**CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE**

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# Nutritional and organoleptic properties of meat from farmed fallow deer (*Dama dama*) at different ways of fattening

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PhD thesis

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**Statement of authorship**

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# Nutritional and organoleptic properties of meat from farmed fallow deer (*Dama dama*) at different ways of fattening


## Abstract

Fallow deer are important meat producing species providing venison and other products to an international market. The present study investigated the effect of different feed rations on growth, carcass characteristics, economic efficiency of the fattening, and chemical composition, physical and technological parameters and sensory attributes of meat from 45 farm-raised male fallow deer. Animals were divided into three separate groups; 15 pasture-fed (Group P), 15 grazed on pasture and supplemented with barley (Group B), 15 grazed on pasture and supplemented with barley and lysine (Group L). Bucks were slaughtered at the age of 17 months in three occasions; after 155, 169 and 183 days on feed, respectively.

The addition of barley to the feed ration significantly increased the weight gain and had a positive effect on the profitability of the fattening, slaughter traits (slaughter weight, carcass weight, dressing percentage), carcass composition (weight of the right carcass half, total meat, high and low-priced meat and the ratio of high/low-priced meat), whereas other slaughter traits (weight of bones and tendons, ratio of meat/bones) and carcass fatness (separable fat and total internal fat content) were more favourable for pasture-fed deer.

The effect of concentrate feeding on physical meat parameters were of smaller magnitude, with significant differences being found only in the weight and some colour parameters (redness, yellowness and chroma values) of *longissimus* muscle. Regarding the technological parameters, the supplemented deer had significantly greater proportion of thawing loss and total weight loss of LL muscle. Diet significantly afftected the dry matter, intramuscular fat, hydroxyproline, insoluble collagen and *n*-3 PUFA content, as well as the ratio of *n*-6/*n*-3 PUFA. Results of the sensory assessment showed a strong intensity of “liver” flavour of meat from supplemented deer and a distinct “grassy” flavour of venison from pasture-fed deer.

The addition of rumen-protected amino acid lysine reduced the deposition of carcass and internal fats without compromising other economically importat traits, whereas physical parameters and organoleptic properties of meat remained unaffected.

Surprisingly, pelvic carcass suspension had a negative effect on the textural parameters of fallow deer meat. Tenderstretch meat was found to have decreased tenderness, juiciness

and chewiness compared to that from Achilles tendon suspension, whereas differences in other sensory attributes were only minor.

The data from this study provide a useful basis and reveal several practical applications worthy of future research, as venison is considired as attractive and health-promoting component of the human diet.

Keywords: Cervidae, venison, nutrition, growth, meat quality

# Nutriční a organoleptické vlastnosti masa farmově chovaných daňků (*Dama dama*) při různých způsobech výkrmu


## Abstrakt

Daňci jsou důležitým živočišným druhem poskytujícím maso a ostatní produkty pro mezinárodní trh. Tato studie se zabývala vlivem různých krmných dávek na růst, charakteristiky jatečného těla, ekonomickou efektivitu výkrmu, chemické složení, fyzikální a technologické parametry, a senzorické vlastnosti masa ze 45 farmově chovaných daňků – špičáků. Zvířata byla rozdělena do tří oddělených skupin; 15 pastevně krmených (skupina P), 15 s pastevním výkrmem a přídavkem ječmene (skupina B), 15 s pastevním výkrmem a přídavkem ječmene a lysinu (skupina L). Daňci byli poraženi ve věku 17 měsíců ve třech porážkových dnech; po 155, 169 a 183 dnech výkrmu.

Přídavek ječmene do krmné dávky signifikantně zvýšil přírůstek a měl pozitivní vliv na ziskovost výkrmu, jatečné parametry (porážková hmotnost, hmotnost jatečně upraveného těla, jatečná výtěžnost), složení jatečného těla (hmotnost pravé půlky a masa z pravé jatečné půlky, hmotnosti a poměr masa I. a II. jakosti), zatímco ostatní jatečné parametry (hmotnost kostí a šlach, poměr maso/kosti) a obsah tuku v jatečném těle (oddělitelný a vnitřní tuk) byly příznivější pro pastevně krmené daňky.

Vliv koncentrovaného krmiva na fyzikální vlastnosti masa byl menší, přičemž významné rozdíly byly zjištěny pouze v hmotnosti a některých parametrech barvy (červenost, žlutost a sytost barvy) svalu *longissimus lumborum*. Pokud se jedná o technologické parametry, sval *longissimus lumborum* daňků s příkrmem ječmene vykazoval významně vyšší podíl ztráty mražením a celkové ztáty hmotnosti. Výživa výrazně ovlivnila obsah sušiny, intramuskulárního tuku, hydroxyprolinu, nerozpustného kolagenu a *n*-3 PUFA, stejně jako poměr *n*-6/*n*-3 PUFA. Výsledky senzorického hodnocení ukázaly silnou intenzitu „chuti jater“ u masa přikrmovaných daňků a výraznou „chuť trávy“ u masa pastevně krmených zvířat.

Přídavek enkapsulované aminokyseliny lysinu do krmné dávky snížil ukládání jatečných lojů a vnitřního tuku bez ovlivnění dalších ekonomicky důležitých parametrů, zatímco fyzikální a senzorické vlastnosti masa zůstaly nedotčeny.

Maso daňků pocházející z jatečné poloviny zavěšené za pánevní sponu vykazovalo překvapivě sníženou křehkost, menší šťavnatost a horší žvýkatelnost v porovnání s masem

pocházejícím z jatečné poloviny zavěšené za Achillovu šlachu. Naproti tomu rozdíly v ostatních senzorických atributech byly jen velmi malé.

Data z této studie poskytují užitečný základ a odhalují několik praktických informací hodných dalšího výzkumu, neboť maso jelenovitých je považováno za atraktivní a zdravou součást lidské stravy.

Klíčová slova: jelenovití, zvěřina, výživa, růst, kvalita masa

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## LIST OF ABBREVIATIONS

AA: amino acid

ADF: acid detergent fibre

ALA: α-linolenic acid

BIF: biceps femoris muscle (*Musculus biceps femoris*)

FA: fatty acid

FAO: Food and Agriculture Organization of the United Nations

IAS: Institute of Animal Science

IMF: intramuscular fat

LSM: the least square mean

MGM: gluteus medius muscle (*Musculus gluteus medius*)

MLL: the longest dorsal muscle (*Musculus longissimus lumborum*)

MUFA: monounsaturated fatty acid

n: number

NDF: neutral detergent fibre

*P*-value: statistical probability

PUFA: polyunsaturated fatty acid

RPAA: rumen-protected amino acid

SED: standard error deviation

SEM: standard error of the mean

SET: semitendinosus muscle (*Musculus semitendinosus*)

SFA: saturated fatty acid

SM: semimembranosus muscle (*Musculus semimembranosus*)

WHC: water-holding capacity

WBSF: Warner–Bratzler shear force

# 1. INTRODUCTION

Deer species have been utilised by humans around the world for hunting and production of meat and other products for centuries. As deer had spread outside their natural habitats in prehistoric times, nowadays their populations can be found throughout the world in both wild and farmed (domestic or semi-domesticated) form (Wiklund et al., 2014). Commercial deer farms have their origin in New Zealand. First deer (*Cervus elaphus*) were brought there from England and Scotland for sport purposes, and released to the nature. Wild populations grew uncontrolled and thus deer were hunted and the export of their meat (referred to as venison) started in the 1960s. As early as 1970s, New Zealand industry pioneers started capturing live deer from the wild and raise them as livestock. A new industry was born and deer farming has also become popular in other countries (Deer Industry New Zealand, 2018).

The potential of farming deer species and their use as meat producers has resulted in easier accessibility of venison also to average consumers. The production of venison under farm conditions also allows for a regular supply of a consistently good meat. In recent years, the popularity of venison has increased worldwide due to its high nutritional value and culinary attractiveness and this has resulted in consumer interest in the consumption of this meat. Moreover, due to mainly extensive breeding system of deer under "natural" conditions, venison is often considered an "organic" and safe product with health-promoting characteristics that make it attractive and highlight its role in the human diet (Wiklund et al., 2014; Ludwiczak et al., 2017).

Overall, growth, carcass composition and meat quality are of utmost importance when the economic value of the animal is evaluated. In the past, several studies have been conducted on how to influence the carcass quantitative parameters and qualitative attributes of venison by different feed rations and/or ways of fattening (Volpelli et al., 2002a; Volpelli et al., 2003; Wiklund et al, 2005; Mulley et al., 2006; Hutchison et al., 2012), age (Volpelli et al., 2003; Żochowska-Kujawska et al., 2019), sex (Hutchison et al., 2010), castration (Tan and Fennessy, 1981; Wiklund et al., 2008a), season and phases of the reproduction cycle (Janiszewski et al., 2008; Polak et al., 2008), production system (Drew, 1992; Razmaitė et al., 2017), body condition (Hutchison et al., 2004; Hutchison et al., 2010), *ante-mortem* handling and slaughter method (Pollard et al., 2002; Mulley et al., 2010), and carcass suspension method (Sims et al., 2004; Wiklund et al., 2004a; Hutchison et al., 2006; Mulley et al., 2006;

Hutchison et al., 2010; Hutchison et al., 2014). However, although a few studies have been published, existing information regarding the effect of different feed rations on carcass parameters, chemical composition, physical attributes, technological and organoleptic properties of venison is still limited. Nevertheless, determination of meat quality in terms of composition and sensory attributes is useful for breeders, sellers and even for consumers making purchasing decisions.

# 2. LITERATURE REVIEW

## 2.1 Origin and distribution of fallow deer

The existence of fallow deer (*Dama* spp.) dates back to more than 4 million years ago (Stachowicz et al., 2014). It is thought that its ancestor came from the Pleistocene species classified as *Pseudodama* (Jensz and Finley, 2013; Chakanya et al., 2016). After the glacial period, fallow deer (*Dama* spp.) have spread outside their native ranges to the Mediterranean region (Southern Europe, North-Western Africa, Middle East, Iran) (Randi and Apollonio, 1988; Jensz and Finley, 2013). To other parts of the Europe, fallow deer have been later reintroduced by the Phoenicians, the Romans and the Normans at the time of Neolith (Randi and Apollonio, 1988; Masseti and Mertzanidou, 2008). Fallow deer have adapted well to a wide range of habitats, their populations have begun to expand also to the North and South America, Australia and New Zealand and their number has been growing steadily over the years (Masseti et al., 2008; Chakanya et al., 2016).

Nowadays, fallow deer populations are established throughout the world (**Figure 1**). The distribution and adaptation of this species is the result of both human activity and environmental conditions (Masseti et al., 2008; Jensz and Finley, 2013). Fallow deer have been relocated all over the world mainly for use in extensive and intensive farm operations, for stocking of parks and preserves and, in some regions, as introduced game species (Mattiello et al., 1997). Thus, the present occurrence of fallow deer is non-natural. According to palaeontological and archaeozoological evidence, there are only two species of fallow deer. The first is the Persian or Mesopotamian fallow deer (*Dama dama mesopotamica*), whose origin and occurrence is limited to small, endangered populations in Turkey and Iran (Masseti et al., 2008; Miller et al., 2016). The second is the European fallow deer (*Dama dama dama*) (**Figure 2**) which is distributed also in other regions of the world, where it has become an important species for sports hunting and farm breeding (Randi and Apollonio, 1988; Arslangündoğdu et al., 2010; Kjellander et al., 2012). The Persian and European fallow deer can be easily distinguished according to their phenotypic characteristics, such as body frame size, antlers and tail colour (Chapman and Chapman 1980; Stachowicz et al., 2014).

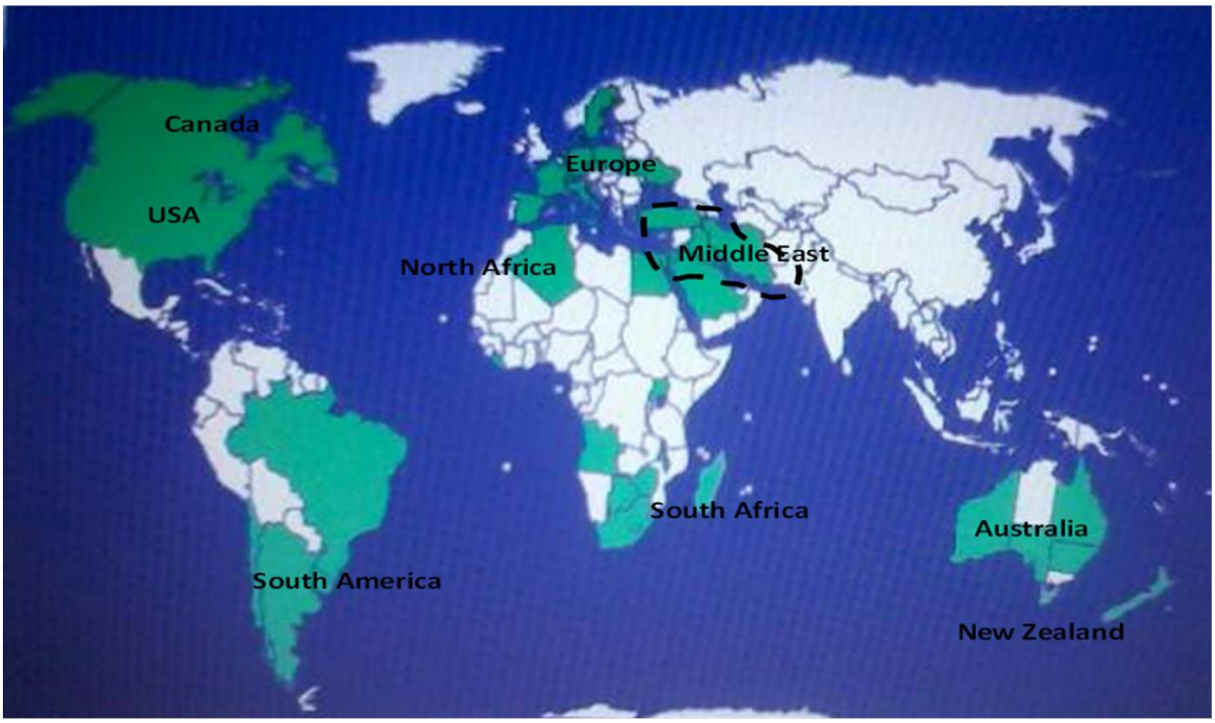



**Figure 1: Origin and distribution of fallow deer (*Dama* spp.) around the world.**

Key: Areas highlighted in green ■ show distribution of fallow deer. Regions highlighted by broken line --- show area of origin of the fallow deer (Chakanya et al., 2016).

Taxonomic classification:

Kingdom: animal (Animalia)

Phylum: vertebrate (Chordata)

Class: mammal (Mammalia; Linnaeus, 1758)

Order: even-toed ungulates (Cetartiodactyla; Owen, 1848)

Family: cervids (Cervidae; Goldfuss, 1820)

Genus: fallow deer (*Dama* spp.; Frisch, 1775)

Species: European fallow deer

(*Dama dama dama*; Linnaeus, 1758)

Mesopotamian or Persian fallow deer

(*Dama dama mesopotamica*; Brooke, 1875)

(Adapted from Jensz and Finley, 2013)

**Figure 2: European fallow deer – *Dama dama dama***

(Photo: author).

## 2.2 Deer farming

As consumers pay more attention to the environment and the conditions surrounding meat production (natural production, low input system etc.), interest in deer farming is growing throughout the world (Hoffman and Wiklund, 2006; Ludwiczak et al., 2017). Deer farming meets the growing interest of consumers for alternatives to traditional types of meat (Volpelli et al., 2002a; Ludwiczak et al., 2017). It also complies with the needs of a society that cares about animal welfare, manipulation and production systems, and is increasingly sensitive to feed additives and environmental pollution (Drew, 1992; Volpelli et al., 2003; Russo, 2005).

Although New Zealand, Australia, China and Canada are countries well known for deer breeding (using farming systems), interest in deer farming is nowadays increasing in European countries where most venison traditionally have been produced from wild hunted deer (Miao et al., 2001; Kuba et al., 2015; Chakanya et al., 2016). Despite an interest in the last century, the USA were a relative newcomer to this industry (Hudson and Adamczewski, 1990) but currently deer farming is one of the fastest growing industries in rural America (Tack et al., 2013). In Europe, deer have been bred from ancient times, and in many countries, breeding has a strong tradition (Bureš et al., 2015). Domestication of deer began many centuries ago in Asia, particularly in China, where deer were kept for velvet antlers (the partly grown and immature antlers) used in traditional medicine (Miao et al., 2001). The history of modern deer farming, however, dates back to the early 1970s and the first country to legalize deer farming was New Zealand (Janiszewski et al., 2008). At the beginning of the 21$^{st}$ century, the number of worldwide farmed or managed deer species was already estimated at five million animals (Hudson, 1999; Daszkiewicz et al., 2015). There are currently > 10,000 farms breeding various deer species (except reindeer operations) in 16 EU countries (Bureš et al., 2015). Specifically, there are > 350 farms in the Czech Republic that are involved in deer breeding (Pařízek, 2013). Around 2000 farms is located in New Zealand, < 200 farms in Australia and > 7800 farms in the USA (Miao et al., 2001; Shapiro, 2010; Deer Industry New Zealand, 2018).

The most abundant deer species under farm conditions are red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) in Europe, Australia, New Zealand and North America, reindeer (*Rangifer tarandus*) in the Scandinavian countries, and wapiti (*Cervus canadensis*) and chital deer (*Axis axis*) in North America (Hoffman and Wiklund, 2006; Florek and Drozd,

2013; Daszkiewicz et al., 2015; Costa et al., 2016). Despite the fact that reindeer herds in the Nordic countries are free-ranging out in forests and the mountain tundra, the production system can be considered as semi-domestication. Traditional reindeer husbandry is managed by the indigenous Sami people and performed in a less-intensive way than typical intensive deer farming. Reindeer are not kept in fenced area but they are handled by the herders twice a year (tagging of new calves in July and slaughter of adult animals in December) (Bjørklund, 1990; Hoffman and Wiklund, 2006; Wiklund et al., 2014).

Commercially, deer are multipurpose animals, providing especially meat to an international market and other important products, such as skin, hair, teeth, etc. for various end users, as well as velvet antlers for oriental medicine (Drew, 1992). However, unlike the permitted harvesting of fully developer antlers (production of jewellery, furniture, decorations etc.) in the European countries, cutting of antlers with velvet from living animals is prohibited by the European Union due to animal welfare reasons and ethical issues (Kuba et al., 2015). Nevertheless, deer farming is not only a source of high-valuable products but also an important alternative to illegally hunted, endangered species of deer (Dahlan, 2009).

Deer represent meat-producing species that exist in both wild and domestic (farmed) form (Wiklund et al., 2014). Deer keeping was originally envisaged as a form of animal production with low initial investment, based on the natural adaptation of indigenous species (Telfer and Scotter, 1975). However, this has evolved into more intensive farming systems, as stocking rates frequently need to be higher than natural densities to be profitable, and seasonal movement of animals must be restricted by fencing (Hudson and Adamczewski, 1990). Nowadays, deer farming takes place in a range of different settings – from very natural habitat (large enclosed landscape areas) similar to the wild conditions to intensive grazing system similar to those of commercial livestock production. Extensive breeding is, however, the most common production system for deer species (Volpelli et al., 2002a).

There is also a need not only to have good breeding facilities but also to be able to demonstrate compliance with the animals´ welfare requirements. Based on the survey performed by Williams et al. (2015), 56% of deer farmers respondents noted that none of the welfare needs were too difficult to achieve. The majority of welfare problems in farmed deer are associated with the handling that may be very stressful to deer and may negatively affect the meat quality (Bornett-Gauci et al., 2006; Williams et al., 2015). In comparison, the welfare of deer in parks is strongly influenced by management and can be reduced by changes in

stocking levels and the provision of supplementary feeding (Green, 2017). Anyway, due to the permanent use of grasslands and minimal negative impacts on the environment, deer breeding can be considered the form of sustainable agriculture (Volpelli et al., 2002b; Kuba et al., 2015).

### 2.2.1 Feeding and diets

Compared to other livestock species, deer keeping under farm conditions is characterized mainly by pasture fattening (Volpelli et al., 2003). However, grazing or browsing alone may be insufficient, especially in the months when grass is not growing, or when stock density exceeds the carrying capacity. It is therefore appropriate to provide supplementary feeding at these higher stocking rates, which also saves pastures from damage when conditions are dry or wet and muddy (Mattiello et al., 1997; Miao et al., 2001; Mulley, 2003; Wiklund et al., 2003a). It can also improve animal welfare, growth, meat and carcass quality, and consequently economic efficiency (Volpelli et al., 2002a, 2003).

A variety of methods to increase meat production through feeding methods and different diets have been performed, and it is generally known that meat production increases with growing dietary crude protein level (Prado et al., 2014). Previous studies dealing with different diets (Volpelli et al., 2002a; Wiklund et al., 2003a; Wiklund et al., 2003b; Wiklund et al., 2005; Phillip et al., 2007) have shown differences in growth, carcass and meat composition of deer that have been grazing pasture and those supplemented with grain-based diet. In general, deer fed/supplemented with concentrates had higher carcass weights and dressing percentages than the animals grazing pasture. Moreover, feeding concentrates may also affect the proportion of anatomical joints and lean cuts, as well as the amount of separable fat as reviewed by Kudrnáčová et al. (2018).

Only a few studies on grain-based supplementation in relation to the technological meat quality parameters have been carried out on cervids. The effect of different diets on physical attributes (pH, colour, WBSF) of deer meat has been evaluated in studies of Volpelli et al. (2003), Wiklund et al. (2005), Wiklund et al. (2006), Hutchison et al. (2012). Resulting values of pH, WBSF and colour parameters in the study of Volpelli et al. (2003) did not differ significantly and they were unaffected by different dietary treatments. Nevertheless, other studies mentioned above concluded significantly lower pH values and more tender meat in deer supplemented with concentrates compared with animals grazing pasture.

#### 2.2.1.1 Amino acids in the diet

Carcass conformation, meat quality and quantity depend on the amount of muscles and skeletal tissue that are related to the accretion of muscle proteins whose deposition requires dietary supply of AAs. Lysine is one of the essential AAs serving as a building block for protein biosynthesis (Wang et al., 2015). Literature indicates that in the past, research has mostly focused on the importance of lysine in the diet of monogastric animals, such as pigs or poultry (Hickling et al., 1990; Coble et al., 2014; Tous et al., 2014; Wang et al., 2015). However, since lysine has been identified as one of the top limiting AA for grazing ruminants (**Figure 3**), research has expanded to also include polygastric animals (Hussein and Berger, 1995; Greenwood and Titgemeyer, 1997; Prado et al., 2014; Torrentera et al., 2017), and very recently to cervids (Huang et al., 2015). Lysine seems to be the AA limiting the ruminal synthesis of microbial protein (Abe et al., 1998; Klemesrud et al., 1999) because some dietary protein escapes the fermentation in rumen and passes to lower gut undegraded. Thus, ruminants have higher metabolizable protein requirements that may exceed their supply (Xue et al., 2011; Prado et al., 2014). The extent of microbial protein breakdown and synthesis results in alterations of AAs absorbed in the gut compared to AAs contained in the animal´s diet (Broderick et al, 1991). It is therefore essential to provide these AAs in a resistant/protected form so that they will withstand microbial degradation in the rumen and will be available up in the abomasum. These preparations, referred to as RPAAs, can be efficiently utilized by ruminants and thus, growth performance and carcass composition may improve (Han et al., 1996). Despite the fact that fallow deer is worldwide one of the most abundant deer species raised under farm conditions, only a few studies have focused on concentrate and AA supplementation in this species. Although a great deal of work has been done to measure and quantify carcass traits and quality attributes of deer meat, only a few such works have been performed for fallow deer (*Dama dama*) and still a considerable amount of information is missing in this research area. Moreover, there are no studies on the potential effect of AA supplementation on carcass parameters or meat quality parameters.

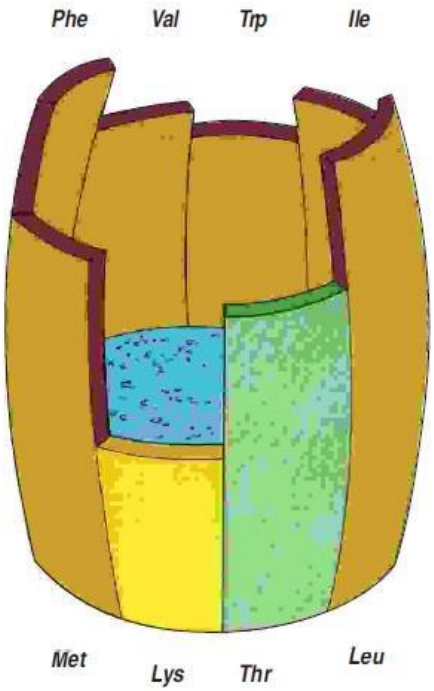



**Figure 3: Limitation in protein synthesis due to the lack of essential AAs in the diet.**

(Häffner et al., 2000)

### 2.3 Venison production

The world population is still growing from the estimated 10 million people at the time of agriculture development (approx. 10,000 years ago), to more than 7 billion people at present. Thus, the demand for animal-based proteins in human diets increases as well, as the wealth of the developing world increases (Cawthorn and Hoffman, 2014). During the last 50 years, average per capita meat consumption rose by more than 45 %, from 23 kg/person/year in 1961 to 42 kg/person/year in 2011 (Sans and Combris, 2015). As a result of the increase in the demand for meat (especially red), interest in venison meat has grown (Poławska et al., 2013). In the 1970s, world trade of venison meat was estimated in one million tonnes per year (FAOSTAT, 2017). Since then, the production has steadily increased to a present figure of ~2 million tonnes annually (Costa et al., 2016). Thus, there is a potential of meat production from various unconventional livestock species under farm conditions. Particularly, utilization of farmed/park-produced deer species and production of deer meat (venison) is a topic of great interest and importance (Babiker et al., 1990; Daszkiewicz et al., 2015; Kuba et al., 2015; Ludwiczak et al., 2017).

Venison is usually referred to as meat from any game animal, including ungulates, birds, reptiles and amphibians, carnivores, rodents and miscellaneous mammals that are suitable for human consumption. However, it is advisable to distinguish game meat from venison. Game animals are being replaced by domesticated and farmed animal species whose meat is then classified as venison, whereas game meat originates from wild, free-ranging animals, as explained and used in the papers of Hoffman and Wiklund (2006), Gill (2007) or Schulp et al. (2014). In contrast, Hoffman and Cawthorn (2012) or Chakanya et al. (2017) have later used the term "game meat" as that derived from ungulates legally harvested in Africa, and venison as meat derived from cervids. This definition is also used for venison in this thesis, despite the fact that deer species under farm conditions in the Czech Republic are considered to be livestock (Jedlička, 2015). Since 1999, meat from farmed deer species can´t be thus labelled as "venison" but as "fallow deer meat", "red deer meat", etc., as stated in the Czech legislation (Zákon č. 166/1999 Sb.; Kupka, 2004). In the studies of Hoffman and Cawthorn (2012) and Cawthorn and Hoffman (2015, 2016), the authors have also broadly defined the word "bushmeat" as meat derived from illegal hunting of various animal species, such as primates, frogs, snakes, rodents etc. This term has already been explained by Milner-Gulland et al. (2003) as the meat of wild animal species hunted for human consumption in tropical areas.

In general, meat is often seen as a major source of fat in the human diet, but increased health concerns have resulted in an emphasis on the production of lean meat and meat products with low fat and cholesterol contents (Dahlan and Norfarizan-Hanoon, 2008). Moreover, food safety crises and livestock diseases have raised several questions and concerns about the risks and benefits of meat consumptions (MacRae et al., 2005; Font-i-Furnols and Guerrero, 2014). Venison may represent a good food commodity for consumers (especially for obese or elderly people) because it is lean and tasty, with a high proportion of polar lipids (phospholipids) and proteins, low in fat, and therefore with positive effects on human health (Dryden, 1997; Dahlan, 2009; Kwiatkowska et al., 2009; Bartoň et al., 2014). Thus, this non-traditional type of meat has also a big potential to be processed into various meat products, such as prosciutto (Piasentier et al., 2002), pâté (Okuskhanova et al., 2016), sausages (Jones et al., 2015; Nagy et al., 2015), or mince meat semi-product (Chakanya et al., 2017). In addition, due to the natural grazing without fattening of feed additives or high caloric fodders, or restricted contact of animals with pharmaceuticals (Kuba et al., 2015), venison has a positive

image as a natural “organic” and safe product (Russo, 2005; Wiklund et al., 2010a; Wiklund et al., 2014; Assenova et al., 2016; Ludwiczak et al., 2017). All the foregoing advantages make venison attractive and highlight its role in the human diet in the term of food safety.

### 2.4 Live weight and carcass parameters

Growth, weight gains and carcass quality are parameters of great economic importance. As shown in **Appendix 1**, research on animal performance and carcass parameters of farm-raised and wild fallow deer began early in the 1980s. Literature indicates that earlier research was focused mostly on animal growth, but with the growing interest in deer farming and venison, interest has progressively expanded to include carcass parameters and later also meat characteristics.

