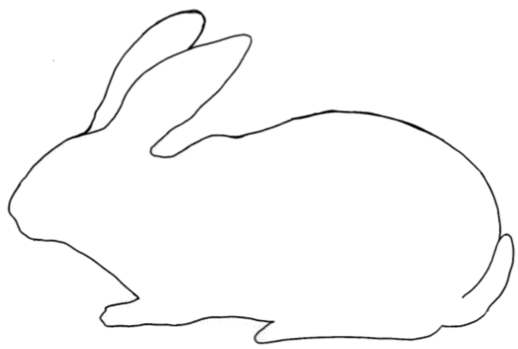
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

Gender-related differences in rabbit meat quality

Skillnader i kaninköttkvalitet relaterade till kön

Jonna Skoglund



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Skillnader i kaninköttkvalitet relaterade till kön

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Abstract

The interest in rabbit meat for human consumption is increasing in Sweden due to its good nutritional value and environmental sustainability. To meet the new interest and to optimize the production of rabbit meat it is important to know the fundamental of rabbit meat quality and what factors affecting it. Therefore, this study aimed to investigate the rabbit meat quality including colour, ultimate pH, cooking loss, tenderness, total fat content, water-holding capacity and some slaughter traits. Additionally, the possible effect of genders was evaluated.

The rabbits were fed *Kalvstart* from Edel and had free access to water and hay. On occasion the animals were given fresh branches, grass, fruit and vegetables. At an age of 17–18 weeks 24 crossbreed rabbits (New Zealand red and Champagne d'Argent, 12 males and 12 females) were slaughtered.

There was no effect of gender on slaughter traits, colour, total fat content, water-holding capacity and tenderness. The ultimate pH measured 24 hours post mortem was significantly lower in the male (5.78±0.05) compared to female rabbit meat (5.97±0.05). The cooking loss was significantly higher in males (14.59±0.47%) compared to females (10.10±0.45%). This study contributes to rise the knowledge about the fundamental properties of rabbit meat quality linked with gender; and can benefit the development of the future of rabbit production.

Keywords: Rabbit, *Oryctolagus cuniculus,* Meat quality, Gender

Sammanfattning

De senaste åren har intresset att äta kaninkött ökat på grund av dess goda näringsvärde och miljövänliga framtoning. För att möta detta nya intresse och optimera produktionen av kaninkött är det viktigt att ha kunskap om de grundläggande faktorerna som påverkar kaninköttets kvalitet. Syftet med detta arbete var därför att undersöka kaninköttets kvalitet med fokus på färg, pH 1 timme efter slakt och 24 timmar efter slakt, koksvinn, mörhet, fettinnehåll och köttets vattenhållandeförmåga, samt några slaktegenskaper. Effekten av kön på kaninköttets kvalitet utvärderade också.

Kaninerna som var en korsning mellan Stora silver och Nya Zeeland röd fick fodret Kalvstart från Edel och hade fri tillgång till vatten och hö. Sporadiskt fick djuren färska grenar, gräs, frukt och grönsaker. Vid en ålder av 17–18 veckor slaktades 24 kaniner, 12 handjur och 12 hondjur.

Kön påverkade inte slaktegenskaper, fetthalt, den vattenhållandeförmågan eller mörhet. Rådande studie visade ett signifikant lägre pH värde på kött från handjur (5,78±0,05) i jämförelse med kött från hondjur. (5,97±0,05). Koksvinnet var signifikant högre i kött från handjur (14,59±0,47%) i jämförelse med kött från hondjur (10,10±0,45%). Denna studie kan bidra till att öka kunskaperna kring de grundläggande egenskaperna av kaninkött och dess eventuella korrelation med kön, samt gynna utvecklingen av framtidens kaninproduktion.

Keywords: Kanin, *Oryctolagus cuniculus*, Köttkvalitet, Kön

Preface

Cattle grazing on the field

Holds sirloin, ribs and flank

Munching grass for higher yield

Tender meat with little spank

Chickens in barn so packed

Two fillets, drumstick, wing

Eating seeds with beaks they cracked

The meat make you sing

Rabbit jumping meadow green

Delicious legs and loin

Tastiest meat you've ever seen

Our diet it should join

-Nils Ewald, 2018

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1 Introduction

1.1 Global consumption of rabbit meat

The domesticated rabbit originate from the European wild rabbit, *Oryctolagus cuniculus* (Johansson, 2015). Historically, the rabbit has been the most important in temperate countries (McNitt *et al.*, 2013) probably due to its Mediterranean origin (Johansson, 2015). Nowadays, the rabbit is to some extent raised in all countries worldwide, either for industrial purposes such as meat production or as pets. The major producers in Europe are Italy, France and Spain where rabbit meat is considered an economically attractive alternative to the meat from larger livestock.

Worldwide rabbit meat production increased by 13% from 2006 to 2016. This increase is mainly due to a large increase in Asia's rabbit production which increased by 26% during the same period (FAOSTAT, 2017a). This reflects the fact that China is the world leading rabbit meat producer (McNitt *et al.*, 2013). In European countries rabbit production is decreasing while in Africa and America the production has been relatively constant in recent years (FAOSTAT, 2017a). The number of slaughtered chickens in Europe is approximately 60 times higher than rabbit, cattle – is 200 times higher and the number of slaughtered pigs is almost 2000 times higher than rabbits (FAOSTAT, 2017b).

In some European countries such as Malta, Cyprus, Italy, Czech Republic, Belgium, Luxemburg, Portugal and France rabbit meat is a common and much appreciated food. In Malta and Italy in 2015 the estimated annual consumption of rabbit meat per person was 8.5 kg and 5 kg, respectively. In other European countries it is less common. For example, in 2015 the estimated Swedish consumption of rabbit meat was 15 gram per person, although recently the interest in eating rabbit meat has increased (Johansson, 2015).

Rabbit meat is also to some extent consumed in Africa. In countries such as Egypt and Algeria rabbit meat is a common food (Dalle Zotte & Szendro, 2011) while eating rabbit meat in Nigeria is more rare. However some recent studies in Nigeria indicated that rabbit meat can be an economical livestock and increase protein intake (Kalio *et al.*, 2008).

