).

Table 4 Summary of Applications of Computed Tomography Imaging for Prediction of Carcass Composition of Sheep and Goat

Specie	Target		Traits	*n*	CT image	Anatomical Landmarks	Data Analysis	R^2	RMSE	Reference
Sheep	In vivo		Muscle, kg	21	2D	TV7,LV2, LV5,FEM	OLS	0.94	0.508	Young, Nsoso, Logan, and Beatson (1996)
			Fat, kg					0.73	0.262	
			Bone, kg					0.93	0.406	
	In vivo	Leg	Muscle, kg	47	2D	CAV3,CAV4,SV4	OLS	0.93		Kvame and Vangen (2006)
			Fat, kg					0.95		
			Bone, kg					0.83		
		Shoulder	Muscle, kg	32		TV6,CV7		0.93		
			Fat, kg					0.96		
			Bone, kg					0.72		
		Mid-Region	Muscle, kg	104		LV4,TV8		0.89		
			Fat, kg					0.98		
			Bone, kg					0.69		
	In vivo		Muscle, kg	160	2D	ISC, LV5,TV8		0.92	0.078	Macfarlane, Lewis, Emmans, Young, and Simm (2006)
			Fat, kg					0.98	0.097	
			Bone, kg					0.83	0.107	

Continued

Table 4 Summary of Applications of Computed Tomography Imaging for Prediction of Carcass Composition of Sheep and Goat—cont'd

Specie	Target	Traits	*n*	CT image	Anatomical Landmarks	Data Analysis	R^2	RMSE	Reference
	Carcass	Muscle, kg	120			PLSR	0.94	0.710	Kongsro, Røe, Aastveit, Kvaal, and Egelandsdal (2008)
		Fat, kg					0.92	0.600	
	In vivo	Body fat, g	22	SCTS (1 mm)		OLS	0.92		Rosenblatt et al. (2017)
		Visceral fat, g					0.94		
		Body fat, g		SCTS (5 mm)			0.90		
		Visceral fat, g					0.96		
Goat	Carcass	Muscle, kg	19	SCTS (5 mm)		OLS	0.95		Silva, Teixeira, Monteiro, Guedes, and Ginja (2015)
		Fat, kg					0.65		

Abbreviations: SCTS, spiral computed tomography scanning; 2D, two-dimensional cross-sectional scans; anatomical landmarks [5th lumbar vertebra (LV5), 2nd lumbar vertebra (LV2), 8th thoracic vertebra (TV8), 6th thoracic vertebra (TV6), 7th thoracic vertebra (TV7), mid-shaft of the femur (FEM), 3rd caudal vertebra (CAV3), 4th caudal vertebra (CAV4), 4th sacral vertebra (SV4), 7th cervical (CV7), ischium (ISC)]; OLS, ordinary least squares regression; PLSR, partial least squares regression; R^2, coefficient of determination; RMSE, root-mean-square error.

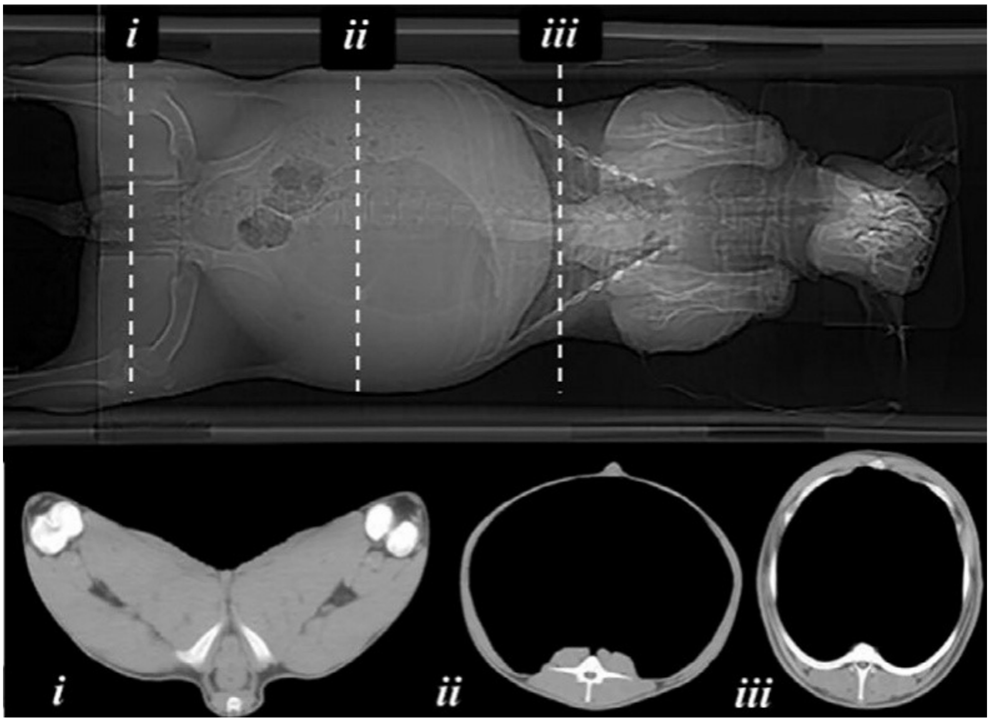

Fig. 1 Three anatomical landmarks that are considered in the cross-sectional CT scans which are obtained at the ischium, fifth lumbar vertebra and eighth thoracic vertebra.

Most of the CT work with sheep uses single slice scanning images resulting in two-dimensional images of the selected anatomical landmarks of the subject (Clelland et al., 2018). Typically, three anatomical landmarks are considered in the cross-sectional CT scans which are obtained at the ischium, 5th lumbar vertebra and 8th thoracic vertebra (Fig. 1). Those three anatomical landmarks are found as an optimum between the practicability of the scanning work and the accuracy. However, the advances in CT technology have led to the development of contiguous scanning procedures such as spiral CT scanning (SCTS). The SCTS is capable of producing a series of images in a single adjacent scan at intervals of as little as 0.6 mm apart (Daumas, Donkó, Maltin, & Bünger, 2015).

The thickness of the slice and the number of slices constitute an accuracy factor of CT. For example, Young et al. (1996) found the best accuracy when using five slices. For the cut thickness between 1 and 5 mm, it does not seem to have much influence when estimating the carcass composition. The advantage is that multiple images can be acquired faster, at reduced intervals, resulting in increased information acquisitions in less time (Clelland et al., 2018). To obtain genetic progress accurate information on the phenotypic characteristics to be chosen is required and CT represents a huge opportunity for this purpose (Bünger et al., 2011). In fact, several studies have shown that CT is a sufficiently precise tool to provide adequate information about the characteristics of interest of the carcass. Moreover, with the recent progress with the image analysis and with a greater diffusion of 3D reconstruction images resulting from SCTS procedures it is possible to increase CT capacity for in vivo studies (Bünger et al., 2014).

The more significant part of the work estimates the composition in carcass tissues since this is the most relevant information for the meat production and quality. There are however some studies that focus their objective on the internal fat depots (Lambe et al., 2003; Rosenblatt et al., 2017). These studies show that CT is competent in the determination of internal fat depots and therefore is a useful tool to understand how those reserves are depleted and repleted throughout an annual production cycle (Lambe et al., 2003).

For carcass composition, some reports in lambs also showed that CT could be used as a tool for virtual dissection (Ho et al., 2014; Kongsro et al., 2008). However, these studies did not specifically focus on differentiating visceral and subcutaneous fat depots, did not acquire volumetric CT data or did not use optimal statistical analyzes.

The prediction of spine length and muscularity is two other objectives that have been successfully addressed using CT (Jones, Lewis, Young, & Wolf, 2002; Lambe et al., 2015). The muscularity has increasingly been encouraged as being preferable to conformation as a measure of the shape of a lamb carcass because unlike conformation, muscularity is independent of carcass fatness and can be objectively obtained using muscle and bone measurements and weights (Hopkins, 1996; Purchas, Davies, & Abdullah, 1991). All that information can be accurately achieved in vivo using CT (Jones et al., 2002). In this work useful in vivo measurements of the width and depth of the LTL muscle and the length of the spine were obtained from CT scans. The ability to accurately obtain bone and muscle measurements places the CT as a suitable tool to include in vivo muscularity measures in sheep genetic selection programs to provide as a method to improve carcass conformation and leanness (Jones, Lewis, Young, & Simm, 2004; Navajas et al., 2007). Table 5 presents some data regarding muscularity prediction of sheep.

Table 6 presents a summary of the use of CT to predict IMF% and meat quality attributes. The results obtained in predicting IMF from CT measurements show that is possible but with moderate accuracy (R^2 between 0.36 and 0.70). However, this technique cannot accurately predict shear force or sensory traits of the meat (Clelland et al., 2018; Lambe et al., 2017). Despite the capacity shown by CT to predict the IMF%, its use in breeding programs is a challenge since this characteristic has an inverse relation with phenotypic CT lean% across all muscles of the carcass (Anderson, Pethick, & Gardner, 2014).

Table 5 Summary of Applications of Computed Tomography Imaging for Prediction of Muscularity Indices of Sheep

Traits	*n*	CT image	Anatomical Landmarks	Data Analysis	R^2	Reference
M3FL	160	2D	LV5,FEM,ISC	OLS	0.48–55.3	Jones et al. (2002)
HLMI	132	SCTS (8 mm)		OLS	0.26–0.79	Navajas et al. (2007)
LRMI	240				0.19–0.30	
CMI	240				0.30	

Abbreviations: M3FL, length of the femur and the combined weight of the three dissected muscles; HLMI, hind leg muscularity index; LRMI, lumbar muscularity index; CMI, carcass muscularity index; SCTS, spiral computed tomography scanning; 2D, two-dimensional cross-sectional scans; anatomical landmarks [5th lumbar vertebra (LV5), mid-shaft of the femur (FEM), ischium (ISC)]; OLS, ordinary least squares regression; R^2, coefficient of determination.

Therefore, there is a balance that must be made to maintain an adequate level of IMF% for optimum eating quality (Anderson et al., 2014).

The scanning time and the CT image analysis are variable but increasingly faster with more modern equipment (Daumas et al., 2015). Also, for cuts, the possibility of doing a multi-object CT analysis in batches of three or more saves money and time (Lambe et al., 2017). The SCTS was found to be very useful for carcass composition prediction (Bunger et al., 2015) but for IMF prediction, the increased image analysis and processing currently required do not justify the increase in accuracy achieved when compared to current scan procedures (Clelland et al., 2018).