Fallow deer have adapted well to the seasonality of climate and feed supply, with a maximum increase of body tissues during the spring and summer months, loss of weight during autumn, and almost no weight gain in winter (Suttie and Webster, 1998; Wiklund et al., 2008b). Among other parameters, sex was also claimed to influence birth weight and growth rate of fallow deer fawns. Krzywiński et al. (1984) reported that the live weight of 20 weeks old fallow does was 18.8% lower than in bucks of the same age. Due to the smaller body frame, fallow deer male and female fawns reach around 30 and 25 kg respectively in 5 months of age (Dryden, 1997). Thus, some differences can be expected in carcass weight, dressing percentage, carcass composition and fat distribution between weaning fawns (< 1 year of age), yearlings (1–2 years of age), juveniles (2–3 years of age) and even adult (> 3 years of age) male and female fallow deer. Such differences were observed in other species of ruminants, such as cattle (Bureš and Bartoň, 2012; Daza et al., 2014), sheep (de Vargas Junior et al., 2014; Santos et al., 2015), goats (Colomer-Rocher et al., 1992; El Muola et al., 1999) or alpacas (Smith et al., 2015).

Deer species in general have a good dressing percentage of 55 to 75%, a higher yield of lean meat (66 to 83% from the carcass) than obtained from the more conventionally raised ruminant species, and a high lean:bone ratio (~5:1) (Dryden, 1997; Volpelli et al., 2002a; Russo, 2005; Suttie, 2012). Carcass fat content in various deer species ranges between 2 and 10% in yearlings and 9 to 15% in 2 years old, contrary to ram lamb and some bull carcasses where fat content may be up to 18–27% (Drew, 1992; Dryden, 1997). Overall, carcass composition is an important factor for meat producers, abattoirs and distributors by

determining the economic value of the animal because different carcass cuts have different commercial values (Sookhareea et al., 2001; Wiklund et al., 2008a; Dahlan, 2009; Kim et al., 2015). However, only few reports evaluated carcass characteristics of fallow deer bucks (male, 50–110 kg) and does (female, 25–50 kg) (McElligott et al., 2001; Janiszewski et al., 2008; Enei, 2010; Stanisz et al., 2015), as well as the effect of different feed rations (Volpelli et al., 2002a; Wiklund et al., 2005) or age (Hogg et al., 1990; Volpelli et al., 2002a; Pinto et al., 2009; Żochowska-Kujawska et al., 2019). In general, above mentioned studies comparing carcass parameters of fallow deer based on different diets or age show that grain-based diet and older age are linked to the to higher live weight, dressing percentage, proportion of individual carcass parts and higher amount of fat in the carcass. Wiklund et al. (2005) analyzed the differences in utility value of 24 fallow deer does at the age of 36 months grazed on natural pasture or fed barley. Results in their study highlighted higher carcass weights and dressing percentage of the grain/hay-fed fallow deer compared to pasture raised deer indicating clear diet-related differences in carcass conformation. In an earlier study, Volpelli et al. (2002a) focused on the carcass composition of farm-raised fallow deer bucks fed with different diets **(Table 1)**. Significant effect of concentrate feeding on hot carcass weight and the proportion of anatomical joints has been found. In particular, the proportion of some cuts, such as neck, thorax, and abdominal region was significantly higher in supplemented deer, whereas animals only grazing pasture provided significantly higher proportion of leg, thoracic limb and lumbar region.

**Table 1: Live weight and carcass characteristics of pasture-fed and concentrate-fed fallow deer (n = 16 per group).**

| Characteristics | Diet | | SED |
|---|---|---|---|
| | Pasture | Concentrates | |
| Live weight (kg) | 45.0 | 49.9 | 4.79 |
| Carcass | | | |
| Hot carcass weight (kg) | 25.8 | 30.8 | 3.61 |
| Dressing percentage (%) | 56.2 | 60.5 | 1.87 |
| Anatomical joints | | | |
| Leg (%) | 38.1 | 37.0 | 1.03 |
| Thorax (%) | 24.6 | 24.8 | 1.01 |
| Thoracic limb (%) | 14.0 | 13.4 | 0.40 |
| Neck (%) | 11.4 | 12.4 | 1.33 |
| Lumbar region (%) | 8.3 | 8.3 | 0.52 |
| Abdominal region (%) | 3.2 | 3.7 | 0.27 |

(Adapted from Volpelli et al., 2002a).

### 2.5 Meat quality

Quality is an arbitrary term including various parameters such as safety, nutrition, overall appearance and stability of the product. One of the definitions of quality is “fitness for use”. All quality parameters have major effects on a consumer’s acceptability, choice and satisfaction (Sigurgisladottir et al., 1997). Muscle and meat characteristics are influenced by both *ante-mortem* (e.g. breed, sex, age, muscle type, nutrition, handling or breeding management) and *post-mortem* factors (e.g. pH, temperature and/or ageing conditions).

#### 2.5.1 Chemical composition

Venison has several desirable attributes as a human food. Deer meat provides a wide variety of important components beneficial for human health. Its energy value ranges from 90 to 110 kcal/100 g (Żochowska-Kujawska et al., 2009), compared to beef, pork, mutton or poultry meat, whose energetic value ranges from 114 to 231 kcal/100 g of muscle tissue (Chizzolini et al., 1999). Deer meat is valued by consumers primarily for its low-fat content, high proportion of lean meat, and as a good source of minerals, essential AAs and PUFA (Higgs, 2000; Russo, 2005; Jarzyńska and Falandysz, 2011; Okuskhanova et al., 2017). Protein content in deer meat may vary between 20 to as high as 25%, thus confirming that

deer meat is also a relatively rich source of proteins (Kasai et al., 1999; Kwiatkowska et al., 2009) and AAs.

Studies of Hoffman et al. (2005), Hoffman et al. (2007b), Cygan-Szczegielniak and Janicki (2012), Strazdina et al. (2013) and Okuskhanova et al. (2017) show that among AAs, alanine, aspartic and glutamic acid, leucine and lysine occur in the meat of venison and game ruminant species at the highest quantities, although their content may differ owing to age, sex and muscle type within the species. However, little data exist on the influence of these factors on the content and composition of AA in deer meat.

**Table 2: Chemical composition of muscles from pasture-fed and concentrate-fed fallow deer (n = 16 per group).**

| | SET | | SED | MLL | | SED |
|---|---|---|---|---|---|---|
| | **Pasture** | **Concentrates** | | **Pasture** | **Concentrates** | |
| Water (%) | 77.58 | 76.89 | 0.66 | 76.27 | 75.76 | 0.54 |
| Protein (%) | 20.46 | 20.90 | 0.60 | 21.56 | 21.78 | 0.58 |
| Fat (%) | 0.55 | 0.78 | 0.17 | 0.56 | 0.72 | 0.14 |
| Ash (%) | 1.10 | 1.13 | 0.03 | 1.12 | 1.15 | 0.04 |
| Total collagen (mg/g) | 2.86 | 2.69 | 0.55 | 3.00 | 2.81 | 0.67 |
| Insoluble collagen (mg/g) | 2.10 | 1.94 | 0.48 | 2.15 | 2.00 | 0.54 |
| Soluble collagen (%) | 27.35 | 27.50 | 8.40 | 26.68 | 30.51 | 11.35 |

(Adapted from Volpelli et al., 2003).

### 2.5.1.1 Lipid, cholesterol and collagen contents

Fat from ruminant species is often seen mostly as a source of energy, SFA and cholesterol, but it is not considered to be a source of nutrients in the human diet (Dryden, 1997). Nevertheless, IMF content is an important aspect of the meat quality because it confers juiciness (Sookhareea et al., 1995), texture and flavour of meat, especially during heat treatment or cooking (Tshabalala et al., 2003; Purslow, 2005). Despite significant differences among individual muscles, IMF content in fallow deer muscle tissue ranges from 0.35 to 9.1 g/100 g (Drew, 1992; Morgante et al., 2003; Volpelli et al., 2003; Mulley et al., 2006; Dahlan and Norfarizan-Hanoon, 2008; Hutchison et al., 2012; Hutchison et al., 2014; Bureš et al.,

2015). However, total fat content depends on many factors. Deer species from temperate climates (e.g. fallow deer, red deer) have a higher fat content than tropical species (e.g. sambar deer, rusa deer) (Dahlan and Norfarizan-Hanoon, 2008). Fat content increases with age, resulting in old and elderly deer sometimes exhibiting unacceptably high fat contents (Dryden, 1997; Lorenzo et al., 2018). Fat content in meat of grazing or wild deer is usually lower than in concentrate-fed or confinement-raised animals **(Table 2)** (Volpelli et al., 2003; Dahlan and Norfarizan-Hanoon, 2008). However, Daszkiewicz et al. (2015) recently showed an opposite environment effect and reported significantly higher fat content in meat of wild fallow deer (0.50 g/100 g) compared to farmed fallow deer (0.24 g/100 g) with no indication of specific effects responsible for this difference.

Cholesterol content in deer meat was determined at 86 mg/100 g in farmed (Dahlan and Norfarizan-Hanoon, 2007) and 102 mg/100 g in wild fallow deer (Ramanzin et al., 2010). These values are comparable to those obtained for lamb, chicken, pork or beef meat (Sinclair et al., 1982; Almeida et al., 2006). Seal et al. (1978) and Card et al. (1985) indicated a correlation between cholesterol content in meat and FA composition in the animal's diet. Compared to SFA that may increase plasma cholesterol levels, MUFA and PUFA do not. Moreover, some MUFA may even have cholesterol-lowering attributes (Daley et al., 2010). Thus, the content of cholesterol in meat may be reflected by the amount and representation of individual FA in the feed ration. Other important factors influencing cholesterol content of venison are animal age and sex, and thus meat of younger animals may contain lower cholesterol levels (Polak et al., 2008; Quaresma et al., 2012).

Collagen is a major protein of the connective tissue that is present in muscles in amount ranging from 1.5% to ~10% of dry weight (Lepetit, 2008). It differs from other proteins by the composition of AAs, particularly by the high content of hydroxy acids and hydroxyproline (which is not found in any other protein). Collagen in the intramuscular connective tissue is arranged into the three layers: *endomysium* (surrounds individual muscle fibres), *perimysium* (bundles individual muscle fascicles) and *epimysium* (surrounds entire muscles) (Dominik et al., 2012) and due to its properties (e.g. cross-linking, solubility, chemical composition), it influences the nutritional, physical and organoleptic properties of meat. It is well known that decreased collagen solubility (due to the cross-linked chains) implies higher WBSF values (tougher meat), and due to the lack of some important AA such as tryptophan and tyrosine, it may also decreases the nutritional value of the meat. Regarding

organoleptic properties, the size of collagen fibres and arrangement of *perimysium* (that represents about 90% of total connective tissue) have a direct effect on toughness/tenderness of the meat. Hence, meat with a proportion of collagen protein below 5% of total protein mass may be defined as tender with delicate structure (Purslow, 2005; Lepetit, 2008; Kwiatkowska et al., 2009; Dominik et al., 2012). Collagen content in deer meat is similar to that in beef but more thermolabile as in lamb meat (Goodson et al., 2001; Volpelli et al., 2003; Dominik et al., 2012). Volpelli et al. (2003) reported a collagen solubility decrease in muscle of older fallow deer (22.58% in the 30-month-old) compared to younger fallow deer (34.61% in the 18-month-old). However, no effect of diet on muscle collagen has been found.

#### 2.5.1.2 Fatty acids

It is widely accepted that both the amount and the structure of FAs play a major role in human health. It is recommended to decrease the intake of SFA, trans-FA and the *n*-6/*n*-3 ratio, and to increase the intake of MUFA and PUFA (WHO & FAO, 2003; Nuernberg et al., 2005; Poławska et al., 2013). Pasture fed deer exhibit a high potential for lean meat venison production, and thus an important benefit of deer meat is the low amount of IMF and thereby favourable ratio of *n*-6/*n*-3 PUFA (Morgante et al., 2003; Volpelli et al., 2003; Wiklund et al., 2003a; Hoffman et al., 2007c; Bureš et al., 2015). Intramuscular lipids are primarily composed of triglycerides (neutral lipids) and phospholipids (polar lipids) with polar lipids being the less saturated. Changes in IMF content have an impact on the intramuscular FA profile, especially on the content of neutral lipids which tend to be more saturated (Legako et al., 2015; Hunt et al., 2016). These changes may be affected by age, sex, nutrition, production region and other factors (Hoffman et al., 2007c). FA composition in deer muscles also changes according to the composition of their feed despite the biohydrogenation of PUFA in the rumen. ALA (C18:3 *n*-3), which is contained in the grass, and linoleic acid (C18:2 *n*-6), which occurs in the concentrated feed are present primarily in the phospholipid fraction of deer IMF and muscles (Wood et al., 2003; Polak et al., 2008). Thus, grass feeding produces a more favourable *n*-6/*n*-3 ratio ranging from 2.1 to 3.4 (the recommendation is < 4), compared to 4.5 to 9.6 for concentrate fed deer (Morgante et al., 2003; Volpelli et al., 2003; Wiklund et al., 2003a; Bureš et al., 2015). Today, the *n*-6/*n*-3 ratio in human diets is often over 10:1 indicating the deficiency of beneicial *n*-3 FA in our diets (Poławska et al., 2013). Although ruminant meats are in general a relatively good source of *n*-3 PUFA due to the presence of ALA in grass, the

content of ALA in venison is markedly higher than in various cattle breeds (Wood et al., 2003; Realini et al., 2004; Nuernberg et al., 2005; Bureš et al., 2015). The high values of ALA found in fallow and also in red deer meat may be the consequence of the very low content of IMF, as well as the fact that both species are grazers.

In general, deer muscles are rich in palmitic (C16:0), stearic (C18:0) and linoleic acid. Different composition of FA in the meat from grazing fallow deer compared to those supplemented with concentrates was observed by Volpelli et al. (2003) **(Table 3)**. Meat from SET muscle obtained from fallow deer bucks grazed on pasture contained significantly lower average concentrations of myristic (C14:0), C16:0, palmitoleic (C16:1 *n*-7), C18:0, oleic (C18:1 *n*-9), C18:2 *n*-6 and adrenic acid (C22:4 *n*-6), as well as lower SFA and MUFA concentrations. Although not significantly different, contents of *cis*-vaccenic (C18:1 *n*-7), arachidonic (C20:4 *n*-6) and docosahexaenoic acid (DHA, C22:6 *n*-3) were slightly lower in the grazing group. Whilst SET samples from supplemented fallow deer contained significantly lower levels of ALA, eicosapentaenoic (EPA, C20:5 *n*-3) and overall concentration of PUFA, whereas content of docosapentaenoic acid (DPA, C22:5 *n*-3) was lower but did not differ significantly between the groups. The use of supplementary feeding caused significant increase in the total content of SFA and MUFA also in LL muscle while the total content of PUFA was lower in this group compared to grazing deer. A marked increase was particularly evident for C14:0, C16:0, C16:1 *n*-7, C18:0, C18:1 *n*-9, C18:2 *n*-6 and C22:4 *n*-6. The pasture-fed group exhibited a significantly higher amount of ALA, EPA and DPA. No signigicant differences in FA composition of *LL* muscle between two dietary treatments were observed for C18:1 *n*-7, C20:4 *n*-6, DHA and dihomo-γ-linolenic acid (DGLA, C20:3 *n*-6). Overall, concentrate feeding caused reduction of the total content of PUFA and significant increase in the *n*-6/*n*-3 ratio.

FAs are involved in various aspects of meat quality, such as texture, shelf life, flavour and odour, thereby affecting sensory properties of deer meat (Cho et al., 2005; Neethling et al., 2016). Due to the different melting points and variation in FA composition, individual FAs have important but diverse effects on the firmness or softness of the fat and meat. The effect of FAs on meat flavour is due to the production of volatile, odourous, lipid oxidation products during heat treatment. Especially unsaturated FAs are important in the development of meat flavour (Wood et al., 2003; Khan et al., 2015). Natural grazing is a source of PUFA and seen as an important contributor to the development of “wild”, “gamey” and “grassy”

flavour in meat (Wiklund et al., 2000; Wiklund et al., 2003b; Finstad et al., 2007), whereas grain-based diets correspond to meat with lower PUFA levels frequently described as having "mild" and "beef-like" flavour (Wiklund et al., 2003a, 2003b). However, a high content of PUFA may negatively affect the oxidation stability and other technological parameters of meat and meat products (Daley et al., 2010; Poławska et al., 2013). Finding that increasing intake of PUFA in the diet is beneficial for human health is in contradiction with the fact that higher contents of PUFA in meat are associated with the lowering its oxidative stability, and gives possible proposal for further investigation.

**Table 3: Fatty acid composition (mg/100 g fresh tissue) of muscles from pasture-fed and concentrate-fed fallow deer (n = 16 per group).**

| **Fatty acid (mg/100 g fresh tissue)** | **SET** | | **SED** | **MLL** | | **SED** |
|---|---|---|---|---|---|---|
| | **Pasture** | **Concentrates** | | **Pasture** | **Concentrates** | |
| C14:0 *iso*[a] | 5.1 | 13.5 | 9.29 | 4.4 | 9.3 | 4.94 |
| C16:0 *iso* | 108.4 | 164.0 | 66.71 | 97.4 | 131.3 | 37.68 |
| C16:1 *n*-7 | 7.7 | 13.3 | 7.10 | 5.9 | 8.7 | 3.92 |
| C18:0 *iso* | 147.8 | 185.3 | 49.50 | 131.4 | 152.1 | 27.37 |
| C18:1 *n*-7 | 62.5 | 99.3 | 46.58 | 49.6 | 71.2 | 23.58 |
| C18:1 *n*-9 | 22.6 | 27.3 | 8.10 | 27.9 | 28.1 | 5.77 |
| C18:2 *n*-6 | 179.0 | 220.6 | 43.24 | 195.0 | 223.4 | 33.02 |
| C18:3 *n*-3 | 30.0 | 24.2 | 7.06 | 32.6 | 23.1 | 5.77 |
| C20:3 *n*-6 | | | | 2.5 | 2.3 | 0.81 |
| C20:4 *n*-6 | 92.4 | 96.8 | 24.58 | 113.8 | 107.4 | 15.62 |
| C20:5 *n*-3 | 13.6 | 9.8 | 4.06 | 20.3 | 13.0 | 4.31 |
| C22:4 *n*-6 | 0.8 | 2.5 | 1.32 | 1.5 | 3.1 | 1.52 |
| C22:5 *n*-3 | 35.9 | 34.2 | 10.15 | 40.6 | 33.7 | 6.32 |
| C22:6 *n*-3 | 2.1 | 2.5 | 2.60 | 2.4 | 2.2 | 1.84 |
| SFA (%) | 36.88 | 39.60 | 4.75 | 31.83 | 35.87 | 3.00 |
| MUFA (%) | 13.09 | 14.70 | 3.05 | 11.25 | 13.07 | 1.89 |
| PUFA (%) | 50.03 | 45.70 | 7.54 | 56.92 | 51.06 | 4.74 |
| *n*-6/*n*-3 | 3.39 | 4.63 | 0.61 | 3.30 | 4.76 | 0.53 |

[a] Isomers with different location of methyl group.

(Adapted from Volpelli et al., 2003).

#### 2.5.1.3 Minerals

It is well known that minerals such as copper, cobalt, selenium, manganese and zinc are very important for grazing ruminants, including deer. Deficiencies can cause severe reproduction problems, restricted growth of young deer and osteochondrosis among others (Wilson and Grace, 2001; Handeland et al., 2008). Contents of iron (particularly its haem form; 50–60%) (Higgs, 2000; Hoffman et al., 2007b; Poławska et al., 2013), potassium, phosphorous, copper, zinc and calcium in deer meat and liver **(Table 4)** are considerably higher than in meat of some other wild or farm-raised ruminant species. Deer are closely associated with the natural environment as they graze and browse on the grasses, herbs, coniferous species, as well as meadow or crop plants, and their meat will thus reflect the mineral composition of their diet. Deer are frequently supplemented with mineral blocks rich in macro and microelements. Moreover, commercially used fields are often fertilized by manure from farms where the domestic animals generally receive large doses of minerals in their feed. This may have a potential impact on the concentration of these elements in plants growing in these fields and thus in deer tissues (Falandysz et al., 2005; Hoffman et al., 2005; Jacela et al., 2010; Skibniewski et al., 2015). Mineral concentration, however, varies across muscles and organs as a function of the type of physical activity, muscle fibre type and various environmental factors (Hoffman et al., 2007b). Especially copper is a major essential trace element for deer and the liver is the main storage organ playing a key role in its metabolism and reflecting the copper status of the animal body. According to Wilson and Grace (2001), Grace and Wilson (2002) or Handeland et al. (2008), the range 4–7 mg/kg liver tissue can be considered critical for clinical disease or retarded growth.

**Table 4: Mineral content (mean ± standard error) in the liver of grazing fallow deer (n = 69; 17 bucks, 52 does).**

| Minerals | Sex | |
|---|---|---|
| | Bucks | Does |
| Macro minerals (g/kg) | | |
| Calcium | 0.09 ± 0.02 | 0.12 ± 0.08 |
| Potassium | 1.80 ± 0.47 | 1.94 ± 0.73 |
| Magnesium | 0.13 ± 0.03 | 0.15 ± 0.03 |
| Sodium | 0.55 ± 0.12 | 0.68 ± 0.26 |
| Phosphorus | 6.27 ± 0.91 | 6.42 ± 1.13 |
| Micro minerals (mg/kg) | | |
| Copper | 21.0 ± 15.1 | 35.3 ± 21.5 |
| Iron | 107 ± 43 | 154 ± 71 |
| Manganese | 3.3 ± 0.8 | 4.0 ± 1.8 |
| Zinc | 31.6 ± 13.9 | 31.1 ± 9.1 |

(Adapted from Vengušt and Vengušt, 2004).

Apart from the fact that deer tissues are rich in minerals (Wiklund et al., 2003b; Kwiatkowska et al., 2009; Poławska et al., 2013), it is also possible to find there some toxic elements. The studies of Lazarus et al. (2005), Srebočan et al. (2006), Srebočan et al. (2011) and Skibniewski et al. (2015) have shown that especially due to the natural diet (holm oak (*Quercus ilex*), mushrooms, cabbage) and the environment, harmful substances such as cadmium, lead, barium or mercury may accumulate in body tissues of wild deer (especially in older animals) in higher concentrations, whereas levels of heavy metals in tissues of farmed animals are much lower (Kramárová et al., 2005a; Assenova et al., 2016). Anyway, observed levels of heavy metals in wild deer do not pose a threat to consumers' health. Overall, the content of both mineral and toxic elements in deer tissues can be influenced by environmental factors, as well as by the age, sex and concentration of minerals in the feed ration (Sales, 1995; Hoffman et al., 2007b).

### 2.5.2 Physical characteristics

From a consumer perspective, the desired physical quality properties of meat are important acceptability factors that are closely related to the texture. These properties include visual attributes perceived directly by the senses of touch, sight and hearing (colour, amount of water and fat, flavour, mouthfeel and overall appearance) (Bourne, 2002; Cawthorn et al., 2018).

#### 2.5.2.1 pH values

One of the most important physical parameters determining the meat quality is the ultimate pH value of meat ($pH_u$; measured approx. 24 h after the slaughter). The $pH_u$ gives information about the technological quality of meat, such as colour, tenderness, WHC, or shelf life (Wiklund et al., 2004b; Wiklund et al., 2010a). Venison (defined as meat derived from cervids) after slaughter has a $pH_{45min}$ in the range of 6.5–7.2 which, in general, falls to 5.8–5.3 within 24–48 hours *post-mortem* as reported by Volpelli et al. (2003), Hutchison et al. (2012), Bykowska et al. (2018a), Ludwiczak et al. (2017), Cawthorn et al. (2018), Kaimbayeva et al. (2018) or Neethling et al. (2018). However, there is a wide variability in the rate of pH decline in deer meat (Sookhareea et al., 1995; Volpelli et al., 2003) due to various *ante-mortem* stress factors such as transportation, chasing or slaughter method (Hoffman et al., 2011; Kudrnáčová et al., 2018). For example, pH decline may be dependent on the relationship between temperature and the *ante-* or *post-mortem* treatment of meat (Hoffman et al., 2007a; Taylor and Hopkins, 2011; Hutchison et al., 2014). Smith and Dobson (1990) detected a higher $pH_u$ (> 5.74) in stressed animals transported to the slaughterhouse, compared to those shot in the paddock without handling ($pH_u$ < 5.74). In contrast, Cifuni et al. (2014) found no difference between the pH of meat frozen and stored for 3 months from stressed, dog hunted deer ($pH_u$ 5.61) and deer shot in the field ($pH_u$ 5.66). Pollard et al. (2002) also noted that the pH values of deer shot in the paddock and deer transported to the slaughterhouse were similar. Expected relationship between increased *ante-mortem* handling and increased pH values has been observed in some studies, but normal $pH_u$ values and physiological responses have also been found in deer species exposed to *ante-mortem* stressors (Wiklund et al., 1995; Grigor et al., 1997; Jago et al., 1997). This suggests a more complex relationship between *ante-mortem* handling and *post-mortem* muscle pH values than predicted only through effects of glycogen depletion (Pollard et al., 2002) and typically found in farmed species. The effects

on ultimate pH values have also been demonstrated to vary due to the degree of tameness (Rehbinder, 1990), or due to the physical condition, sex or age of the animals (Wiklund et al., 1995), whereas effect of diet is likely ambiguous. The studies of Volpelli et al. (2003) and Hutchison et al. (2012) observed no effect of concentrate feeding on $pH_u$ values in fallow deer **(Table 5)**. On the contrary, significantly lower pH values in deer supplemented with concentrates compared with animals grazing pasture were reported by Wiklund et al. (2005) and Wiklund et al. (2006).

#### 2.5.2.2 Meat colour

One of the most important factors affecting consumer's choice and acceptability of the meat is its colour. Despite the fact that dark meat is usually associated with DFD defect (dark, firm and dry meat), in case of deer meat, more intense bright-cherry red colour is connected with freshness and good quality, and being considered by consumers a typical feature of venison (Ramanzin et al., 2010; Font-i-Furnols and Guerrero, 2014; Neethling et al., 2018). Objective colour evaluation is performed by reflectance spectroscopy using co-ordinates determining lightness ($L^*$), chromaticity ($a^*$, $b^*$), chroma ($C^*$) indicating the colourfulness and hue angle ($h^*$) determining the qualitative attribute of colour. The colour co-ordinate $a^*$ (redness) is the most sensitive parameter of colour measurement, characterising red meat colour and its stability, whereas $b^*$ co-ordinate (yellowness) is associate with scorching and overall product degradation (García-Esteban et al., 2003; Pathare et al., 2013). Meat colour co-ordinates may be connected with various intrinsic (e.g. muscle type, pH values, sex) and extrinsic (e.g. diet, production system) factors.

Feeding regime may influence the concentration of muscle myoglobin, while the farming system may cause changes in physical activity and influence metabolism (Priolo et al., 2001; Mancini and Hunt, 2005). According to Hoffman et al. (2005), muscles of wild animals work harder than those of farm-raised, and as a consequence contain higher amount of myoglobin responsible for dark colour. Thus, meat from wild grass-fed animals tends to be darker than from animals kept at the farm and finished on concentrates (Muir et al., 1998; Hopkins and Nicholson, 1999; Vestergaard et al., 2000). However, Volpelli et al. (2003), Mulley et al. (2006) and Hutchison et al. (2012) reported no significant effect of diet on the colour of muscles from pasture-fed fallow deer and those supplemented with concentrates **(Table 5)**. Possibly due to the high content of pro-oxidants such as iron and copper, deer meat

has low colour stability at different storage conditions (Ramanzin et al., 2010). Therefore, the use of pasture containing higher levels of antioxidants is recommended as a way of improving colour stability, instead of the major use of concentrate feeding (Wood et al., 2003; Nuernberg et al., 2005; Wiklund et al., 2005; Hoffman and Wiklund, 2006; Mulley et al., 2006; Wiklund et al., 2006), or by vitamin E supplementation (Okabe et al., 2002; Florek and Drozd, 2013).

#### 2.5.2.3 Warner–Bratzler shear force

Meat tenderness is highly variable among animal species as a result of various extrinsic and intrinsic factors. However, the differences are given mainly by proteolytic enzyme activity (ageing), different IMF and collagen content, muscle fibre characteristics and anatomical position of each muscle (Picard et al., 1998; Chriki et al., 2012; Żochowska-Kujawska et al., 2012; Cawthorn et al., 2018). Only minor differences in WBSF values (meat tenderness) in relation to the diet have been observed in fallow deer. No significant effect of the diet fed to fallow deer in Italy has been reported by Volpelli et al. (2003). However, these findings are in contrast to that of Hutchison et al. (2012) for fallow deer in Australia. Animals supplemented with concentrates had significantly higher content of IMF and thus produced more tender meat than those with pasture fattening.

### 2.5.3 Technological parameters

Thawing loss, drip loss/purge, cooking/grilling loss and losses caused by the press test all belong to technological parameters and they are characterized by the formation of exudates from meat. All these parameters cause weight loss of the meat which is undesirable from both an economic and consumer acceptability perspective (Cawthorn et al., 2018). Results from the measurement of weight loss are considered to be good indicators of WHC and closely correlate with meat juiciness and tenderness (Pearce et al., 2011; Okuskhanova et al., 2017).

No significant differences in cooking loss (Volpelli et al., 2003) or purge (Wiklund et al., 2005; Hutchison et al., 2012) were observed between fallow deer grazing pasture and those supplemented with concentrates. Similar results have been reported also for elk meat (Kim et al., 2017), beef (Avilés et al. 2015; Patino et al., 2015) or llama meat (Mamani-Linares and Gallo, 2014). However, this effect of diet is in contradiction with the results of Wiklund et al. (2006) for red deer meat, who reported significantly lower drip loss (purge) in meat from the pasture-fed deer compared with the group fed pellets after three weeks of

storage. The authors suggest that the differences in drip loss could be related to a variation in meat composition, i.e. levels of vitamin E, which positively correlates with increased WHC in meat.