Rabbits convert fibrous vegetation to energy and muscles which later become meat (McNitt *et al.*, 2013). Rabbits are well known to have high reproductive rates, early maturity (Dalle Zotte & Szendro, 2011) and a higher feed conversion ratio than other meat animals (Harcourt-Brown, 2002). Additionally, low land requirement makes rabbit meat sustainable (Ortiz Hernández & Rubio Lozano, 2001). In Sweden, the emission of CO_2 for one kilo rabbit meat is with bone is 2.6 kg. For pork meat the number is slightly higher (3.4 kg) and in beef considerable higher (19.8 kg), while chicken meat is lower (1.9 kg) (Nilsson, 2017).

1.2 Research question and aim

The preferences for consumers regarding meat quality are constantly changing. Previously, the food choices were mainly based on the balance between income and price, availability, the visual appearance and eating satisfaction. More recently, consumers are focusing on healthiness, sensory quality (Dalle Zotte, 2002) and sustainable foods (Bonamigo *et al.*, 2017). Due to the good nutritional value of rabbit meat, high reproductive rates, early maturation, high feed conversion, low land requirement and low CO_2 emissions, rabbit meat could be an excellent food that meets these modern demands.

It is unlikely the market for a high-priced rabbit would be profitable. Instead the industry should reduce the cost to be more competitive (McNitt *et al.*, 2013). To optimize the production, it is important to get the highest slaughter yield on a low cost as well as low waste and a high-quality meat. To achieve this, knowledge on fundamental properties of rabbit meat is required.

Which of the meat qualities that is the most important for the consumers, depends on various factors. According to Bailey (1972), the most important factor is tenderness although Dalle Zotte (2002) suggest that the colour is the main quality trait. Grunert (1997) states that the combination of fat content and colour is the most important product characteristic. It is hard to exactly know which the most important factor is, but it can be concluded that many sensory traits are important in some way, and a combination of great standards will result in a high-quality meat.

Therefore, the aim of the present study was to investigate rabbit meat quality including slaughter traits, colour, pH, cooking loss, tenderness, total fat content and water-holding capacity. Additionally, the possible effect of gender will be evaluated. For these purposes, meat from both male and female rabbits were used.

2 Background

2.1 Slaughter traits

Rabbits are usually slaughtered at a certain weight or age depending on the production strategy (McNitt *et al.*, 2013). To improve the characteristics of rabbit meat, it is common to crossbreed (McNitt *et al.*, 2013; Piles *et al.*, 2004). The breeding system harnesses the genetic variation to obtain better values for certain traits (McNitt *et al.*, 2013). Common traits are higher daily weight gain, better slaughter traits and a higher feed efficiency (Piles *et al.*, 2004). The most common breed for meat production is the New Zeeland white, and the second most common breed is the Californian. They are used for their many desirable characteristics such as high growth rate, good carcass quality and prolificacy. Crosses between New Zealand and California is also common (McNitt *et al.*, 2013). Other commercial breeds such as Champagne d'Argent, Dutch and Chinchilla are varieties which are used to a minor extent for crossbreed or are purebreds. All mentioned breeds belong to the larger rabbit varieties, used for meat production. The ideal weight at slaughter is between 4.5 and 5.0 kg (Johansson, 2015) and about 66% of the animal consist of muscle and eatable parts (Ouhayoun & Dalle Zotte, 1993). The most common cuts that are used for human consumption is the back piece, which is called loin and the legs. Slaughter traits that are monitored commonly evaluated in studies, are carcass weight, slaughter ratio, yields and different ratios such as bone-to-meat ratio or head ratio (Palka *et al.*, 2016; Dalle Zotte & Paci, 2014). To obtain both a financially and environmental sustainable meat it is important to have high slaughter ratio especially when the goal is to produce a meat with a high yield at low cost (Ouhayoun & Dalle Zotte, 1993).

The determination of sex is usually made based on the clear descended testicles on entire males that shows at 10–12 weeks. Besides the testicles, the bucks tend to be larger and they have broader heads. The does often have a dewlap that characterizes them (Harcourt-Brown, 2002).

2.2 Nutrition value

Rabbit meat has a high nutritional value (Dalle Zotte & Szendro, 2011) with a total mineral content of 1.2±1.5% and high protein content about 21.0 ±1,5% in fresh meat (Combes, 2004). Rabbits also have a high conversion of proteins and can convert 20%, which is slightly higher than pigs that convert 18% (Eriksson, 2013), and cattle 9–12% (Nistor *et al.*, 2013). Due to the high nutritional value, rabbit meat was suggested as a functional food. It is mainly due to its low content of sodium (49mg/100g) and high content of phosphorous (277mg/100g), and also its favourable fat constituents with low mono-saturated fatty acids levels high levels of poly-unsaturated fatty acids, including n-3 fatty acids. Moreover rabbit meat is a good source of vitamins B (Dalle Zotte & Szendro, 2011; Combes, 2004). The nutritional value together with the low fat and high protein content makes rabbit meat an excellent part of a human diet (Table 1.)(Adrian *et al.*, 1981). Rabbit meat has a rather high energy value of 603kJ/144kcal in the loin and 899kJ/215kcal in the fore legs per 100g. The high energy value depends on the protein content that contributes to about 80% of the energy (Dalle Zotte & Szendro, 2011). The nutrition values vary considerably between different muscles, for example the fat content can vary between 0.65±0.4% in the *longissimus dorsi* (Metzger *et al.*, 2003) to 9.2±0.39% in a part of the hind leg (Nistor *et al.*, 2013).

Table 1. *Nutritional values from studies on rabbit meat. The analysis are made on unspecified muscle expressed as Mean ± SE (Baiomy & Hassanien, 2011; Ghosh & Mandal, 2008) or on the hind leg expressed as Mean ± SD (Nistor et al., 2013; Metzger et al., 2003)*

	(Baiomy & Hassanien, 2011)		(Ghosh & Mandal, 2008)	(Metzger *et al.*, 2003)		(Nistor *et al.*, 2013)
	Male	Female		Cage	Pen	
Moisture (%)	69.9±1.51	70.3±1.49	70.0±1.49	73.9±0.	75.0±1.1	68.5 ±1.05
Protein (%)	20.6±1.06	20.1±1.12	20.3±0.74	21.5±0.3	21.3±0.4	21.2±0.79
Fat (%)	7.99±0.44	7.75±0.42	7.81±0.29	3.36±0.1	2.48±1.1	9.2 ±0.38
Ash (%)	1.01±0.07	0.96±0.09	0.93±0.06	1.31±0.06	1.29±0.07	1.1 ±0.08

2.3 Meat colour

One of the most important factor affecting consumer choice of meat is its colour when raw (Dalle Zotte, 2002). It is also the first sensory property the consumer perceives when judging the appearance of a fresh piece of meat (Maj *et al.*, 2012). Since consumers associate freshness and quality with a species-specific colour it is essential to meet the consumer demands to avoid rejection at purchase (Dalle Zotte, 2002), therefore colour stability is of utmost importance in meat (Font-i-Furnols & Guerrero, 2014). The colour intensity of rabbit meat is considered the lightest among meat production animals, thus the colour intensity is very low (Maj *et al.*, 2012).