Prediction of sheep and goat carcass composition and meat quality using CT scanning has been investigated in several countries and it is expected that the confirmation about new CT phenotypic information in breeding programs will allow paying more attention to the characteristics of the carcass and the quality of the meat that are more valued by the market (Scholz et al., 2015). Finally the CT ability to have in vivo information about internal fat or pelvic dimensions as indicators for ease of lambing can have an impact on meat production systems and in the welfare of sheep (Lambe et al., 2003; Morgan-Davies et al., 2018; Scholz et al., 2015).

2.3 Use of Computer Vision

Many of the quality attributes affecting meat can be determined by visual inspection and image analysis. Computer vision has become an essential

Table 6 Summary of Applications of Computed Tomography Imaging for Prediction of Meat Quality Attributes of Sheep

Target	Traits	n	CT image	Anatomical Landmarks	Data Analysis	R^2	RMSE	Reference
In vivo	IMF, %	160	2D	ISC, LV5, LV2, TV8, TV6	OLS	0.57	0.608	Macfarlane, Young, Lewis, Emmans, and Simm (2005)
In vivo	IMF, %	370	2D	ISC, LV5, TV8	OLS	0.51–0.68	0.39–0.48	Clelland et al. (2014)
				LV5		0.51–0.65	0.40–0.48	
Loin	IMF, %	303	SCTS (8 mm)		OLS	0.36	0.620	Lambe et al. (2017)
	Shear force, kgF					0.03	−0.830	
	Texture					0.08	−0.530	
	Flavor					0.09	−0.370	
	Juiciness					0.06	−0.370	
	Liking					0.10	−0.390	
Loin	IMF, %	377	SCTS (8 mm)		OLS	0.51–0.70	0.48–0.38	Clelland et al. (2018)
	Shear force, kgF					0.02–0.06	0.16–0.16	
	IMF, %		SCTS + 2D	ISC, TV8		0.50–0.71	0.47–0.37	
	Shear force, kgF					0.03–0.13	0.16–0.15	

Abbreviations: IMF, intramuscular fat; SCTS, spiral computed tomography scanning; 2D, two-dimensional cross-sectional scans; anatomical landmarks [5th lumbar vertebra (LV5), 2nd lumbar vertebra (LV2), 8th thoracic vertebra (TV8), 6th thoracic vertebra (TV6), ischium (ISC)]; OLS, ordinary least squares regression; R^2, coefficient of determination; RMSE, root-mean-square error.

technology for the quality control in the meat industry, which continually demands new and better applications (Ma et al., 2016).

Most studies that apply computer vision system (CVS) on carcass grading with small ruminants have been carried out on sheep (Hopkins, Safari, Thompson, & Smith, 2004; Ngo et al., 2016; Rius-Vilarrasa et al., 2010). In general, the CVS is used to the prediction of the lean meat yield (LMY%) and the saleable meat yield (SMY%). Typically, the predictions are supported in carcass weight and carcass measurements obtained from the CVS (Hopkins et al., 2004). Examples of CVS operating with lambs are the VIAScan, Cedar Creek Company, Australia (Hopkins et al., 2004), VSS 2000, E + V GmbH, Germany (Rius-Vilarrasa et al., 2010) and LVS, Research Management Systems—RMS, USA (Cunha et al., 2004). Fig. 2 illustrates lamb carcass images in the VSS 2000 system (Rius-Vilarrasa, Buenger, Maltin, Matthews, & Roehe, 2009).

Over the years, the CVS developed for sheep intent to be used in online in the abattoirs as an alternative to subjective grading systems. For example,

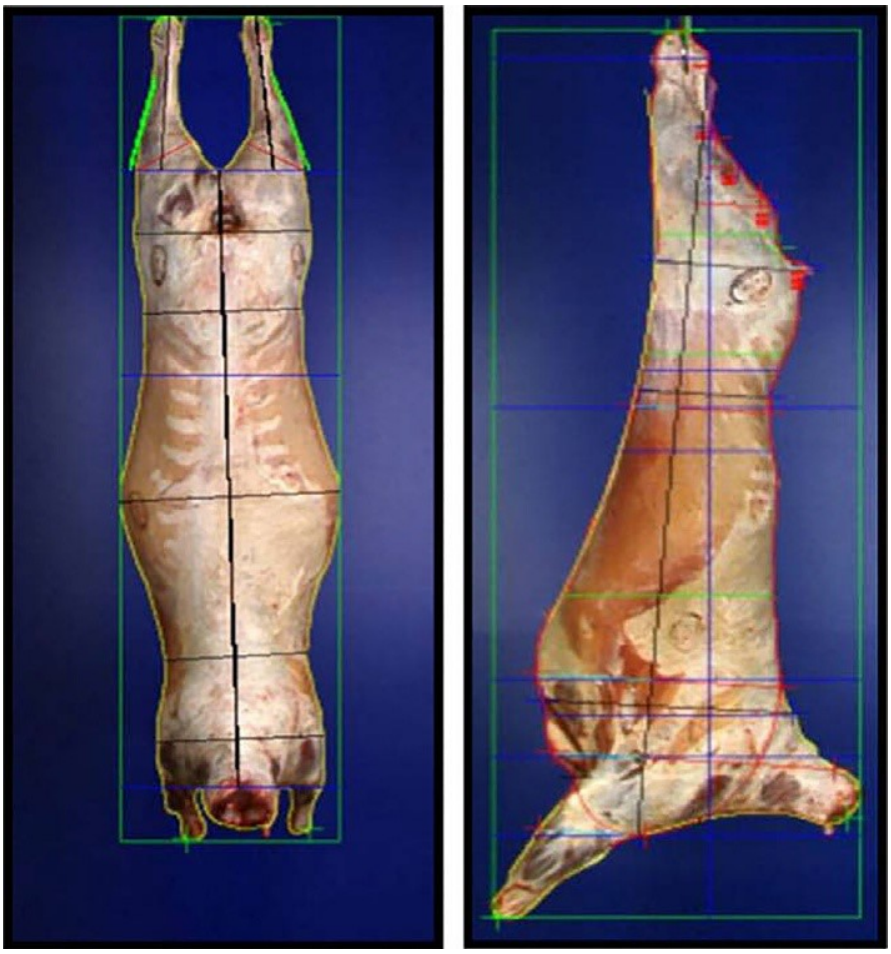

Fig. 2 Images of lamb carcass obtained with a VSS 2000 system.

in the study of Einarsson, Eythorsdottir, Smith, and Jonmundsson (2014), a CVS was applied for objectively evaluating the carcass as an alternative to the EUROP classification. Moreover, the carcass assessment can be performed without interrupting the normal flow of the slaughterhouse (Allen, 2007; Pabiou et al., 2011). Those CVS are costly but can offer a favorable cost/benefit when applied in a large number of carcasses (Craigie et al., 2012). The accuracy and speed of the assessment are key aspects to the success of a CVS and foreknowledge this technique as one to be elected for grading carcasses in the future (Hopkins, Gardner, & Toohey, 2015).

The prediction of LMY% and SMY% (Hopkins et al., 2004; Rius-Vilarrasa et al., 2010), assuming itself as a tool to discriminate the carcasses differently, aiming to achieve a value-based marketing system (Craigie et al., 2012). Table 7 summarizes the results of the estimated LMY% and SMY% of sheep carcasses by CVS.

The results obtained with CVS can be used commercially to accurately classify the carcasses which facilitate the development of a fair pricing system based on LMY% and not on carcass weight (Brady et al., 2003). When comparing the EUROP classification system and the CVS VIAscan, Einarsson et al. (2014) verified that the latter could be more effective in predicting LMY% in lambs. On the other hand, also using VIAscan in lamb carcasses, Hopkins et al. (2004) found reasonable values to predict lean meat yield ($R^2 = 0.52$). Concerning salable meat yield (SMY%), Stanford et al. (1998) reported that the VIAscan system showed the better ability for SMY% prediction when compared to the Canadian classification system. Using the CVS LVS technology, Cunha et al. (2004) found R^2 values of 0.68 for the SMY % when they included the warm carcass weight in the model, and when

Table 7 Examples of CVS to Predict Lean Meat Yield (LMY%) and Saleable Meat Yield (SMY%)

Carcass Trait	*n*	CVS	R^2	RMSE	Reference
LMY%	862	VIAscan®	0.36	2.57	Einarsson et al. (2014)
	360	VIAscan®	0.52	2.17	Hopkins et al. (2004)
SMY%	1211	VIAscan®	0.71		Stanford et al. (1998)
	149	LVS	0.68	0.02	Cunha et al. (2004)
	149	LVS	0.72	0.02	Cunha et al. (2004)
	246	LVS	0.60	0.03	Brady et al. (2003)

Abbreviations: RMSE, Residual mean square error; LVS, lamb vision system.

the fat percentage was involved in the prediction model, the accuracy was improved to 0.72. Similar results were found by Brady et al. (2003) who reported an *R* of 0.60 when evaluating the LVS system together with the hot carcass weight to predict SMY%.

With the use of CVS, it is possible to predict the weight and yield of the cuts in the carcass. The coefficients of determination and residual mean square errors for the prediction of carcass cut weight and yield of sheep obtained by CVS are presented in Table 8. Analyzing the prediction power

Table 8 Prediction of Carcass Cut Weight and Yield of Sheep Obtained by CVS

Cut	*n*	Equipment	R^2	RMSE	Reference
Tenderloin kg	792	LDG	0.60		Ngo et al. (2016)
Loin kg			0.62		
French rack kg			0.76		
Rump kg			0.75		
Leg kg			0.94		
Middle kg			0.94		
Shoulder kg			0.95		
Leg kg	443	VSS2000	0.97	0.16	Rius-Vilarrasa et al. (2009)
Chump kg			0.94	0.04	
Loin kg			0.89	0.20	
Middle kg			0.86	0.16	
Shoulder kg			0.96	0.22	
Total primal kg			0.99	0.25	
Shoulder kg	246	LVS	0.85	0.50	Brady et al. (2003)
Middle kg			0.72	0.35	
Loin kg			0.75	0.20	
Leg kg			0.85	0.45	
Subprimal yield%	149	LVS	0.66	0.02	Cunha et al. (2004)
Leg %	862	VIAscan®	0.60	1.04	Einarsson et al. (2014)
Loin %			0.31	0.72	
Shoulder %			0.47	1.16	

Subprimal yield% = percentage based on the cold carcass weight of the leg, loin, middle and shoulder.

of the carcass measurements obtained through a simple CVS (Lamb digital grading—LDG) on the weight of lamb carcass cuts, Ngo et al. (2016) found results ranging from moderate to high (R^2 ranging from 0.60 to 0.95). For the main cuts (leg and shoulder), they found R^2 with high accuracy capacity explaining 94% and 95% of the variation of their weight, respectively.