**Table 5: Physical and technological parameters of muscles from pasture-fed and concentrate-fed fallow deer (n = 16 per group).**

| | SET | | SED | MLL | | SED |
|---|---|---|---|---|---|---|
| | **Pasture** | **Concentrates** | | **Pasture** | **Concentrates** | |
| pH | | | | | | |
| 9 hrs | 5.48 | 5.40 | 0.15 | 5.35 | 5.37 | 0.07 |
| 24 hrs | 5.53 | 5.53 | 0.20 | 5.47 | 5.50 | 0.13 |
| 48 hrs | 5.63 | 5.62 | 0.17 | 5.60 | 5.61 | 0.13 |
| Colour | | | | | | |
| *L** | 35.84 | 35.72 | 2.48 | 33.36 | 34.48 | 2.15 |
| *a** | 22.03 | 21.37 | 2.63 | 22.69 | 23.74 | 2.33 |
| *b** | 3.78 | 2.99 | 2.70 | 3.60 | 4.10 | 1.98 |
| WBSF (kg) | | | | 4.40 | 4.63 | 1.02 |
| Cooking loss (%) | | | | 26.72 | 26.25 | 4.11 |
| Drip loss (%) | 2.86 | 3.12 | 1.34 | | | |

(Adapted from Volpelli et al., 2003).

### 2.5.4 Organoleptic properties

Differences in texture, flavour and appearance are very important attributes affecting the market of domestic as well as game meats (Wiklund et al., 2003b; Resurreccion, 2004). These specifications are often established according to the amount of IMF, which influences many sensory descriptors of meat. A higher content of IMF has a positive effect on the sensory qualities of meat, such as flavour, tenderness or juiciness (Fernandez et al., 1999; Hoffman et al., 2007d). Nevertheless, despite the fact venison being considered a low-fat meat, it can score higher for organoleptic properties compared to meat from other livestock, such as beef, pork or poultry (Rødbotten et al., 2004; Wiklund et al., 2009; Bureš et al., 2015).

Tenderness, an important factor to the sensory quality of meat, varies between species. IMF content, composition of connective tissues, location and physical activity of muscles all influence tenderness (Purchas et al., 2002; Joo et al., 2013). The tenderness of deer meat is comparable or superior to beef (Bureš et al., 2015). This result is in accordance with Rødbotten et al. (2004) who compared the sensory profile of meat from 15 species and found

that roe deer meat was more tender than beef. Similar result obtained Wiklund et al. (2009) who noted significant differences in the sensory attributes between beef and venison. Venison scored better in all assessed parameters but the most obvious difference was in tenderness.

The sensory attributes of meat are also dependent on the type of diet (Rødbotten et al., 2004). It has been shown that the feeding regime and the type of feed consumed by animals prior to slaughter alter the flavour and composition of the meat (Hutchison et al., 2012). Wiklund et al. (2003a, 2003b) and Finstad et al. (2007) reported that free-ranging animals produced meat with more "wild" and "gamey" flavour, whereas farmed deer fed with grain-based diet had more "mild" and "beef-like" flavour. The results from the study of Wiklund et al. (2000) showed that a pasture-fed deer produced venison with more off-flavours compared to those supplemented with commercial deer pellets.

Mulley et al. (2006) investigated the influence of supplementary feeding on organoleptic properties of venison from fallow deer. The only significant difference in sensory attributes detected by panellists was flavour strength between animals fed barley compared to those pasture-fed, with venison from grain-fed animals having a stronger flavour **(Table 6)**. It is therefore appropriate to ensure supplementary feeding for animals, at least during the finishing phase, to produce carcasses that consistently meet market requirements (Russo, 2005; Mulley et al., 2006).

**Table 6: Sensory evaluation (mean ± standard error) of venison from pasture-fed and concentrate-fed fallow deer (n = 12 per group).**

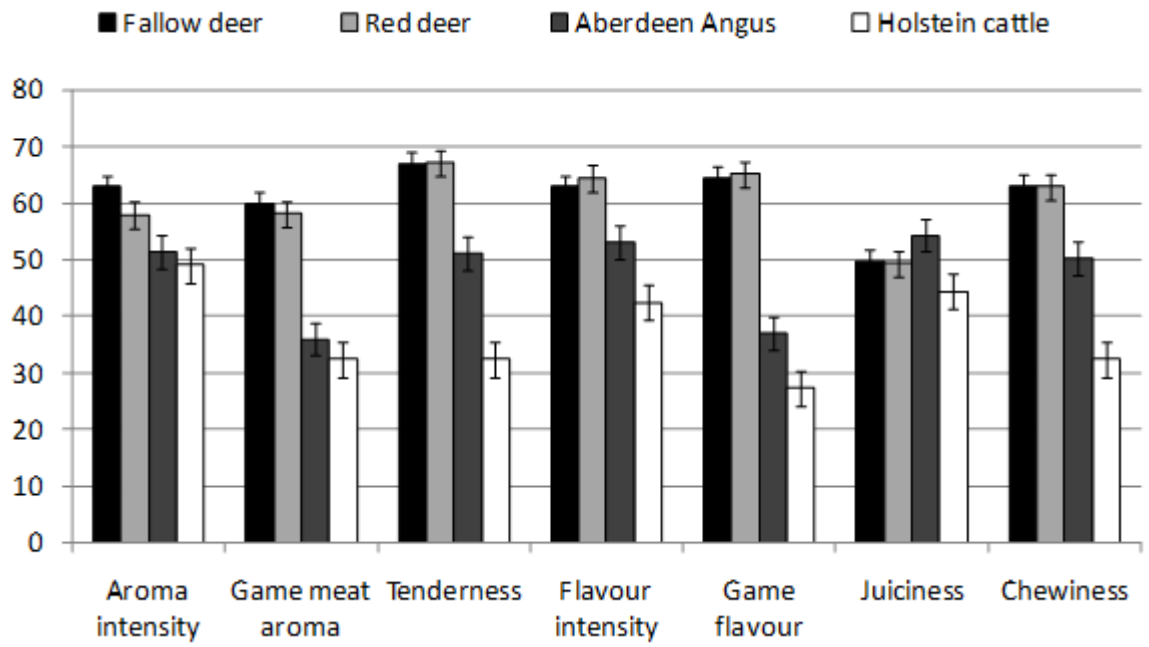
| Sensory attributes | Diet | | Scale |
|---|---|---|---|
| | Pasture | Concentrates | |
| Colour | $8.56^{a} \pm 2.35$ | $8.21^{a} \pm 2.48$ | 0 = extremely pale, 12.5 = extremely dark |
| Aroma | $8.34^{a} \pm 2.41$ | $8.14^{a} \pm 2.32$ | 0 = dislike extremely, 12.5 = like extremely |
| Aroma strength | $7.88^{a} \pm 2.51$ | $8.03^{a} \pm 2.63$ | 0 = none, 12.5 = extremely strong |
| Flavour | $9.49^{a} \pm 2.18$ | $9.97^{a} \pm 1.95$ | 0 = dislike extremely, 12.5 = like extremely |
| Flavour strength | $8.08^{a} \pm 2.13$ | $8.52^{b} \pm 1.84$ | 0 = none, 12.5 = extremely strong |
| Game flavour | $6.99^{a} \pm 2.81$ | $7.29^{a} \pm 2.67$ | 0 = none, 12.5 = extremely strong |
| Tenderness | $9.74^{a} \pm 2.39$ | $10.03^{a} \pm 2.16$ | 0 = extremely tough, 12.5 = extremely tender |
| Juiciness | $8.34^{a} \pm 2.81$ | $8.39^{a} \pm 2.72$ | 0 = extremely dry, 12.5 = extremely juicy |
| Overall liking | $10.13^{a} \pm 2.38$ | $10.55^{a} \pm 1.90$ | 0 = dislike extremely, 12.5 = like extremely |

Measurements with the same letter in columns are not significantly different.

The 12.5 cm line scale was used for the assessment.

(Adapted from Mulley et al., 2006).

Generally, flavours of various meat species are similar but differ in intensity (Rødbotten et al., 2004). The flavour of deer meat is strong, but meat from younger animals and does has less intensive flavour than that of adult bucks (Ramanzin et al., 2010). Bureš et al. (2015) compared the samples of meat from fallow deer, red deer, Aberdeen Angus and Holstein cattle aged for 7 days **(Graph 1)**. The panelists were not able to recognize the difference between the samples from fallow deer and red deer, whereas marked differences between venison and beef in most sensory attributes were observed. In their study, venison had greater aroma and flavour intensity than beef, which may be partially explained by differences in the FA composition of muscle lipids.




**Graph 1: Sensory evaluation of grilled LL muscles aged for 7 days (internal temperature of 70 °C on glass/ceramic plate grill) from fallow deer (n = 9), red deer (n = 9), Aberdeen Angus (n = 9) and Holstein cattle (n = 9)**.

Key: Aroma intensity, game meat aroma, flavour intensity, game flavour, juiciness: 0 = low, 100 = high; tenderness: 0 = though, 100 = tender; chewiness: 0 = scarcely chewable, 100 = easily chewable (Adapted from Bureš et al., 2015).

### 2.6 Carcass suspension

Palatability (depending on the sensory properties such as taste, odour or texture) is one of the most important attributes for the consumers in determining eating quality of meat, with flavour and texture being the two major factors (Donini et al., 2009; Rafe, 2019).

In the late 1960s and early '70s, rapid carcass chilling and freezing before the onset of *rigor mortis* resulting in tough meat led to extensive research on meat tenderness (Sørheim and Hildrum, 2002). Thus, the relationship between meat textural parameters and different carcass suspension methods has been greatly studied since an article from New Zealand was published as early as in 1960 (Ahnström, 2008). The author of this article suggests that meat

texture (mainly tenderness) can be manipulated by means of stretching through the use of different suspension methods of the carcass **(Figure 4)** (Locker, 1960; Hostetler et al., 1970).

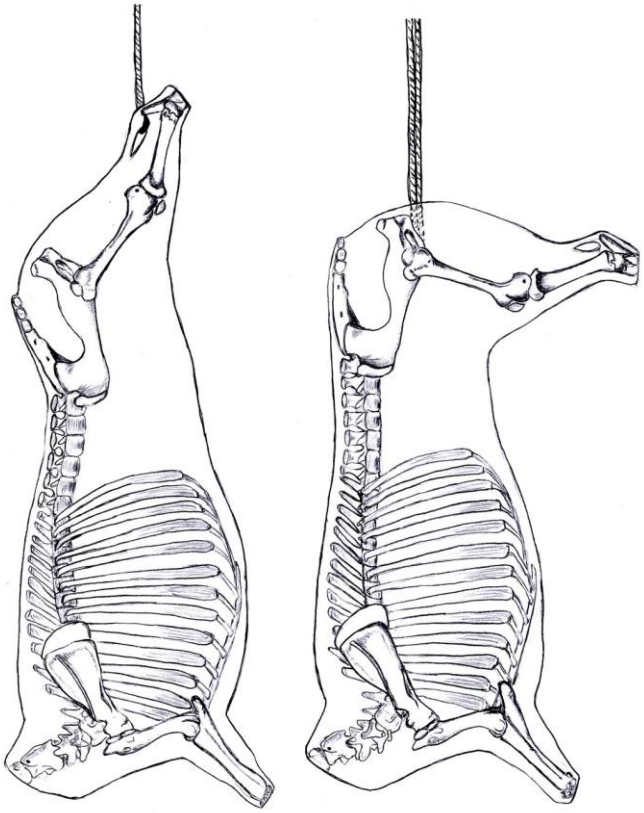


**Figure 4: Schematic drawing of carcass suspension methods.**

The Achilles tendon method (left) and the Tenderstretch method (right).

(Ahnström, 2008)

The traditional way of carcass suspension is by the hind leg using a hook passed behind the Achilles tendon. This method pulls back the hind leg, the spine is curved and carcass weight puts muscles into tension, thus contracts them as they go through *rigor mortis*. While muscles are in tension, muscle fibres overlap and muscles in the loin area and in the pelvic limb are allowed to shorten resulting in less tender meat (Hostetler et al., 1970; Ahnström et al., 2012).

On the other hand, pelvic suspension (known also as hip suspension, aitch-bone hanging, or 'Tenderstretch' presented by The Texas A&M Research Center) is a method where the carcass is hung through the eye of the aitchbone (*obturator foramen*) or the pelvic ligament, which leads to a carcass position more typical for the animals´ natural state. When

pelvic suspension is applied to a carcass, the hind legs hang free, vertically from the carcass, at a 90° angle. This relaxed position leads to straightening of the vertebral column so the number of muscles (MLL, SM, MGM, SET) are stretched when they enter *rigor* mortis. The stretching prevents muscle contraction and shortening, and affects the structure of myofibrils in muscle tissue greatly. The stretched muscles have longer sarcomeres and smaller muscle fibre diameter resulting in more tender meat compared to Achilles-hung samples (Hostetler et al., 1970; Sørheim and Hildrum, 2002; Ahnström, 2008; Warriss, 2010).

This quality assuring intervention may reduce drip loss/purge and improve the tenderness of the affected muscles of 15 to 40% (Hopkins et al., 2000; Ahnström et al., 2012). A number of studies support the positive effects of Tenderstretch on tenderness and/or juiciness of beef (Hostetler et al., 1970; Ahnström et al., 2012; Liu et al., 2016), lamb or goat (Hopkins et al., 2000; Thompson et al., 2005; Basinger et al., 2019), alpaca (Smith et al., 2017) and venison (Sims et al., 2004; Wiklund et al., 2004a; Hutchison et al., 2006; Mulley et al., 2006; Hutchison et al., 2010; Wiklund et al., 2012; Hutchison et al., 2014).

Sims et al. (2004) and Mulley et al. (2006) evaluated the differences in tenderness between muscles from fallow deer carcasses being placed in different hanging positions whilst entering *rigor mortis*. The tenderness of MLL, BIF, SM, *aductor femoris* and *vastus lateralis* was significantly improved as a result of pelvic suspension in young fallow deer bucks (18 months old). However, for the older fallow deer bucks (≥ 36 months old), significant effect of pelvic suspension on meat tenderness were only found in BIF and SM samples, and no significant impact at all on tenderness in muscles from fallow deer does (24 months old) was detected. In addition to increasing the tenderness level, Tenderstretch had also the ability to reduce drip loss and thus to enhance the juiciness of MGM muscle. Further studies confirmed these findings of increased tenderness and juiciness of several muscle samples from both fallow deer bucks and does (Hutchison et al., 2010; Hutchison et al., 2014). Similarly, as showed in the study of Hutchison et al. (2006), pelvic suspension used on fallow deer carcasses decreased drip loss and WBSF values of MLL samples. Thus, tenderstretched muscles scored significantly higher for both tenderness and juiciness in the sensory analysis.

The positive effect of pelvic suspension on tenderness in venison from the reindeer steers is reported by Wiklund et al. (2012). For this study, significant effect of Tenderstretch was found for MLL with values from pelvic-suspended carcasses being lower. This finding was confirmed by the trained panellists, who rated the samples derived from aitch-bone hung

carcasses to be more tender. By contrast, juiciness was not affected by carcass suspension method. On the other hand, Wiklund et al. (2004a) pointed out that the carcass suspension method had an effect on drip loss and purge of fallow deer meat. Tenderstretch reduced purge in the vacuum-packed samples, while fresh meat exhibited significantly lower drip loss with Achilles tendon suspension.

However, research in the area of deer meat quality is very limited and further studies of the relationship between carcass suspension methods and consumer acceptance of venison are essential.

## 3. AIMS AND HYPOTHESES

**A1:** To evaluate the effect of different feed rations on the growth, carcass parameters and economic efficiency of the fattening.

**A2:** To evaluate the effect of different feed rations on the chemical composition, physical and technological parameters and organoleptic properties of meat from farm-raised fallow deer.

**A3:** To evaluate the effect of different carcass suspension methods on the sensory attributes of fallow deer meat.

**H1:** Composition of the feed ration and supplementation with barley will affect growth, carcass composition and economic efficiency of the fattening.

**H2:** Composition of the feed ration will affect chemical compostion, physical and technological parameters, and organoleptic properties of meat.

**H3:** Pelvic suspension method will positively affect the quality attributes of fallow deer meat.

# 4. MATERIALS AND METHODS

All experimental procedures used in this experiment were approved by the Animal Care Committee of the IAS.

## 4.1 Animals, performance and diet

A total of 45 fallow deer bucks **(Appendix 2)** at an initial age of 11 months and an average live weight 28.2±1.8 kg were involved in the experiment. The animals were fattened during the year 2015 on the farm Mnich near Kardašova Řečice situated in Southern Bohemia (49°16'71.9"N; 14°90'05.2"E). All animals originated from the same herd. Individual bucks were identified with plastic ear tags, and based on their body weights, they were assigned into three separate groups of 15 animals and placed into three 2-ha adjoining paddocks (0.13 ha/animal). The bucks were weighed three times (until the onset of fraying) during the experiment, and paddocks were switched among the groups at six-week intervals.

The groups were assigned to three different dietary treatments. Group P received only pasture, group B received pasture supplemented with barley, and group L received pasture supplemented with barley and lysine (LysiPEARL$^{TM}$ in the amount of 5 g/day). The LysiPEARL$^{TM}$ preparation (Kemin Industries, Inc., Iowa, USA) consisted of 50 % of synthetic lysine and 50% of hydrolysed palm oil. Animals were supplemented with encapsulated RPAA lysine **(Appendix 3)** that prevented its accessibility to rumen microorganisms and ensured its release in the abomasum. Supplementation with concentrates was done once daily via wooden troughs placed in the pasture. One meter of trough length was available for each animal. All groups received a mineral mixture lick (Premin Slanisko, VVS Verměřovice Ltd., Czech Republic). The finishing period was divided into two phases. In the first phase (90 days from the end of April until the end of July), the B and L groups received barley in the amount of 0.2 kg/day per animal, whereas in the second phase (on average 79 days, from the beginning of August until slaughter) the dose of barley was increased to 0.4 kg/day per animal. Group L received the same amount of lysine (5 g/animal/day) over the entire experiment.

## 4.2 Feed chemical composition

The average chemical composition of the barley and pasture (consisted of herbaceous representatives of common pasture vegetation) is shown in **Table 7**. During the experiment, forage samples were collected three times from three locations within each paddock

(beginning of the fattening, middle/at the beginning of the second phase and at the end). All diet samples were freeze-dried (Freeze dryer ALPHA 1-4 LSC, Martin Christ Gefriertrocknungsanlagen GmbH, Germany), and the average nutrient composition was analysed as described by Jančík et al. (2017). The chemical composition of pasture samples was determined according to the following methods:

Dry matter: oven drying for 6 h at 105 °C to a constant weight (AOAC, 1990).

Ash: oven drying for 6 h at 550 °C (ISO 2171, 2007).

Crude fat: 6 hours extraction with petroleum-ether using Soxtec 1043 (FOSS Tecator AB, Höganäs, Sweden).

Nitrogen: Kjeldahl method (Kjeltec AUTO 1030 Analyser, Höganäs, Sweden) according to AOAC 976.05 (AOAC, 2005).

Crude protein: calculated as N × 6.25.

ADF and lignin: determined according to AOAC 973.18 (AOAC, 2005).

NDF: analysed in the presence of sodium sulphite and α-amylase (Van Soest et al., 1991).

**Table 7: Chemical composition of the pasture and barley supplemented to the animals.**

| Composition (g/kg dry matter) | Barley | Pasture |
|---|---|---|
| Crude protein | 11.27 | 12.74 |
| Crude fat | 2.44 | 1.91 |
| Crude fibre | 6.68 | 31.61 |
| Ash | 2.51 | 8.49 |
| Nitrogen-free compounds | 77.10 | 45.25 |
| Lignin | 0.83 | 5.00 |
| ADF | 7.26 | 35.23 |
| NDF | 30.40 | 65.42 |

### 4.3 Slaughter process, carcass composition and muscle sampling

The experiment was terminated in October with the slaughtering of the bucks at an average age of 17 months. On each of three slaughter days (155, 169 and 183 days on feed, respectively), 15 animals (5 from each group) were randomly selected and stunned with a captive bolt within a handling box, weighed (slaughter weight – used for the calculation of slaughter characteristics), bled and eviscerated directly on the farm, and then transferred in a refrigerator truck to the experimental slaughterhouse of IAS for further processing. Within 5

hours after slaughter, the carcasses were uniformly dressed and divided along the spine into two halves. After splitting the carcass, both sides were suspended with the use of S-shaped hooks. The right side from each carcass was hung by the conventional Achilles tendon suspension, while the left side was suspended by the aitchbone (*obturator foramen*) **(Appendix 4)**. Pelvic suspension allows the hind leg to hang free at 90° angle towards the vertebrae whilst the carcass was hanging through the eye of the aitchbone. This procedure was implemented as the carcasses entered the slaughterhouse chiller between 5–6 hours after slaughter. The weights of internal fat depots (kidney, rumen and scrotal fat) and dressed carcass weights were recorded. The dressing percentage was calculated as (carcass weight/slaughter weight) × 100.

After chilling for 96 hours, the cold carcass weights were recorded, and the right sides were divided into standardised commercial joints. The joints were separated into lean meat, bones, tendons, and separable fat (subcutaneous and intermuscular), and their respective weights were recorded. The total meat yield was calculated as the lean meat from all joints plus the lean trimmings. The meat from the trimmed rump, shoulder, loin and tenderloin was considered high-priced meat, and the lean meat from the remaining joints plus the lean trimmings were considered low-priced meat. The whole LL and SET muscles were collected from each right carcass half. The samples of MLL **(Figure 5)** and SET **(Figure 6)** taken for further analyses were placed into polyethylene bags and labelled.

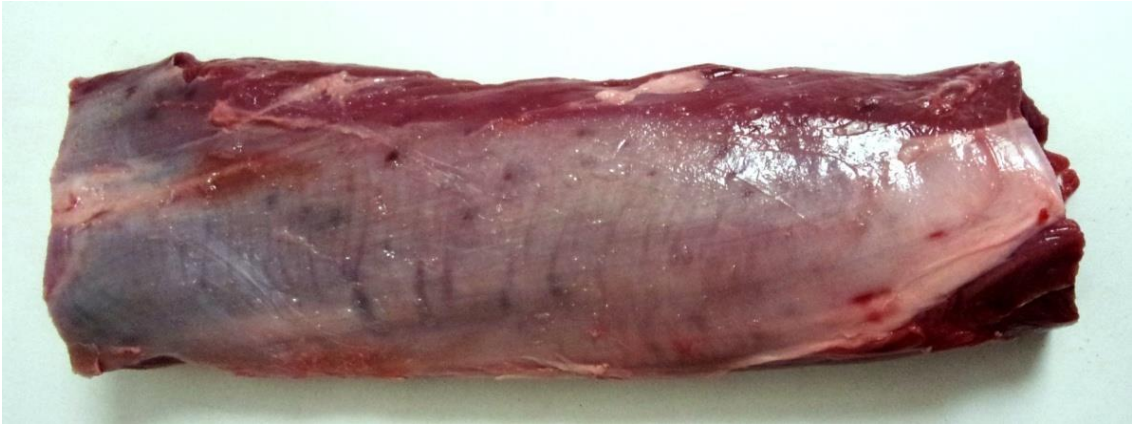


**Figure 5: The sample of LL muscle.** (Photo: author)

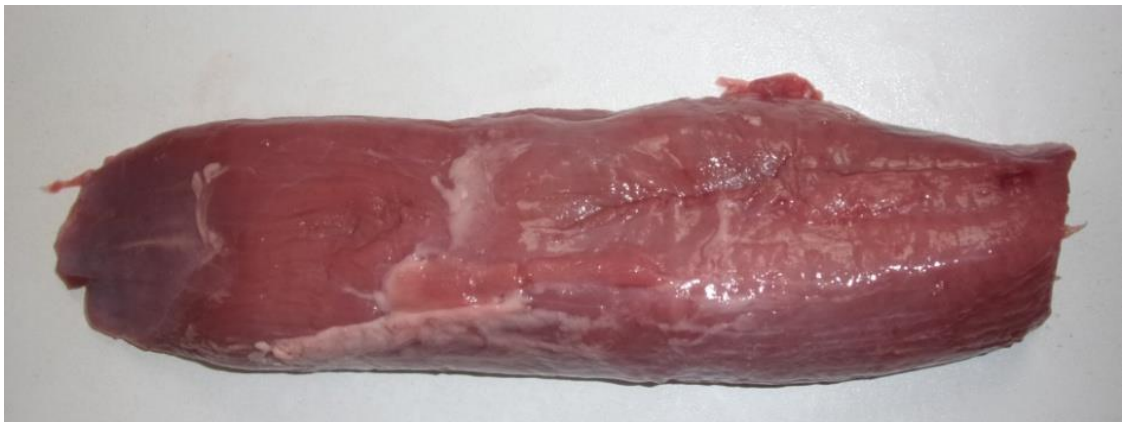


**Figure 6: The sample of SET muscle.** (Photo: author)

### 4.4 Chemical composition

Two days after the slaughter, approximately 200 g of muscle tissue from each sample was homogenized in the blender, frozen at -20 °C and used to determine the dry matter, protein, ash, AAs, FAs, IMF and total collagen content, including determination of the proportion of the heat-soluble fraction of collagen.

#### 4.4.1 Dry matter, protein and fat contents

The proportion of dry matter was determined by the gravimetric method where a given quantity was weighed from the homogenized sample. This amount was dried at +105 °C in the oven until the constant weight was reached (AOAC, 1990). The dried sample was subsequently pulverized using the Grindomix GM 200 knife mill (Retsch, Haan, Germany).

Nitrogen was converted by the mineralization process to ammonia, which was determined by the titration after distillation. The content of N-substances (proteins) was determined using a conversion factor 6.25 (Kjeltec 2400/ 2460, FOSS Tecator AB, Höganäs, Sweden) (ISO 1871, 2009).

Fat from the dried sample was extracted with an organic solvent (petroleum ether), which was then allowed to evaporate, and the residue was dried and weighed. Determination was performed using a Soxtec Avanti 2055 (FOSS Tecator AB, Höganäs, Sweden) (ISO 1444, 1996).

### 4.4.2 Content of heat-soluble collagen

The solubility of collagen was determined by extraction of two fat-free 1g meat samples by heating in a water bath for 63 minutes at 77 °C in Ringer´s solution. The samples were then placed in a centrifuge and centrifugated twice at 4,000 rpm for 10 minutes to separate the supernatant from the sediment. The filtrates were analyzed for the content of AA hydroxyproline using a Varian Cary 50 Probe (Mulgrave, Australia). Hydroxyproline was determined based on the colour reaction of its oxidation product 4-dimethylaminobenzaldehyde (Bergman and Loxley, 1963). Conversion factors of 7.52 for soluble collagen (supernatant) and 7.25 for insoluble collagen (sediment) were used for recalculation (Cross et al., 1973). The total collagen content was determined as the sum of two fractions and expressed in grams of collagen per 1 kg of muscle tissue. Soluble collagen was calculated and expressed as a proportion of total collagen content (Hill, 1966).

### 4.4.3 Amino acid composition

To determine the AA content, the samples were homogenized and dried at +103 °C to achieve a constant weight (ISO 712, 2009). The AA content was determined using the AAA 400 automatic AA analyzer (Ingos, Prague, Czech Republic). The samples were hydrolyzed with 6M HCl at +110 °C for 23 hours. For analysis of cysteine and methionine, the samples were oxidized with the mixture of 85% formic acid and 30% hydrogen peroxide (9:1) prior to hydrolysis (European Commission, 2009). The content of tryptophan was not determined for methodological reasons, due to its decomposition by oxidative degradation during acid hydrolysis (Yamada et al., 1991; Rutherfurd et al., 2015).

### 4.4.4. Fatty acid composition

The content of FAs was determined by the extraction of total lipids. The fat for analysis was extracted after the alkaline hydrolysis according to Folch et al. (1957), followed by trans-methylation of FAs (ISO 12966-2, 2017). The analysis was performed with a HP 6890 gas chromatograph (GC/FID) (Agilent Technologies, Santa Clara, CA, USA) using a 60m DB-23 capillary column with a length of 60 m × 0.25 mm × 0.25 μm (cyanopropyl-methylpolysiloxane) (J&W Agilent Technologies, Santa Clara, CA, USA). Injector and detector temperatures were 230 and 260 °C respectively, and nitrogen at 0.8 ml/min was used as a carrier gas. An initial column temperature of 120 °C was held for 6 min., then increased

to 170 °C (gradient 15 °C/min.), then to 210 °C (gradient 3 °C/min., held for 13.5 min.). At last, the temperature was increased at 40 °C/min. up to the final temperature of 230 °C held for 7 min.; the split was at 1:40. FAs were identified by comparison of retention times to those of a standard FAME mixture (Supelco 37, Bellefonte, PA, USA). Contents of FA (mg/100 g muscle tissue) were determined with nonadecanoic acid (C19:0) as an internal standard. Proportions of FA (g/100 g of FA determined) were expressed as percentages of the total area of injected methyl esters. The atherogenic index (AI) was calculated using the following equation: AI = (C12:0 + 4 × C14:0 + C16:0)/(ΣMUFA + ΣPUFA) (Ulbricht and Southgate, 1991).

### 4.5 Physical analyses

#### 4.5.1 pH measurement

pH readings were obtained using a puncture probe (SenTix Sp) connected to a pH meter 3310 set (WTW, Weilheim, Germany) at 45 min, 8 hours and 96 hours *post-mortem* in the LL and at 96 hours in the SET samples, with these $pH_{96hrs}$ readings being considered the ultimate pH values ($pH_u$).