The colour of meat depends on the amount and chemical form of myoglobin in the muscle tissue (Mancini & Hunt, 2005) which in turn depend on breed, sex, age, muscle type, feeding and slaughter strategy (Ouhayoun & Dalle Zotte, 1993). Post slaughter pH and water-holding capacity affect both colour as well as anatomical and biochemical traits such as muscle type, proportions, and glycogen and lipid content affect. During the first 24 hours post slaughter the main difference in colour in rabbits is mainly the redness and yellowness while lightness does not change as much. Therefore it has been suggested that the main reason for colour changes 24 hours post mortem is muscle proteins shifting chemically (Maj *et al.*, 2012).

CIELAB colour system is a method for colour estimation in three dimensions, were the values gives the coordinates. The three dimensions are L*, a* and b*, were L* describes lightness to darkness, a* describes redness and b* describes yellowness (Ouhayoun & Dalle Zotte, 1996).The lightness is described by the vertical coordinate L* that ranges from 0 to 100 where 0 is black and 100 is the lightest, white. The a*-value is the horizontal coordinate and ranges from 60 to 60 were 60 is red and –60 is green. the same is for b* but 60 represent yellow and –60 blue (AMSA, 1991).

2.4 Meat pH

It is important to control the pH in meat due to many reasons. For example, meat pH is known to impact the water-holding capacity and the lightness of the meat. The greater pH-drop results in lower water-holding capacity and lower pH will give rise to a lighter meat (Ouhayoun & Dalle Zotte, 1993). It has also been linked to tenderness and affect the eating quality (Wang *et al.*, 2016; Ouhayoun & Dalle

Zotte, 1996). Furthermore, pH is important from a microbiological point of view. For rabbit meat, pH value of 6 or lower is considered safe, while higher values are considered unsuitable for eating (Dalle Zotte, 2002).

Since meat is a semi-solid compound the pH is measured by the H^+ concentration in the liquid phase which is balanced with the solid phase (Ouhayoun & Dalle Zotte, 1996). The first thing that happens after slaughter is that the remaining energy in the muscles is consumed and the muscles thus become more acidic (Ouhayoun & Dalle Zotte, 1993). Within a few hours post mortem, meat reaches its ultimate pH. The rate of pH-drop and the final pH value depends on muscle type and the amount of ATP in muscle (Ouhayoun & Dalle Zotte, 1996). In one animal, pH can vary with 1 pH unit depending on muscle type and location (Ouhayoun & Dalle Zotte, 1993). The red muscles which are located mainly in the fore part of the rabbit, will reach ultimate pH slower than in the structural muscles such as the loin (Ouhayoun & Dalle Zotte, 1993).

2.5 Fat content

Fat content in meat is related to the expected overall quality and healthiness (Resurreccion, 2004). A low fat content is considered attractive by the consumers (Grunert, 1997). The average fat content in rabbit meat is considered low, approximately 4g/100 g (SLV, 2017), but the content vary with muscle type (Ouhayoun & Dalle Zotte, 1996). The fat content of the loin is generally lower compared to other muscles, and varies from below 1% (Pla *et al.*, 1998; Xiccato *et al.*, 1994) up to 2.3% (Ortiz Hernández & Rubio Lozano, 2001). The highest fat content was measured in the fore leg, up to 8.8% (Dalle Zotte & Szendro, 2011). Fat content also varies with age and feed (Ouhayoun & Dalle Zotte, 1996). Compared to other animals, rabbit meat has a lower cholesterol content (Dalle Zotte & Szendro, 2011) and a more desirable omega-3/omega-6 fatty acid ratio (Combes, 2004), which is important due to a low amount of omega-3 in today's western diet (Simopoulos, 2008).

2.6 Cooking loss

Rabbit meat is mainly consumed cooked. When heating, the meat proteins start to denature at 37°C up to 75°C, depending on protein. It causes the shrinkage of the connective tissue and also shrinkage of muscle fibres, destruction of cell membranes and aggregation of sarcoplasmic proteins (Honikel, 1998). These structural changes result in a loss of both liquid and soluble components, expressed as the cooking loss of the meat, causing a less juicy meat (Aaslyng *et al.*, 2003).

Cooking loss depends on the cooking regime. A common way is cooking the meat in a closed environment such as vacuum (Dalle Zotte *et al.*, 2016a) or in a plastic bag (Cavani *et al.*, 2000), but other methods are also used for example in oven (Piles *et al.*, 2000).

2.7 Water-holding capacity

Juiciness is the sensory measurement of the feeling in the mouth when moisture is released during chewing and an indirect measurement of the moisture content (Coggins, 2012). It is dependent on both the water-holding capacity in the raw meat (Ouhayoun & Dalle Zotte, 1996) and on the loss occurring when cooking the meat. A low water-holding capacity and cooking loss will give a high juiciness (Coggins, 2012). Juiciness is important for eating quality since it contributes to a good mouth feel. Moisture release helps with the chewing process and increases the taste experience by getting flavour components to the taste buds (Aaslyng *et al.*, 2003). A low juiciness is associated with a lower eating quality of the meat. Except from eating quality the water holding capacity of the raw meat is important for meat appearance in packages. High leakage in the package may reduce the desire to buy the meat while firm meat with little or no leakage increases the attractiveness to the consumer. The fact that meat weight is the foundation of pricing, is also an important feature (Offer *et al.*, 1989).

The water-holding capacity is usually measured in raw meat using several different methods including drip loss, filter paper loss and centrifugation (Ouhayoun & Dalle Zotte, 1996).

2.8 Tenderness

At the point of consumption both visual appearance and in-mouth perception are important (Font-i-Furnols & Guerrero, 2014). In-mouth perception depends on the meat tenderness to a great extent.