Similar results were reported by Rius-Vilarrasa et al. (2009), who compared the CVS technology with the EUROP classification system used in the United Kingdom, and observed that the CVS provided an excellent accuracy to predict leg and shoulder weight (R^2 of 0.97 and 0.96, respectively). On the other hand, Brady et al. (2003), to evaluate the potential of the CVS measurements plus hot carcass weight, show that it is possible to an explain of 85%, 72%, 75%, and 86% of the variation in weight of the shoulder, rib, loin and leg, respectively. According to these authors (Brady et al., 2003), the CVS technique has the potential to help in the grading process in the lamb meat industry. Regarding the prediction performance of the subprimal yield%, which represents the percentage based on the cold carcass weight of the leg, loin, middle and shoulder, Cunha et al. (2004) using a similar CVS approach verified that the method explained 66% of the variation of those cuts. Einarsson et al. (2014) showed that the CVS VIASscan system was able to explain 60%, 31% and 47% of the variation of the lean meat yield of the leg, loin and shoulder, respectively. According to these authors (Einarsson et al., 2014), the VIAscan is an automatic CVS able to predict the meat yield of cuts of carcass lambs. In addition to the cuts, Hopkins (1996) showed the feasibility of using a CVS to evaluate the muscularity of the carcass. On the other hand, the CVS is also suitable to predict carcass composition. For example, Lambe et al. (2009) using a CVS by combining different measurements, accurately predict the dissected carcass muscle weight (adjusted R^2 0.93 in Texel—TEX, and 0.88 in Scottish Black Sheep—SBF) and fat weight (adjusted R^2 0.84 in TEX, and 0.87 in SBF).

Unlike beef or pork meat, the use of CVS to assess intramuscular or marbling in sheep is less frequent. By combining different measurements, Lambe et al. (2009) achieved reasonable predictions of intramuscular fat (adjusted R^2 0.56 in TEX, and 0.48 in SBF). These authors also predicted the shear force using a CVS with low to moderate accuracy (adjusted $R^2 < 0.33$ across breeds and cuts). In a previous study, Lambe et al. (2008) have identified the potential of different in vivo measurement obtained with computed tomography and a CVS applied in live sheep, to predict intramuscular fat, shear force and ultimate pH of muscles. The results found are considered low for shear force and ultimate pH but for intramuscular fat, the predictions in combinations of CT and CVS taken in live lambs could be employed to genetic improvement of carcass quality traits.

2.4 Use of Near Infrared Spectroscopy

The near-infrared spectroscopy (NIRS) using the Fourier transform (FT) is a technology known by the end of 1960s when a computerized spectrophotometer NIR was developed, and its applicability to the analysis of meat was shown (Ben-Gera & Norris, 1968). NIRS measures the absorption of electromagnetic radiation from 750 to 2500 nm wavelengths, corresponding to overtones and combinations of vibrational modes of C—H, O—H and N—H chemical bonds. Recording the electromagnetic radiation absorbed from those molecular bonds in the NIR wavelengths produces spectra which are unique to a sample acting as a "fingerprint." The collected spectrum includes data related to the chemical and physical properties of organic molecules in the sample and, therefore, important information on sample composition (Prieto et al., 2017).

NIRS technology is currently a highly versatile tool used in diverse fields including the food industry and, particularly, in animal science to predict the chemical and physical composition of meat of different species (Weeranantanaphan, Downey, Allen, & Sun, 2011). The high versatility of the technology is being used for large-scale in meat quality evaluation, to predict chemical composition and identification and authentication of meat products. The use of technology was not so popular in lamb or goat meat because the information on the use of NIR spectroscopy in lamb or goat meat is relatively scant in comparison with other meats or meat products. The electromagnetic scanning was tested as objective means for assessing lamb carcass composition (Berg, Forrest, Thomas, Nusbaum, & Kauffman, 1994; Berg, Neary, Forrest, Thomas, & Kauffman, 1997). Kruggel, Field, Riley, and Horton (1981) in a study on ground raw lamb meat using NIRS suggested that the technology was more suitable for the fat and moisture determination than the protein. Viljoen, Hoffman, and Brand (2007) using NIRS concluded that the technology could be used as a rapid tool for predicting the proximal chemical composition and certain minerals in freeze-dried mutton. Andrés et al. (2007) investigated in lamb meat samples the association between chemical composition and meat quality traits scored by a trained sensory panel and absorbance data from NIR spectroscopy. The results suggested that the most important regions of spectra to estimate sensory characteristics of lamb meat are related to the absorbance of intramuscular fat and water parameters. Guy, Prache, Thomas, Bauchart, & Andueza (2011) comparing two lamb meat preparations (ground vs intact, non-ground meat samples) determined whether NIRS was feasible for accurate predictions of fatty acids profile. Results indicated that the prediction models are much better using ground than intact non-ground samples and the models obtained are satisfactory for fatty acids groups or individual fatty acids presented in medium to high concentrations as total saturated fat, *cis* and monounsaturated fat, but are lower for fatty acids presented at low or very low concentrations as polyunsaturated fatty acids. On the same way, Pullanagari, Yule, and Agnew (2015) evaluated the use of visible near infrared spectroscopy (Vis-NIRS) to quantify the fatty acid composition of intact lamb meat under commercial abattoir conditions. Those authors concluded that even though the prediction accuracies of individual fatty acids were low the Vis-NIRS could be used as a screening tool at abattoir.

The potential of NIRS to classify the geographical origin and predict the isotope of carbon $\delta^{13}C$ and nitrogen $\delta^{15}N$ of lamb meat combined with chemometrics particularly the application of partial least squares regression methodology (PLSR) was tested with promising results by Sun, Guo, Wei, and Fan (2012). However, in goats there are not many studies about the reliability and accuracy of the use of NIR spectroscopy to characterize the meat composition. A study by Teixeira et al. (2015) was the first approach to test the ability of NIRS to estimate the protein, moisture, connective tissue, ash and fat content in the LM muscle of goat meat. So, the NIRS technology combined with chemometrics would be a useful tool to know raw goat meat composition and select material for improving the quality of meat processing.

2.5 Use of Hyperspectral Imaging

Hyperspectral imaging is an emerging technology designed initially for remote satellite vigilance with military purposes but has been extended for use in astronomy and observing the territory (Goetz, 2009; Van der Meer et al., 2012). However, in the last years, it has begun to be applied as a rapid, reliable, non-destructive and non-invasive tool in the food industry (Gowen, O'Donnell, Cullen, Downey, & Frias, 2007; Liu, Pu, & Sun, 2017). Those characteristics are opening the possibility to apply hyperspectral imaging to the prediction of meat quality and meat classification (Cheng, Nicolai, & Sun, 2017; Xu & Sun, 2017).

In recent years, different image-based or spectroscopic techniques have been used to measure the various attributes of meat quality (Su, He, & Sun, 2017). Among these, the hyperspectral imaging (HIS) technique is recognized as a versatile technique for rapid quantitative, non-reagent and non-invasive applications in the red meat industry (Xu & Sun, 2017). In this point will be emphasized the use of HSI to sheep meat to evaluate sensorial, chemical, technological and classification attributes. For goat meat, like other techniques, there is scarce or just non available information.

The sensorial, chemical, technological, adulteration, authentication and discrimination attributes, which have been investigated using HIS for sheep meat and meat products, are presented in Table 9. In this section the quality attributes of red meats classification proposed by Xu and Sun (2017) are followed.

The sensory attributes have a significant influence on the evaluation of the meat by consumers. Color represents one of the most important sensory attributes since it is generally used as an indicator of the freshness of meat, and an attractive and stable color in the meat has a significant influence on the purchase decision made by the consumer (Grunert, Bredahl, & Brunsø, 2004). Several studies developed HSI as a non-contact measurement technique of color in meat (Table 1). It was found that HSI and multivariable models for prediction of color component L* (R^2 from 0.77 to 0.97) were good, yet prediction of the other color components b* and a* showed some discrepancies (R^2 of 0.48 and 0.84, respectively, and R^2 of 0.26 and 0.82, for b*and a*, respectively). The lower values were reported by Qiao, Ren, et al. (2015) who stated that HSI still proved to be a useful technique to predict complex quality traits such as color, even though prediction performance was low and requires further improvement.

The tenderness is an expression of meat texture and is the most important sensory quality attribute related to consumer satisfaction (Xu & Sun, 2017). Concerning sensory tenderness, only one reference associated with HSI and lamb meat was described (Kamruzzaman, ElMasry, et al., 2013). Four experienced panelists evaluated the sensory tenderness. The results are modest compared with those of Warner–Bratzler shear force (WBSF) ($R_{cv}=0.84$ and 0.69 for WBSF and sensory tenderness, respectively). Nevertheless, Kamruzzaman, ElMasry, et al. (2013) argue that prediction of sensory characteristics may be improved if the tested samples are segregated into more specific sub-groups.

Efforts on using HSI for assessing lamb meat chemical composition have been investigated by several researchers (Kamruzzaman, ElMasry, et al., 2012a;

Table 9 Summary of Applications of HSI for Evaluating Quality Attributes of Sheep Meat

Quality Attributes		Wavelength Range (nm)	Multivariable Analysis	Accuracy	References
Sensory	a*	400–1000	PLSR	$R^2=0.84$	Kamruzzaman, Makino, and Oshita (2016a) and Kamruzzaman, Makino, and Oshita (2016b)
Sensory	a*	400–863	PCA. SVM	$R^2=0.48$	Qiao, Ren, et al., 2015
Sensory	b*	400–1000	PLSR	R2 = 0.82	Kamruzzaman et al. (2016a) and Kamruzzaman et al. (2016b)
Sensory	b*	400–863	PCA. SVM	$R^2=0.26$	Qiao, Ren, et al., 2015
Sensory	L*	900–1700	PLSR	$R^2=0.91$	Kamruzzaman, ElMasry, Sun, Allen (2012b)
Sensory	L*	400–1000	PLSR	$R^2=0.97$	Kamruzzaman et al. (2016a)
Sensory	L*	400–863	PCA. SVM	$R^2=0.77$	Qiao, Ren, et al., 2015
Sensory	Tenderness	900–1700	PLSR	$R_{cv}=0.69$	Kamruzzaman, ElMasry, Sun, and Allen (2013)
Chemical	Protein	900–1700	PLSR	$R^2=0.85$	Kamruzzaman, ElMasry, Sun, and Allen (2012a)
Chemical	Protein	1021–1396	MLR	$R_c=0.80$	Pu, Sun, Ma, Liu, and Kamruzzaman (2014)
Chemical	Water	900–1700	PLSR	$R^2=0.88$	Kamruzzaman, ElMasry, et al. (2012a)
Chemical	Water	1021–1396	MLR	$R_c=0.91$	Pu et al. (2014)
Chemical	Fat	900–1700	PLSR	$R^2=0.91$	Kamruzzaman, ElMasry, et al. (2012a)
Chemical	Fat	1021–1396	MLR	$R_c=0.95$	Pu et al. (2014)
Chemical	IMF%	550–1700	PLSR	$R^2_{cv}=0.67$	Craigie et al. (2017)
Chemical	SFA	550–1700	PLSR	$R^2_{cv}=0.68$	Craigie et al. (2017)
Chemical	MUFA	550–1700	PLSR	$R^2_{cv}=0.70$	Craigie et al. (2017)
Chemical	FPUFA	550–1700	PLSR	$R^2_{cv}=0.53$	Craigie et al. (2017)