#### 4.5.2 Colour measurement

Instrumental colour was measured on LL and SET samples 96 hours *post-mortem* using a portable spectrophotometer (CM-2500d, Minolta, Osaka, Japan; aperture size of 8 mm including specular component and 0% UV; illuminant/observer of D65/10°; zero and white calibration). The results were expressed by the *L** (lightness), *a** (redness) and *b** (yellowness) co-ordinates of the CIELab colorimetric space (CIE, 1971; Honikel, 1998). Three measurements per sample distributed on the muscle cross-section surface were taken after 30 min of air exposure to allow blooming and an effort was made by the operator to avoid the areas of dense connective tissue or fat. The *a** and *b** values were subsequently used in the calculation of chroma (*C**, saturation index= $(a^{*2} + b^{*2})^{½}$ and hue angle (°) = $\tan^{-1}$ (*b**/*a**). The mean values of the three measurements for each attribute were determined for each muscle from each animal, with these values being used for statistical analyses.

### 4.5.3 Warner–Bratzler shear force measurement

Shear force was measured in cooked samples of LL and SET muscles that had been previously aged for 14 days (first four days within whole carcass halves and then vacuum-packed in plastic bags and aged at +4 °C for an additional 10 days). Following this, the samples were removed from the vacuum packaging and cut into 20-mm thick steaks. The steaks were cooked on a double glass/ceramic plate grill (VCR 6l TL, Fiamma, Aveiro, Portugal) preheated to +200 °C, until an interval temperature of +70 °C was reached, as determined by a digital temperature probe (AD14TH, Ama-Digit, Kreuzwerheim, Germany). The cooked samples were subsequently cooled at +4 °C and the centre of each steak was divided into four rectangular blocks (20 mm × 10 mm × 10 mm), cutting perpendicularly to the muscle fibre direction. Care was taken to ensure that no visible connective tissue was included in the core. The peak force required to shear the samples across fibres was recorded using an Instron Universal Texture Analyzer 3365 (Canton, MA, USA) fitted with a V-shaped Warner–Bratzler (WB) shear blade running at a crosshead speed of 100 mm/min. The maximum mean force in newtons (N) required to shear through the sample was based on at least nine measurements per each muscle from each animal.

## 4.6 Technological analyses

### 4.6.1 Thawing and grilling loss

MLL and SET samples were weighed prior to vacuum packaging in order to determine the initial weight. After thawing (prior to the sensory analysis), the samples were weighed again to determine the weight remaining after purge. Thaw loss was calculated as the difference in the weight of fresh samples which were frozen and subsequently thawed. Results of the moisture loss were expressed as a percentage of the initial weight of each muscle sample.

To determine grilling loss, meat samples were weighed before and after the heat treatment. Individual slices with thickness of 20 mm prepared were weighed to obtain their initial weight. After weighing, the portions were placed on a double sided glass-ceramic plate grill (VCR 6l TL, Fiamma, Aveiro, Portugal) preheated at 200 °C. Once the required temperature of +70 °C has been reached, the samples were removed from the grill and after

3-minute resting period were weighed again. Losses during the heat treatment were expressed as a percentage of the raw weight of each portion (Honikel, 1998).

### 4.7 Sensory analyses

Muscle samples intended for sensory analyses were divided into two groups (MLL and SET), vacuum packed and aged for 14 days at +4 °C. After that, samples were frozen and stored at -20 °C until the sensory analyses was carried out. One day prior to the sensory analysis, samples were removed from the freezer and placed in a refrigerator where they were defrosted at +4 °C inside the plastic bag. Upon thawing, the samples were cut into slices of 20 mm in thickness and grilled on a double sided glass-ceramic plate grill (VCR 6l TL, Fiamma, Aveiro, Portugal) preheated at 200 °C to a final internal temperature of +70 °C **(Appendix 5)**, measured with a digital probe thermometer (AD14TH, Ama-Digit, Kreuzwertheim, Germany). After the heat treatment and 3-minute resting period, peripheral parts were removed and slices were cut into 20 × 20 × 20 mm cubes. Samples were placed into covered glass containers and encoded using three-digit numeric codes. The samples were kept at +60 °C until they were served to the assessors and analysed.

The sensory panel was composed of 10 experienced and trained assessors (ISO 13300-2, 2006) with previous experience in the sensory evaluation of venison. Prior to the testing phase, portions from the six of 45 fallow deer bucks were used to train the panel during the two training sessions, where eleven sensory attributes were decided upon and elucidated. Reference samples were used during the training period to help the panel define the attributes **(Table 8)**. Within the training period, each panel member received one block from each fallow deer portion, and the reference sample.

Evaluations were performed in the sensory laboratory (ISO 8589, 2007) in separate booths to prevent the visual contact of assessors with the surroundings. All analyses were conducted under controlled environmental conditions and red light to mask visual differences among the samples. The assessment was carried out using a quantitative descriptive analysis with a complete and balanced design. Five sets of three samples were randomly presented to the assessors within each of the three separate assessment days. Each set evaluated within one day consisted of three samples from the sirloin (MLL) of three animals differing in groups, which were slaughtered on the same day. The 100mm graphical unstructured line scale was used for the assessment **(Appendix 6)**, which was then transformed to the numerical scale (0-

100) for the further calculation. Bread, 10-degree beer or water was served to the panellists as a taste neutralizer. Through the sessions preceding the own assessment, the panellists were provided with reference samples to train and help them define the attributes. The panellists evaluated a total of 9 characteristics in MLL samples: intensity of aroma and flavour, game aroma and flavour intensity, tenderness, juiciness, grassy flavour, liver flavour, astringency flavour. Evaluation of SET samples was based on 8 sensory parameters: intensity of aroma and flavour, game aroma and flavour intensity, fibrosity, tenderness, juiciness, chewiness. Applied sensory descriptors, their characteristics and method of assessment are presented in **Table 8**.

**Table 8: Descriptions and scales for assessment of each attribute used during descriptive sensory analyses.**

| Sensory attribute | Description and evaluation | Scale |
|---|---|---|
| Aroma intensity | The overall intensity of aroma upon removing the cover, in first few sniffs. | 0 = very low, 100 = very high |
| Flavour intensity | The overall intensity of flavour after 5–10 chewings. | 0 = very low, 100 = very high |
| Game aroma intensity | Odour associated with the meat from wild animal species in first few sniffs. | 0 = very low, 100 = very high |
| Game flavour intensity | Flavour associated with the meat from wild animal species after 5–10 chewings. | 0 = very low, 100 = very high |
| Tenderness | Impression of tenderness during mastication; force required to chew the sample, after 2–3 chewings. | 0 = very tough,<br>100 = very tender |
| Juiciness | Amount of moisture released; the impression of juiciness after 2–3 chewings. | 0 = very dry, 100 = very juicy |
| Chewiness | The ease of chewing; residual tissue remaining after mastication, after at least 15 chewings. | 0 = scarcely chewable,<br>100 = easily chewable |
| Fibrosity | Extent to which fibres are perceived during chewing, fineness or coarseness degree after 5–10 chewings. | 0 = very coarse,<br>100 = very fine |
| Grassy flavour | Fresh, clean, green, grass-fed flavours. | 0 = very low, 100 = very high |
| Liver flavour | Fresh liver flavour, slight bitterness. | 0 = very low, 100 = very high |
| Astringency flavour | Dry, mouth-puckering, sharp, metallic, bitter. | 0 = very low, 100 = very high |

### 4.8 Statistical analyses

The data were evaluated by the statistical software SAS 9.4 (SAS, 2006). Each variable was previously tested for normality using the Kolmogorov-Smirnov goodness of fit test and for homogeneity of variance with the Levene test. Data were analysed with a mixed linear model and parameters were estimated by the restricted maximum likelihood (REML) method using the MIXED procedure. The statistical model for carcass parameters and chemical composition of the meat involved the fixed effect of diet and the random effect of the day of slaughter. The model used for the evaluation of sensory analyses included the random effect of panellists. The data in tables are expressed as the least square means (LSM) with the corresponding standard errors of the mean (SEM; n = 15). Thus, bar charts presenting the same numbers are depicted without the addition of standard error bars. The Tukey-Kramer´s range tests were used for *post-hoc* analyses. Differences were considered significant at the level of $P < 0.05$. A probability level of 5% was considered significant for all significance tests.

# 5. RESULTS

## 5.1 Growth performance

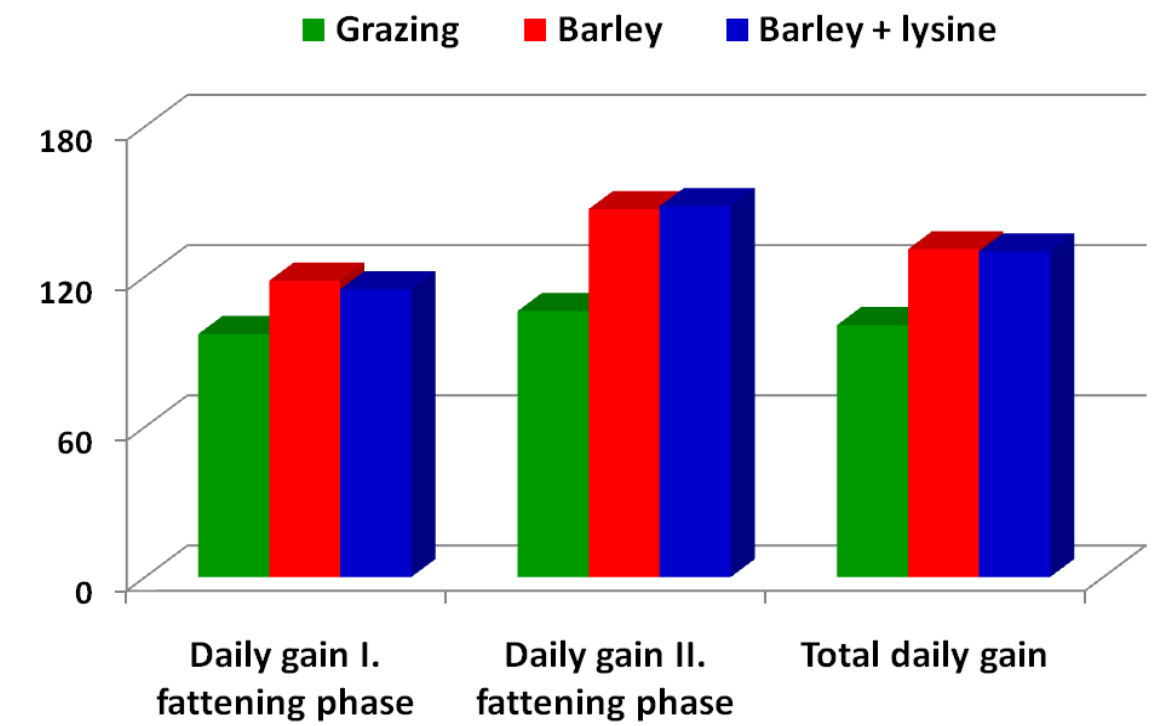
Animal performance and slaughter traits over the entire experiment are presented in **Table 9**. While the average live weight of fallow deer at the beginning of the experiment was 28.2±1.8 kg, and the average slaughter weight was 48.5±3.5 kg. As expected, there were no differences in the initial weight ($P > 0.05$) among the three dietary treatment groups. Significant differences attributable to different dietary treatments were observed in the growth of deer, particularly in the second part of the experimental period. The live weight at the end of fattening phase I tended to be higher in groups B and L than in group P, although not significantly different ($P = 0.054$). Groups B and L gained faster than group P in both fattening phases ($P < 0.001$) and over the entire experiment ($P < 0.001$) **(Graph 2)**. The differences in gain between the grain-supplemented groups B and L and the grazing deer P were 30.3 and 29.4 g/day, respectively. Overall, supplemented deer (Groups B and L) showed significantly better fattening ability compared to animals only grazing pasture, as shown in **Graph 3**. Moreover, at slaughter, B and L animals were 5.2 and 4.5 kg heavier on average, respectively, than group P animals ($P < 0.001$).

The grain-fed deer (Groups B and L) produced carcasses that were 5.4 and 4.8 kg heavier, respectively, with 5% higher dressing percentages ($P < 0.001$) than the pasture-fed (Group P) animals. However, the addition of lysine to the barley had no significant effect on any of the growth parameters or carcass dressing percentage when compared with supplementation with barley alone. Concentrate feeding resulted in a marked increase in the proportion of internal fat ($P < 0.001$), which was nearly 2.5-fold higher in group B than that recorded in group P ($P < 0.001$). Fallow deer receiving the lysine (Group L) had a significantly lower proportion of internal fat ($P < 0.05$) than that found in group B, but a significantly higher proportion ($P < 0.001$) than group P.

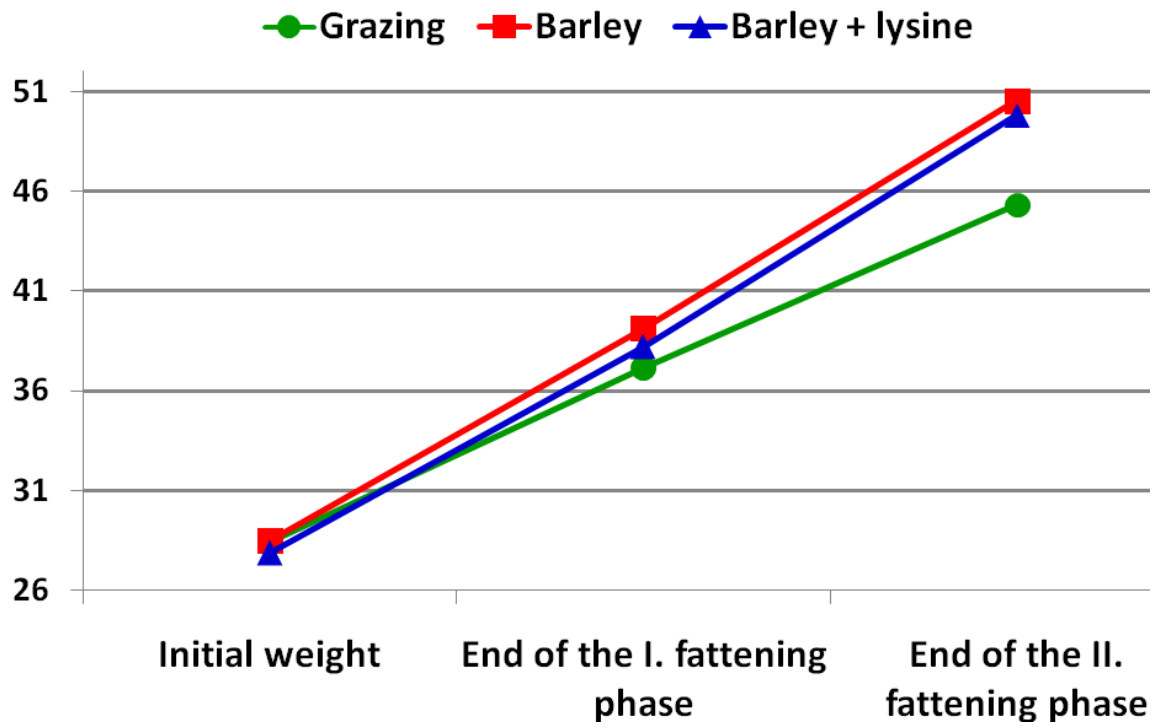
**Table 9: Growth performance and slaughter traits of fallow deer bucks (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **Initial weight [kg]** | 28.4 | 28.5 | 27.9 | 0.47 | 0.589 |
| **Weight at the end of the I. fattening phase [kg]** | 37.1 | 39.1 | 38.2 | 0.56 | 0.054 |
| **Slaughter weight [kg]** | **45.3**$^{B}$ | **50.5**$^{A}$ | **49.8**$^{A}$ | 1.03 | < 0.001 |
| **Daily gain - phase I [g/day]** | **97.1**$^{B}$ | **118.4**$^{A}$ | **115.0**$^{A}$ | 3.80 | 0.001 |
| **Daily gain – phase II [g/day]** | **106.3**$^{B}$ | **147.0**$^{A}$ | **148.2**$^{A}$ | 1.41 | < 0.001 |
| **Daily gain – entire experiment [g/day]** | **100.7**$^{B}$ | **131.0**$^{A}$ | **130.1**$^{A}$ | 6.22 | < 0.001 |
| **Carcass weight [kg]** | **23.0**$^{B}$ | **28.4**$^{A}$ | **27.8**$^{A}$ | 0.48 | < 0.001 |
| **Dressing percentage [%]** | **50.8**$^{B}$ | **56.2**$^{A}$ | **55.9**$^{A}$ | 0.46 | < 0.001 |
| **Total internal fat [% slaughter weight]** | **0.83**$^{C}$ | **1.97**$^{A}$ | **1.65**$^{B}$ | 0.08 | < 0.001 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).




**Graph 2: Weight gains [g/day] of fallow deer (n = 45) during the experiment.**




**Graph 3: Fattening ability [kg] of fallow deer (n = 45) during the experiment.**

### 5.2 Carcass characteristics and economic efficiency of the fattening

The different dieatry treatments significantly affected most of the carcass composition traits **(Table 10)**. Group P produced leaner and lighter carcasses with lower amounts of meat, bones and tendons, and separable fat ($P < 0.001$) compared with groups B and L. A 19% higher right side weight, as well as the weight of meat obtained from this carcss half were recorded in deer supplemented with concentrates, compared to the pasture-fed animals P **(Graph 4)**.

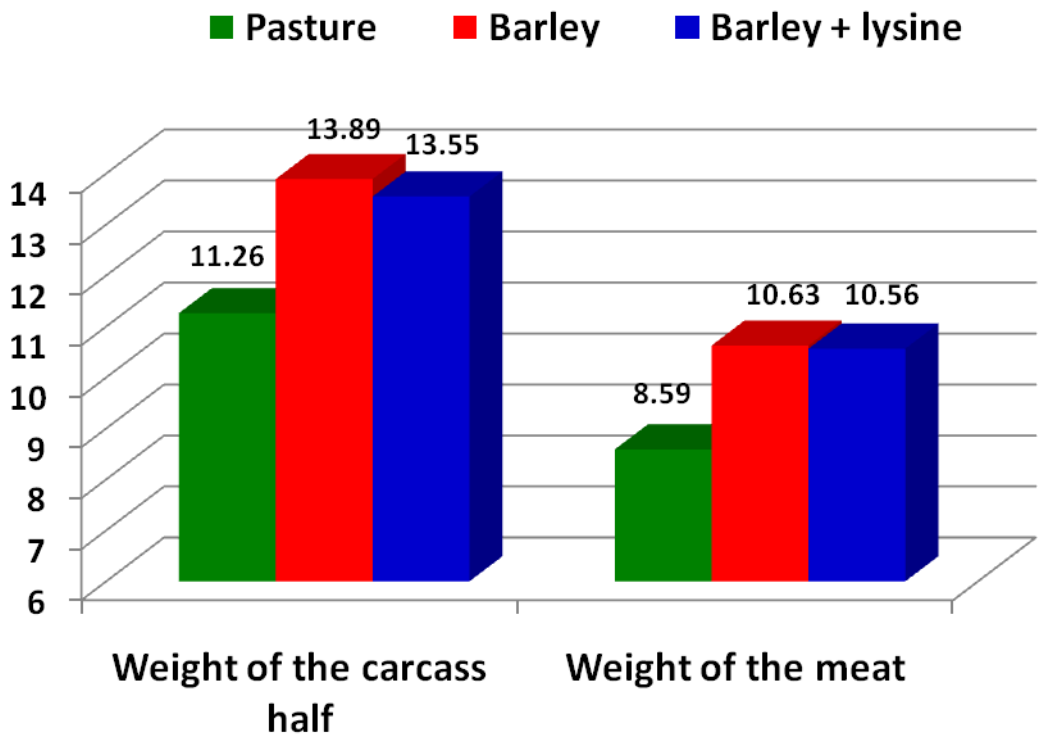
Group P had the lowest amount of high-priced meat in the carcass ($P < 0.001$), but the proportion of the right-side weight in the group P was higher ($P < 0.001$) than that in group B and similar to that in group L. While respect to high-priced meat, group P had the highest proportion of meat from the rump ($P < 0.001$), the group L had the highest proportion of meat from the shoulder ($P < 0.001$) and a higher proportion of meat from the tenderloin than group B ($P < 0.05$). Compared with groups B and L, pasture-fed animals (Group P) exhibited a lower proportion of low-priced meat ($P < 0.001$) and a lower ratio of meat to bones ($P < 0.001$), but a higher proportion of bones and tendons and ratio of high- to low-priced meat ($P < 0.001$ and $P < 0.01$, respectively).

**Table 10: Carcass composition and characteristics of the right carcass half from fallow deer bucks (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **Weight [kg]** | | | | | |
| **Right-side weight** | **11.26**$^{B}$ | **13.89**$^{A}$ | **13.65**$^{A}$ | 0.24 | < 0.001 |
| **Total meat** | **8.59**$^{B}$ | **10.63**$^{A}$ | **10.56**$^{A}$ | 0.20 | < 0.001 |
| **Bones and tendons** | **2.52**$^{B}$ | **2.84**$^{A}$ | **2.81**$^{A}$ | 0.05 | < 0.001 |
| **Separable fat** | **0.16**$^{C}$ | **0.42**$^{A}$ | **0.28**$^{B}$ | 0.04 | < 0.001 |

| | | | | | |
|---|---|---|---|---|---|
| **High-priced meat** | **5.24**$^{B}$ | **6.24**$^{A}$ | **6.29**$^{A}$ | 0.13 | < 0.001 |
| **Low-priced meat** | **3.34**$^{B}$ | **4.39**$^{A}$ | **4.27**$^{A}$ | 0.10 | < 0.001 |
| **Right side proportion [%]** | | | | | |
| **Total meat** | 76.21 | 76.59 | 77.34 | 0.38 | 0.052 |
| **Bones and tendons** | **22.34**$^{A}$ | **20.46**$^{B}$ | **20.57**$^{B}$ | 0.29 | < 0.001 |
| **Separable fat** | **1.45**$^{C}$ | **2.95**$^{A}$ | **2.09**$^{B}$ | 0.29 | < 0.001 |
| **High-priced meat** | **46.52**$^{A}$ | **45.01**$^{B}$ | **46.22**$^{AB}$ | 0.34 | 0.004 |
| **Low-priced meat** | **29.69**$^{B}$ | **31.58**$^{A}$ | **31.12**$^{A}$ | 0.50 | 0.001 |
| **Meat [%]** | | | | | |
| **Rump** | **31.40**$^{A}$ | **29.85**$^{B}$ | **30.34**$^{B}$ | 0.21 | < 0.001 |
| **Shoulder** | **7.30**$^{B}$ | **7.32**$^{B}$ | **8.40**$^{A}$ | 0.26 | < 0.001 |
| **Loin** | 5.82 | 5.92 | 5.44 | 0.28 | 0.821 |
| **Tenderloin** | **2.00**$^{AB}$ | **1.92**$^{B}$ | **2.04**$^{A}$ | 0.05 | 0.033 |
| **Ratio** | | | | | |
| **Meat/bones** | **3.42**$^{B}$ | **3.75**$^{A}$ | **3.77**$^{A}$ | 0.06 | < 0.001 |
| **High/low-priced meat** | **1.57**$^{A}$ | **1.43**$^{B}$ | **1.48**$^{B}$ | 0.04 | < 0.001 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).




**Graph 4: Weight of the right carcass half and total weight of the meat [kg].**

An analysis was conducted to evaluate the economic benefit of concentrate supplementation of grazing fallow deer. **Table 11** shows that supplemented deer had higher weight gain and carcass weight. Thus, overall higher sales were obtained from the carcasses of supplemented deer. Despite the additional feeding costs for barley and lysine, the total profit from supplemented deer (Groups B and L) was higher of 414 CZK (15.4 EUR) = 16.4% (Group B) and 249 CZK (9.2 EUR) = 9.8% (Group L), excluding personnel costs.

**Table 11: Economic efficiency of the fattening.**

| | Pasture | Barley | Lysine | Difference | |
|---|---|---|---|---|---|
| | | | | Barley | Lysine |
| **Weight gain [g/day]** | 100.7 | 131.0 | 130.1 | 23.1 % | 22.6 % |
| **Carcass weight [kg]** | 23.0 | 28.4 | 27.8 | 5.4 | 4.8 |
| **Price per carcass [CZK]** | 2531.7 | 3126.2 | 3060.2 | 594.5 | 528.5 |
| **Price per carcass [Eur]** | 93.7 | 115.8 | 113.3 | 22.1 | 19.6 |
| **Additional feeding costs per animal [CZK]** | - | 180.4 | 279.3 | 414.1 | 249.2 |
| **Additional feeding costs per animal [Eur]** | - | 6.7 | 10.3 | 15.4 | 9.2 |

The average price of the feeding barley in 2015 was 3.63 CZK/kg (0.135 Eur/kg).

The average price of the LysiPEARL$^{TM}$ preparation was 117 CZK/kg (4.35 Eur/kg).

Both prices are excluding VAT.

(Adapted from MZe ČR; Roubalová, 2015).

From the **Graphs 2, 3** and **4**, and **Tables 9, 10** and **11** it can be concluded that **H1: "Composition of the feed ration and supplementation with barley will affect growth, carcass composition and economic efficiency of the fattening", has been confirmed.**

### 5.3 Meat quality

The term quality covers all the features that can be measured or/and described. Thus, meat quality attributes are included in proximate chemical composition, physical characteristics, technological parameters and organoleptic properties.

### 5.3.1 Proximate chemical composition

#### 5.3.1.1 Dry matter, protein and fat contents

The chemical composition of meat (LL) from the three treatment groups differed significantly in some parameters (**Table 12)**. Supplemented deer B and L showed slight but significant increase in the content crude fat ($P < 0.001$) and a consequent reduction of water content and thus significantly higher content of dry matter ($P < 0.001$). Furthemore, supplemented deer B produced venison with significantly higher content of insoluble collagen ($P = 0.013$) compared to grazing deer P, and significantly higher content of hydroxyproline ($P = 0.004$) than group L deer supplemented with RPAA lysine.

**Table 12: Proximate chemical composition [g/kg muscle] of LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **Dry matter** | 253.31$^{B}$ | 258.14$^{A}$ | 261.19$^{A}$ | 1.67 | < 0.001 |
| **Protein** | 233.90 | 235.43 | 235.47 | 2.05 | 0.384 |
| **Crude fat** | 4.05$^{B}$ | 7.81$^{A}$ | 7.43$^{A}$ | 0.46 | < 0.001 |
| **Hydroxyproline** | 0.51$^{AB}$ | 0.55$^{A}$ | 0.47$^{B}$ | 0.02 | 0.004 |
| **Insoluble collagen** | 1.80$^{B}$ | 2.07$^{A}$ | 1.88$^{AB}$ | 0.10 | 0.013 |
| **Soluble collagen** | 1.45 | 1.53 | 1.39 | 0.10 | 0.270 |
| **Total collagen** | 3.25 | 3.60 | 3.27 | 0.16 | 0.063 |
| **Soluble collagen [%]** | 44.65 | 42.26 | 42.40 | 1.81 | 0.077 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).

#### 5.3.1.2 Amino acid composition

No apparent effects of barley or lysine supplementation have been observed in AA composition of LL muscle of fallow deer in this study **(Table 13)**. No significant differences have been found between individual dietary treatments. Regardless the nutrition, among AAs, glutamic acid + glutamine, aspartic acid + asparagin, lysine and leucine occurred in the meat from fallow deer at the highest quantities. Moreover, the total amount of AAs in the LL muscle of the animals examined was between 80.8 and 81.41 g/100 g of muscle tissue. The content of essential and semi-essential AAs in the meat was 41.38–41.52 g/100 g of muscle tissue.

**Table 13: Amino acid composition [g/100 g muscle] of LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **Essential and Semi-essential**[a] | | | | | |
| **Histidine** | 3.70 | 3.67 | 3.73 | 0.04 | 0.575 |
| **Isoleucine** | 4.10 | 4.09 | 4.14 | 0.04 | 0.622 |
| **Leucine** | 6.98 | 7.03 | 7.09 | 0.07 | 0.526 |
| **Lysine** | 7.14 | 7.01 | 7.04 | 0.10 | 0.602 |
| **Methionine** | 2.38 | 2.37 | 2.39 | 0.02 | 0.517 |
| **Phenylalanine** | 3.59 | 3.53 | 3.60 | 0.04 | 0.464 |
| **Threonine** | 3.83 | 3.84 | 3.85 | 0.04 | 0.946 |
| **Valine** | 4.34 | 4.39 | 4.36 | 0.06 | 0.789 |
| **Non-essential** | | | | | |
| **Alanine** | 4.78 | 4.85 | 4.88 | 0.05 | 0.372 |
| **Arginine** | 5.32 | 5.33 | 5.32 | 0.06 | 0.984 |
| **Aspartic acid + Asparagin** | 7.95 | 7.93 | 8.07 | 0.09 | 0.527 |
| **Cysteine** | 0.78 | 0.78 | 0.78 | 0.01 | 0.706 |
| **Glutamic acid + Glutamine** | 12.38 | 12.37 | 12.61 | 0.16 | 0.497 |
| **Glycine** | 3.47 | 3.49 | 3.54 | 0.05 | 0.589 |
| **Proline** | 3.08 | 3.11 | 3.11 | 0.04 | 0.874 |
| **Serine** | 3.11 | 3.14 | 3.16 | 0.03 | 0.582 |
| **Tyrosine** | 3.87 | 3.82 | 3.74 | 0.06 | 0.380 |

[A, B, C] Values in a row with different superscripts differ significantly ($P < 0.05$).