Tenderness is often defined as easiness of chewing and it has been shown that a high tenderness gives rise to a feeling of freshness and increased quality perception for the consumer (Coggins, 2012). It can be measured either by a sensory panel (Ouhayoun & Dalle Zotte, 1996) or by measuring the force needed to cut the meat (Honikel, 1998), the latter being a much cheaper, quicker and easier method (Harris, 1976).The Warner-Bratzler shear force technique is the most common instrumental method for evaluating meat tenderness. It measures the maximum force needed to cut the meat and the work required (Novaković & Tomašević, 2017). The tenderness of rabbit meat has shown maximum toughness a few hours after slaughter when it enters rigor mortis. When this state has passed, tenderness increases for up to six days (Mestre Prates *et al.*, 2002).

The tenderness is dependent on structural elements in the meat such as sarcomere length, pH, water retention of the myofibrillar structure and amount of connective tissue (Ouhayoun & Dalle Zotte, 1996), which all vary between muscle type. Therefore, the tenderness also varies between muscle type. Muscles used for movement, for example the legs, often have higher amounts of connective tissue compared to structural muscles such as the loin, and therefore have a lower tenderness (Coggins, 2012).

3 Materials and method

3.1 Animals

The study was conducted during the winter 2018. Rabbit's meat samples were collected from a conventional farm located in Avesta Krylbo, Sweden. All animals were a crossbreed of Champagne d'Argent and New Zealand red. They were fed 1–1.5 dl of the commercial feed *Kalvstart* from Edel (Table 2) per animal and day and had free access to water and hay. The rabbits were given fresh branches, grass, fruit and vegetables on occasion. The male rabbits were kept 17 rabbits on 10x4 m while the female rabbits were kept on 7x3m.

Table 2. Nutritional value of the feed Kalvstart from Edel (Edelfoder, 2017)

Energy (MJ)	13
Protein (g)	200
Fat (g)	45
Starch (g)	270
NDF (g)	255
Dry matter (%)	87
Calcium (g)	11
Phosphorus (g)	8
Magnesium (g)	3.0
Vitamin A (IE)	10 000
Vitamin D (IE)	2 800
Vitamin E (mg)	60
Copper (mg)	7
Selenium (mg)	0.5

A total of 24 rabbits (12 males and 12 females) at an age of 17–18 weeks were slaughtered. The slaughter was carried out on the farm during one session, using a captive bolt pistol followed by severing of the carotid arteries and jugular vein. The weight of the body after bleeding was recorded. The skin was removed from the body, the gastrointestinal tract together with the urogenital was removed, followed by removal of head, tail and paws; the weight of the carcass was measured. The carcasses were hung in a cold room and pH (pH1) was measured 1 hour after slaughter. A pH-meter with a penetrating electrode was used and adjusted to muscle temperature at each measurement. After chilling, the loin was separated from the rest of the body. This was done by cutting between the second and third vertebrae and removing the hind legs (Figure 1). The loins were weighted, and the meat packed into plastic bags and transported to a laboratory in Uppsala.

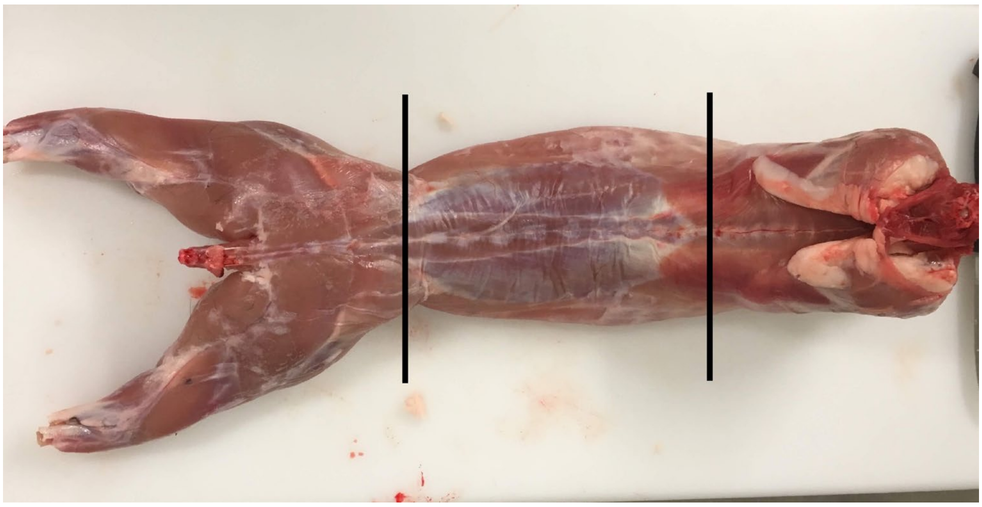

Figure 1. Cutting of the carcass. The middle part (the loin), have been used for all experiments.

The colour measurements and ultimate pH were conducted on fresh meat 24 hours after slaughter, stored in 4°C overnight. All other measurements were made on meat that been stored in a freezer at –20°C. The loin was frozen intact, except from a small muscle piece on the inside of the loin that were frozen individually. The loins were vacuum packed (Multivac A6900, Wolfertschwenden, Germany) prior to the freezing and the small muscles were packed in small plastic zip bags. The loin was used for analysis of colour, pH, cooking loss and tenderness, while the small muscle piece was used for fat analysis and water-holding capacity analysis on raw meat.

Figure 2. The loin. The marked muscles were separated from the loin and frozen individually for later analysis of fat content and water-holding capacity.

3.2 Colour

At approximately 24 hours post mortem, the colour was measured in three sites on the surface of the inside of the loin (Figure 3). The measurements were conducted using Chroma Meter CR-300 Minolta 1991 (Singapore), following the guideline (AMSA, 1991). All measurement was made before the small muscle were separated from the loin.

Figure 3. The loin. The circles indicate the site for colour measurements.

3.3 Ultimate pH

Ultimate pH was determined 24 hours post mortem. A Knick Portamess 913 X pH (Berlin) pH-meter with a penetrating electrode was used and the pH-meter was adjusted to muscle temperature at each measurement. The measurements were made on the same site on each sample, between two muscles to avoid any damage on the meat (Figure 4).