Tecnological	pH	900–1700	PLSR	$R_{cv}^2 = 0.65$	Kamruzzaman, ElMasry, et al. (2012b)
Tecnological	pH	400–863	PCA. SVM	$R_{cv}^2 = 0.38$	Qiao, Ren, et al., 2015
Tecnological	pH	550–1700	PLSR	$R_{cv}^2 = 0.71$	Craigie et al. (2017)
Tecnological	MIRINZ SF	400–863	PCA. SVM	$R_{cv}^2 = 0.41$	Qiao, Ren, et al., 2015
Tecnological	WBSF	900–1700	PLSR. MLR. SPA	$R_{cv}^2 = 0.84$	Kamruzzaman, ElMasry, et al. (2013)
Tecnological	WBSF	400–1000	PLSR	$R_{cv}^2 = 0.89$	Wang et al. (2016)
Tecnological	WHC	900–1700	PLSR	$R_{cv}^2 = 0.77$	Kamruzzaman, ElMasry, et al. (2012b)
Tecnological	WHC	400–1000	PLSR. LS-SVM	$R^2 = 0.92$	Kamruzzaman et al. (2016b)
Adulteration	Minced lamb meat	900–1700	PCA. PLSR. MLR	$R_{cv}^2 = 0.98$	Kamruzzaman, Sun, ElMasry, and Allen (2013)
Adulteration	Red-meat products	548–1701	CNN	94.4%	Al-Sarayreh, Reis, Qi Yan, and Klette (2018)
Discrimination	Raw meat	900–1700	PCA. PLS-DA	98.7%	Kamruzzaman, Barbin, ElMasry, Sun, and Allen (2012)
Discrimination	LM, PM, ST, Sm	380–1028	PCA. LMS	96.7%	Sanz et al. (2016)
Discrimination	LM, PM, ST	900–1700	PCA. LDA	100.0%	Kamruzzaman, ElMasry, Sun, and Allen (2011)
Discrimination	Raw meat	1000–2500	LDA	100.0%	Qiao, Peng, Wei, and Li (2015)
Discrimination	Raw meat	1000–2500	LDA	87.5%	Qiao, Peng, Chao, and Qin (2016)

Abbreviations: LS-SVM, least square support vector machine; MLR, multiple linear regression; PCA, principal component analysis; PLS, partial least square regression; PLS-DA, partial least square discrimination analysis; R_c, correlation coefficient in the calibration set; R_c^2, determination coefficient in the calibration set; R_{cv}, correlation coefficient of cross validation; R_{cv}^2, determination coefficient of cross validation; Rp, correlation coefficient in the prediction set; Rp2, determination coefficient in the prediction set; SVM, support vector machine; CNN, convolution neural networks; WHC, water holding capability; IMF%, intramuscular fat percentage; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; WBSF, Warner-Bratzler shear force; MIRINZ SF, MIRINZ shear force; LM, longissimus thoracis et lumborum muscle; PM, Psoas major; Sm, semimembranosus; ST, semitendinosus.

Pu et al., 2014). The results show the feasibility of HSI to yield a good accuracy to predict protein, water and fat (R^2 range from 0.80 to 0.95). More recently, Kamruzzaman et al. (2016a, 2016b) using a HSI system (400–1000 nm) to predict water in lamb, but also in beef and pork meat in an industrial environment, showed that the best model explains 97% of the water variations in meat. This result confirms the HSI as a suitable technology for the prediction of water content in red meat.

When it comes to lamb, relatively few studies have been carried out using HSI for IMF%, and fatty acid content prediction. In a recent work, Craigie et al. (2017) used HSI (550–1700 nm) for simultaneous prediction of the IMF% and content of 34 fatty acids. Results demonstrated that HSI has the potential for predicting fatty acids content of lamb LM muscle samples, where cross-validated R^2 values ranging from 0.03 for lignoceric acid (C24:0) to 0.70 for oleic acid (C18:1c9). The prediction accuracy for IMF% ($R^2_{cv}=0.67$), saturated fatty acid—SFA ($R^2_{cv}=0.68$), monounsaturated fatty acid—MUFA ($R^2_{cv}=0.70$), polyunsaturated fatty acid—PUFA ($R^2_{cv}=0.53$) content in LM muscle. The encouraging results of this work allowed Craigie et al. (2017) to anticipate the possibility of improving the robustness of the technology for objective, rapid non-invasive assessment of lamb meat quality in a meat processing plant environment.

Besides sensory and chemical attributes, research on lamb meat quality using HSI has also been addressed to predict technological attributes such as pH, shear force and water holding capability (WHC). The pH has a significant influence on the storage and quality of red meat by affecting its WHC and color (Povše, Čandek-Potokar, Gispert, & Lebret, 2015). The models found for the pH showed reasonable prediction performance (R^2_{cv} between 0.38 and 0.71).

Warner–Bratzler shear force (WBSF) is the most common mechanical method to measure meat tenderness objectively. This trait is associated with juiciness and flavor of meat, which lead consumers to accept paying more for tender meat (Schulze-Ehlers & Anders, 2018). The HIS was utilized to predict instrumental (WBSF and MIRINZ SF) tenderness of lamb meat (Kamruzzaman, ElMasry, et al., 2013; Qiao, Ren, et al., 2015; Wang et al., 2016). Reasonable accuracy was obtained from HIS coupled with PLSR models to predict WBSF (R^2_{cv} of 0.84 and 0.89), but for MIRINZ SF the result was less predictable ($R^2=0.41$).

Regarding WHC, Kamruzzaman, ElMasry, et al. (2012b) applied a HIS using 237 wavelengths and a PLSR model which could explain 77% of the variation of that quality attribute. In more recent work, Kamruzzaman et al. (2016a) tested effective wavelengths to be used in the design of a multispectral system for online monitoring of WHC in red meats including beef, lamb, and pork. With the approach in this work, a good accuracy was achieved ($R^2=0.92$).

Over the last few years, several non-destructive technologies have been developed to predict meat adulteration (Kamruzzaman, Makino, & Oshita, 2015). However, the non-destructive detection and quantification of adulteration in minced lamb remains a challenge. To solve this problem, HSI was used to detect the level of adulteration in minced lamb meat (Kamruzzaman, Sun, et al., 2013). In this work, the minced lamb meat was adulterated with minced pork, kidney, heart and lung around 2–40%, in increments of approximately 2%. Although it has not been possible to recognize the degree of adulteration in the different samples using visual evaluation in their RGB images, this adulteration is clearly distinguished in the final prediction maps with a linear color scale resulting from the HSI analysis (Fig. 3).

The HSI can also detect the adulteration of meat taking into account its state (fresh, frozen, thawed, and packing/unpacking). Using this, Al-Sarayreh et al. (2018) reported that the best model performance shows a 94.4% overall classification accuracy independent of the state of the products.

The HSI has also shown to be very accurate in discriminating different muscles and meats of different species. Using HSI and multivariate analysis, Sanz et al. (2016) and Kamruzzaman et al. (2011) showed that it is possible to discriminate correctly 96.7% and 100%, respectively, of four (LM, PM, ST, Sm) and three (LM, PM, ST) muscles of lamb carcasses. For the meat of

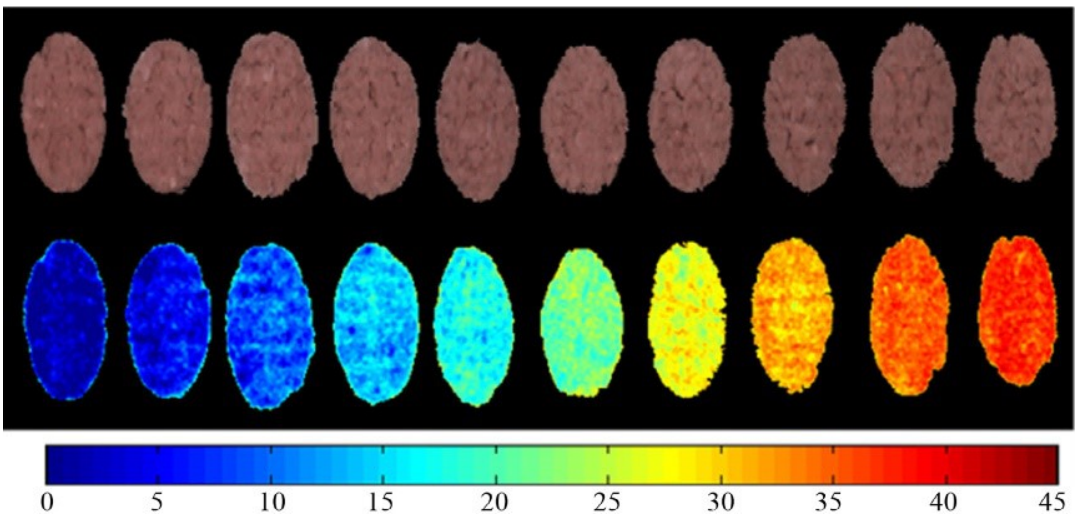

Fig. 3 Prediction maps with a linear color scale resulting from the HSI analysis for adulteration distinction.

different species (lamb, beef and pork) several works (Kamruzzaman, Barbin, et al., 2012; Qiao et al., 2016; Qiao, Peng, et al., 2015) clearly showed that the combination of HSI and multivariate analysis was accurate on the identification and authentication of red meat species. The accuracy yielded 87.5–100% of the overall classification.