[a] The content of tryptophan was not determined due to its decomposition during acid hydrolysis.

### 5.3.1.3 Fatty acid composition

The most obvious differences when comparing the three dietary treatment groups was significantly higher content of *n*-3 FAs ($P = 0.011$), and as a consequence, significantly lower *n*-6/*n*-3 ratio ($P = 0.024$) in the meat from pasture-fed deer (Group P) compared to deer with grain-based diet and lysine supplementation (Group L) **(Table 14)**. The FAs primarily responsible for this increase were C18:3 *n*-3 and C22:5 *n*-3. On the contrary, LL muscles of supplemented deer (Groups B and L) contained slightly higher content of 18:2 *n*-6 typical for concentrated feed. The addition of dietary lysine to the feed ration was responsible for slightly decrease of C18:3 *n*-3, C22:5 *n*-3 and 18:2 *n*-6 in the meat of group L compared with group B.

The muscle lipid FA contents and proportions in fallow deer venison are presented in **Tables 15** and **16**. Only major and nutritionally important FAs, representing more than 96% of total FAs, are reported. FA profiles were compared between the grass-fed and concentrate-fed deer. Neither the use of pasture fattening nor the supplementation with barley or RPAA lysine caused the significant differences in AI and in the FA composition of LL muscles analysed.

**Table 14: Fatty acid sums and proportions [%] in LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **SFA** | 38.55 | 38.51 | 39.47 | 0.71 | 0.561 |
| **MUFA** | 35.04 | 35.11 | 35.73 | 0.77 | 0.782 |
| **PUFA** | 25.36 | 25.37 | 23.82 | 0.63 | 0.148 |
| ***n*-6** | 17.79 | 18.33 | 17.30 | 0.47 | 0.307 |
| ***n*-3** | **7.57**$^{A}$ | **7.03**$^{AB}$ | **6.52**$^{B}$ | 0.23 | 0.011 |
| ***n*-6/*n*-3** | **2.38**$^{B}$ | **2.63**$^{AB}$ | **2.67**$^{A}$ | 0.08 | 0.024 |
| **PUFA/SFA** | 0.67 | 0.66 | 0.61 | 0.02 | 0.153 |
| **MUFA/SFA** | 0.92 | 0.91 | 0.91 | 0.03 | 0.960 |
| **AI** | 0.47 | 0.47 | 0.49 | 0.02 | 0.667 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).

**Table 15: Fatty acid contents [mg/100 g muscle] in LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **C14:0** | 12.54 | 14.58 | 14.37 | 1.87 | 0.698 |
| **C14:1 *n*-5** | 0.90 | 1.12 | 1.17 | 0.18 | 0.533 |
| **C16:0** | 213.38 | 241.41 | 245.04 | 28.40 | 0.691 |
| **C16:1 *n*-7** | 16.87 | 19.96 | 21.29 | 3.12 | 0.593 |
| **C18:0** | 126.41 | 135.63 | 139.33 | 13.67 | 0.790 |
| **C18:1 *n*-7** | 20.48 | 21.83 | 21.90 | 2.56 | 0.908 |
| **C18:1 *n*-9** | 303.69 | 333.12 | 328.58 | 41.71 | 0.866 |
| **C18:1 *trans*-11** | 4.36 | 4.81 | 4.49 | 0.49 | 0.801 |
| ***cis*-9, *trans*-11[a]** | 1.27 | 1.21 | 1.31 | 0.17 | 0.925 |
| **C18:2 *n*-6** | 127.28 | 143.82 | 132.51 | 17.25 | 0.788 |
| **C18:3 *n*-3** | 28.63 | 29.15 | 25.62 | 2.89 | 0.650 |
| **C18:3 *n*-6** | 1.75 | 1.95 | 1.76 | 0.18 | 0.667 |
| **C20:3 *n*-6** | 2.23 | 2.41 | 2.39 | 0.28 | 0.874 |
| **C20:4 *n*-3** | 0.22 | 0.22 | 0.20 | 0.02 | 0.894 |
| **C20:4 *n*-6** | 37.09 | 40.73 | 38.86 | 4.72 | 0.862 |
| **C20:5 *n*-3** | 12.78 | 12.58 | 11.73 | 1.24 | 0.819 |
| **C22:4 *n*-6** | 0.66 | 0.68 | 0.67 | 0.12 | 0.992 |
| **C22:5 *n*-3** | 19.79 | 21.47 | 19.45 | 2.09 | 0.767 |
| **C22:6 *n*-3** | 8.46 | 8.33 | 8.52 | 1.49 | 0.996 |
| **Total fat** | 959.87 | 1059.55 | 1042.57 | 121.48 | 0.825 |

[A, B, C] Values in a row with different superscripts differ significantly ($P < 0.05$).

[a] CLA – Conjugated linoleic acid.

**Table 16: Fatty acid proportions [%] in LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **C14:0** | 1.34 | 1.37 | 1.37 | 0.10 | 0.972 |
| **C14:1 *n*-5** | 0.10 | 0.10 | 0.11 | 0.01 | 0.756 |
| **C16:0** | 22.46 | 22.59 | 23.25 | 0.38 | 0.297 |
| **C16:1 *n*-7** | 1.70 | 1.75 | 1.96 | 0.09 | 0.124 |
| **C18:0** | 13.55 | 13.26 | 13.61 | 0.38 | 0.785 |
| **C18:1 *n*-7** | 2.13 | 2.06 | 2.12 | 0.07 | 0.771 |
| **C18:1 *n*-9** | 30.87 | 30.96 | 31.33 | 0.73 | 0.898 |
| **C18:1 *trans*-11** | 0.48 | 0.48 | 0.44 | 0.03 | 0.464 |
| ***cis*-9, *trans*-11[a]** | 0.13 | 0.12 | 0.12 | 0.01 | 0.388 |
| **C18:2 *n*-6** | 13.08 | 13.60 | 12.80 | 0.39 | 0.341 |
| **C18:3 *n*-3** | 3.07 | 2.86 | 2.59 | 0.18 | 0.178 |
| **C18:3 *n*-6** | 0.20 | 0.19 | 0.17 | 0.01 | 0.294 |
| **C20:3 *n*-6** | 0.24 | 0.24 | 0.23 | 0.01 | 0.869 |
| **C20:4 *n*-3** | 0.02 | 0.02 | 0.02 | 0.01 | 0.169 |
| **C20:4 *n*-6** | 3.89 | 3.92 | 3.73 | 0.19 | 0.766 |
| **C20:5 *n*-3** | 1.40 | 1.24 | 1.19 | 0.07 | 0.079 |
| **C22:4 *n*-6** | 0.06 | 0.06 | 0.06 | 0.01 | 0.631 |
| **C22:5 *n*-3** | 2.18 | 2.12 | 1.89 | 0.11 | 0.155 |
| **C22:6 *n*-3** | 0.82 | 0.72 | 0.77 | 0.06 | 0.438 |

[A, B, C] Values in a row with different superscripts differ significantly ($P < 0.05$).

[a] CLA – Conjugated linoleic acid.

### 5.3.2 Physical characteristics

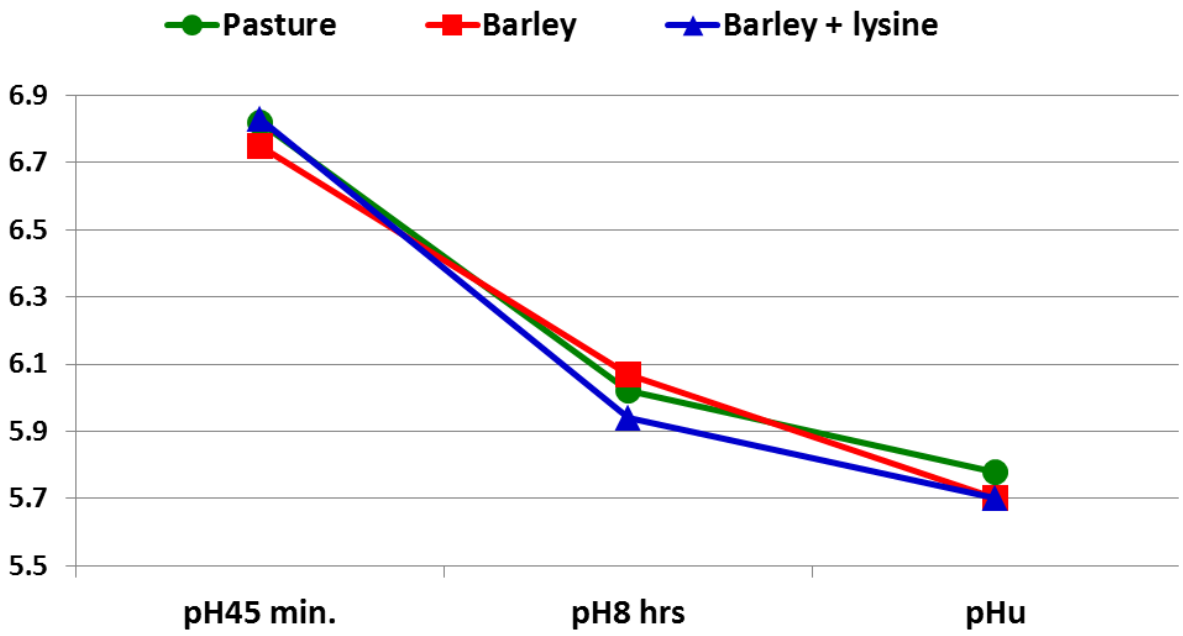
The weights, pH values, colour parameters and WBSF measured in LL and SET muscles of fallow deer bucks are presented in **Table 17**. There were no significant differences observed for any physical components unless where stated. The supplemented diets resulted in heavier LL muscles in groups B and L compared with group P ($P < 0.05$), whereas no apparent dieatry effect ($P = 0.472$) on the weight of the SET muscle was observed among the individual groups. In addition, diet had no apparent effect on pH values of either LL or SET muscles after slaughter. Although not significant, lower decrease of pH values was observed in LL muscle of grazing deer (Group P) caused by the pasture fattening. Supplemented groups B and L obtained more saccharides from the concentrated feed. During *post-mortem* changes, muscle saccharides were break down to glycogen (energy) that was further converted to lactic acid, and this resulted in slightly lower pH values of supplemented deer **(Graph 5)**.

Although the differences of most colour parameters in both muscles were not significant, the tendency in colour was similar. Overall, the lightness ($L^*$) values were numerically lower for both LL and SET muscles from group P animals indicating darker meat. Meat of deer supplemented with concentrates (Groups B and L) exhibited slightly lighter colour due to higher content of IMF. Diet appeared to have significant effect to the redness ($a^*$) and yellowness ($b^*$) parameters of the LL muscle, with more intensely red and yellow meat in group B than in group P ($P < 0.001$ and $P < 0.01$, respectively). Group P had both the lowest $a^*$ and $b^*$ values for both LL and SET muscles, significantly so for the LL muscle indicating less red and yellow meat. The highest values of saturation index (chroma) were observed in the LL muscl from group B ($P < 0.001$). Chroma values for SET muscle did not differ significantly among individual dieatry treatments.

**Table 17: Physical characteristics of LL and SET muscles from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| ***Longissimus lumborum*** | | | | | |
| **Weight [g]** | **832.9**$^{B}$ | **966.5**$^{A}$ | **941.5**$^{A}$ | 30.00 | 0.010 |
| **$pH_{45min}$** | 6.82 | 6.75 | 6.83 | 0.19 | 0.758 |
| **$pH_{8hrs}$** | 6.02 | 6.07 | 5.94 | 0.10 | 0.171 |
| **$pH_u$** | 5.78 | 5.70 | 5.70 | 0.24 | 0.347 |
| **Colour** | | | | | |
| **Lightness [*L**]** | 35.32 | 36.59 | 36.68 | 0.71 | 0.285 |
| **Redness [*a**]** | **12.26**$^{B}$ | **14.98**$^{A}$ | **13.38**$^{AB}$ | 0.39 | < 0.001 |
| **Yellowness [*b**]** | **9.90**$^{B}$ | **12.26**$^{A}$ | **11.31**$^{AB}$ | 0.44 | 0.002 |
| **Chroma [*C**]** | **15.77**$^{B}$ | **19.39**$^{A}$ | **17.55**$^{B}$ | 0.52 | < 0.001 |
| **Hue angle [°]** | 55.52 | 54.05 | 52.09 | 2.58 | 0.644 |
| **WBSF [N]** | 24.63 | 26.59 | 26.14 | 2.16 | 0.295 |
| ***Semitendinosus*** | | | | | |
| **Weight [g]** | 184.8 | 176.2 | 178.5 | 5.11 | 0.472 |
| **$pH_u$** | 5.93 | 5.88 | 5.77 | 0.28 | 0.126 |
| **Colour** | | | | | |
| **Lightness [*L**]** | 37.65 | 39.91 | 40.01 | 1.01 | 0.186 |
| **Redness [*a**]** | 12.28 | 13.58 | 13.26 | 0.68 | 0.385 |
| **Yellowness [*b**]** | 10.88 | 13.03 | 12.94 | 0.67 | 0.048 |
| **Chroma [*C**]** | 16.47 | 18.88 | 18.60 | 0.86 | 0.110 |
| **Hue angle [°]** | 48.01 | 40.44 | 39.66 | 3.88 | 0.255 |
| **WBSF [N]** | 41.77 | 39.21 | 43.37 | 2.41 | 0.252 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).




**Graph 5: pH values measured after the slaughter.**

### 5.3.3 Technological parameters

The thawing loss, grilling loss and total weight loss of LL muscle from fallow deer fed the three experimental diets are depicted in **Table 18**. There was found a significant effect of diet on some technological parameters of fallow deer meat with the LL muscles from the grain-supplemented bucks (Groups B and L) having significantly greater thawing loss ($P < 0.001$), as well as total weight loss ($P = 0.023$), while the values for pasture-fed deer (Group P) being the lowest. By contrast, diet had no significant effect on the grilling loss.

**Table 18: Technological parameters [%] of LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **Thawing loss** | **4.88**$^{B}$ | **7.73**$^{A}$ | **7.35**$^{A}$ | 0.38 | < 0.001 |
| **Grilling loss** | 18.69 | 18.47 | 20.00 | 0.86 | 0.406 |
| **Weight loss** | **23.57**$^{B}$ | **26.20**$^{A}$ | **27.35**$^{A}$ | 0.98 | 0.023 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).

### 5.3.4 Organoleptic properties

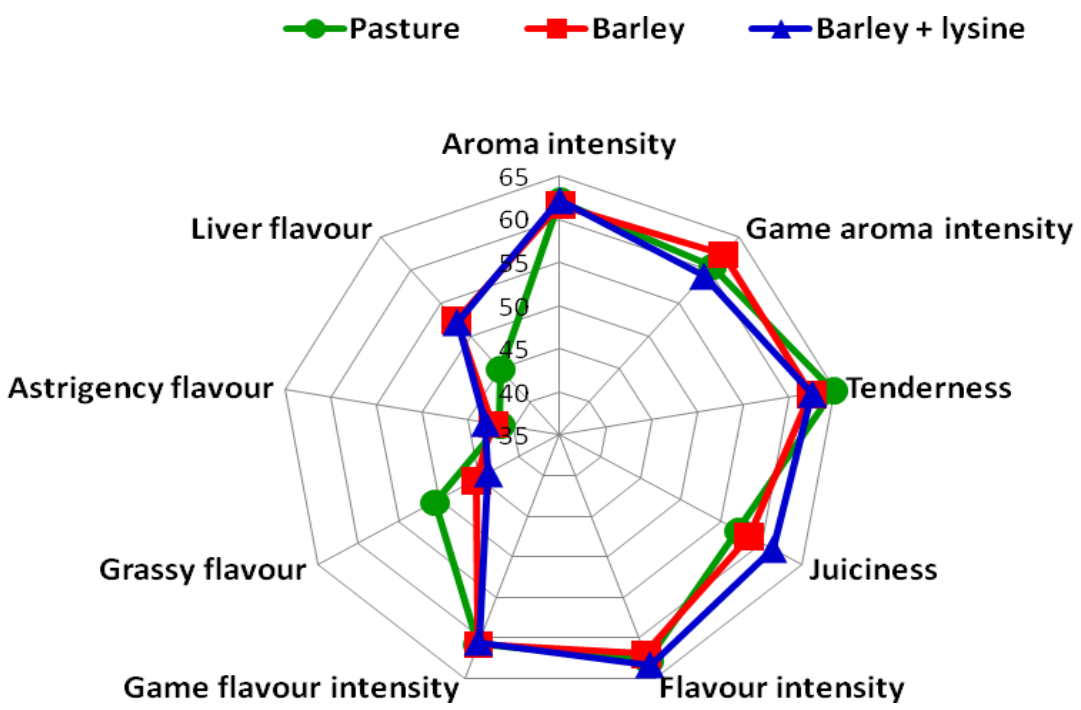
Eating quality parameters of LL muscle are summarised in **Table 19**. The sensory profile of venison in this study was conducted with descriptors that are general, such as intensity of aroma and flavour, game aroma and flavour intensity, grassy, liver and astringency flavour, tenderness and juiciness. Results of the sensory analyses show that organoleptic properties were not greatly affected by diet. Although results did not differ significantly, grass-fed animals P tended to have tougher and less juicy meat than deer B and L supplemented with concentrates. Some flavour differences between fallow deer raised on pasture or fed concentrates are reported in **Graph 6**. The only difference in sensory attributes detected by panellist was a difference in flavour between grain-fed animals and those grazing pasture. It is clear that significantly stronger intensity of "grassy" flavour ($P = 0.008$) has been found in the pasture-fed animals P. On the contrary, "liver flavour" was more intense in deer with grain-based diet (Groups B and L) ($P = 0.003$).

No significant effect of lysine supplementation on sensory attributes of fallow deer meat has been observed in this study.

**Table 19: Sensory characteristics of grilled LL muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Pasture (n = 15) | Barley (n = 15) | Barley + lysine (n = 15) | SEM | *P*-value |
|---|---|---|---|---|---|
| **Odour intensity** | 62.15 | 61.69 | 62.23 | 2.76 | 0.957 |
| **Game aroma intensity** | 60.52 | 62.35 | 59.11 | 2.49 | 0.268 |
| **Tenderness** | 64.92 | 62.45 | 62.59 | 3.47 | 0.472 |
| **Juiciness** | 57.17 | 58.47 | 61.47 | 3.36 | 0.114 |
| **Flavour intensity** | 62.82 | 61.96 | 63.40 | 3.23 | 0.712 |
| **Game flavour intensity** | 60.81 | 60.79 | 60.55 | 2.89 | 0.988 |
| **Grassy flavour** | **50.58**$^{A}$ | **45.42**$^{B}$ | **43.91**$^{B}$ | 2.43 | 0.008 |
| **Astringency flavour** | 41.56 | 42.33 | 43.11 | 3.01 | 0.769 |
| **Liver flavour** | **44.98**$^{B}$ | **52.33**$^{A}$ | **52.08**$^{A}$ | 2.90 | 0.003 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P < 0.05$).




**Graph 6: Sensory analysis of grilled LL muscle (internal temperature of 70 °C on glass/ceramic plate grill) from fallow deer grazed pasture (n = 15), supplemented with barley (n = 15) and supplemented with barley + lysine (n = 15).**

Key: Aroma intensity, game meat aroma, flavour intensity, game flavour intensity, juiciness, grassy flavour, astringency flavour, liver flavour: 0 = very low, 100 = very high. Tenderness: 0 = very tough, 100 = very tender.

Composition of the feed ration influenced some attributes of chemical composition (content of dry matter, crude fat, hydroxyproline, insoluble collagen, *n*-3 FA and *n*-6/*n*-3 ratio), physical characteristics (weight, redness, yellowness and chroma values of LL muscle) and sensory properties (grassy and liver flavour) of fallow deer meat. Thus, **H2: "Composition of the feed ration will affect chemical compostion, physical and technological parameters, and organoleptic properties of meat", has been confirmed.**

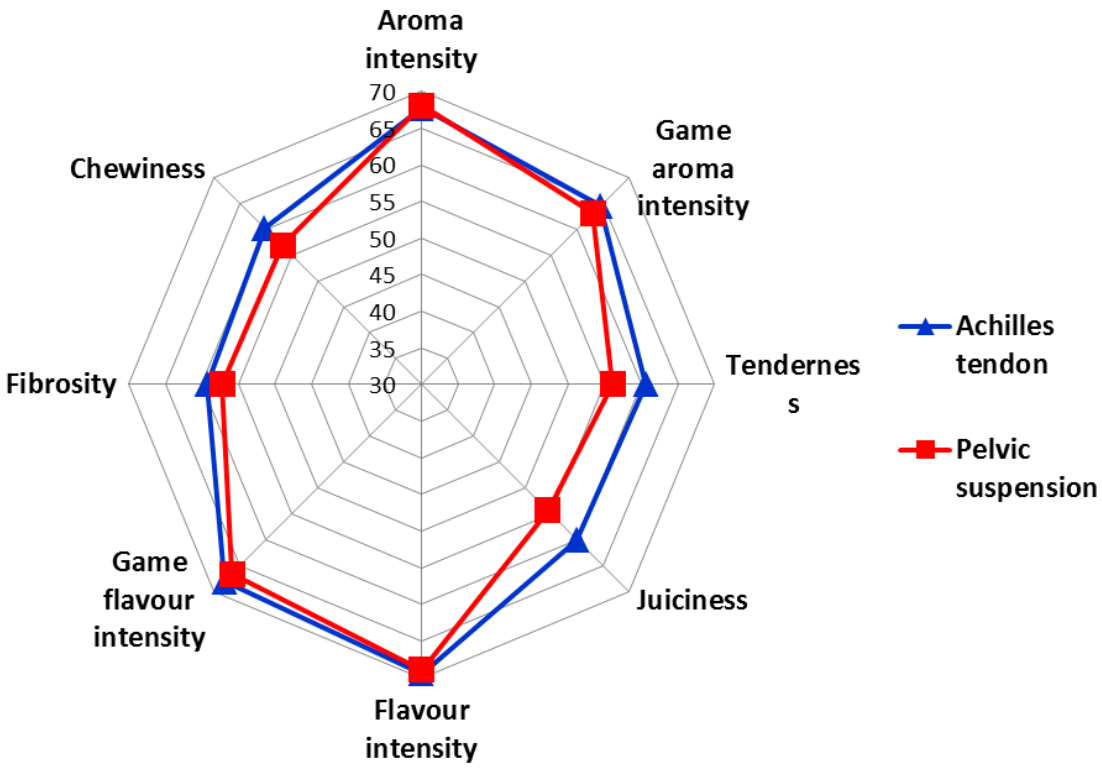
### 5.4 Carcass suspension

The sensory evaluation score of SET muscle from fallow deer hung by either the Achilles tendon or by pelvic suspension is presented in **Table 20**. The following sensory attributes were used to evaluate venison eating quality in this study: intensity of aroma and flavour, tenderness, juiciness, fibrosity and chewiness. When the data were analysed for differences between the trained sensory panel evaluation of fallow deer venison from carcasses hung by either pelvic suspension or Achilles tendon, the Tenderstretch method scored significantly lower for tenderness ($P$ = 0.001), juiciness ($P$ < 0.001) and chewiness ($P$ = 0.020). There were no statistical differences between the Achilles hung and tenderstretched carcasses for the sensory meat quality parameters of odour, flavour and fibrosity.

**Table 20: Sensory characteristics of grilled SET muscle from fallow deer (n = 45), indicated as least square mean (LSM) and standard error of the mean (SEM).**

| | Carcass suspension | | SEM | *P*-value |
|---|---|---|---|---|
| | Pelvic suspension (n = 45) | Achilles tendon (n = 45) | | |
| **Aroma intensity** | 67.11 | 66.84 | 3.86 | 0.770 |
| **Game aroma intensity** | 62.35 | 63.71 | 4.01 | 0.244 |
| **Tenderness** | **55.23**$^{B}$ | **59.71**$^{A}$ | 2.88 | 0.001 |
| **Juiciness** | **54.05**$^{B}$ | **59.74**$^{A}$ | 2.76 | < 0.001 |
| **Flavour intensity** | 66.02 | 66.46 | 3.76 | 0.664 |
| **Game flavour intensity** | 63.98 | 65.41 | 3.68 | 0.243 |
| **Fibrosity** | 56.48 | 58.47 | 2.97 | 0.188 |
| **Chewiness** | **54.26**$^{B}$ | **57.68**$^{A}$ | 3.49 | 0.020 |

$^{A, B, C}$ Values in a row with different superscripts differ significantly ($P$ < 0.05).




**Graph 7: Sensory analysis of grilled SET muscle (internal temperature of 70 °C on glass/ceramic plate grill) from fallow deer grazed pasture (n = 15), supplemented with barley (n = 15) and supplemented with barley + lysine (n = 15).**

Key: Aroma intensity, game aroma intensity, flavour intensity, game flavour intensity, juiciness: 0 = very low, 100 = very high. Tenderness: 0 = very tough, 100 = very tender. Chewiness: 0 = scarcely chewable, 100 = easily chewable. Fibrosity: 0 = very coarse, 100 = very fine.

**Table 20** and **Graph 7** suggest that **H3: "Pelvic suspension method will positively affect the quality attributes of fallow deer meat", has been rejected.**

# 6. DISCUSSION

The experiment was performed with the aim of evaluating the effect of diet on the animals' growth rates, carcass composition, proximate chemical composition, physical and technological quality attributes, and organoleptic properties of fallow deer venison. Fallow deer bucks were reared under identical conditions and all of them entered the experiment at a similar average live weight. Animals were assigned into three different dietary treatment groups – P (pasture fattening), B (pasture fattening + barley supplementation) and L (pasture fattening + supplementation with barley and RPAA lysine). The addition of lysine-containing preparation has been verified because this essential amino acid belongs to those that are very often insufficient in the feed rations for ruminants. As far as could be ascertained, the current study is the first one to focus on the effect of RPAA lysine on the growth, carcass characteristics and quality attributes of meat obtained from fallow deer.

**Growth performance**

Barley-supplemented animals clearly showed greater daily live weight gain during the entire experimental period. This finding is in agreement with previous studies of concentrate-fed versus pasture fed deer, where a positive effect of the concentrates on growth performance has also been reported (Brelurut et al., 1995; Volpelli et al., 2002; Wiklund et al., 2003b; Wiklund et al., 2005; Phillip et al., 2007). Diet was a significant source of variation of daily weight gain, particularly during the second fattening phase, during which groups B and L received a double dose of barley (0.4 kg/day/animal).

As shown in **Figure 7**, there was 46 tropical days (temperature above 30 °C) in the Czech Republic in 2015, although long-term average is only 13 days. Extreme draught conditions during the summer months were responsible for an inadequate pasture capacity, althought the grazing area was sufficient and the stocking rate did not exceed the carrying capacity of the pasture (0.13 ha/animal). Over this period, deer supplemented with concentrates (Groups B and L) were shown to produce greater weight gain than did pasture-fed deer (Group P). As with our results, Bovolenta et al. (2013) also reported better growth rates for fallow deer supplemented with concentrates compared with those only grazing pasture. This difference was associated with the poor herbage allowance that was not able to fully satisfy the nutritional requirements of the pasture-fed animals.

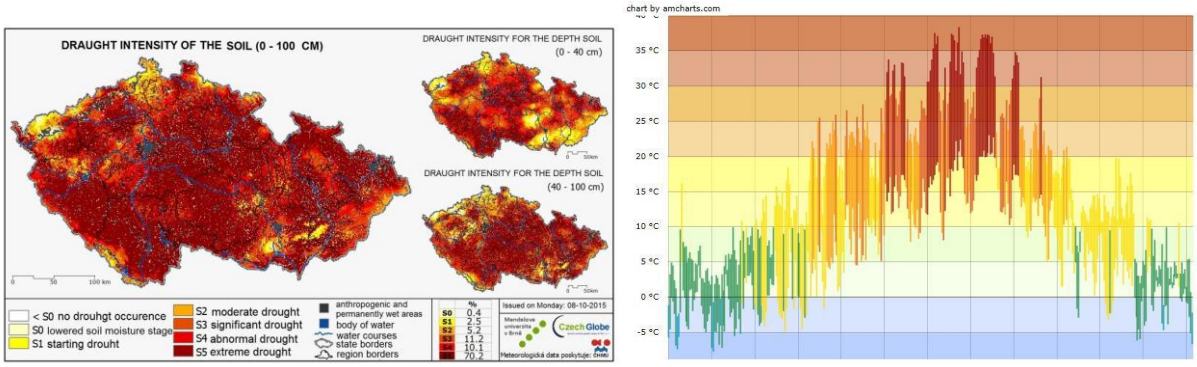



**Figure 7: Draught intensity in the Czech Republic [August 2015].**
(Adapted from ČHMÚ; Daňhelka et al., 2015).

The differences between groups B and L and thus the effect of RPAA lysine on growth performance were smaller in magnitude. These results are broadly in agreement with those of Huang et al. (2015), who reported no effect of lysine supplementation (crude protein-deficient diets with 3 g/kg lysine, 3 g/kg lysine + 1 g/kg methionine, and 3 g/kg lysine + 2 g/kg methionine) on growth performance in sika deer (*Cervus Nippon*). Similarly, Hussein and Berger (1995) and Klemesrud et al. (1999) found no significant differences in performance responses to supplemental RPAA lysine in cattle.