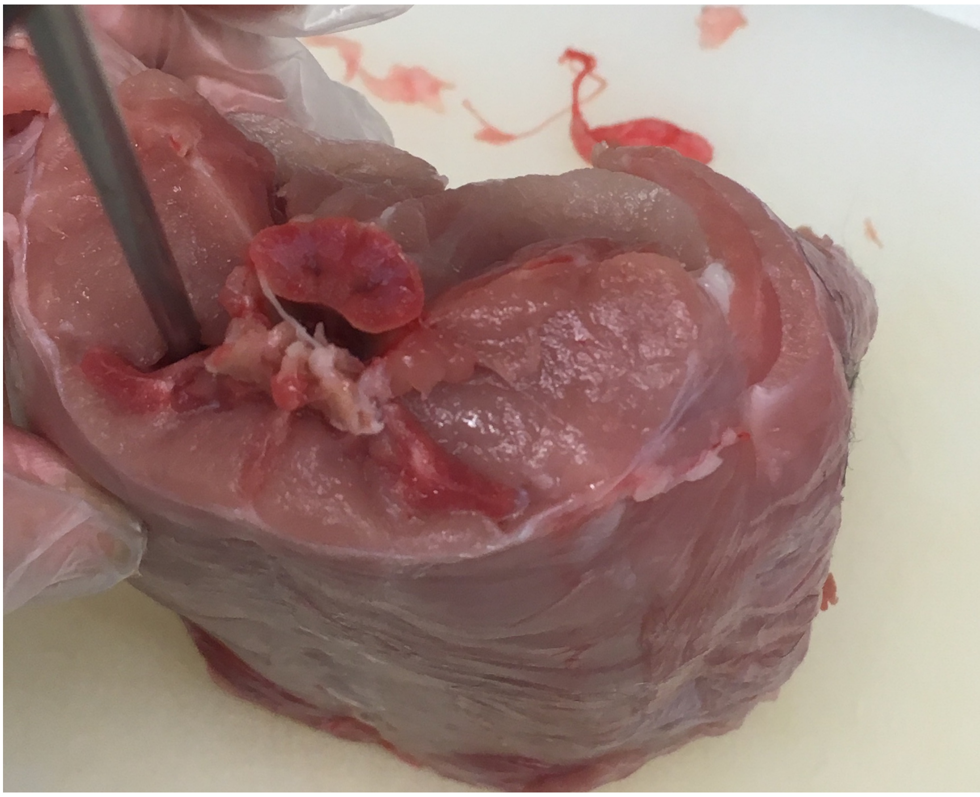

Figure 4. Site of the electrode insert spot for the ultimate pH measurements.

3.4 Fat content

The small muscle from inside of the loin was used for fat content measurements (Figure 2). The fat extraction was performed as previous described by Hara and Radin (1978) with modifications (Pickova *et al.*, 1997). A brief summary of the experimental procedure follows. Prior to analysis, the samples were stored in –20°C. Approximately 2 g of rabbit meat was semi-thawed and chopped roughly and homogenized with 15 ml 3:2 (v/v) hexane: iso propanol, (HIP) using Ultra-turrax (T25 basic, IKA-Werke, Germany). The samples were transferred to a teflon tube, 12 ml of Na_2SO_4 was added and tube well shaken. The samples were centrifuged at 1079 g for 5 minutes using a Sorvall Super T21 (SL-50T rotor, Newtown, Connecticut, U.S.A.) and the upper phase was transferred into a test tube. Hexane (2 ml) was added and centrifuged again at the same conditions. Then, the upper phase was transferred into a test tube and evaporated in a N_2 atmosphere until dry. Then, 1 ml of hexane was added, and the samples weighed on a microbalance (Mettler Toledo UMT2, Greifensee, Switzerland).

3.5 Cooking loss

The loin samples were thawed in 4°C overnight and kept in room temperature for 3 hours prior to heat treatment. The samples were cooked in a water bath (Tectron-Bio 100, Barcelona) in vacuum bags, at 70°C for 120 min with constant circulation, followed by cooling under running water for 30 min. The samples were removed from the vacuum bags, dried with paper and weighted (Flintab CountMaster 19-36 Jönköping). The samples were kept in 4°C overnight. Cooking loss was calculated by following equation:

$$\text{Cooking loss}(\%) = \frac{\text{Weight prior to cooking} - \text{Weight post cookin}}{\text{Weiaht prior to cookina}}$$

3.6 Water-holding capacity

Water-holding capacity was analysed on the small muscle inside the loin. The sample was stored in a freezer at –20ºC prior to analysis. It was thawed in 4ºC until uniform temperature and cut in pieces weighing approximate 5 g each. The weight was recorded. The sample was put between two filter papers (Munktell 00A 125mm Ø) under a weight of 2000g for 10 min and final weight was measured. The water-holding capacity was calculated by following equation:

$$\text{Water} - \text{holding capacity} = \frac{\textit{Initial weight} - \textit{Final weigh}}{\textit{Initial weight}}$$

3.7 Tenderness

The same samples as for the cooking loss analysis were used for the Warner-Bratzler shear test. Right and left *longissimus dorsi* muscles were dissected and three pieces from each muscle were cut along the fibre direction in 10 x 10mm. The shear force was measured using TA.HD*i* Texture analyser (Hamilton, MA) with a shear blade. The load cell was 50 kg and the speed 50–100mm/min. Both maximum and total forces were measured.

3.8 Statistical analysis

Statistical analysis was performed with the Statistical Analysis System, version 9.4 (SAS Institute, Cary, NC, USA). First, the distribution of the data was estimated using the Kolmogorov-Smirnov Test. Then the difference in measured parameters between meat from male and female animals were analysed using the GLM procedure (PROC GLM), the modelling gender as a fixed factor.

4 Results

4.1 Slaughter traits

The carcass weight did not differ between males and females, 1.7±0.07kg for both. Similarly, loin weight and slaughter ratio were similar in male and female animals (Table 3).

4.2 Colour

The result from the colour measurements are described by three factors L*, a* and b*. No significant differences regarding colour were observed (Table 3).

4.3 Meat pH

The pH measured 1 hours post slaughter was similar in males (6.46±0.07) and females (6.51±0.07). The pH 24 hours post slaughter was significantly lower in males (5.78±0.05) compared to females (5.97±0.05) (Table 3).

4.4 Fat content

The total fat content was similar in males (1.08±0.05 %) and females (1.10±0.0 6%) (Table 3).

4.5 Cooking loss

The cooking-loss was significantly higher in males (14.59±0.47%) compared to females (10.10±0.45%). Despite this the water-holding capacity were only slightly higher in male rabbit meat (16.19±1.01) compared to the female rabbit meat (14.51±1.01). But the difference is not significant (Table 3).

4.6 Tenderness

Neither maximum nor total forces were affected by gender (Table 3).