2.6 Use of Raman Spectroscopy

Among the several spectroscopic technologies available, Raman spectroscopy has been in recent years the focus of particular interest to applications in meat quality assessment (Fowler, Schmidt, Scheier, & Hopkins, 2018; Kucha, Liu, & Ngadi, 2018). Raman spectroscopy is based on the inelastic scattering of light that occurs when a sample is exposed to a high energy monochromatic light beam (e.g., a laser), which interacts with the sample molecules (Motoyama, 2017; Qin, Kim, Chao, & Cho, 2017). The irradiation of molecular structures by laser light stimulates different molecules in a way that makes possible their measurement. In fact, the difference between the wavelength of the light source and the wavelength of diffuse light that is related to the presence of specific molecules and functional groups can be portrayed as spectral fingerprints (Herrero, 2008). Raman spectroscopy can, therefore, be used to measure the amount or concentration of a chemical constituent in a sample. This technique has been widely used as an analytical tool in many research fields ranging from archeology, forensics, biomedical, and food sciences (Fowler et al., 2018). In the latter area, several authors (Damez & Clerjon, 2008; Fowler et al., 2018) pointed out that Raman spectroscopy is of particular interest to applications in meat quality assessment. In this section, we will examine the Raman spectroscopy to predict meat quality traits of sheep and goat.

The Raman spectroscopy applied in the evaluation of meat characteristics has been mainly oriented to pork meat (Bauer, Scheier, Eberle, & Schmidt, 2016; Olsen, Rukke, Flåtten, & Isaksson, 2007; Scheier, Scheeder, & Schmidt, 2015; Scheier & Schmidt, 2013). However, there are also several studies in which Raman spectroscopy was applied to sheep (Table 10).

For goat, very little research has been conducted with the Raman spectroscopy, only one report related with determination of the origin of meat was published (Boyaci et al., 2014) and no studies have been conducted to investigate this technique to predict meat and meat eating quality on this species. For sheep most of the works aimed at the prediction of meat quality attributes such as shear force (related with tenderness), cooking losses, color and pH (Fowler et al., 2018).

Table 10 Summary of Applications of Raman Spectroscopy for Evaluating Quality Attributes of Lamb Meat

Quality Attributes	Unit	*n*	Muscle	Aging time (days)	Multivariable Analysis	R^2	R^2_{cv}	RMSE	RMSECV	Reference
Shear force	N	70	LM	1	PLSR	0.79		0.11	0.31	Schmidt, Scheier, and Hopkins (2013)
Shear force	N	70	LM	Day 1		0.86		0.10	0.26	Schmidt et al. (2013)
Cooking loss	%	70	LM	Day 1		0.79		3.20	0.09	Schmidt et al. (2013)
Cooking loss	%	70	LM	Day 1		0.83		0.03	0.08	Schmidt et al. (2013)
Shear force	N	80	LM	Day 1	PLSR		0.06	13.60		Fowler, Schmidt, van de Ven, Wynn, and Hopkins (2014a)
Shear force	N	80	LM	Day 5				10.00		Fowler et al. (2014a)
Shear force	N	80	SM	Day 1	PLSR		0.27		11.48	Fowler, Schmidt, van de Ven, Wynn, and Hopkins (2014b)
Shear force	N	81	SM	Day 5			0.17		12.20	Fowler et al. (2014b)
pH 24		80	SM	Day 1	PLSR		0.48		0.12	Fowler, Schmidt, van de Ven, Wynn, and Hopkins (2015)
pHu		80	SM	Day 1			0.59		0.07	Fowler, Schmidt, et al. (2015)
Purge loss	%	80	SM	Day 1			0.42		0.90	Fowler, Schmidt, et al. (2015)

Continued

Table 10 Summary of Applications of Raman Spectroscopy for Evaluating Quality Attributes of Lamb Meat—cont'd

Quality Attributes	Unit	*n*	Muscle	Aging time (days)	Multivariable Analysis	R^2	R^2_{cv}	RMSE	RMSECV	Reference
L*		80	SM	Day 1			0.32		1.96	Fowler, Schmidt, et al. (2015)
Purge loss	%	80	SM	Day 5			0.33		0.94	Fowler, Schmidt, et al. (2015)
L*		80	SM	Day 5			0.22		1.87	Fowler, Schmidt, et al. (2015)
PUFA	mg/100 g	80	LM	Day 1	PLSR	0.93	0.21		46.57	Fowler, Ponnampalam, Schmidt, Wynn, and Hopkins (2015)
MUFA	mg/100 g	80	LM	Day 1		0.54	0.16		400.30	Fowler, Ponnampalam, et al. (2015)
SFA	mg/100 g	80	LM	Day 1		0.08	0.01		358.72	Fowler, Ponnampalam, et al. (2015)
IMF	mg/100 g	80	LM	Day 1		0.08	0.02		1.12	Fowler, Ponnampalam, et al. (2015)
PUFA:SFA		80	LM	Day 1		0.21	0.13		0.06	Fowler, Ponnampalam, et al. (2015)

Abbreviations: N, Newton; LM, longissimus thoracis et lumborum muscle; SM, semimembranosus muscle; PLSR, partial least squares regression; R^2, coefficient of determination; R^2_{cv}, coefficient of determination for cross validation; RMSE, root mean square error; RMSECV, root mean square error of validation; PUFA, polyunsaturated fatty acid; MUFA, monounsaturated fatty acid; SFA, saturated fatty acid; IMF, intramuscular fat.

The prediction of lamb meat quality attributes using Raman spectroscopy is generally significant, but there is some inconsistency in the results of the studies. For example, Fowler et al. (2014a) found that Raman spectroscopy has no ability to predict shear force in lamb LM ($R^2_{cv} = 0.06$), whereas Schmidt et al. (2013) obtained determination coefficients (R^2) of 0.79 and 0.86 to that trait from two measurement sites of the lamb LM muscle. In another study, Fowler et al. (2014b) found that the use of Raman spectra allowed a more accurate prediction of Semimembranosus (SM) muscle shear force (reduction in RMSE of 12.9% and 7.6%, for muscle aging during 1 and 5 days post-mortem, respectively) than for models using traditional predictors like cooking loss, sarcomere length, pHu and particle size.

Although all those studies used the same handheld Raman spectroscopy device and analyzed the LM and SM muscles of lambs with similar weight, the above-mentioned studies differ in some aspects of methodology that may explain the differences found. In fact, as in the work of Fowler et al. (2014a), Raman spectroscopy measurements were performed in fresh intact muscle samples while in the work of Schmidt et al. (2013) the measurements were taken after the muscle had been frozen and thawed. Some authors (Herrero, 2008; Li-Chan, 1996) stated that Raman spectroscopy is sensitive to the changes associated with freezing and thawing of meat, which may explain the differences. To address this problem, Fowler, Ponnampalam, et al. (2015) carried out a study in which they predicted meat quality traits in two experiments, one with fresh and other with freezing/thawing lamb SM muscle samples, and it was concluded the unability of Raman spectroscopy to predict shear force values in both experiments. However, the prediction was possible for other meat quality attributes (R^2 from 0.22 to 0.59).

In addition to the prediction of the meat quality attributes, the Raman spectroscopy is also able to classify samples of several species. For example, Beattie, Bell, Borggaard, Fearon, and Moss (2007) applied a combination of Raman spectroscopy with multivariate and neural network analytical methods, and reported an accuracy between 96.7% and 99.6% of classifying the fat from chicken, beef, lamb and pork species. This discrimination was also reported by Boyaci et al. (2014) working with Raman spectroscopy and using the principal component analysis (PCA). They successfully classified fat samples of seven different meat species (cattle, sheep, pig, fish, poultry, goat and buffalo). In addition to this fat classification attributes, the Raman spectroscopy was also suitable to predict the concentrations of the major fatty acids groups like PUFA, MUFA and SFA, as well IMF (Fowler, Ponnampalam, et al., 2015), without the drawbacks of traditionally methods which involve the extraction and purification of FAs which are costly, destructive, time consuming and requiring large amounts of chemicals and extensive sample preparation. The Raman spectroscopy was also considered valid to discriminate between tough and tender fresh lamb SM muscles using the intensity of spectral peaks that correspond to the tyrosine doublet at 826 and 853 cm^{-1} and α-helix at 930 cm^{-1} (Fowler et al., 2014b).

Most of the work performed with sheep used a handheld Raman spectroscopic device where its sensor head is in a robust waterproof casing (Fig. 4). This device was developed in Germany (Schmidt, Sowoidnich, Maiwald, Sumpf, & Kronfeldt, 2009) and was described as a better versatile approach for application in the meat industry than a benchtop instrument (Craigie et al., 2015; Fowler et al., 2018). Moreover, the fact that this technique requires almost no sample preparation is not influenced by variation in water content and is very fast to analyze a sample, makes Raman spectroscopy suitable for in line use in the meat industry (Fowler et al., 2018; Schmidt et al., 2013).

As for other spectroscopic techniques Raman spectra contain many dependent variables, so multivariate analysis techniques are required for prediction of meat quality attributes. The Partial least squares discriminant analysis performed well for classification (Beattie et al., 2007) and the PLSR has been the most used multivariate analysis method with this technique (Fowler et al., 2018).

Fig. 4 Application of a handheld Raman spectroscopic device to a meat sample.

When compared with other spectroscopic techniques (NIRS or HSI), there has been relatively limited research with Raman spectroscopy for meat quality prediction and meat classification in sheep and goat species. The inconsistent results did not adequately demonstrate the ability of this technique to assess the meat quality of sheep and goat. However, before Raman spectroscopy can be adopted extensively in the industry, more research is needed to identify the best meat quality attributes to predict and identify factors that are contributing to the differences between predictive models. Nevertheless, as technology advances, it is expected that Raman spectroscopy is one of the techniques of choice for evaluating meat quality.

3. NEW SHEEP AND GOAT MEAT PRODUCTS

Small ruminants' meats are traditionally worldwide consumed and particularly in Mediterranean countries. Consumers prefer young or light sheep and goats animals' meat (Risvik, 1994; Rodrigues & Teixeira, 2010), characterized as tenderer when compared to older or heavier animals (Rodrigues & Teixeira, 2009). This type of meat is consumed as fresh meat, mainly roasted or grilled.