**Slaughter traits**

In this study, concentrate supplementation of fallow deer increased carcass weights, similar to other studies with fallow deer (Volpelli et al., 2002; Wiklund et al., 2005), red deer (Phillip et al., 2007) and reindeer (Wiklund et al., 2003b). By contrast, Wiklund et al. (2003a) reported slightly higher carcass weights of red deer grazing natural pasture compared with those fed a pelleted feed mixture, although this difference was not significant.

Fallow deer in this experiment showed good dressing percentage, similar to those reported previously for fallow deer (Hogg et al., 1990; Volpelli et al., 2002; Bovolenta et al., 2013; Janiszewski et al., 2015), but lower than those observed by Wiklund et al. (2005) or Stanisz et al. (2015). In agreement with other studies comparing carcass traits in deer (Volpelli et al., 2002; Phillip et al., 2007), the supplemented deer from groups B and L produced heavier carcasses and had higher dressing percentage, mostly due to their markedly higher deposition of internal fat. Similar effect of diet on internal fat deposition were previously

reported by Phillip et al. (2007) in red deer fed diets with different ratios of concentrate:dried and pelleted roughage.

It is noteworthy, that supplementation with lysine (Group L) significantly decreased the internal fat, as well as carcass fat proportions of fallow deer in this study. The close correlation between internal fat and separable fat indicates that the total fatness of fallow deer could be affected by lysine supplementation. Lipogenesis inhibition and repartitioning of nutrients towards lean tissue deposition rather than fat deposition as a result of increasing dietary lysine levels was previously reported in broilers (Sibbald and Wolynetz, 1986; Hickling et al., 1990; Grisoni et al., 1991), ducks (Attia, 2003) and pigs (Tous et al., 2014). However, the true reason for the reduced fatness in fallow deer supplemented with lysine is not clear and requires more investigation.

**Carcass composition**

As a result of concentrate supplementation, the B and L animals in this study produced higher amount of meat indicating increased muscle development. However, the total meat proportion did not differ significantly among individual dietary treatments. The separable lean meat proportion in our study was broadly within the range 72.7–76.0% reported by Drew (1992) for all farmed deer species less than 26 months of age. Similar results have been found by Volpelli et al. (2002) for fallow deer aged 14 to 30 months. Significantly higher weights of lean meat were reported for fallow deer fed concentrates in a daily amount of 500 g dry matter/head (40% maize, 25% sugar beet pulp, 20% alfalfa, 13% soy flakes, 2% mineral and vitamins) compared with fallow deer grazing on herbage for 4 months. However, the opposite trend was observed by Phillip et al. (2007) in red deer with slightly higher lean meat proportion in red deer fed forage:concentrate in the ratio 75:25 than those with ratios 50:50 and 25:75.

There was found a significant effect of diet on the ratio of high- to low-priced meat, weight and proportion of low- and high-priced meat, and proportions from the rump, shoulder and tenderloin. Due to the better growth performance of supplemented animals (Groups B and L), the supplemented deer in this study produced higher amounts of both high- and low-priced meat. However, the proportion of high-priced meat was higher in group P, mainly due to the higher proportion of meat from the rump. As with our results, Volpelli et al. (2002) also reported significantly higher weight of the rump in fallow deer supplemented with

concentrates. However, due to their heavier weight, the proportion of the rump was higher in pasture-fed deer.

Data reported in **Table 10** show significantly higher amounts but lower proportions of bones and tendons in carcasses of B and L deer. These results are consistent with those of feeding experiment comparing pasture-fed and concentrate-fed fallow deer (Volpelli et al., 2002) and those of Phillip et al. (2007), who reported decreasing bone yield proportion with increasing diet concentrates levels in red deer.

In the present study, concentrate feeding in the form of barley had a major impact on carcass fatness with the highest amount and proportion of separable fat in group B. This increase in carcass fatness with grain-based diets is consistent with the results of Volpelli et al. (2002) on fallow deer or those reported by Phillip et al. (2007) for red deer. In addition, Wiklund et al. (2003b) observed higher amount of separable fat in reindeer fed a commercial feed mixture compared to those grazed on natural pastures. Similar to the effects on internal fat depots, the addition of dietary lysine decreased both the amount and proportion of the separable fat in barley-supplemented deer. The decrease in carcass fatness might be a matter of concern as venison is valued for its low but favourable fat content, and this result indicates that the total fatness of fallow deer meat/muscle could be reduced by RPAA lysine supplementation.

**Economic efficiency of the fattening**

The purchase price of venison in the Czech Republic is relatively unstable, depending on the overall market situation. It is subjected to the same economic market laws as other foods (e.g. pork or beef), and its value per unit is equally dependent on demand and supply (Kupka, 2004; Vodňanský, 2007). Deer farmers are thus searching for ways to achieve maximum yield and profit with low/decreased feed expenses.

Low-cost, pasture-based forage systems are widely used practice in deer farming (Volpelli et al., 2003). Properly managed pastures are high in nutritive value and offer an opportunity to reduce the costs of producing forage during the grazing season (Soder and Rotz, 2001). The quality of pasture can be assessed in terms of animal performance which is dependent on various factors such as feed intake, nutrient and energy concentration or digestability. These requirements represent the amount of feed which must be consumed to sustain a defined level of production. Sufficient nutrients and energy must be therefore

supplied to the animals to meet metabolic demands for any specified level of performance (e.g. live weight gain, carcass conformation). Feed requirements can be expressed as digestible and metabolizable energy - the most limiting factor for grazing ruminants and meat production (Mertens, 1994; Caton and Dhuyvetter, 1997; Soder and Rotz 2001).

Supplementation of deer with concentrates proved to be favourable with respect to the animal performance and some aspect of the meat quality. However, the key question becomes whether the supplementation is profitable also for deer breeders. As expected, daily weight gain, carcass weight and dressing percentage increased as concentrate supplementation was implemented to the feed ration. Despite the additional feeding costs for barley (3.63 CZK/kg), the overall higher profits (of 414 CZK/carcass) were obtained for pasture-fed deer with barley supplementation.

**Dry matter, protein, fat and ash content**

In comparison with fallow deer grazing pasture, venison from deer supplemented with concentrates contained higher amount of dry matter and IMF. These findings are consistent with the results of Volpelli et al. (2003) for LL and SET muscles from farm-raised fallow deer. Higher contents of dry matter (LL: 24.24 vs 23.73; SET: 23.11 vs 22.42 %) and IMF (LL: 0.72 vs 0.56; SET: 0.78 vs 0.55 %) have been detected in both muscles of concentrate-fed fallow deer compared to those with pasture fattening. Anyway, despite the differences due to the experimental factors, the fat content of fallow deer venison is very low, as previously documented by Bureš et al. (2015), Piaskowska et al. (2016) or Bykowska et al. (2018b). This fact promotes the importance of venison in the human diet.

Collagen is a major component of the intramuscular connective tissue that is responsible for toughness/tenderness of meat (Lepetit, 2008; Dominik et al., 2012). Supplementation with barley had an effect on the content of insoluble collagen in LL muscle indicating the dependence such that the meat is less tender the more insoluble collagen there is, and the WBSF value is therefore slightly higher than in pasture-fed deer. Opposite trend has been observed by Volpelli et al. (2003). Although results did not differ significantly, slightly higher content of insoluble collagen but lower WBSF values have been reported for fallow deer grazing pasture than those supplemented with concentrates.

As proline is the second most abundant AA in barley (Wu et al., 2010), one would assume that venison from fallow deer fed barley would contain higher amount of

hydroxyproline (a metabolite of proline) than that from pasture-fed deer. Interestingly, meat from fallow deer supplemented with barley and RPAA lysine contained lower amount of hydroxyproline than meat of animals grazing pasture, and significantly lower amount than in meat of animals supplemented only with barley. It is possible that incorporation of lysine to the feed ration may affect the proline catabolism through multiple pathways (Jimenez and Rosenbloom, 1974; Wu et al., 2010). Regrettably, there is a lack of data that compare the proximate composition of venison from deer fed different diets.

**Amino acid composition**

Venison is considered to be an important source of essential AAs due to its relatively high content of proteins (Higgs, 2000; Kwiatkowska et al., 2009; Cygan-Szczegielniak and Janicki, 2012; Okuskhanova et al., 2017). The AA composition of meat has been noted to be influenced by factors such as production region (possibly due to variation in vegetation and thus the composition of the diet) (Hoffman et al., 2007b) or sex (Cygan-Szczegielniak and Janicki, 2012). On the contrary, species (Sales, 1995; Okuskhanova et al., 2017) or age (Hoffman et al., 2007b; Lorenzo et al., 2018) seem not to have a significant effect.

The two AAs present at highest levels were glutamic acid + glutamine, aspartic acid + asparagin, wich contributed 12.4 to 12.6, 7.9 to 8.1 g/100 g of muscle, respectively. In regard to the essential AAs, leucine and lysine were present at the highest levels, both in an amount of 7.0 to 7.1 g/100 g of muscle. A similar trend has been observed by Cygan-Szczegielniak and Janicki (2012) in roe deer (*Capreolus capreolus* L.), with leucine and lysine being the two essential AAs, and glutamic acid and aspartic acid being two non-essential AAs present at highest levels. As with our results, the essential amino acids with the highest concentration in the LL muscles of red deer reported by Okuskhanova et al. (2017), are lysine (9.85 g/100 g) and leucine (7.40 g/100 g).

The values of total amount of AAs (80.8–81.41 g/100 g muscle tissue) detected in the meat of fallow deer in this study are considerably lower than those given by Cygan-Szczegielniak and Janicki (2012) for roe deer (94.52 and 96.91 g/100 g). Regarding the content of essential and semi-essential AAs that are known to have beneficial effects on human health, our results (41.38–41.52 g/100 g of muscle tissue) are broadly in accordance with the value 42.61 g/100 g obtained by Okuskhanova et al. (2017) for red deer meat. Noticeably higher amount (54.31 and 56.35 g/100 g) has been found by Cygan-Szczegielniak

and Janicki (2012) in roe deer venison of 2–3 years-old bucks and does but markedly lower amount (27.65 g/100 g) has been reported in red deer meat by Strazdina et al. (2013). Although the AA profiles vary little between species, the above-mentioned differences might be due to many reasons, such as age, sex etc. (Sales, 1995).

**Fatty acid composition**

Individual FAs have different effects on the concentrations of low-density lipoprotein cholesterol. While MUFA and PUFA are beneficial for human health, SFA increase cholesterol concentrations associated with increased risk of cardiovascular diseases. It is therefore recommended to replace SFA with MUFA and PUFA, and decrease the *n*-6/*n*-3 ratio (WHO & FAO, 2003; Salter, 2013).

Dietary lipids (specifically PUFA) are hydrogenated by microorganisms in the rumen. However, some dietary PUFA escape rumen biohydrogenation leading to an increased content of SFA in ruminant meats (Wood et al., 2003). Several studies performed on ruminants have indicated that the fatty acid composition in meat may change in response to different diets (Manley and Fors, 1979; Volpelli et al., 2003; Wiklund et al., 2003a; Phillip et al., 2007). In general, concentrates are a good source of C18:2 *n*-6, whereas forage diet is rich in ALA and DPA (Wood et al., 2003; Polak et al., 2008). As expected, the meat from pasture-fed deer in this study exhibited a higher content of *n*-3 PUFA and thus also more favourable ratio of *n*-6/*n*-3 due to the presence of ALA and DPA in the grass. This is in accordance with the results reported for fallow deer (Volpelli et al., 2003), red deer (Wiklund et al., 2003a), rusa deer (Dahlan and Norfarizan-Hanoon, 2007) or cattle (Melton et al., 1982).

No effect of the diet has been observed in the contents and proportions of individual FAs. In contrast to these results, the use of concentrate feeding in the study of Volepelli et al. (2003) caused an increase in the content of SFA and MUFA in supplemented deer compared to those grazing pasture. Similarly, Wiklund et al. (2003a) and Phillip et al. (2007) reported a significant effect of diet on the composition of some FAs in LL muscles from pasture- and pellet-fed red deer.

Since various FAs have different effects on human health, Ulbricht and Southgate (1991) proposed two indices, AI and thrombogenic index, that might better characterize the atherogenic and thrombogenic potential of the diet than just PUFA/SFA ratio (Fehily et al., 1994). Although AI obtained in the present study did not differ significantly among individual

dietary treatments, all the AI values are favourable, as it is assumed that AI < 1 is beneficial for human health (Pilarczyk and Wójcik, 2015).

Nevertheless, further research on deer meat is warranted to investigate the content of conjugated linoleic acid (CLA) noted for numerous human health benefits as well as the relationship between health-promoting and negative health effects of FAs using atherogenicity and thrombogenicity indices (Nantapo et al., 2015). The way of enhancement of the amounts of favourable *n*-3 FA in deer meat may be another topic of interest.

**pH values**

Venison (defined as meat derived from cervids) pH value after slaughter ranges from 6.5 to 7.2 and falls to a normal range of 5.8–5.3 within 24–48 hours *post-mortem* as reported by several authors (Volpelli et al., 2003; Hutchison et al., 2012; Ludwiczak et al., 2017; Bykowska et al., 2018b; Cawthorn et al., 2018; Neethling et al., 2018). Decrease in pH and acidification of muscles after slaughter is desirable mainly due to better microbial stability of the meat and thus prolonged shelf life. However, due to various *ante-mortem* stress factors such as transportation, chasing or slaughter method (Hoffman et al., 2011; Kudrnáčová et al., 2018), fallow deer can be suspected to exhibit the phenomenon known as DFD defect, typically found when meat $pH_u$ is > 6 (Wiklund et al., 2004b; Daszkiewicz et al., 2015). Unlike higher $pH_u$ values ($pH_u$ > 6.0) indicating increased risk of DFD meat reported for deer in Poland (Daszkiewicz et al., 2015) or UK (MacDougall et al., 1979), no $pH_u$ values > 6.0 were recorded in this work. In general, the differences between the groups in pH values measured after slaughter were small and not significant. In agreement with our results, previous studies also reported no effect of concentrate feeding on $pH_u$ values in fallow deer (Volpelli et al., 2003; Wiklund et al., 2005; Hutchison et al., 2012) or red deer (Wiklund et al., 2006).

**Meat colour**

The colour of meat strongly affects consumer acceptability and influences consumer purchase decisions (Mancini and Hunt, 2005). As reviewed by Neethling et al. (2017), consumers perceive bright, cherry-red meat as more fresh and wholesome in comparison with discoloured and/or dark meat, which is usually associated with the DFD defect. However, as pointed out by Ramanzin et al. (2010), in case of venison, more intense or darker red colour

seems to be acceptable to consumers as it is considered a typical feature of this type of meat. Darker and red-brown colour of venison can be attributed to higher content of myoglobin in comparison with meat of other domestic livestock species (Young and West, 2001). According to Volpelli et al. (2003), this darker colour is characterised by $L^*$ value < 40, high $a^*$ values and lower $b^*$ values.

The meat from animals finished on pasture diets is usually darker than the meat from animals finished on concentrate diets (Priolo et al., 2001). As reported by these authors, several factors are responsible for this difference, but pH and IMF appear to have the greatest impact. However, only minor differences in some colour parameters were observed in our study. Numerically higher $L^*$ values (lighter meat) were detected for both muscles in concentrate-fed groups. Similarly, Volpelli et al. (2003), Mulley et al. (2006) or Hutchison et al. (2012) reported no significant effect of diet with or without concentrates on the colour parameters of muscles from fallow deer but with similar tendency of meat lightness. A possible explanation, as proposed in a review (Priolo et al., 2001), is that commonly farmed ruminants have higher levels of (visible) IMF, which reflects light and thus gives a lighter appearance (higher $L^*$ values). By contrast, cervids have low levels of IMF (Kudrnáčová et al., 2018), even when fed supplements, and thus would not necessarily have statistically higher $L^*$ values than only pasture/forage-reared fallow deer.

The $a^*$ value is known to be in a close relationship with the myoglobin content in meat, whereas the $b^*$ value is related to redness and lightness of meat. In general, the greater the myoglobin content in meat, the higher the $a^*$ and $b^*$ values (Vestergaard et al., 2000; Kim et al., 2010). Significant differences were found in our study between groups P and B in the redness and yellowness of LL muscle showing higher $a^*$ and $b^*$ values (higher redness and yellowness) in supplemented deer. Since the $a^*$ and $b^*$ values are used to calculate chroma values, muscles with significantly higher $a^*$ and/or $b^*$ values will also have a higher chroma values (Cawthorn et al., 2018), as observed in the LL muscle of group B. Similarly, Vestergaard et al. (2000) reported higher redness, yellowness and chroma values in LL muscles of concentrate-fed bulls, although pigmentation was higher in bulls grazing pasture. Nevertheless, these colour differences were probably primarily attributable to differences in physical activity rather than feeding level, as group P likely spent more time foraging to consume sufficient feed, particularly during the dry period.

Although not all differences were detected as significant, it appears that the meat from supplemented fallow deer was lighter, had more intensely red and yellow colour, and higher chroma value than that from animals only grazing pasture. However, as reported by Hopkins and Nicholson (1999), direct effect of the diet on meat colour is considered rare and dependent rather on the effect of diet on muscle myoglobin. Anyway, the colour of both muscles reflects the known characteristics of venison that is attractive to consumers.

**Warner–Bratzler shear force**

Meat tenderness is highly variable among animal species as a result of various extrinsic and intrinsic factors (Cawthorn et al., 2018). However the differences are given mainly by proteolytic enzyme activity, different collagen content, muscle fibre characteristics and anatomical position of each muscle (Picard et al., 1998; Chriki et al., 2012; Cawthorn et al., 2018). While beef LL is classified into intermediate tenderness category, the SET muscle is considered to be tough (Sullivan and Calkins, 2011). As well as for fallow deer, Cawthorn et al. (2018) and Dominik et al. (2011) also noted differences in tenderness among muscles with LL muscle being stated as inherently tender. Our results are in broad agreement with these observations, although the comparison of muscles was not the subject of this study.

As only minor differences in shear force values (meat tenderness) were observed in this study, it can be concluded that the dietary treatment had no effect on the tenderness of fallow deer meat. These results correspond with those reported for fallow deer in Italy (Volpelli et al., 2003). On the contrary, Mulley et al. (2006) reported significantly lower WBSF for meat samples from fallow deer fed concentrates compared to those grazing pasture. Similar results were obtained by Hutchison et al. (2012) for fallow deer in Australia. Supplementation with barley (800 g/animal/day) had an indirect effect on shear force values, and as a consequence of concentrate feeding, supplemented animals had a significantly higher IMF content and thus produced more tender meat than those with pasture fattening.

**Technological parameters**

The terms thawing loss, thermal drip (cooking/grilling loss, drip loss/purge refer to the loss of water from muscle tissue. They closely correlate with WHC, as they are important parameters that influence total weight loss, and they are thus related also to some organoleptic properties of meat (Warner, 2014).

Thawing loss of LL muscle in the present study ranged between 4.88 and 7.73%. Slightly higher values of thawing loss (8.26–9.20%) were presented by Cifuni et al. (2014) for fallow deer meat after 3 months of freezer storage. These values are overall higher than those reported by Daszkiewicz et al. (2017b) for 10-month freezer storage LL muscle (2.3%) from fallow deer, but markedly lower than those observed by Mulley et al. (2006) for LL muscle (17.89–19.79%) of fallow deer does. These data indicate that freezing, freezer storage, and thawing compromise the WHC of meat. As a result, the WHC of thawed meat decreases and total weight loss increases.

No difference was found in grilling loss between the samples collected from fallow deer fed different diets. The obtained values range from 18.47 to 20.00%, similar to other studies with fallow deer (Piaskowska et al., 2018a; Ludwiczak et al., 2017). The values of grilling loss of LL muscle recorded in this study are, however, nearly 1.5-fold lower than those for cooking loss of different muscles from wild fallow deer, as presented by Cawthorn et al. (2018), or Piaskowska et al. (2015) for both wild fallow deer bucks and does. Similarly, Stanisz et al. (2015) noted slightly higher values of thermal drip of SM samples obtained from fallow deer bucks (27.4%) and does (26.4%) aged from 31 to 32 months. By contrast, Żochowska-Kujawska et al. (2019) reported generally lower cooking loss of different muscles from fallow deer of various ages, ranging from 11.29% (BIF sample; 18 months old animals) to 19.32% (BIF sample; 54 months old animals).

In the current study, thawing loss and total weight loss of LL muscle increased with the addition of barley to the feed ration. The result that diet influences the thawing loss and total weight loss of fallow deer muscle is in agreement with that for cooking loss, drip loss or purge of red deer (Wiklund et al., 2006) and fallow deer (Volpelli et al., 2003; Wiklund et al., 2005; Mulley et al., 2006; Hutchison et al., 2012) fed different diets. No significant differences in purge/freeze-thaw loss (Wiklund et al., 2005; Mulley et al., 2006; Hutchison et al., 2012) and cooking loss (Volpelli et al., 2003) were observed between fallow deer grazing pasture and those supplemented with concentrates. However, this effect of diet is in contradiction with the results of Wiklund et al. (2006) for red deer meat, who reported significantly lower drip loss (purge) in meat from the pasture-fed deer compared with the group fed pellets after 3 weeks of storage.

The effect of diet on thawing loss is not clear, although it could be possibly linked to slightly lower pH values in carcasses from the supplemented animals, as the loss of water

from meat is known to be associated with the $pH_u$ values (Cawthorn et al., 2018). It is also suggested that the differences could be related to a variation in levels of antioxidants (e.g. vitamin E) in muscle tissue, which positively correlate with increased WHC in meat (Cheah et al., 1995; Zhao et al., 2013; Maraba et al., 2018). In addition, these differences might be due to different methods of measurement used, as other experiments use different procedures based on different temperatures and times.

**Organoleptic properties**

Sensory evaluation is designed to measure the eating quality, based on evaluation of predictive characteristics (Hutchison et al., 2012). Meat acceptability parameters include, among others, various organoleptic components such as flavour, odour and texture (e.g. tenderness, juiciness, chewiness). Trained sensory panel or consumers are widely used for the assessment of unprocessed meat (Toscas et al., 1999). However, there is a lack of studies that compare the sensory attributes of deer venison affected by different feed rations or feeding systems.

In general, red meat from animals raised on pasture is considered by consumers to be different than that obtained from animals with grain-based diet, especially in terms of "grassy", "milky" or "game" and "liver" or "fatty" flavour (Young et al., 1999; Priolo et al., 2001). The terms "grassy" or "game" flavour mostly indicates meat from animals raised on forage diets (Larick et al., 1987; Wiklund et al., 2003a), whereas "liver" or "fatty" flavour is characteristic for grain-fed animals (Melton et al., 1982). Similar descriptors have been previously used for beef (Monsón et al., 2005; Nuernberg et al., 2005; Campo et al., 2006), lamb meat (Priolo et al., 2002; Nute et al., 2007), venison (Wiklund et al., 2000; Wiklund et al., 2003a, 2003b; Mulley et al., 2006; Finstad et al., 2007) or game meat (North and Hoffman, 2015). It is likely, that increased "liver" or "fatty" flavour intensities contribute to stronger and more desirable flavoured meat as animals are fed concentrates (Melton et al., 1982; Mulley et al., 2006). However, as reviewed by Priolo et al. (2001), the consumer´s preferences between different flavours are very individual and dependent on various factors, such as culture or previous experiences.

Our resutlts suggest that venison from concentrate-fed fallow deer scored higher for "liver flavour", whereas greater intensity of "grassy" flavour has been detected in meat of animals with pasture fattening. As there were no significant differences in other sensory

descriptors, panellists were not able to detect differences between pasture and concentrate-fed fallow deer in juiciness or tenderness, although the content of IMF, which is often positively associated with these sensory properties (Fernandez et al., 1999; Hoffman et al., 2007d), was markedly higher in supplemented deer. These data are supported by other studies which also reported different flavour profiles of venison from deer fed concentrates or grazed pasture. As with our results, "grassy" flavour of red deer meat grazing pasture compared to pelleted-fed animals received higher scores from trained panellists in a study of Wiklund et al. (2000) with no differences for any of the other attributes assessed. Similarly to our study, Wiklund et al. (2003b) comparing sensory attributes of venison from reindeer reported significantly greater "liver flavour" in animals fed a commercial feed mixture compared to those grazed on natural pasture. By contrast, Forss et al. (1979) reported no evidence of ability to dicriminate between samples obtained from red deer fed different diets. The trained sensory panel was not able to distinguish grassfed venison from feedlot in tenderness, juiciness, flavour or overall acceptability.

There have been identified more than 1000 volatile compounds responsible for differences in meat flavour (Mottram, 1998) and some of them can be influenced by different dieatry components. The diet-specific differences can be paritally explained by differences in the FA composition of muscle lipids (Elmore et al., 1999). Generally, a higher proportion of long, unsaturated FAs responsible for "grassy" and "game" flavour were found in meat from grazing animals compared with animals fed a grain-based diet (Wiklund et al., 2000; Wiklund et al., 2003b; Finstad et al., 2007). A "grassy" flavour and aroma is also determined by products of α-linolenic acid oxidation and its derivatives (hexanal) (Priolo et al., 2001). Studies of Barbieri et al. (1992) and Flores et al. (1997) on dry-cured hams suggest that "grassy" or "green" aroma is also linked to 1-penten-3-ol, as well as selected aldehydes such as hexanal (greenish), octanal (green-fresh) and nonanal (green). However, the unsaturated FAs are more prone to oxidation and thus, they may contribute to the development of various "off-flavours" in meat (Demeyer, 1999; Wood et al., 2003; North and Hoffman, 2015). The enhanced *post-mortem* proteolytic activity often results in the development of "off-flavours" and formation of bitter-tasting peptides that are sometimes described as "liver" flavour (Rousset-Akrim et al., 1997; Yancey et al., 2006). These findings are supported by Fisher et al. (2000), who attributed a stronger liver flavour in lamb meat to the susceptibility of *n*-3 PUFA to peroxidation. Although the meat derived from grass-fed animals often have a higher

oxidative stability due to higher concentrations of antioxidants (Nuernberg et al., 2005), Wiklund et al. (2000) and Wiklund et al. (2003b) reported the meat from pellet-fed animals to have less "off-flavours" compared with those fed on the pasture. This indicates that natural grazing is contributor to the development of various "off-flavours" in meat, depending on effects of the FA composition. However, several authors suggested that a liver-like flavour is not linked only to lipid oxidation. Yancey et al. (2006) determined the total iron, pigment concentration, lipid oxidation and fatty acid composition, and their relationship to "livery" flavour development in beef muscles. The results suggest, that "livery" flavour is rather attributable to total iron content and myoglobin concentration. Rousset-Akrim et al. (1997) found higher liver-like flavour intensities in meat derived from 8.5 years old ewes suggesting that the enhanced intensity may have its origin in age-related metabolic changes of muscle tissue. Nonetheless, as stated by Yancey et al. (2006), "liver"flavour is a complex trait that cannot be related to any single characteristic.

The differences between groups B and L and thus the effect of RPAA lysine on organoleptic properties were of smaller magnitude. The effect of different lysine/methionine ratio and protein level on sensory attributes of meat from ruminants has been evaluated only by Prado et al. (2015). These authors reported overall higher acceptability, tenderness and flavour of meat from steers fed a diet containing high protein (16.8% DM basis) and high lysine/methionine ratio (3.4) compared with the meat from animals fed a diet with low protein level (14.6% DM basis) and low lysine/methionine ratio (3.0). Nevertheless, to our knowledge, no studies have been carried out on cervids and thus, this aspect warrants further research.

**Carcass suspension**

It is well known that *post-mortem* conditions (e.g. storage and processing conditions) affect the odour and flavour, as well as the textural parameters of meat that are involved in its palatability and overall acceptability (Khan et al., 2016). The Tenderstretch method resulted in more tender meat in previous studies on fallow deer (Sims et al., 2004; Wiklund et al., 2004a; Hutchison et al., 2006; Mulley et al., 2006; Hutchison et al., 2010; Hutchison et al., 2014), red deer (Hutchison et al., 2010) and reindeer (Wiklund et al., 2012), as determined by shear force measurement and/or sensory evaluation by either trained panel members or consumers.

For this study, pelvic suspension method instead of the normal carcass position hung by the Achilles tendon resulted in decreased tenderness, juiciness and chewiness in SET muscle of fallow deer bucks but not for other parameters tested. This finding is inconsistent with several previous studies. In the studies of Hutchison et al. (2006) and Hutchison et al. (2010), panellists clearly distinguished differences in tenderness, juiciness and overall liking for venison from fallow deer and red deer carcasses hung through the aitchbone compared with the Achilles tendon suspension, with tenderstretched carcasses scored better for all these parameters. This result is in accordance with Mulley et al. (2006) who performed the sensory evaluation of venison from Achilles-hung and pelvic-suspended carcasses and found that the Tenderstretch method significantly improved the tenderness in meat from young fallow deer and was responsible for lower purge loss of vacuum-packed samples. This results on the positive effects of pelvic suspension on WHC support earlier findings in fallow deer (Wiklund et al., 2004a), though the positive effects of the Tenderstretch on purge were also reported. A similar trend in meat tenderness was observed by Wiklund et al. (2012) for reindeer meat. The samples from pelvic-suspended carcasses were more tender, as assessed by the trained sensory panel and by shear force measurement, however juiciness remained unaffected. Similarly, the studies of Hutchison et al. (2014) and Sims et al. (2004) reported that pelvic suspension of fallow deer carcasses produced venison (the most valuable carcass cuts) significantly more tender than that from carcasses hung by the Achilles tendon, as evaluated based on the instrumental meat quality attributes (WBSF).