Table 3. *Rabbit meat characteristics from male and female animals. Described by LSM±SE*[1]

Measured parameters	Male	Female	p-value
Carcass weight (kg)	1.71±0.07	1.71±0.07	0.972
Weight loin (kg)	0.45±0.02	0.47±0.02	0.701
Slaughter ratio (%)	52.50±0.83	53.09±0.68	0.586
pH 1 h post mortem	6.46±0.07	6.51±0.07	0.582
Ultimate pH	5.78±0.05	5.97±0.05	0.008
L*	44.82±0.54	45.21±0.54	0.615
a*	–0.57±0.44	–1.67±0.44	0.087
b*	18.26±0.26	17.86±0.26	0.289
Fat %	1.08±0.05	1.10±0.06	0.849
Cooking loss (%)	14.59±0.47	10.10±0.45	0.001
Water-holding capacity (%)	16.19±1.01	14.51±1.01	0.252
Tenderness (force, N)	10.36±0.76	11.59±0.76	0.262
Tenderness (area, Nmm)	49.41±5.27	56.39±5.27	0.359

1. LSM, least square mean; SE, standard error.

5 Discussion

5.1 Slaughter traits

5.1.1 Carcass weight

In the present study, there were no significant differences in carcass weight between sexes. These results are in line with the result from previous studies (Dalle Zotte & Paci, 2014; Ortiz Hernández & Rubio Lozano, 2001; Cavani *et al.*, 2000). However, Blasco and Gómez (1993) states that male rabbits generally weight more than females. In contrast, Trocino *et al.* (2003) found that live female rabbits were significantly heavier, but produced lower slaughter ratio compared to male rabbits. These differences were explained by the higher gut contents in female rabbits.

Rabbits slaughtered at the approximate same age in a study by Cavani *et al.* (2000) had carcass weights of 1.703kg which well agrees with the present study were the mean weight was 1.71±0.07, for both males and females.

In many species males have a higher growth potential than females, but when rabbits are slaughtered prior to adult weight the differences are rarely noticeable (Ortiz Hernández & Rubio Lozano, 2001). This might be the reason for no difference between sexes regarding slaughter and carcass weight. However, in a study by Blasco and Gómez (1993) it is stated that not even at an age of 50 weeks the adult weight is reached, which means that the adult weight and a difference in carcass weight is rarely reached in the farm.

The animals used in the present study were slaughtered at an age of 17–18 weeks. When studying gender, the stage of maturity is essential. In rabbits, bucks usually reach puberty later than does (Harcourt-Brown, 2002). Since rabbits often are slaughtered at a certain age, males and females are at different maturity stages. Maturity stage and age have been proven to affect carcass weight (Hernández *et al.*, 2004).

5.1.2 Slaughter ratio

No significant difference in slaughter ratio between genders was observed in the present study. This agrees with Ortiz Hernández and Rubio Lozano (2001) and Jehl *et al.* (2000). Maj *et al.* (2009) could not find a difference in slaughter ratio between genders but found a significant breed-related differences. The slaughter ratio in the above mentioned studies ranged from 53.1 to 61.4% and according to Jehl *et al.* (2000) the slaughter ratio increases with age.

In a study by Dalle Zotte (2005), the slaughter ratio differed between males and females, where males had a higher percentage than females, 59.0% and 57.6% respectively. This is believed to be caused by a higher percentage of gastrointestinal tract in female rabbits. In a study by Dalle Zotte and Paci (2014) there was a significant difference in the weight of the gastrointestinal tract between genders but no significant difference in slaughter ratio. This indicates that the gastrointestinal tract not necessarily is always the reason for the significant difference in slaughter ratio between gender.

5.1.3 Loin weight

The present study did not show any significant differences between the genders regarding the weight of the loin. Similarly, Dalle Zotte and Paci (2014) showed no effect of gender on loin weight. However, Trocino *et al.* (2003) demonstrated that the *longissimus* muscle weights were significantly higher in females compared to males. In the current study the average weight of the loin was 0.45±0.02kg for males and 0.47±0.02kg for females. The values are slightly higher compared to those reported by Lukefahr *et al.* (1983).

5.2 Colour

The meat colour parameters measured 24 hours post mortem were not affected by gender. However, a trend towards a slightly higher a*-value in males compared to females was observed. This indicates a redder meat in males than females. Similar result was reported by Cavani *et al.* (2000) were the authors found that females had a significant lower a*-value in the *L. lumborum* 24 hours post mortem.
The majority studies reported no effect of gender on meat colour. Carrilho *et al.* (2009) determined the colour in *L. dorsi* 48h after slaughter and couldn't find any difference between genders. These results were in agreement with Maj *et al.* (2012) that did not find any significant difference in colour of the *L. dorsi* 24 hours after slaughter, and Xiccato *et al.* (1994) who concluded that there were no effects of gender on *L. dorsi* meat colour. Some studies suggested a trend towards the fact that male rabbit meat consequently has a higher colour intensity than female, but the results are inadequate. In a study of Trocino *et al.* (2003) the b*-value was significantly higher in the *L. lumborum* in females than in males, 24 hours post mortem. No difference between other colour parameters was observed in that study.

In the present study the meat was stored prior to colour measurement for 24h in 4°C. According to Honikel (1998) the meat should not be stored in temperatures higher than 3°C to avoid changes in colour. Although, since all meat was handled the same way the differences should be the same in all meat samples.

5.3 Meat pH

In present study the pH was measured both at 1h and 24h post mortem. Lazzaroni *et al.* (2009) conducted a similar experiment and reported pH at 1 hours post mortem of 6.4±0.15 in male and of 6.4±0.17 in female rabbits, which corresponds well with the current study. Neither study found an effect of gender on pH 1 hour after slaughter.

Several studies have evaluated ultimate pH, mainly measured 24 hours post mortem as in the present study (Dalle Zotte *et al.*, 2016b; Lazzaroni *et al.*, 2009; Trocino *et al.*, 2003). These studies reported no significant difference between males and females when measuring pH in *L. lumborum*. But in the present study the male ultimate pH was significant lower compared to females. Carrilho *et al.* (2009) reported no effect of gender on ultimate pH of *L. dorsi* and Cavani *et al.* (2000) reported no effect of gender on ultimate pH of *L. lumborum* 36 h post mortem. However, the pH was overall slightly lower when measuring pH after 36 hours instead of 24 hours post mortem. Which reflects the fact that the pH is constantly dropping for up to 7 days (Mačanga *et al.*, 2011).

In present study the ultimate pH was measured between the muscles to keep the muscles intact and be able to use for further studies. In all previous studies the pH measurements were made inside the muscles, which in the present study might have contributed to the difference in ultimate pH.