Meat from older and heavier animals has very low acceptability and market value, due to its hardness, poor structure and, normally, unpleasant taste and aroma. Occasionally, it is consumed in traditional dishes cooked for long time and very seasoned. Such meat is more suitable to process as drought, cured with salts or smoked meat products (Webb, Casey, & Simela, 2005), and new products can be produced. In the last years, there have been several studies concerning the incorporation of meat from culled sheep and goats in processed products, nuggets (Banerjee et al., 2012; Das, Anjaneyulu, Gadekar, Singh, & Pragati, 2008), dry-cured sheep and goat meat (Costa et al., 2011; de Andrade et al., 2017; Teixeira et al., 2011), *mantas* (Oliveira et al., 2014; Ortega, Chito, & Teixeira, 2016), fermented sausages (Cosenza, Williams, Johnson, Sims, & McGowan, 2003; Nassu, Aparecida, Gonçalves, & Beserra, 2002; Nassu, Gonçalves, & Beserra, 2002; Nassu, Gonçalves, Pereira da Silva, & Beserra, 2003; Stajić, Stanišić, Perunović, Živković, & Žujović, 2011), fresh sausages (Leite et al., 2015; Paulos et al., 2015), cured legs (Pugliese et al., 2009; Sañudo et al., 2016; Stojković et al., 2015; Teixeira et al., 2017; Tolentino, Estevinho, Pascoal, Rodrigues, & Teixeira, 2017; Villalobos-Delgado et al., 2014), pâtés or other patties (Amaral et al., 2015; Dalmás, Bezerra, Morgano, Milani, & Madruga, 2011; Devatkal, Narsaiah, & Borah, 2010; Dutra et al., 2013; Villalobos-Delgado et al., 2015), or mortadella (Guerra et al., 2011). All those processed products gave added value to meats in view that they would not be well accepted by consumers as raw meat. In this section the physicochemical, sensory and microbiological analysis were made.

3.1 Physicochemical Quality

In the last two decades, several studies evaluating the physicochemical characteristics of those new sheep and goats' products were done. The main physicochemical attributes studied by the several authors are summarized in Table 11.

Studying the effects of ageing, salting and air-drying in goat meat, Teixeira et al. (2011), and comparing sheep and goat meat Ortega et al. (2016), both observed significant differences in meat color, referring that changes of a* and b* reflected the myoglobin oxidation during refrigeration and ageing processes. Also, salting and air-drying affected the C* and H* parameters and meat became darker. Very important for the final product preservation was the water activity (aw) reduction with salting and air-drying processes verified by the referred authors. The ageing process also promoted the toughness reduction, observed by a decrease in shear force. Salted goat and lamb meat obtained from heavier carcasses can have a leverage with the higher dressing yield (Costa et al., 2011). These products have high protein and a low balanced fat content (Costa et al., 2011; Oliveira et al., 2014). Oliveira et al. (2014) also reported the resistance to oxidative processes of both goat and ewe mantas.

Stajić et al. (2011) compared the use of beef vs goat meat in fermented sausages and observed no significant differences in terms of physicochemical parameters between the two variants at the end of production., except for a* value (11.72 beef and 14.15 goat). Similar results were registered by Lu et al. (2014).

Dutra et al. (2013) reported that increasing the substitution of pork meat by meat from adult sheep ham-type pâtés affected only the characteristics related to the increase in the concentration of total heme pigments. Increasing the amount of sheep meat in the formulation resulted in darker pâtés with a more intense red color.

A new sheep meat product (dry-cured lamb leg) was studied by Villalobos-Delgado et al. (2014) and tumbling and ripening time effects were considered. Conclusions from this study were that quality of dry-cured

Table 11 Summary of Principal Studies on Physicochemical Evaluation on the New Products From Sheep and Goat Meats

Attributes	Product	Effects	Reference
L*a*b* color, aw, pH, Water Holding Capacity, DO* (myoglobin), Shear Force	Goat *longissimus thoracis et lumborum*, *subscapular* and *semimembranosus* muscles	Aging, salting and air-drying	Teixeira et al. (2011)
Moisture, ashes, protein, lipids	Salted goat and lamb meat	Any (only descriptive)	Costa et al. (2011)
pH, aw, protein, moisture, ash, TBARS	Ewe and goat meat cured product: manta	Species	Oliveira et al. (2014)
pH, aw, Water Holding Capacity, texture, L*a*b* color	Ewe and goat meat cured product: manta	Species, aging, sampling area, salting	Ortega et al. (2016)
Aw, pH, ash, moisture, protein, total fat, fatty acids	Sheep and goats' fresh sausages with different levels of pork fat	Species, fat level	Leite et al. (2015)
Moisture, ash, protein, lipid, starch, chloride, emulsion stability, WHC, pH, aw, L*a*b* color	Goat mortadella with different levels of fat and goat meat from discarded animals	Lipid %	Guerra et al. (2011)
Moisture, NaCl, aw, protein, fat, ash, pH, free fatty acids, water soluble nitrogen, volatile compounds	Dry-cured lamb leg	Tumbling, time	Villalobos-Delgado et al. (2014)
Water, protein, lipids, ash contents, pH, aw, TBARS, heme pigments, L*a*b* color	Cooked ham-type pâté elaborated with sheep meat	% of adult sheep meat to replace pork meat	Dutra et al. (2013)
pH, aw, moisture, protein, lipids, L*a*b* color, nitrites	Lamb pâté prepared with "variety meat"	Storage time and packaging	Amaral et al. (2015)
pH, aw, moisture, NaCl, L*a*b* color, protein, collagen, fat, cholesterol, fatty acids, TBARS	Sheep and goat cured legs	Species, salting, ripening	Teixeira et al. (2017)

Continued

Table 11 Summary of Principal Studies on Physicochemical Evaluation on the New Products From Sheep and Goat Meats—cont'd

Attributes	**Product**	**Effects**	**Reference**
Moisture, ash, lipids, protein, carbohydrates, acidity, pH, aw, L*a*b* color	Lamb pâté prepared with "variety meat"	Different formulations (goat meat 20%)	Dalmás et al. (2011)
TBARS, proteincarbonyls, pH, L*a*b* color	Lean lamb patties	Addiction of hop (infusion or powder), storage period	Villalobos-Delgado et al. (2015)
Weight loss, pH, non-protein nitrogen content, basic chemical composition, instrumental color	Goat meat fermented sausage (Sucuk)	Species	Stajić et al. (2011)
pH, hardness, springiness, cohesiveness, adhesiveness, L*a*b* color	Sheep meat fermented sausage	Species	Lu, Young, and Brooks (2014)
Moisture, protein, fat, ash, pH, water activity, moisture/protein ratio, TBARS	Goat meat fermented sausage	Natural antioxidant percentage	Nassu et al. (2003)
pH, aw	Sheep and goat cured legs	Species, seasoning time	Tolentino et al. (2017)

lamb legs was mainly affected by processing time: moisture decreased, and protein, fat and ashes contents increased from day 1 to day 71. Also, pH, free fatty acids and water-soluble nitrogen increased with processing time. In a similar product studied by Teixeira et al. (2017) conclusions were that pH (5.7–5.8) and aw (0.87 and 0.83) values, which are comparable to those found by Tolentino et al. (2017), showed that goat and sheep cured legs can be a safe product with shelf life stability in relation to microbial growth. The high protein (46.2% and 38.4%) and low fat (5.3% and 8.7%) percentages show that the effect of salting and ripening processes makes the goat and sheep cured legs an interesting and nutritionally balanced meat product with a low cholesterol content and PUFA/SFA (P/S) and n-6/n-3 ratios within the guidelines recommended by the several world food organizations.

Leite et al. (2015) studying the effect of adding different pork fat levels to sheep and goats' meat fresh sausages found significant differences between species and fat levels addition in all physicochemical attributes. Pork backfat addition modified the fatty acid profile, prompting a significant reduction in the relative percentages of major fatty acids. With the addition of pork fat an increase in oleic and linoleic acids and PUFA/SFA ratio was observed. Authors pointed out that the ratio PUFA n6/n3 is impaired with the addition of pork backfat.

Effect on the quality of lamb pâté prepared with meat having different storage times and packaging was studied by Amaral et al. (2015). These authors observed a significant effect of the storage time, but not of the packing method, on the product stability. In this study, the lamb pâté also lead to a reduction in moisture content, protein, pH, aw, nitrite and redness intensity (a*), and a slight increase in luminosity (L*), yellow intensity (b*), TBARS and texture parameters.

To overcome the disadvantages of using synthetic antioxidants, several studies were made to study the effect of natural antioxidants in sheep and goats' new products. For example, in goat meat fermented sausages Nassu et al. (2003) studied the effect on lipids oxidation of two different levels of a natural antioxidant (Rosemary, 0.025% and 0.05%) and concluded that the formulations containing 0.05% rosemary showed the best characteristics in relation to oxidative stability, with the lowest initial values for TBARS. Antioxidant effects of fruit extracts were evaluated by Devatkal et al. (2010) on goat patties, who concluded that kinnow rind powder (KRP), pomegranate rind powder (PRP) and pomegranate seed powder (PSP) had potential to be used as natural anti-oxidants in meat products. The antioxidant potential of broccoli powder extract (BPE) was evaluated and validated in goat meat nuggets by Banerjee et al. (2012). Hop powder and hop infusion antioxidant activity were studied in lamb patties by Villalobos-Delgado et al. (2015). The addition of hop improved lipid and color stability of raw patties during refrigeration and frozen storage, although the improvement was stronger in refrigerated-stored patties. Similarly, the use of hop appeared to reduce lipid and protein oxidation of cooked patties during refrigerated storage. Hop powder showed higher antioxidant effect than hop infusion.

The overall results indicate that the use of meat from adult or discarded sheep and goats in the preparation of new products could be an alternative to the traditional use of these meats, generating new products with physicochemical characteristics that comply with the legislative recommendations and exhibit quality and acceptance values similar to those of traditional products, while conferring higher added value to the productive sector.

3.2 Sensory Quality

The final objective of a new product is to accomplish demands and expectations of consumers. Besides the physicochemical analysis of the new products, their organoleptic characteristics and how consumers will accept them should be evaluated. Sensory analysis is the best way to study and predict food products acceptance by consumers. When studying the quality of new sheep and goats' products, several authors made their sensory evaluation, by stablishing a sensory profile by trained taste panels and/or evaluating likings or preferences by consumers.

Table 12 summarizes the main sensory studies performed on new meat processed products incorporating sheep and goat meat.

The possibility of the use of goat meat in the production of traditional sucuk (a traditional Turkish style dry-fermented sausage of ground meat, usually beef) was studied by Stajić et al. (2011), and the authors observed no significant differences in cut appearance, color and odor. However, in terms of appearance, texture and taste, evaluated in a 9 points scale from 1 (extremely unacceptable) to 9 (extremely acceptable) assessors gave smaller grades to goat than beef sucuk, but they also refer that those grades were higher than 5. The authors suggested the replacement of goat fat by beef fat, to appease the specific goat flavor, to make the product more acceptable to consumers that may not be used to such flavor.