The literature indicates that the Tenderstretch method is usually applied within 45 to 90 min. after bleeding, while the muscles are still extensible and in the *prae-rigor* state (Sørheim and Hildrum, 2002). For this reason we can assume that the time *post-mortem* is the major limiting factor and that it is necessary to maintain the period between the death of the animal and the carcass hanging below one hour. However, the Tenderstretch in this experiment was applied 5–6 hours after bleeding. Thus, we can speculate that the negative changes in some textural parameters were most likely as a result of delayed pelvic suspension after slaughter and ongoing *post-mortem* processes in meat rather than the result of the Tenderstretch method.

However, pelvic suspension influences muscles in the carcass differently and in addition, slower ageing rates observed in pelvic-suspended muscles (Thompson, 2002) may decrease the variance in palatability of meat obtained from tenderstretched and Achilles-hung

carcasses with the ongoing ageing period. A study of Bouton and Harris (1972) showed that the tenderness of LL and SM samples from pelvic-suspended beef carcasses at two and a half days after slaughter were equal to the tenderness of non-stretched muscles after 2 weeks of ageing. In a study of Joseph and Connolly (1977), the results of sensory analysis did not show any tenderness changes in beef SET samples as a result of tenderstretching. Similarly, WBSF values obtained by Bouton et al. (1973) for mutton SET samples were not significantly affected by the pelvic suspension method.

Another possible explanation for our results is the higher quantity of collagen fibres per $cm^2$ in the SET muscle that has to be cut during WBSF measurement and/or chewing during the sensory analysis. And so, the high content of connective tissue in the SET muscle determines the tenderness more than the possible stretching of myofibrillar proteins during carcass pelvic suspension (Crouse et al., 1984; Sørheim and Hildrum, 2002).

# 7. CONCLUSION

Since deer farming has become more popular and venison has become accessible also for common consumers, the outcomes of this study are important for the assessment of marketing quality of farmed fallow deer. The results of this study suggest that by meeting the animal´s requirements for amino acids without overfeeding, efficiency of protein utilization can be maximized. Supplementation with concentrates in the form of barley was an effective nutritional strategy to enhance the growth, performance and carcass yield of fallow deer bucks and it had a substantial impact on the profitability of fallow deer farm in this experiment. This strategy has led, however, to an increase in internal and carcass fatness. On the contrary, addition of RPAA lysine to the barley-based diet decreased the total fatness of the fallow deer. Further research is required to determine whether lysine and/or other AA supplementation could also improve/enhance other attributes of venison that is considered by consumers a healthy alternative to traditional types of meat. Moreover, while the effect of supplementation with RPAA lysine on the performance, carcass traits and meat qualitative parameters is ambiguous, further research in this area is suggested as the direction to the future and as a valuable contribution to the field.

On the other hand, diet appeared to have a less pronounced effect on some physical parameters of LL muscle and no effect on the physical aspects of SET muscle, with inconclusive results. The obtained $pH_u$ values indicated no incidence of DFD meat, and colour parameters were generally desirable for venison derived from fallow deer. In contrast, the results of this study emphasis the fact that diet may have a significant effect on the chemical composition of fallow deer meat, as a result of variation in the available nutrients. Diet significantly affected the dry matter, IMF, hydroxyproline, insoluble collagen and *n*-3 PUFA content, as well as the ratio of *n*-6/*n*-3. Taking into account the overall low amount of IMF and beneficial ratio of *n*-6/*n*-3 PUFA, fallow deer venison can be acknowledged as a health-promoting and valuable food source. The experimental diets caused noticeable differences in grilling loss and total weight loss between LL muscles of pasture-fed and grain-fed deer.

From the results of sensory assessment, it can be concluded that deer grazing on pasture produced venison with increased “grassy” flavour intensity, whereas grain-based diet was responsible for strong “liver” flavour of the meat. It is of great interest to explore further how the consumers appreciate venison produced within different feeding regimes.

Furthermore, this knowledge may be of some importance to deer farmers producing fallow deer venison for particular market preferences.

Tenderstretch had a negative effect on the textural parameters of fallow deer meat. It resulted in significant decreases in tenderness, juiciness and chewiness. However, these negative textural changes were most likely as a result of delay in *post-mortem* pelvic suspension. This suggests that carcass suspension by the aitchbone should be applied in *prae-rigor* state, within one hour after the animal bleeding.

This study provides insight in the various qualitative parameters of the meat derived from farm-raised fallow deer bucks, as affected by different diets. However, this effect of diet should be evaluated also in other species-specific categories such as fawns, juveniles, or does and bucks at different ages. Moreover, it is apparent from this study that there are number of factors that warrant further research for the promotion of fallow deer meat or/and venison as an alternative to traditional red meat products. In order to meet the potential of farming deer species as meat producers and to meet target market specifications, further investigations in this area are required. Particular attention should be drawn towards the effects of various slaughter methods or ageing conditions on meat quality of farm-raised fallow deer.

# 8. REFERENCES

Abe M., Iriki T., Funaba M., Onda S. (1998). Limiting amino acids for a corn and soybean meal diet in weaned calves less than three months of age. *Journal of Animal Science 76 (2),* 628–636.

Ahnström M. L. (2008). *Influence of pelvic suspension on beef meat quality.* Doctoral thesis. Swedish University of Agricultural Sciences, Faculty of Natural Resources and Agricultural Sciences. Uppsala, p. 75. ISBN: 978-91-85913-94-7.

Ahnström M. L., Hunt M. C., Lundström K. (2012). Effects of pelvic suspension of beef carcasses on quality and physical traits of five muscles from four gender-age groups. *Meat Science 90 (3),* 528–535.

Almeida J. C., Perassolo S., Camargo J. L., Bragagnolo N., Gross J. L. (2006). Fatty acid composition and cholesterol content of beef and chicken meat in Southern Brazil. *Revista Brasileira de Ciências Farmacêuticas 42 (1),* 109–117.

AOAC. (1990). *Official methods of analysis of AOAC International (15$^{th}$ edn).* Washington, DC: Association of Official Analytical Chemists, p. 69. ISBN: 0935584420.

AOAC. (2005). *Official methods of analysis of AOAC International (18$^{th}$ edn).* Gaithersburg, MD: Association of Official Analytical Chemists, p. 96. ISBN: 0935584773.

Arslangündoğdu Z., Kasparek M., Sarıbaşak H., Süleyman-Kaçar M., Yöntem O., Tuğrul-Şahin M. (2010). Development of the population of the European Fallow Deer, *Dama dama dama* (Linnaeus, 1758), in Turkey. *Zoology in the Middle East 49 (1),* 3–12.

Asher G. W., Day A. M., Barrell G. K. (1987). Annual cycle of liveweight and reproductive changes of farmed male fallow deer (*Dama dama*) and the effect of daily oral administration of melatonin in summer on the attainment of seasonal fertility. *Journal of Reproduction and Fertility 79 (2),* 353–362.

Assenova B., Okuskhanova E., Rebezov M., Korzhikenova N., Yessimbekov Z., Dragoev S. (2016). Trace and toxic elements in meat of maral (red deer) grazing in Kazakhstan. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 7 (1),* 1425–1433.

Attia Y. A. (2003) Performance, carcass characteristics, meat quality and plasma constituents of meat type drakes fed diets containing different levels of lysine with or without a microbial phytase. *Archives of Animal Nutrition 51 (1),* 39–48.

Avilés C., Martínez A. L., Domenech V., Peña F. (2015). Effect of feeding system and breed on growth performance, and carcass and meat quality traits in two continental beef breeds. *Meat Science 107,* 94–103.

Babiker S. A., El Khider I. A., Shafie S. A. (1990). Chemical composition and quality attributes of goat meat and lamb. *Meat Science 28 (4),* 273–277.

Barbieri G., Bolzoni L., Parolari G., Virgili R., Buttini R., Careri M., Mangia A. (1992). Flavor compounds of dry-cured ham. *Journal of Agricultural and Food Chemistry 40 (12),* 2389–2394.

Bartoň L., Bureš D., Kotrba R., Sales J. (2014). Comparison of meat quality between eland (*Taurotragus oryx*) and cattle (*Bos taurus*) raised under similar conditions. *Meat Science 96 (1),* 346–352.

Basinger K. L., Shanks B. C., Apple J. K., Caldwell J. D., Yancey J. W. S., Backes E. A., Wilbers L. S., Johnson T. M., Bax A. L. (2019). Application of tension to *prerigor* goat carcasses to improve cooked meat tenderness. *Meat Science 147,* 1–5.

Bergman I., Loxley R. (1963). Two improved and simplified methods for the spectrophotometric determination of hydroxyproline. *Analytical Chemistry 35 (12),* 1961–1965.

Bjørklund I. (1990). Sámi reindeer pastoralism as an indigenous resource management system in Northern Norway: A contribution to the common property debate. *Development and Change 21 (1),* 75–86.

Bornett-Gauci H. L. I., Martin J. E., Arney D. R. (2006). The welfare of low-volume farm animals during transport and at slaughter: A review of current knowledge and recommendations for future research. *Animal Welfare 15 (3),* 299–308.

Bourne M. C. (2002). *Food texture and viscosity: Concept and measurement*. New York, NY: Academic Press, p. 423. ISBN: 978-0-12-119062-0.

Bouton P. E., Harris P. V. (1972). Effects of some post-slaughter treatments on the mechanical properties of bovine and ovine muscles. *Journal of Food Science 37 (4),* 539–543.

Bouton P. E., Harris P. V., Shorthose W. R., Baxter R. I. (1973). A comparison of the effects of aging, conditioning and skeletal restraint on the tenderness of mutton. *Journal of Food Science 38 (6),* 932–937.

Bovolenta S., Corazzin M., Messina M., Focardi S., Piasentier E. (2013). Supplementary feeding of farmed fallow deer: Effect on milk composition and fawn performance. *Italian Journal of Animal Science 12 (4),* 596–603.

Brelurut A., Theriez M., Bechet G. (1995). Effects of winter feeding level on the performance of red deer calves (*Cervus elaphus*). *Animal Science 60 (1),* 151–156.

Broderick G. A., Wallace R. J., Orskov E. R. (1991). Control of rate and extent of protein degradation. In: Tsuda T., Sasaki Y., Kawashima R. (Eds.). *Physiological aspects of digestion and metabolism in ruminants. Proceedings: 7th International Symposium on Ruminant Physiology*. London: Academic Press Ltd, pp. 541–592. ISBN: 9780323138611.

Bureš D., Bartoň L. (2012). Growth performance, carcass traits and meat quality of bulls and heifers slaughtered at different ages. *Czech Journal of Animal Science 57 (1),* 34–43.

Bureš D., Bartoň L., Kotrba R., Hakl J. (2015). Quality attributes and composition of meat from red deer (*Cervus elaphus*), fallow deer (*Dama dama*) and Aberdeen Angus and Holstein cattle (*Bos taurus*). *Journal of the Science of Food and Agriculture 95 (11)*. 2299–2306.

Bykowska M., Stanisz M., Ludwiczak A., Skladanowska J., Ślósarz P. (2018a). Quality of meat from three muscles of farmed fallow deer (*Dama dama*). *Animal Production Science 58 (2)*, 376–384.

Bykowska M., Stanisz M., Ludwiczak A., Składanowska J., Ślósarz P. (2018b). Effect of muscle, time *post-mortem* and sex on the quality of meat from fallow deer (*Dama dama*) farmed in Poland. *Small Ruminant Research 160*, 12–18.

Campo M. M., Nute G. R., Hughes S. I., Enser M., Wood J. D., Richardson R. I. (2006). Flavour perception of oxidation in beef. *Meat Science 72 (2)*, 303–311.

Card W. C., Kirkpatrick R. L., Webb K. E., Scanlon P. F. (1985). Nutritional influences on NEFA, cholesterol, and ketones in white-tailed deer. *The Journal of Wildlife Management 49 (2)*, 380–385.

Caton J. S., Dhuyvetter D. V. (1997). Influence of energy supplementation on grazing ruminants: Requirements and responses. *Journal of Animal Science 75 (2)*, 533–542.

Cawthorn D.-M., Hoffman L. C. (2014). The role of traditional and non-traditional meat animals in feeding a growing and evolving world. *Animal Frontiers 4 (4)*, 6–12.

Cawthorn D.-M., Hoffman L. C. (2015). The bushmeat and food security nexus: A global account of the contributions, conundrums and ethical collisions. *Food Research International 76 (P4)*, 906–925.

Cawthorn D.-M., Hoffman L. C. (2016). Controversial cuisine: A global account of the demand, supply and acceptance of “unconventional” and “exotic” meats. *Meat Science 120*, 19–36.

Cawthorn D.-M., Fitzhenry L. B., Muchenje V., Bureš D., Kotrba R., Hoffman L. C. (2018). Physical quality attributes of male and female wild fallow deer (*Dama dama*) muscles. *Meat Science 137*, 168–175.

Čelechovská O., Malota L., Zima S. (2008). Entry of heavy metals into food chains: A 20-year comparison study in Northern Moravia (Czech Republic). *Acta Veterinaria Brno 77 (4)*, 645–652.

Chakanya C., Dokora A. E. M., Muchenje V., Hoffman L. C. (2016). The fallow deer (*Dama* spp.); endangered or not? *Der Zoologische Garten 85 (3-4)*, 160–172.

Chakanya C., Arnaud E., Muchenje V., Hoffman L. C. (2017). Colour and oxidative stability of mince produced from fresh and frozen/thawed fallow deer (*Dama dama*) meat. Meat *Science 126*, 63–72.

Chapman N. G., Chapman D. I. (1980). The distribution of fallow deer: A worldwide review. *Mammal Review 10 (2-3)*, 61–144.

Cheah K. S., Cheah A. M., Krausgrill D. I. (1995). Effect of dietary supplementation of vitamin E on pig meat quality. *Meat Science 39 (2)*, 255–264.

Chizzolini R., Zanardi E., Dorigoni V., Ghidini S. (1999). Calorific value and cholesterol content of normal and low-fat meat and meat products. *Trends in Food Science & Technology 10 (4-5)*, 119–128.

Cho S. H., Park B. Y., Kim J. H., Hwang I. H., Kim J. H., Lee J. M. (2005). Fatty acid profiles and sensory properties of *Longissimus dorsi*, *Triceps brachii*, and *Semimembranous* muscles

from Korean Hanwoo and Australian Angus beef. Asian-Australasian *Journal of Animal Sciences 18 (12)*, 1786–1793.

Chriki S., Gardner G. E., Jurie C., Picard B., Micol D., Brun J.-P., Journaux L., Hocquette J.-F. (2012). Cluster analysis application identifies muscle characteristics of importance for beef tenderness. *BMC Biochemistry 13 (29)*, 1–11.

Cifuni G. F., Amici A., Contò M., Viola P., Failla S. (2014). Effects of the hunting method on meat quality from fallow deer and wild boar and preliminary studies for predicting lipid oxidation using visible reflectance spectra. *European Journal of Wildlife Research 60 (3)*, 519–526.

Coble K. F., Dritz S. S., Usry J. L., Nemechek J. E., Tokach M. D., DeRouchey J. M., Goodband R. D., Woodworth J. C., Hill G. M. (2014). Effects of standardized ileal digestible lysine level in diets containing tribasic copper chloride on finishing pig growth performance, carcass characteristics, and fat quality. *Swine Day (2014)*, 138–154.

Colomer-Rocher F., Kirton A. H., Mercer G. J. K., Duganzich D. M. (1992). Carcass composition of New Zealand Saanen goats slaughtered at different weights. *Small Ruminant Research 7(2)*, 161–173.

Commission Internationale de l´Eclairage (CIE). (1971). Colorimetry: Official recommendations of the International Commission on Illumination. *Publication CIE No. 15 (E-1.3.1)*. Paris: Boreau Central de la CIE, p. 124.

Costa H., Mafra I., Oliveira M. B. P. P, Amaral J. S. (2016). Game: Types and composition. In: Caballero B., Finglas P. M., Toldrá F. (Eds.). *Encyclopedia of food and health*. Oxford: Academic Press, pp. 177–183. ISBN: 0123849535.

Cross H. R., Carpente Z. L., Smith G. C. (1973). Effects of intramuscular collagen and elastin on bovine muscle tenderness. *Journal of Food Science 38 (6)*, 998–1003.

Crouse J. D., Cross H. R., Seideman S. C. (1984). Effects of a grass or grain diet on the quality of three beef muscles. *Journal of Animal Science 58 (3)*, 619–625.

Curry J. W., Hohl R., Noakes T. D., Kohn T. A. (2012). High oxidative capacity and type IIx fibre content in springbok and fallow deer skeletal muscle suggest fast sprinters with a resistance to fatigue. *The Journal of Experimental Biology 215 (22)*, 3997–4005.

Cygan-Szczegielniak D., Janicki B. (2012). Amino acids content and basic chemical composition of roe deer (*Capreolus capreolus* L.) meat. *Polish Journal of Veterinary Sciences 15 (4)*, 645–649.

Dahlan I. (2009). Characteristics and cutability of farmed rusa deer (*Cervus timorensis*) carcasses for marketing of venison. *Asian-Australasian Journal of Animal Sciences 22 (5)*, 740–746.

Dahlan I., Norfarizan-Hanoon N. A. (2007). Fatty acid profiles and cholesterol composition of venison from farmed deer. *Journal of Animal and Veterinary Advances 6 (5)*, 650–657.

Dahlan I., Norfarizan-Hanoon N. A. (2008). Chemical composition, palatability and physical characteristics of venison from farmed deer. *Animal Science Journal 79 (4)*, 498–503.

Daley C. A., Abbott A., Doyle P. S., Nader G. A., Larson S. (2010). A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutrition Journal 9 (1)*, 10.

Daňhelka J., Bercha Š., Boháč M., Crhová L., Čekal R., Černá L., Elleder L., Fiala R., Chuchma F., Kohout M., Kourková H., Kubát H., Kukla P., Kulhavá R., Možný M., Reitschläger J. D., Řičicová P., Sandev M., Skřivánková P., Šercl P., Štěpánek P., Valeriánová A., Vlnas R., Vrabec M., Vráblík M., Zahradníček P., Zrzavecký M. (2015). Vyhodnocení sucha na území České republiky v roce 2015. Praha: ČHMÚ, 2015, p. 160.

Daszkiewicz T., Hnatyk N., Dąbrowski D., Janiszewski P., Gugołek A., Kubiak D., Śmiecińska K., Winarski R., Koba-Kowalczyk M. (2015). A comparison of the quality of the *Longissimus lumborum* muscle from wild and farm-raised fallow deer (*Dama dama* L.). *Small Ruminant Research 129*, 77–83.

Daszkiewicz T., Kubiak D., Hołdyńska E., Piaskowska N. (2017a). The comparison of meat quality from different carcass cuts of male fallow deer (*Dama dama* L.). *Polish Journal of Natural Sciences 32 (2)*, 273–281.

Daszkiewicz T., Lipowski T., Kubiak D. (2017b). Effect of freezer storage on quality of *M. longissimus lumborum* from fallow deer (*Dama dama* L.). *South African Journal of Animal Science 47 (6)*, 834–841.

Daza A., Rey A. I., López-Carrasco C., López-Bote C. J. (2014). Effect of gender on growth performance, carcass traits and meat quality of calves of Avileña-Negra Ibérica breed fattened under free-range conditions. *Spanish Journal of Agricultural Research 12 (3)*, 683–693.

Demeyer D. (1999). Lipid composition of beef in relation to feeding, nutrition and technology. *Proceedings: 45th International Congress of Meat Science and Technology (ICoMST), 1–6 August. Japan 1999: Yokohama*, pp. 30–38.

Dominik P., Saláková A., Steinhauser L., Buchtová H. (2011). Chemical and textural parameters of farmed fallow deer meat. In: Vorlová L., Janštová B., Cupáková Š. (Eds.). *Sborník přednášek XIII. konference mladých vědeckých pracovníků*. Brno: Veterinární a farmaceutická univerzita Brno, pp. 19–21. ISBN: 978-80-7305-010-8.

Dominik P., Pavlík Z., Steinhauserová I., Saláková A., Buchtová H., Steinhauser L. (2012). The effect of soluble collagen on the texture of fallow deer meat. *Maso International 1 (1)*, 57–61.

Donini L. M., Savina C., Cannella C. (2009). Appetite and ageing. In: Raats M., van Staveren W., de Groot L. (Eds.). *Food for the ageing population.* Cambridge: Woodheat Publishing Ltd., pp. 43–72. ISBN: 978-1-84569-193-6.

Drew K. R. (1992). Plenary Lecture: Venison and other deer products. In: Brown R. D. (Ed.). *The biology of deer*. New York, NY: Springer Science & Business Media, pp. 225–232. ISBN: 1461227828.

Dryden G. M. (1997). Venison in the human diet – Is venison a low-fat meat? *Proceedings of the Nutrition society of Australia 21*, pp. 44–51.

Elmore J. S., Mottram D. S., Enser M., Wood J. D. (1999). Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. *Journal of Agricultural and Food Chemistry 47 (4)*, 1619–1625.

El Muola I. H. A., Babiker S. A., El Khidir O. A., Ibrahim S. E. (1999). Meat production from female goat kids compared with males. *The Journal of Agricultural Science 133 (2)*, 223–226.

Enei G. G. (2010). *Resultados y lecciones en producción y procesamiento de carnes exóticas. Proyectos de innovación en la XIV Región de Los Ríos*. Santiago de Chile: Ograma Ltda., p. 52. ISBN: 978-956-328-070-8.

European Commission. (2009). Commission regulation (EC) No. 152/2009 of 27 January 2009 laying down the methods of sampling and analysis for the official control of feed. *Official Journal of the European Communities L 54*, p. 130.

Falandysz J., Szymczyk-Kobrzyńska K., Brzostowski A., Zalewski K., Zasadowski A. (2005). Concentrations of heavy metals in the tissues of red deer (*Cervus elaphus*) from the region of Warmia and Mazury, Poland. *Food Additives and Contaminants 22 (2)*, 141–149.

Fehily A. M., Pickering J. E., Yarnell J. W. G., Elwood P. C. (1994). Dietary indices of atherogenicity and thrombogenicity and ischaemic heart disease risk: the Caerphilly Prospective Study. *British Journal of Nutrition 71 (2)*, 249–257.

Fernandez X., Monin G., Talmant A., Mourot J., Lebret B. (1999). Influence of intramuscular fat content on the quality of pig meat – 2. Consumer acceptability of *M. longissimus lumborum*. *Meat Science 53 (1)*, 67–72.

Finstad G., Wiklund E., Long K., Rincker P., Oliveira A., Bechtel P. (2007). Feeding soy or fish meal to Alaskan reindeer (*Rangifer tarandus tarandus*) – Effects on animal performance and meat quality. *Rangifer 27 (1)*, 59–76.

Fisher A. V., Enser M., Richardson R. I., Wood J. D., Nute G. R., Kurt E., Sinclair L. A., Wilkinson R. G. (2000). Fatty acid composition and eating quality of lamb types derived from four diverse breed × production systems. *Meat Science 55 (2)*, 141–147.

Florek M., Drozd L. (2013). Związki bioaktywne w mięsie jeleniowatych. *Medycyna Weterynaryjna 69 (9)*, 535–539. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84885348072&partnerID=tZOtx3y1.

Flores M., Grimm C. C., Toldrá F., Spanier A. M. (1997). Correlations of sensory and volatile compounds of Spanish "Serrano" dry-cured ham as a function of two processing times. *Journal of Agricultural and Food Chemistry 45 (6)*, 2178–2186.

Folch J., Lees M., Sloane-Stanley G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *The Journal of Biological Chemistry 226 (1).* 497–509.

Font-i-Furnols M., Guerrero L. (2014). Consumer preference, behavior and perception about meat and meat products: An overview. *Meat Science 98 (3)*, 361–371.

Forss D. A., Manley T. R., Platt M. P., Moore V. J. (1979). Palatability of venison from farmed and feral red deer. *Journal of the Science of Food and Agriculture 30 (9),* 932–935.

García-Esteban M., Ansorena D., Gimeno O., Astiasarán I. (2003). Optimization of instrumental colour analysis in dry-cured ham. *Meat Science 63 (3),* 287–292.

Gill C. O. (2007). Microbiological conditions of meats from large game animals and birds. *Meat Science 77 (2),* 149–160.

Goodson K. J., Miller R. K., Savell J. W. (2001). Carcass traits, muscle characteristics, and palatability attributes of lambs expressing the callipyge phenotype. *Meat Science 58 (4),* 381–387.

Grace N. D., Wilson P. R. (2002). Trace element metabolism, dietary requirements, diagnosis and prevention of deficiencies in deer. *New Zealand Veterinary Journal 50 (6),* 252–259.

Green P. (2017). Monitoring the health and welfare of free-living deer in deer parks. *In Practice 39 (1),* 34–40.

Greenwood R. H., Titgemeyer E. C. (1997). Limiting amino acids for growing Holstein steers limit-fed soybean hull-based diets. *Journal of Animal Science 78 (7),* 1997–2004.

Grigor P. N., Goddard P. J., Cockram M. S., Rennie S. C., Macdonald, A. J. (1997). The effects of some factors associated with transportation on the behavioural and physiological reactions of farmed red beer. *Applied Animal Behaviour Science 52 (1–2),* 179–189.

Grisoni M. L., Uzu G., Larbier M., Geraert P. A. (1991). Effect of dietary lysine level on lipogenesis in broilers. *Reproduction, Nutrition, Development 31 (6),* 683–690.

Häffner J., Kahrs D., Limper J., de Mol J., Peisker M., Williams P. (2000). *Amino acids in animal nutrition*. Eisenberg: AgriMedia GmBH, p. 60. ISBN: 3-86037-126-6.

Han K., Ha J. K., Lee S. S., Ko Y. G., Lee H. S. (1996). Effect of supplementing rumen-protected lysine on growth performance and plasma amino acid concentrations in sheep. *Asian-Australasian Journal of Animal Sciences 9 (3)*, 309–313.

Handeland K., Bernhoft A., Aartun M. S. (2008). Copper deficiency and effects of copper supplementation in a herd of red deer (*Cervus elaphus*). *Acta Veterinaria Scandinavica 50 (1)*, 8.

Hickling D., Guenter W., Jackson M. E. (1990). The effects of dietary methionine and lysine on broiler chicken performance and breast meat yield. *Canadian Journal of Animal Science 70 (2)*, 673–678.

Hill F. (1966). Solubility of intramuscular collagen in meat animals of various ages. *Journal of Food Science 31 (2)*, 161–166.

Higgs J. D. (2000). The changing nature of red meat: 20 years of improving nutritional quality. *Trends in Food Science & Technology 11 (13)*, 85–95.

Hoffman L. C., Kritzinger B., Ferreira A. V. (2005). The effects of region and gender on the fatty acid, amino acid, mineral, myoglobin and collagen contents of impala (*Aepyceros melampus*) meat. *Meat Science 69 (3)*, 551–558.

Hoffman L. C., Wiklund E. (2006). Game and venison – Meat for the modern consumer. *Meat Science 74 (1)*, 197–208.

Hoffman L. C., Kroucamp M., Manley M. (2007a). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 1: Physical meat attributes as influenced by age, gender and production region. *Meat Science 76 (4)*, 755–761.

Hoffman L. C., Kroucamp M., Manley M. (2007b). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 2: Chemical composition of springbok meat as influenced by age, gender and production region. *Meat Science 76 (4)*, 762–767.

Hoffman L. C., Kroucamp M., Manley M. (2007c). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 3: Fatty acid composition as influenced by age, gender and production region. *Meat Science 76 (4)*, 768–773.

Hoffman L. C., Kroucamp M., Manley M. (2007d). Meat quality characteristics of springbok (*Antidorcas marsupials*). 4: Sensory meat evaluation as influenced by age, gender, and production region. *Meat Science 76 (4)*, 774–778.

Hoffman L. C., van Schalkwyk S., Muller M. (2011). Quality characteristics of blue wildebeest (*Connochaetes taurinus*) meat. *South African Journal of Wildlife Research 41 (2)*, 210–213.

Hoffman L. C., Cawthorn D.-M. (2012). What is the role and contribution of meat from wildlife in providing high quality protein for consumption? *Animal Frontiers 2 (4)*, 40–53.

Hogg B. W., Catcheside L. M., Mercer G. J. K. (1990). Carcass composition in male fallow deer: Age and castration effects on dissected tissue distribution. *Animal Science 51 (2)*, 405–413.

Honikel K. O. (1998). Reference methods for the assesment of physical characteristics of meat. *Meat Science 49 (4)*. 447–457.

Hopkins D. L., Nicholson A. (1999). Meat quality of wether lambs grazed on either saltbush (*Atriplex nummularia*) plus supplements or lucerne (*Medicago sativa*). *Meat Science 51 (1)*, 91–95.

Hopkins D. L., Littlefield P. J., Thompson J. M. (2000). The effect on tenderness of super tenderstretching. *Asian-Australasian Journal of Animal Sciences 13 (Supplement)*, 240.

Hostetler R. L., Landmann W. A., Link B. A., Fitzhugh H. A. (1970). Influence of carcass position during *rigor mortis* on tenderness of beef muscles: Comparison of two treatments. *Journal of Animal Science 31 (1),* 47–50.

Huang J., Zhang T. T., Kun B., Li G. Y., Wang K. Y. (2015). Effect of supplementation of lysine and methionine on growth performance, nutrient digestibility and serum biochemical indices for growing sika deer (*Cervus Nippon*) fed protein deficient diet. *Italian Journal of Animal Science 14 (1),* 61–65.

Hudson R. J. (1999). Livestock diversification: Issues and trends. In: Hudson J. R. (Ed.). *Encyclopedia of life support systems (EOLSS), Vol. 1*. Paris: Eolss Publishers, Management of Agricultural, Forestry and Fisheries Enterprises, pp. 361–374. ISBN: 1848261993.