5.4 Fat content

The result from present study showed no significant difference between fat content of male and female rabbit meat. The study of Cavani *et al.* (2000) showed no effect of gender on the on intramuscular fat in the *L. lumborum* muscle. It agrees with the results from Ortiz Hernández and Rubio Lozano (2001) who investigated *L. dorsi* with the result of 2.19% of males and 2.24% of females, but with no significant difference. Xiccato *et al.* (1994) investigated *L. dorsi* and reported fat contents of 1.1% fat in male and 1.0% in female rabbits. None of the studies found significant gender-related differences. However, the total amount of adipose tissue in females tended to be higher (Piles *et al.*, 2000; Pla *et al.*, 1998).

In a study of Dalle Zotte *et al.* (2016a) no significant difference between gender in total lipid content was observed in the hind leg. However, some differences in the fatty acid profile were observed between genders. The proportions of total saturated fatty acids, C18:3 n-3 and C20:3 n-6 were affected by gender, resulting in a more favourable saturated fatty acid: unsaturated fatty acid ratio in females.

5.5 Cooking loss

The cooking loss were significantly lower in meat from females (10.10±0.45%) compared to meat from males (14.59±0.47%).

A number of studies have been made on cooking loss in rabbits and the majority did not find any difference between genders, even though many different cooking methods were used. Methods such as cooking in a water bath in vacuum-bags (Dalle Zotte *et al.*, 2016b; Xiccato *et al.*, 199; Trocino *et al.*, 2015)), in water bath in plastic bag without vacuum (Cavani *et al.*, 2000), in electric oven (Piles *et al.*, 2000; Pla *et al.*, 1998) or on an electric stove been investigated (Ortiz Hernández & Rubio Lozano, 2001).

Ortiz Hernández and Rubio Lozano (2001) investigated the cooking loss of the breed Rex and found a significantly lower loss in males (4.78%) compared to females (5.17%). However, the same study did not find any differences between gender, when investigating three different breeds. These results indicate breed-related differences should be taken in consideration when studying rabbit meat quality and differences between male and female animals.

The cooking loss is dependent on the cooking method and thus results from different studies are not necessarily comparable. The method must also be constant for all samples in a study, which can be hard to achieve. There are several different methods for cooking the meat, and the method highly affects the structure of the meat and its properties. The reason for using a sous-vide method for the cooking is because this method is regarded as highly reproducible. Other methods, for example cooking in oven, grill or in microwave, are more difficult to control, which can result in irregular meat temperatures. Biological factors can also affect the cooking loss. The size of the rabbit and bone to meat ratio might affect the degree of cooking in the meat. The cooking loss increases with cooking temperature and reaches a maximum at 80°C. Therefore, a difference in inner temperature would affect the degree of cooking loss. Due to no control of the inner temperature in the present study, it is difficult to establish a constant inner temperature. Nevertheless, the heat treatment lasted for 120 minutes, which we believe resulted in a constant temperature.

5.6 Water-holding capacity

In the present study the loss of water when placing meat under a weight was similar in male and female meat. This agrees with the findings of Cavani *et al.* (2000) who found no significant difference between genders when investigating the water-holding capacity in rabbits in the *L. lumborum*. Similarly, Tărnăuceanu and Pop (2016) found no differences between gender when studying the *L. dorsi* muscle when using a similar method. Although, in two different leg muscles, meat from females had a higher degree of water loss.

Lebas *et al.* (2000) and Carrilho *et al.* (2009) used minced samples the measure water-holding capacity. Carrilho *et al.* (2009) showed a slightly higher water-holding capacity in males compared to females, while Lebas *et al.* (2000), found different results depending on the age at slaughter.

The water-holding capacity in the present study are higher than the values obtained by Tărnăuceanu and Pop (2016) and Bianchi *et al.* (2006), similar as the ones obtained by Lafuente and López (2014) and lower than the water-holding capacity found by Simonová *et al.* (2010). All studies measured the water-holding capacity in some of the muscles of the loin except from Lafuente and López (2014) who used the hind limb muscles for analysis. The breed and slaughter age vary highly between the mentioned studies, which is the probable reason for the large variation between studies.

Prior to the measurement of water-holding capacity the meat was stored at –20°C and thawed. Freezing can have an effect on the structural properties of the meat and normal freezing of –12°C might decrease the water-holding capacity of the meat. However, when freezing at –20°C as in the present study the water-holding capacity is not affected to the same extent. Due the same treatment of all samples the effect of freezing should be the same in both male and female meat (Dalle Zotte, 2002).

5.7 Tenderness

In this study the maximum force needed to cut the meat and the total force did not differ between females and males. Interestingly, Carrilho *et al.* (2009) reported a more tender meat from male rabbits compared to females. Overall, the studies on tenderness in male and female meat show agreeing results. Numerous studies have been made on tenderness but as far as we know no study on cooked meat showed a significant difference (Carrilho *et al.*, 2009; Polak *et al.*, 2006; Xiccato *et al.*, 1994)(Dalle Zotte *et al.*, 2016b; Trocino *et al.*, 2015; Ortiz Hernández & Rubio Lozano, 2001; Lebas *et al.*, 2000). Lebas *et al.* (2000) reported that the maximum force for cutting the meat from males were significantly higher (52.2N) compared to the females (39.5N). That study expressed a much lower tenderness than the other studies and the deviating result may depend on the fact that the study was made on fresh meat, while all other measured tenderness on cooked meat. But as meat generally is cooked prior to consumption it is highly relevant to measure it cooked. This indicates that there might be a difference in tenderness in raw meat but when cooked the differences are minimized.

Another reason for conflicting results might be that the studies used different breeds (Ariño *et al.*, 2006), but other studies show that the shear force in cooked meat in different breeds tend to be similar (Ortiz Hernández & Rubio Lozano, 2001). Which indicate that there are differences between some breeds but between other breeds there are no difference.

The cooking temperature is also an important factor affecting the tenderness. Therefore, the tenderness measurements rely on the fact that the cooking made prior to analysis is the same. Due to biological differences in rabbits such as size and bone-to-meat ratio the degree of cooking and cooking loss might be affected, and a constant cooking is hard to maintain. When Combes *et al.* (2004) investigated the effect of endpoint temperature a difference of 5°C gave a difference in stress of 10.7 N/cm2 and an energy increase of 35 mJ. The same study also concluded that the difference was the highest between 65°C and 80°C, which is within the temperature range used in the current study. Therefore, the cooking temperature must be controlled. To assure no effect of the cooking regime it might have been wise to do more controls of the temperature than made in this study.