Villalobos-Delgado et al. (2014) evaluated the effect of tumbling after dry-salting and processing time on the sensory characteristics of dry-cured lamb legs. They found no differences between Control, short tumbling,

Table 12 Summary of Principal Studies on Sensory Evaluation on New Products From Sheep and Goat Meat

Number of Panelists	Attributes	Product	Training	Scale	Reference
12	Flavor (saltiness, bitterness, lamb flavor, pungent flavor); Texture (harness, juiciness, pastiness)	Dry-cured lamb leg	Previous experience and 2 1-h sessions	1—lowest to 5—highest	Villalobos-Delgado et al. (2014)
9	Appearance, cut appearance, color, odor, texture and taste	Dry-fermented sausages (goat and beef)	Previous experience	1—extremely unacceptable, 9—extremely acceptable	Stajić et al. (2011)
9	Taste, flavor, texture and appearance	Sheep and goat dry-cured legs	Previous experience and specific training	10-cm continuous, left anchor—lowest intensity, right anchor—highest intensity	Tolentino et al. (2017)
10	Appearance (color, fat color, marbling and brightness), aroma (intensity, meat, acid, sweet, rancid, cured), taste (intensity, persistence, meat, rancid, salty, sweet, acid, cured) and texture (hardness, fibers feeling, and juiciness)	Sheep and goat cured legs	Previous experience and specific training	10-cm continuous, left anchor—lowest intensity, right anchor—highest intensity	Teixeira et al. (2017)
8	Appearance (fat yellowness, redness, marbling), texture (fat firmness, hardness, dryness, juiciness), flavor (smoke, garlic, saltiness, bitterness, acidity, mature, cured, metallic, rancid, and soapy), and aroma intensity	Dry-cured sheep hams	Trained	9-point structured scale, using quantitative-descriptive analysis	Stojković et al. (2015)

Continued

Table 12 Summary of Principal Studies on Sensory Evaluation on New Products From Sheep and Goat Meat—cont'd

Number of Panelists	Attributes	Product	Training	Scale	Reference
7	Oxidized flavor intensity (control vs hop infusion vs sodium ascorbate)	Lean lamb patties cooked (refrigerated 4 °C 3 days)	Trained two 1-h sessions	Ranking test, 5-point descriptive scale, in which 1 denoted imperceptible oxidized flavor and 5 denoted extremely high oxidized flavor	Villalobos-Delgado et al. (2015)
6	Hop flavor intensity (control vs infusion vs powder)	Freshly cooked lamb patties	Trained one half-hour session	Ranking test	Villalobos-Delgado et al. (2015)
80 potential consumers	Appearance, color, odor, flavor, goat flavor and overall acceptance	Goat mortadella prepared with different levels of fat and goat meat from discarded animals	No training	Nine-point hedonic scale where 1 = dislike extremely, 5 = neither like or dislike, and 9 = like extremely	Guerra et al. (2011)
26 non-trained individuals two sessions	Taste, spicy taste, texture and overall acceptability	Sheep and goat fresh sausages with different levels of pork fat	No training	Unstructured 10 cm scale with anchors at the extremities (0 "do not like" to 10 "like very much")	Leite et al. (2015)
30 non-trained individuals	Texture, taste, aroma, appearance, global acceptability	Goat meat fermented sausage with different levels of fat addition	No training	Hedonic nine-points scale from dislike extremely to like extremely	Nassu, Aparecida, et al. (2002)
50 non-trained panelists	Overall acceptance	Cooked ham-type pâté elaborated with sheep meat	No training	Nine-point hedonic scale (1 "less preferred than the reference," 5 "preferred equal to the reference" and 9 "preferred more than the reference")	Dutra et al. (2013)

375 individuals	Maturation time—price, smoking, sodium reduction	Dry-cured sheep ham	No training	No scale	de Andrade et al. (2017)
375 individuals	Natural antioxidant, smoking, sodium reduction	Sheep meat coppa	No training	No scale	de Andrade et al. (2017)
320 individuals (Chinese, sub-Saharan, Andeans, Spanish)	Overall acceptability	"Cecina"—dry-cured ewe legs with different fatness levels	No training	Hedonic nine-points scale from dislike extremely to like extremely	Sañudo et al. (2016)
126 consumers (58 students and the staff members from the Catering School, 40 students from the Department of Food Hygiene and Technology, 28 staff members from the Instituto de Ganadería de Montaña research centre)	Flavor score/liking	Lean lamb patties	No training	Structured hedonic scale ranging from 1—extremely disliking and 9—extremely liking	Villalobos-Delgado et al. (2015)
60 consumers	Liking of flavor	Sheep meat fermented sausage	No training	9-point category scale ranging 1 (dislike extremely) to 9 (like extremely)	Lu et al. (2014)

ST and long tumbling, LT, except for pastiness, although the authors suggested the higher pastiness of tumbled legs would not be so strong as to be considered a defect of eating quality.

The production process and quality of two different dry-cured sheep hams from Western Balkan countries were studied by Stojković et al. (2015) and significant differences in volatile compounds content and sensory properties between sheep ham produced in different locations (Bosnia and Herzegovina—B&H, and Montenegro—MN) were found. B&H production differed from MN in: duration of smoking (14 vs 7 days), ripening time in air (7 vs 14 days) and additives; B&H hams were added garlic and peppercorn. Sheep ham from MN had a strong smoke flavor (from furans and phenols) and salty taste. B&H sheep hams were rich in sulfuric compounds due to added garlic, with less salty taste. The salting phase of the B&H ham seemed to involve fermentation and may be of critical importance for the safety of low salt dry cured ham production.

Villalobos-Delgado et al. (2015) studied the effect of hop as an antioxidant on lean lamb patties and tested the flavor and oxidized flavor intensity by a trained taste panel. The conclusions were that panelists found control (no antioxidant) patties as those with highest oxidized flavor intensity, showing that hop can be used as an ingredient in patty making to minimize the flavor deterioration through oxidation. Also, patties had higher flavor intensity when hop was used as a powder than when used as infusion or not used at all.

Sensory characteristics of sheep and goat cured legs were studied by Tolentino et al. (2017). Nineteen attributes of appearance, taste, aroma and texture were evaluated, and the conclusions were that significant differences among the treatments were found by the panelists. Goats legs were characterized as harder and less juicy than sheep legs and sheep meat with longer time of cure was the brightest and sheep meat with smaller time of cure the most succulent. Goat meat presented higher values of rancid and acid flavor, and sheep meat submitted to more seasoning time presented the most intense flavor and sheep in less time had the lowest intensity in all the attributes of taste. The sensory profile and the differences between sheep and goat cured legs were also evaluated later by Teixeira et al. (2017). These authors showed that the attribute that discriminates the best among sheep and goats cured legs are related to texture: hardness, followed by juiciness, adhesiveness and fibers feeling, and the least discriminating between one product and another is the acid taste, aroma intensity and marbling. Results from both studies indicate sheep and goat cured legs as tender, juicy, with median tastes and aromas, and with a dark color.

A sensory evaluation throughout acceptance and purchase intention of goat mortadella with different fat and goat meat percentages by 80 potential consumers was performed by Guerra et al. (2011). Their results showed that an acceptable value-added goat meat product can be produced, considering that all the formulations were accepted and sensory evaluated. The goat mortadella with less percentage of fat and more goat meat was the preferred choice of the consumers for all the studied sensory attributes, except for texture.

Lu et al. (2014) compared the sensory characteristics of fermented, cured sausages made from equivalent muscle groups of beef, pork, and sheep meat. They stated that the last had no commercial examples and represented an unexploited opportunity once have observed no significant differences between species in mean texture (hardness, springiness, adhesiveness, cohesiveness) following anaerobic fermentation (96 h, 30 °C), and only minor differences were observed in color. However, the same authors referred that although not consumer tested, it is argued that consumers would be able to pick a texture difference due to different fat melting point ranges, highest for sheep meat. Lu et al. (2014) also performed a sensory evaluation to understand if the peculiar sheep meat flavor could be covered or even eliminated to please consumers unused with this type of product. They simulated a very strong characteristic producing a mixed sheep meat and beef sausage, spicing it, or not, with 4-methyloctanoic, 4-methylnonanoic acid, and skatole (5.0, 0.35, and 0.08 mg/kg, respectively). They also, variably, added sodium nitrite (at 0.1 g/kg) and a garlic/rosemary flavor. Spiked sheep meat flavor caused an overall significant decrease from 5.83 to 5.35 in mean liking on a 1–9 scale using 60 consumers, but an increase from 5.18 to 6.00 was observed when garlic/rosemary was added (Lu et al., 2014). Nitrite had no effect on liking (5.61 vs 5.58). Conclusions suggested that "sheep meat flavor could be suppressed to appeal to unhabituated consumers. Commercial examples could thus be made for these consumers, but the mandatory use of the name 'mutton' in some markets would adversely affect prospects."

When writing about fermented products, particularly fermented sausages, the use of starter cultures should be considered. Everson, Danner, and Hammes (1970) had referred that the right physiologically active starter culture would improve the uniformity of fermented products in terms of flavor, appearance and texture. Sensory evaluation of fermented mutton sausage, using *Pediococcus acidilactici* H and *Lactobacillus plantarum* 27 as starter cultures, had shown acceptable scores after 60 days of storage at 4 °C (Wu, Rule, Busboom, Field, & Ray, 1991). The use of different starter cultures in the processing of goat meat fermented sausages by Nassu, Gonçalves, and Beserra (2002) produced average values between 5.5 and 5.9 for global sensory acceptability, using a 9 points hedonic scale. Global acceptability, aroma, taste and texture mean values presented no significant differences for all treatments, but appearance had the smallest value when the treatment with SPX (*Staphylococcus xylosus* and *Pd. pentosaceus*) culture was used. The authors referred the use of isolated observations from the judges as "rancid," "soap," which can be attributed to the products fat oxidation or even to the lipolytic action of microorganisms present in the cultures used. Using lactic starter cultures of *Lb. casei*, *Lb. plantarum* and *Pd. pentosaceus* (Mukherjee, Chowdhury, Chakraborty, & Chaudhuri, 2006) studied the effect of fermentation and drying temperature on the characteristics of goat meat (Black Bengal variety) dry sausages. Results were that the samples fermented at 30 °C, followed by drying at 10 °C, were the most acceptable samples regarding sensory characteristics as taste, flavor, texture and overall acceptability in a 5 points hedonic scale.

Consumers and processors are concerned about the safety of synthetic food additives, as some products like synthetic antioxidants used to mask or improve sensory characteristics can have health implications. So, a renewed interest in natural antioxidants and its research has increased. The use of additives in fermented sausages can improve sensory characteristics, as registered by Nassu et al. (2003). In a study on using goat meat in processing of fermented sausage, salami type, they observed that the incorporation of rosemary minimized oxidized goat aroma and flavor. Also, Paulos et al. (2015) observed that the use of paprika had an influence on the presence and intensity of flavor, spiciness, and off-odor in sausages made from heavy sheep and goat meat when studying their sensory characteristics. Sausages without paprika presented higher spicy intensity, flavor intensity, and off-flavor than sausages with paprika, which had higher odor intensity and sweetness. Paprika masks the less pleasant sensory characteristics of this type of meat. Related to species, these authors found that goat sausages were harder and more fibrous, while sheep sausages were juicier. Besides the effect of additives on sensory characteristics, results of Paulos et al. (2015) show that consumers generally accepted fresh sausages made of sheep and goat meat, with an average of 6 in a scale of 10, and no marked preferences were observed for sheep, goat or seasoning, used to mask some unpleasant characteristics like taste, odor or flavor.

The hedonic test performed by Villalobos-Delgado et al. (2015) on the effect of using hop as an antioxidant in lean lamb patties revealed significant differences in flavor acceptance between powder and both control and infused patties. Control and infused patties flavors were better scored than powder patties flavor. Hop is characterized by an intense smell and a bitter taste for which the numerous components of its essential oil and resin are responsible (Canbaş, Erten, & Özşahin, 2001; Steinhaus, Wilhelm, & Schieberle, 2006).

When processing meat products, fat addition can be an important matter. Verifying the addition of diverse fat contents (5%, 10% and 20%) effect on the sensory acceptance of a goat meat fermented sausage, Nassu, Aparecida, et al. (2002) observed no significant differences in the measured sensory attributes (appearance, aroma, taste, texture and global acceptability) using a 1–9 hedonic scale. Also, no significant differences were found by Dutra et al. (2013) in consumers preferences when studying the effect of meat replacement (pork by adult sheep meat) on cooked ham-type pâté elaborated with sheep meat. However, Leite et al. (2015) refer that overall acceptability was significantly affected by fat level and species of sheep and goat sausages. The goat sausages manufactured with higher fat content presented the highest scores of consumers' preference.

In a cross-cultural study of dry-cured sheep meat acceptability by native and immigrant consumers in Spain, Sañudo et al. (2016) concluded that "'cecina' from cull ewes was well accepted by the consumers independently from their cultural background and even when considering very low consumption rates of lamb. In general, the finishing level (fatness) of the animals was not a criterion to modify overall acceptability, although some groups of consumers prefer lean animals. Given its good overall acceptability and its economic advantages in comparison with the fresh product, it is evident that the production of 'cecina' would have a positive economic outcome for breeders".

Results from de Andrade et al. (2017) work showed a significant impact of process parameters on consumer choice for processed sheep meat dry-cured products. These authors reported that consumers have a positive attitude toward salt reduction and the use of natural antioxidants which can stress the development of improved meat processing techniques based on scientific knowledge offering potential benefits for both the meat industry and public health. Also, when understanding consumer perception for this type of products de Andrade et al. (2017) reinforce the need to include consumption contexts, as snack or as an appetizer with friends, which can lead to different results.

Effect of storage time and packaging on the quality of lamb pâté prepared with "variety meat" was studied by Amaral et al. (2015). Conclusions from this study were that "considering the trend toward the use of edible by-products, the preparation of pâtés is a viable alternative to add value to lamb 'variety meat', as well as providing greater profitability. As for stability, the lamb pâtés showed good microbiological quality being fit for human consumption, therefore met the requirements of the legislation, however, its shelf life was limited by decrease in sensory attributes texture and overall impression."

Generally, studies based on new sheep and goat meat products lead to the conclusion that such unique processed meat products, especially the ones with healthy claims, could represent opportunities for the sheep meat chain in general. Producers, industry and society would benefit from the development of better quality products that can satisfy modern market demands. Further research should be conducted to study how consumers perceive the sensory and hedonic characteristics of these products.

3.3 Food Safety

Food safety is a major concern for consumers and a major concern for the industries. When talking about food safety, microbiological safety is the most discussed, and to assess it several procedures and analysis are performed in order to achieve the safety and quality of food involved to safeguard public health and provide assurance on food safety (Centre for Food Safety, 2007), but microbiological analysis alone cannot guarantee the safety of food and microbiological criteria should be used to support good hygienic practice (GHP), good manufacturing practices (GMP), good agricultural practices (GAP) and implementation of food safety risk management systems such as hazard analysis and critical control point (HACCP) systems (Health Protection Agency, 2009; van Schothorst, Zwietering, Ross, Buchanan, & Cole, 2009). Microbiological safety plays an important role to be taken both by government and food industry for identifying, assessing and managing risks associated with the consumption of food and drink (Stringer, 2005). To accomplish their roles, the authorities can and should follow the recommended stepwise by International Commission on Microbiological Specifications for Foods (ICMSF, 1997), for the management of microbiological hazards in foods in international trade, applying existing Codex documents in a logical sequence (van Schothorst, 1998).

Fermentation and drying have been reported as the oldest methods for food preservation and consequently the consumption of these products by humans dates from immemorial times (Nassu et al., 2003). According to Bourdichon et al. (2012) fermentation plays different roles in food processing and the major roles related to food safety are (1) Preservation of food through formation of inhibitory metabolites such as organic acid (lactic acid, acetic acid, formic acid, propionic acid), ethanol, bacteriocins, etc., often in combination with decrease of water activity (by drying or use of salt) (Gaggia, Di Gioia, Baffoni, & Biavati, 2011; Paul Ross, Morgan, & Hill, 2002); (2) Improving food safety through inhibition of pathogens (Adams & Mitchell, 2002; Adams & Nicolaides, 1997) or removal of toxic compounds (Hammes & Tichaczek, 1994). Recent studies focused on fermented foods, including fermented meat products, proved that these products are an excellent source of microorganisms with probiotic characteristics (Marco et al., 2017). In a study on the effect of curing and fermentation on the microflora of meat of various animal species (cattle, wild boar, deer, goat and horse), the inhibitory effect of aw, pH and the produced lactic acid bacteria (LAB) on the pathogenic bacteria was observed during the fermentation process (Paleari, Bersani, Moretti Vittorio, & Beretta, 2002). In the raw materials, the referred authors noted the normal flora as the presence of *St. aureus* and coliforms in all the samples and none had *Salmonella* or *L. monocytogenes*. Nevertheless, at the final of the fermentation process, an increase of LAB that exerts an antagonistic action on contaminating flora was noted.

Dominant volatiles in MN sheep hams were smoke components (furans and phenols), acids, aldehydes, alcohols, and esters (Stojković et al., 2015). This fact suggests that smoking process could be better controlled in an industrial facility. Furans and derivates are classified by the International Agency for Research on Cancer (IRAC, 1995) as possible carcinogenic compounds. Increased attention is paid to their derivates (furan, 2-furfural, furfuryl alcohol, and penthylfuran), which are considered toxic for human and animal health (Perez-Palacios, Petisca, Pinho, & Ferreira, 2012).

The final content of 4.5% NaCl (or lower) in sheep ham is challenging in terms of unwanted bacterial growth, but preferable regarding health recommendations (Stojković et al., 2015). Salt content depends on production practices; for Spanish lamb ham Villalobos-Delgado et al. (2014) reported 7.96% NaCl and water activity (aw) of 0.88, for dry cured legs Teixeira et al. (2017) found values of 3.8% NaCl and aw of 0.83 on goats, and 4.7% and 0.87 on sheep, after salting and ripening processes. The pH and aw values found showed that processing could have an important role in controlling the meat spoiling promoting safety and shelf life stability of the products with respect to microbial growth. For Norwegian Fenalår (dry-cured lamb or sheep leg) 5–10% NaCl was registered (Håseth, Thorkelsson, Puolanne, & Sidhu, 2014). Skerpikjøt (air-dried and unsalted lamb meat product) with aw value 0.90 has no salt addition (Håseth et al., 2014), which was linked directly to incidences of botulism (Stojković et al., 2015).

4. CONCLUSIONS AND FUTURE TRENDS

The growing demand for sheep and goat meat products, in recent past, has been driven mainly by animal science and technology, especially regarding production systems, slaughter procedures and carcass fabrication and grading, meat processing, food quality and safety as well consumer preferences and satisfaction.

Technological developments will continue to contribute to a higher efficiency of procedures and better quality in sheep and goat meat products. Because of the importance of carcass composition, ultrasonic techniques, optical and spectroscopy methods or vision image analysis systems have been and will be devised to assess it from rapid and single measurements and to use more sophisticated procedures. For research purposes, some of these techniques have been used to assess body composition in both the live animal and the carcass in sheep and goats and will continue to be studied in the coming years with redoubled interest from the producer, abattoir, retailer and meat industry. Particularly the use of computed tomography and computer vision as alternative methods to carcass dissection should be further studied and its applicability confirmed and officially recognized by the competent livestock entities. The research on the use of non-invasive and non-destructive technologies like NIRS, Hyperspectral Imaging or Raman Spectroscopy to predict food composition, to monitoring composition and physicochemical food properties during processing will be increasingly important for a higher performance in processing sheep and goat meat products. The development of general, robust, and more reliable models to swiftly assess sheep and goat carcass and body compositions should be developed in the near future, as well as the implementation of a modern and objective on-line technique for carcass evaluation and marketing classification based in the electronic technologies associated to new statistical analysis methods. The use of these technologies will be more and more important once offers the possibility to enhance the quality of processing and to improve consumer safety. However, more research should be developed to optimize and promote the use of different technologies applications in sheep and goat meat processing, reducing costs, saving energy and being environmentally friendly and at the same time ensuring the quality and food safety.

The rediscovery of a new generation of meat processed products based in sheep or goat meat associated with a developing of functional foods will be an interesting food research field meeting the new deals of meat industry.

Eating quality is also an important factor in food choice especially if it is a new sheep and goat processed product. If it looks attractive, smells good and tastes good the consumer decision to purchase is stimulated. Consequently, sensory quality studies supported by trained and consumer panels associated with different statistical analysis methodologies will always be a priority. At the same time the studies on the nutritional value of sheep and goat products should be improved contributing to product differentiation in the meat market and to add value across the meat chain, giving better information to consumers and enhancing goat and sheep meat properties of wholesome food. Additionally, everything concerning food safety should be considered in future, particularly the increasing importance of traceability and the consumer request of detailed information (from the farm to the fork) corresponding to their expectations. Quality and meat safety will undoubtedly be important issues with increasing concerns in the next future and research should be awarded of this fact.

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