The cooking time also affects the tenderness. In the present study the meat was cooked for 120 min. When Carrilho *et al.* (2009) cooked rabbit for only 15 min at 75°C the shear force was lower, resulting in a more tender meat. Other studies have shown that after 40 min of cooking (at 80°C) additional heating will not affect tenderness. A cooking-time of 120 min as in the present study should be sufficient to ensure that the cooking duration would not cause a difference in tenderness.

Before the tenderness measurements the meat was frozen and kept in –20°C and thawed prior to heat treatment. This might have affected the tenderness and allowed the meat to age (Honikel, 1998), resulting in a more tender meat (Mestre Prates *et al.*, 2002). The effect of freezing was minimized by handling all samples in the same way.

Previous studies have shown that rabbit meat is tenderer compared to meat from other animals (Dransfield *et al.*, 1981). Studies on other animals have shown a correlation between tenderness and collagen content (D'Alessandro *et al.*, 2012; Liu *et al.*, 1996). The *Longissimus lumvorum* in rabbits have a collagen content of 16.4±2.3 mg/g muscle and bovine, pork and chicken have displayed about the same value or slightly higher in the corresponding muscles. The reason seems to be the higher amount of heat-soluble collagen in rabbit meat compared to other animals, rabbit 75.3±8.1%, bovine 19%, pork 17% and chicken 26%. When heat treated a higher amount of collagen will denature in rabbits compared to other meats, which give more tender meat (Combes *et al.*, 2004). This can be correlated with the fact that rabbit meat seems to show a difference between gender when raw but not as cooked meat.

Rabbits are smaller animals than many other tend for human consumption. When analysing tenderness according to present method, that are applicable for all kind of meat, it can therefore be difficult to obtain sufficient amount of muscle for sampling. When measuring the tenderness and shear force it might be difficult to obtain enough amount from precise spot and uniform geometry (Ouhayoun & Dalle Zotte, 1996). The *L. dorsi* is one of the largest muscles and the only in rabbits that have a constant muscle fibre direction, hence appropriate for this kind of analysis. According to Honikel (1998), the fibre lengths should be 5 mm minimum when performing tenderness measurements, which is not possible due to the small size of the rabbit. Further Honikel (1998) suggest that a minimum of 10 measurements per samples is needed to achieve a reliable result, due to the small body size of the rabbit this is not possible and therefore only six measurements on each animal was made, which might have contributed to a lower accuracy in the present study.

5.8 Further studies

Rabbit meat differs a lot from other meats and to the best of our knowledge, no studies are available on the preference regarding rabbit meat. Thus, sensory studies are essential to increase our knowledge on meat preferences and select right directions in the development of food products from rabbit meat. In such studies consumers should be involved.

Due to demographical changes in Sweden and Europe the recent years the sensory preferences would most likely differ between native and immigrants. Sensory studies that evaluate the effect of these demographical changes on the demand of development of food products from rabbit meat would increase our knowledge. Also in this sort of studies consumers should be involved.

Since rabbit meat production can be performed in many different ways, several factors can affect potential differences between gender of rabbit meat quality. Such factors that should be evaluated would be; age at slaughter as well as slaughter weight, hypothetical transport to slaughterhouse and feeding regime.

6 Conclusion

Overall, there were no effects of gender on rabbit meat quality on the majority of the parameters measured. Ultimate pH was significantly lower cooking losses were significantly higher in meat from male compared to female animals. Therefore, gender can be considered as a minor factor when producing rabbit meat from with crossbreed Champagne d'Argent and New Zealand red slaughtered at 17–18 weeks. Other factors such as breed, age/slaughter weight, transport to slaughter and feeding regime should be included in further studies.

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Appendix 1: Popular scientific summary

Gender-related differences in rabbit meat quality

The last couple of years the interest and awareness of eating healthy and sustainable food have increased. Rabbit meat is a type of meat that is both healthy and more sustainable than conventional meat. To get a broader understanding about rabbit meat properties this study has been made focusing on rabbit meat quality, trying to find out if there is a difference in rabbit meat quality between gender.

Worldwide rabbit meat production has increased by 13% from 2006 to 2016, and parallel the interest in rabbit meat for human consumption have increased in Sweden. This is due to its good nutritional value and environmental sustainability. To meet the new interest, it is important to optimize the production of rabbit meat and to know the fundamental of rabbit meat quality and what factors affecting it. By studying common meat quality traits such as colour, ultimate pH, cooking loss, tenderness, total fat content, water-holding capacity and some slaughter traits, this study have been trying to figure out if gender is a significant factor when producing rabbit meat. For these purposes, meat from both male and female rabbits have been used.

Rabbits are known to convert fibrous vegetation as well as having a high reproductive rate, early maturity and a higher feed conversion ratio than other meat animals. Together with low land requirement this makes rabbit meat sustainable. In Sweden, the emission of CO_2 for one kilo rabbit meat with bone is 2.6 kg. For pork meat the number is slightly higher and in beef considerable higher, while chicken meat is lower.

Rabbit meat has a high nutritional value and high protein content. Protein contributes to about 80% of the energy in the meat and results in a quite high energy content about 603 kJ/144 kcal in the loin. Rabbit meat have a low sodium content, high phosphorous content and a favourable fatty acid profile. Moreover, rabbit meat is a good source of vitamins B. The nutritional value together with the low fat and high protein content makes rabbit meat an excellent part of a human diet. The nutrition values and other properties vary considerably between different muscles, for this study all analysis have been made on the loin.

The rabbits in this study were slaughtered at an age of 17–18 weeks 24 crossbreed rabbits (New Zealand red and Champagne d'Argent, 12 males and 12 females). The colour was measured with a Minolta Chroma Meter, the cooking-loss was measured by calculating the weigh-loss after heat treatment, the pH was measured with a penetrating electrode, the tenderness was measured with the Warner-Bratzler method, the water-holding capacity was measured by calculating the weigh-loss after applying a pressure and the fat was extracted and determined from total extracted lipids.

Overall, there were no effects of gender on rabbit meat quality on the majority of the parameters measured. Ultimate pH was significantly lower, cooking losses were significantly higher in meat from male compared to female animals. Therefore, gender can be considered as a minor factor when producing rabbit meat from with crossbreed Champagne d'Argent and New Zealand red slaughtered at 17–18 weeks. Other factors such as breed, age/slaughter weight, transport to slaughter and feeding regime should be included in further studies on what factors affecting the quality of rabbit meat.