Hudson R. J., Adamczewski J. Z. (1990). Effect of supplementing summer ranges on lactation and growth of wapiti (*Cervus elaphus*). *Canadian Journal of Animal Science 70 (2),* 551–560.

Hunt M. R., Legako J. F., Dinh T. T. N., Garmyn A. J., O' Quinn T. G., Corbin C. H., Rathmann R. J., Brooks J. C., Miller M. F. (2016). Assessment of volatile compounds, neutral and polar lipid fatty acids of four beef muscles from USDA Choice and Select graded carcasses and their relationships with consumer palatability scores and intramuscular fat content. *Meat Science 116*, 91–101.

Hussein H. S., Berger L. L. (1995). Feedlot performance and carcass characteristics of Holstein steers as affected by source of dietary protein and level of ruminally protected lysine and methionine. *Journal of Animal Science 73 (12)*, 3503–3509.

Hutchison C. L., Flesch J. S., Mulley R. C. (2004). The relationship between body condition score and venison quality in entire and castrated fallow deer (*Dama dama*) bucks. *Animal Production in Australia 25 (1),* 264.

Hutchison C. L., Flesch J. S., Mulley R. C. (2006). The effect of pelvic suspension on the biochemical and sensory quality of venison from red deer (*Cervus elaphus*) and fallow deer (*Dama dama*). *Advances in deer biology: Deer in a changing world. Proceedings: 6th International Deer Biology Congress, 7–11 August 2006, Czech Republic: Prague*, pp. 234–240. ISBN: 9788086454733.

Hutchison C. L., Mulley R. C., Wiklund E., Flesch J. S. (2010). Consumer evaluation of venison sensory quality: Effects of sex, body condition score and carcase suspension method. *Meat Science 86 (2),* 311–316.

Hutchison C. L., Mulley R. C., Wiklund E., Flesch J. S. (2012). Effect of concentrate feeding on instrumental meat quality and sensory characteristics of fallow deer venison. *Meat Science 90 (3),* 801–806.

Hutchison C. L., Mulley R. C., Wiklund E., Flesch J. S., Sims K. L. (2014). Effect of pelvic suspension on the instrumental meat quality characteristics of red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) venison. *Meat Science 98 (2),* 104–109.

ISO 1444. (1996). *Meat and meat products – Determination of free fat content.* Geneva, Switzerland: International Organization for Standardization, p. 4.

ISO 13300-2. (2006). *Sensory analysis – General guidance for the staff of a sensory evaluation laboratory – Part 2: Recruitment and training of panel leaders.* Geneva, Switzerland: International Organization for Standardization, p. 11.

ISO 2171. (2007). *Cereals, pulses and by-products – Determination of ash yield by incineration.* Geneva, Switzerland: International Organization for Standardization, p. 11.

ISO 8589. (2007). *Sensory analysis – General guidance for the design of test rooms.* Geneva, Switzerland: International Organization for Standardization, p. 16.

ISO 712. (2009). *Cereals and cereal products – Determination of moisture content – Reference method.* Geneva, Switzerland: International Organization for Standardization, p. 16.

ISO 1871. (2009). *Food and feed products – General guideline for the determination of nitrogen by the Kjeldahl method.* Geneva, Switzerland: International Organization for Standardization, p. 7.

ISO 12966-2. (2017). *Animal and vegetable fats and oils – Gas chromatography of fatty acid methyl esters – Part 2: Preparation of methyl esters of fatty acids.* Geneva, Switzerland: International Organization for Standardization, p. 15.

Jacela J. Y., Derouchey J. M., Tokach M. D., Goodband R. D., Nelssen J. L., Renter G., Dritz S. S. (2010). Feed additives for swine: Fact sheets – High dietary levels of copper and zinc for young pigs, and phytase. *Journal of Swine Health and Production 18 (2),* 87–91.

Jago J. G., Harcourt R. G., Matthews L. R. (1997). The effect of road-type and distance transported on behaviour, physiology and carcass quality of farmed red deer (*Cervus elaphus*). *Applied Animal Behaviour Science 51 (1–2),* 129–141.

Jančík F., Kubelková P., Kubát V., Koukolová M., Homolka P. (2017). Effects of drying procedures on chemical composition and nutritive value of alfalfa forage. *South African Journal of Animal Science 47 (1),* 96–101.

Janiszewski P., Dmuchowski B., Gugołek A., Żełobowski R. (2008). Body weight characteristics of farm-raised fallow deer (*Dama dama* L.) over the winter period. *Journal of Central European Agriculture 9 (2),* 337–342.

Janiszewski P., Daszkiewicz T., Cilulko J. (2015). The effect of wintering conditions on the body weight and carcass quality of farm-raised fallow deer (*Dama dama*). *Bulgarian Journal of Agricultural Science 21 (3),* 668–673.

Jarzyńska G., Falandysz J. (2011). Selenium and 17 other largely essential and toxic metals in muscle and organ meats of red deer (*Cervus elaphus*) – Consequences to human health. *Environment International 37 (5)*, 882–888.

Jensz K., Finley L. (2013). Species profile for the Fallow deer, *Dama dama*. Hobart, Tasmania: Latitude 42 Environmental Consultants Pty Ltd, p. 18.

Jimenez S., Rosenbloom J. (1974). Decreased thermal stability of collagens containing analogs of proline or lysine. *Archives of Biochemistry and Biophysics 163 (2)*, 459–465.

Jones M., Hoffman L. C., Muller M. (2015). Oxidative stability of blesbok, springbok and fallow deer droëwors with added rooibos extract. *South African Journal of Science 111 (11−12)*, 1–8.

Joo S. T., Kim G. D., Hwang Y. H., Ryu, Y. C. (2013). Control of fresh meat quality through manipulation of muscle fiber characteristics. *Meat Science 95 (4)*, 828–836.

Joseph R. L., Connolly J. (1977). The effects of suspension method, chilling rates and *post mortem* ageing period on beef quality. *International Journal of Food Science & Technology 12 (3)*, 231–247.

Kasai T., Sakai H., Ishijima Y., Hasegawa T. (1999). Proximate composition, properties of lipid and mineral contents in Yeso sika deer (*Cervus nippon yesoensis*) meat. *Nippon Shokuhin Kagaku Kogaku Kaishi 46 (11)*, 710–718.

Kaimbayeva L. A., Malysheva E. S., Kazikhanov R., Kazikhanova S. R. (2018). Investigation on autolytic processes and microstructural changes in red deer meat. *Pakistan Journal of Zoology 50 (4)*, 1341−1346.

Khan M. I., Jo C., Tariq M. R. (2015). Meat flavor precursors and factors influencing flavor precursors – A systematic review. *Meat Science 110*, 278−284.

Khan M. I., Jung S., Nam K. C., Jo C. (2016). *Postmortem* aging of beef with a special reference to the dry aging. *Korean Journal for Food Science of Animal Resources 36 (2),* 159–169.

Kim G. D., Jeong J. Y., Hur S. J., Yang H. S., Jeon J. T., Joo S. T. (2010). The relationship between meat color (CIE *L** and *a**), myoglobin content, and their influence on muscle fiber characteristics and pork quality. *Korean Journal for Food Science of Animal Resources 30 (4),* 626–633.

Kim S.-W., Kim K.-W., Park S.-B., Kim M.-J., Yim D.-G. (2015). The effect of castration time on growth and carcass production of elk bulls. *Journal of Animal Science and Technology (2015) 57 (39),* https://doi.org/10.1186/s40781-015-0072-2.

Kim K. W., Park H. S., Lee S. S., Yeon S. H., Cho C. Y., Kim S. W., Lee J. (2017). Effects of different feeding regimes on deer meat (venison) quality following chilled storage condition. *Korean Journal for Food Science of Animal Resources 37 (4),* 511–517.

Kjellander P., Svartholm I., Bergvall U. A., Jarnemo A. (2012). Habitat use, bed-site collection and mortality rate in neonate fallow deer *Dama dama*. *Wildlife Biology 18 (3),* 280–291.

Klemesrud M. J., Klopfenstein T. J., Stock R. A., Lewis A. J., Herold D. W. (1999). Effect of dietary concentration of metabolizable lysine on finishing cattle performance. *Journal of Animal Science 78 (4),* 1060–1066.

Kramárová M., Massányi P., Jančová A., Toman R., Slamečka J., Tataruch F., Kováčik J., Gašparík J., Naď P., Skalická M., Koréneková B., Jurčík R., Čuboň J., Haščík P. (2005a). Concentration of cadmium in the liver and kidneys of some wild and farm animals. *Bulletin of the Veterinary Institute in Pulawy 49 (4),* 465–469.

Krzywiński A., Niedbalska A., Twardowski L. (1984). Growth and development of hand reared fallow deer fawns. *Acta Theriologica 29 (29),* 349–356.

Kuba J., Landete-Castillejos T., Udała J. (2015). Red deer farming: Breeding practice, trends and potential in Poland – A review. *Annals of Animal Science 15 (3),* 591–599.

Kudrnáčová E., Bartoň L., Bureš D., Hoffman L. C. (2018). Carcass and meat characteristics from farm-raised and wild fallow deer (*Dama dama*) and red deer (*Cervus elaphus*): A review. *Meat Science 141,* 9–27.

Kupka J. (2004). Jak je to doopravdy na trhu se zvěřinou? *Myslivost 52 (82),* 14–15.

Kwiatkowska A., Żmijewski T., Cierach M. (2009). Utility value of carcass of European deer (*Cervus elaphus*) and its meat evaluation. *Polish Journal of Food and Nutrition Sciences 59 (2),* 151–156.

Larick D. K., Hedrick H. B., Bailey M. E., Williams J. E., Hancock D. L., Garner G. B., Morrow R. E. (1987). Flavor constituents of beef as influenced by forage- and grain-feeding. *Journal of Food Sciences 52 (2),* 245–251.

Lazarus M., Vicković I., Šoštarić B., Blanuša M. (2005). Heavy metal levels in tissues of red deer (*Cervus elaphus*) from Eastern Croatia. *Arhiv Za Higijenu Rada I Toksikologiju 56 (3),* 233–240. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16180608.

Lazarus M., Prevendar-Crnić A., Bilandžić N., Kusak J., Reljić S. (2014). Cadmium, lead, and mercury exposure assessment among Croatian consumers of free-living game. *Archives of Industrial Hygiene and Toxicology 65 (3),* 281–292.

Legako J. F., Dinh T. T. N., Miller M. F., Brooks J. C. (2015). Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions. *Meat Science 100,* 246–255.

Lepetit J. (2008). Collagen contribution to meat toughness: Theoretical aspects. *Meat Science 80 (4),* 960–967.

Liu Y., Mao Y., Liang R., Zhang Y., Wang R., Zhu L., Han G., Luo X. (2016). Effect of suspension method on meat quality and ultra-structure of Chinese Yellow Cattle under 12–18 °C *pre-rigor* temperature controlled chilling. *Meat Science 115*, 45–49.

Locker R. H. (1960). Degree of muscular contraction as a factor in tenderness of beef. *Journal of Food Science 25 (2)*, 304–307.

Lorenzo J. M., Maggiolino A., Gallego L., Pateiro M., Serrano M. P., Domínguez R., García A., Landete-Castillejos T., De Palo P. (2018). Effect of age on nutritional properties of Iberian wild red deer meat. *Journal of the Science of Food and Agriculture 99 (4)*, 1561–1567.

Ludwiczak A., Stanisz M., Bykowska M., Składanowska J., Ślósarz P. (2017). Effect of storage on quality traits of the *semimembranosus* muscle of farmed fallow deer (*Dama dama*) bucks and does. *Animal Science Journal 88 (8)*, *1149*–1155.

MacDougall D. B., Shaw B. G., Nute G. R., Rhodes D. N. (1979). Effect of pre-slaughter handling on the quality and microbiology of venison from farmed young red deer. *Journal of the Science of Food and Agriculture 30 (12)*, 1160–1167.

MacRae J., O' Reilly L., Morgan P. (2005). Desirable characteristics of animal products from a human health perspective. *Livestock Production Science 94 (1–2)*, 95–103.

Maggiolino A. M., Pateiro M., Serrano M. P., Landete-Castillejos T., Domínguez R., García A., Gallego L., De Palo P., Lorenzo J. M. (2018). Carcass and meat quality characteristics from Iberian wild red deer (*Cervus elaphus*) hunted at different ages. *Journal of the Science of Food and Agriculture 99 (4)*, 1938–1945.

Mamani-Linares L. W., Gallo C. (2014). Meat quality, proximate composition and muscle fatty acid profile of young llamas (*Lama glama*) supplemented with hay or concentrate during the dry season. *Meat Science 96 (1)*, 394–399.

Mancini R. A., Hunt M. C. (2005). Current research in meat color. *Meat Science 71 (1),* 100–121.

Maraba K. P., Mlambo V., Yusuf A. O., Marume U., Hugo A. (2018). Extra dietary vitamin E – selenium as a mitigation strategy against housing-induced stress in Dohne Merino lambs: Effect on growth performance, stress biomarkers, and meat quality. *Small Ruminant Research 160,* 31–37.

Masseti M., Pecchioli E., Vernesi C. (2008). Phylogeography of the last surviving populations of Rhodian and Anatolian fallow deer (*Dama dama dama* L., 1758). *Biological Journal of the Linnean Society 93 (4),* 835–844.

Mattiello S., Mattiangeli V., Bianchi L., Carenzi C. (1997). Feeding and social behavior of fallow deer (*Dama dama* L.) under intensive pasture confinement. Journal *of Animal Science 75 (2),* 339–347.

McElligott A. G., Gammell M. P., Harty H. C., Paini D. R., Murphy D. T., Walsh J. T., Hayden T. J. (2001). Sexual size dimorphism in fallow deer (*Dama dama*): Do larger, heavier males gain greater mating success? *Behavioral Ecology and Sociobiology 49 (4),* 266–272.

Melton S. L., Black J. M., Davis G. W., Backus W. R. (1982). Flavor and selected chemical components of ground beef from steers backgrounded on pasture and fed corn up to 140 days. *Journal of Food Science 47 (3),* 699–704.

Mertens D. R. (1994). Regulation of forage intake. In: Fahey G. C. (Ed.). *Forage quality, evaluation, and utilization.* Madison, WI: American Society of Agronomy, Inc., pp. 450–493. ISBN: 0-89118-119-9.

Miao Z. H., Glatz P. C., English A., Ru Y. J. (2001). Managing fallow deer (*Dama dama*) and red deer (*Cervus elaphus*) for animal house research. *ANZCCART Fact Sheet (Adelaide),* 1–8.

Miller H., Carden R. F., Evans J., Lamb A., Madgwick R., Osborne D., Symmons R., Sykes N. (2016). Dead or alive? Investigation long-distance transport of live fallow deer and their body parts in antiquity. *Environmental Archaeology 21 (3)*, 246–259.

Milner-Gulland E., Bennett E. L., SCB, 2002 Annual Meeting Wild Meat Group (2003). Wild meat: The bigger picture. *Trends in Ecology and Evolution 18 (7)*, 351–357.

Monsón F., Sañudo C., Sierra I. (2005). Influence of breed and ageing time on the sensory meat quality and consumer acceptability in intensively reared beef. *Meat Science 71 (3)*, 471–479.

Morgante M., Valusso R., Pittia P., Volpelli L. A., Piasentier E. (2003). Quality traits of fallow deer (*Dama dama*) dry-cured hams. *Italian Journal of Animal Science 2 (1)*, 557–559.

Mottram D. S. (1998). Flavour formation in meat and meat products: A review. *Food Chemistry 62 (4)*, 415–424.

Muir P. D., Smith N., Wallace G., Cruickshank G., Smith D. (1998). The effect of short-term grain feeding on liveweight gain and beef quality. *New Zealand Journal of Agricultural Research 41 (4)*, 517–526.

Mulley R. C. (2003). The feed requirements of adult red deer. In: Casey M. J. (Ed.). *The nutrition and management of deer on grazing systems. Proceedings of a New Zealand Grassland association, 8–9 November 2002.* New Zealand: Wellington, Lincoln University, pp. 51–57. ISBN: 0473093901.

Mulley R. C., English A. (1992). Evaluation of carcass composition changes to fallow bucks castrated prepuberally. In: Brown R. D. (Ed.). *The biology of deer*. New York, NY: Springer Science & Business Media, pp. 238–243. ISBN: 1461227828.

Mulley R. C., Hutchison C. L., Flesch J. S., Wiklund E., Nicetic O. (2006). Venison quality – the relationship of body condition score with consumer perception. *Rural Industries Research and Development Corporation, Canberra, Australia. Publication no. 06/043*, p. 42. ISBN: 1-74151-306-5.

Mulley R. C., Falepau D. F., Flesch J. S., Wiklund E. (2010). Rate of blood loss and timing of exsanguination on prevalence of ecchymosis in fallow deer (*Dama dama*). *Meat Science 85 (1),* 21–25.

Nagy M., Muresan C., Socaci S. A., Tofană M., Farcas A., Biris S. E. (2015). Study on influence of different types of meat on the quality of meat products. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Food Science and Technology 72 (2),* 215–218.

Nantapo C., Muchenje V., Nkukwana T., Hugo A., Descalzo A., Grigioni G., Hoffman L. C. (2015). Socio-economic dynamics and innovative technologies affecting health-related lipid content in diets: Implications on global food and nutrition security. *Food Research International 76 (4),* 896–905.

Neethling J., Hoffman L. C., Muller M. (2016). Factors influencing the flavour of game meat: A review. *Meat Science 113,* 139–153.

Neethling N. E., Suman S. P., Sigge G. O., Hoffman L. C., Hunt M. C. (2017). Exogenous and endogenous factors influencing color of fresh meat from ungulates. *Meat and Muscle Biology 1 (1),* 253–275.

Neethling N. E., Sigge G. O., Hoffman L. C., Suman S. P. (2018). Color stability of fallow deer (*Dama dama*) *Infraspinatus, Longissimus thoracis et lumborum,* and *Biceps femoris* muscles during refrigerated storage. *Meat and Muscle Biology 2 (1),* 162–176.

North M. K., Hoffman L. C. (2015). Changes in springbok (*Antidorcas marsupialis*) *Longissimus thoracis et lumborum* muscle during conditioning as assessed by a trained sensory panel. *Meat Science 108*, 1–8.

Nuernberg K., Dannenberger D., Nuernberg G., Ender K., Voigt J., Scollan N. D., Wood J. D., Nute G. R., Richardson R. I. (2005). Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of longissimus muscle in different cattle breeds. *Livestock Production Science 94 (1–2)*, 137–147.

Nute G. R., Richardson R. I., Wood J. D., Hughes S. I., Wilkinson R. G., Cooper S. L., Sinclair L. A. (2007). Effect of dietary oil source on the flavour and the colour and lipid stability of lamb meat. *Meat Science 77 (4)*, 547–555.

Okabe Y., Watanabe A., Shingu H., Kushibiki S., Hodate K., Ishida M., Ikeda S., Takeda T. 2002. Effects of α-tocopherol level in raw venison on lipid oxidation and volatiles during storage. *Meat Science 62 (4)*, 457–462.

Okuskhanova E., Assenova B., Rebezov M., Yessimbekov Z., Kulushtayeva B., Zinina O., Stuart M. (2016). Mineral composition of deer meat pate. *Pakistan Journal of Nutrition 15 (3)*, 217–222.

Okuskhanova E., Assenova B., Rebezov M., Amirkhanov K., Yessimbekov Z., Smolnikova F., Nurgazezova A., Nurymkhan G., Stuart M. (2017). Study of morphology, chemical, and amino acid composition of red deer meat. *Veterinary World 10 (6)*, 623–629.

Pathare P. B., Opara U. L., Al-Said F. A.-J. (2013). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology 6 (1)*, 36–60.

Patino H. O., Medeiros F. S., Pereira C. H., Swanson K. C., McManus C. (2015). Productive performance, meat quality and fatty acid profile of steers finished in confinement or supplemented at pasture. *Animal 9 (6)*, 966–972.

Pearce K. L., Rosenvold K., Andersen H. J., Hopkins D. L. (2011). Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes – A review. *Meat Science 89 (2)*, 111–124.

Phillip L. E., Oresanya T. F., Jacques J. S. (2007). Fatty acid profile, carcass traits and growth rate of red deer fed diets varying in the ratio of concentrate:dried and pelleted roughage, and raised for venison production. *Small Ruminant Research 71 (1–3)*, 215–221.

Piasentier E., Morgante M., Valusso R., Ferrara C., Bovolenta S., Volpelli L. A. (2002). Il prosciutto di daino (*Dama dama*): Aspetti chimico nutrizionali. *Notiziario Ersa 15 (6)*, 41–43.

Piaskowska N., Daszkiewicz T., Kubiak D., Janiszewski P. (2015). The effect of gender on meat (*Longissimus lumborum* muscle) quality characteristics in the fallow deer (*Dama dama* L.). *Italian Journal of Animal Science 14 (3845)*, 389–393.

Piaskowska N., Daszkiewicz T., Kubiak D., Zapotoczny P. (2016). Quality of meat (*longissimus dorsi*) from male fallow deer (*Dama dama*) packaged and stored under vacuum and modified atmosphere conditions. *Asian-Australasian Journal of Animal Sciences 29 (12)*, 1782–1789.

Picard B., Duris M. P., Jurie C. (1998). Classification of bovine muscle fibres by different histochemical techniques. *Histochemical Journal 30 (7)*, 473–479.

Pilarczyk R., Wójick J. (2015). Fatty acids profile and health lipid indices in the *longissimus lumborum* muscle of different beef cattle breeds reared under intensive production systems. *Acta Scientiarum Polonorum Zootechnica 14 (1)*, 109–126.

Pinto F., Tarricone S., Marsico G., Forcelli M. G., Celi R., Rasulo A. (2009). Nutritional quality of meats from young fallow deer (*Dama dama*) of different ages. *Progress in Nutrition 11 (1)*, 57–67.

Polak T., Rajar A., Gašperlin L., Žlender B. (2008). Cholesterol concentration and fatty acid profile of red deer (*Cervus elaphus*) meat. *Meat Science 80 (3)*, 864–869.

Poławska E., Cooper R. G., Jóźwik A., Pomianowski J. (2013). Meat from alternative species – Nutritive and dietetic value, and its benefit for human health – A review. *CyTA – Journal of Food 11 (1)*, 37–42.

Pollard J. C., Littlejohn R. P., Asher G. W., Pearse A. J. T., Stevenson-Barry J. M., McGregor S. K., Manley T. R., Duncan S. J., Sutton C. M., Pollock K. L., Prescott J. (2002). A comparison of biochemical and meat quality variables in red deer (*Cervus elaphus*) following either slaughter at pasture or killing at a deer slaughter plant. *Meat Science 60 (1)*, 85–94.

Prado I. N., Campo M. M., Muela E., Valero M. V., Catalan O., Olleta J. L., Sañudo C. (2014). Effects of castration age, dietary protein level and lysine/methionine ratio on animal performance, carcass and meat quality of Friesian steers intensively reared. *Animal 8 (9)*, 1561–1568.

Prado I. N., Campo M. M., Muela E., Valero M. V., Catalan O., Olleta J. L., Sañudo C. (2015). Effects of castration age, protein level and lysine/methionine ratio in the diet on colour, lipid oxidation and meat acceptability of intensively reared Friesian steers. *Animal 9 (8)*, 1423–1430.

Priolo A., Micol D., Agabriel J. (2001). Effects of grass feeding systems on ruminant meat colour and flavour. A review. *Animal Research 50 (3)*, 185–200.

Priolo A., Micol D., Agabriel J., Prache S., Dransfield E. (2002). Effect of grass or concentrate feeding systems on lamb carcass and meat quality. *Meat Science 62 (2)*, 179–185.

Purchas R. W., Burnham D. L., Morris S. T. (2002). Effects of growth potential and growth path on tenderness of beef longissimus muscle from bulls and steers. *Journal of Animal Science 80 (12)*, 3211–3221.

Purslow P. P. (2005). Intramuscular connective tissue and its role in meat quality. *Meat Science 70 (3)*, 435–447.

Quaresma M. A. G., Trigo-Rodrigues I., Alves S. P., Martins S. I. V., Barreto A. S., Bessa R. J. B. (2012). Nutritional evaluation of the lipid fraction of Iberian red deer (*Cervus elaphus hispanicus*) tenderloin. *Meat Science 92 (4)*, 519–524.

Rafe A. (2019). Improving texture of foods using emerging hydrocolloids. In: Razavi S. M. A. (Ed.). *Emerging natural hydrocolloids: Rheology and functions.* Hoboken, NJ: John Wiley & Sons, Inc., pp. 499–523. ISBN: 978-1-119-41866-5.

Ramanzin M., Amici A., Casoli C., Esposito L., Lupi P., Marsico G., Mattiello S., Olivieri O., Ponzetta M. P., Russo C., Marinucci M. T. (2010). Meat from wild ungulates: Ensuring quality and hygiene of an increasing resource. *Italian Journal of Animal Science 9 (3)*, 318–331.

Randi E., Apollonio M. (1988). Low biochemical variability in European fallow deer (*dama dama* L.): Natural bottlenecks and the effects of domestication. *Heredity 61 (3)*, 405–410.

Razmaitė V., Šiukščius A., Šveistienė R., Bliznikas S., Švirmickas G. J. (2017). Comparative evaluation of *longissimus* and *semimembranosus* muscle characteristics from free-living and farmed red deer (*Cervus elaphus*) in Lithuania. *Zoology and Ecology 27 (2)*, 176–183.

Realini C. E., Duckett S. K., Brito G. W., Dalla Rizza M., De Mattos D. (2004). Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. *Meat Science 66 (3)*, 567–577.

Rehbinder C. (1990). Management stress in reindeer. *Rangifer 10 (3)*, 267–288.

Resurreccion A. V. A. (2003). Sensory aspects of consumer choices for meat and meat products. *Meat Science 66 (1)*, 11–20.

Rødbotten M., Kubberød E., Lea P., Ueland Ø. (2004). A sensory map of the meat universe. Sensory profile of meat from 15 species. *Meat Science 68 (1),* 137–144.

Roubalová M. (2015). *Situační a výhledová zpráva Krmiva*. Praha: Mze ČR, 2015, p. 70. ISBN: 978-80-7434-255-4.

Rousset-Akrim S., Young O. A., Berdagué J.-L. (1997). Diet and growth effects in panel assessment of sheepmeat odour and flavour. *Meat Science 45 (2),* 169–181.

Ru Y. J., Glatz P. C., Bao Y. M. (2005). Effect of salt level in water on feed intake and growth rate of red and fallow weaner deer. *Asian-Australasian Journal of Animal Sciences 18 (1),* 32–37.

Russo C. (2005). Relazione sulla qualità della carcassa e della carne di daino (*Dama dama*). *Annali della Facoltà di Medicina veterinaria LVIII,* 207–212.

Rutherfurd S. M., Richardson R. K., Moughan P. J. (2015). The stability of tryptophan, 5-methyl-tryptophan and α-methyl-tryptophan during NaOH hydrolysis of selected foods. *Food Chemistry 188,* 377–383.

Sales J. (1995). Nutritional quality of meat from some alternative species. *World Review of Animal Production 30 (1–2),* 48–56.

Salter A. M. (2013). Dietary fatty acids and cardiovascular disease. *Animal 7 (1),* 163–171.

Sans P., Combris P. (2015). World meat consumption patterns: An overview of the last fifty years (1961-2011). *Meat Science 109,* 106–111.

Santos V. A. C., Cabo A., Raposo P., Silva J. A., Azevedo J. M. T., Silva S. R. (2015). The effect of carcass weight and sex on carcass composition and meat quality of "Cordeiro Mirandês" – Protected designation of origin lambs. *Small Ruminant Research 130,* 136–140.

SAS. (2006). *Release 9.1 (TS1M3) of the SAS® System for Microsoft® Windows®*. SAS Institute Inc., Cary, NC, USA.

Schulp C., Thuiller W., Verburg P. (2014). Wild food in Europe: A synthesis of knowledge and data of terrestrial wild food as an ecosystem service. *Ecological Economics 105*, 292–305.

Seal U., Nelson M., Mech L., Hoskinson R. (1978). Metabolic indicators of habitat differences in four Minnesota deer populations. *The Journal of Wildlife Management 42 (4)*, 746–754.

Shapiro S. (2010). *Deer industry database. RIRDC publication no. 09/175*, p. 25.

Sibbald I. R., Wolynetz M. S. (1986). Effects of dietary lysine and feed intake on energy utilization and tissue synthesis by broiler chicks. *Poultry Science 65 (1)*, 98–105.

Sigurgisladottir S., Torrissen O., Lie Ø., Thomassen M., Hafsteinsson H. (1997). Salmon quality: Methods to determine the quality parameters. *Reviews in Fisheries Science 5 (3)*, 223–252.

Sims K. L., Wiklund E., Hutchison C. L., Mulley R. C., Littlejohn R. P. (2004). Effect of pelvic suspension on the tenderness of meat from fallow deer (*Dama dama*). *Proceedings: 50th International Congress of Meat Science and Technology (ICoMST), 8–13 August 2004. Finland: Helsinki*, pp. 119–122. ISBN: 9521019603.

Sinclair A. J., Slattery W. J., O' Dea K. (1982). The analysis of polyunsaturated fatty acids in meat by capillary gas-liquid chromatography. *Journal of the Science of Food and Agriculture 33 (8)*, 771–776.

Skibniewski M., Skibniewska E. M., Kośla T. (2015). The content of selected metals in muscles of the red deer (*Cervus elaphus*) from Poland. *Environmental Science and Pollution Research International 22 (11)*, 8425–8431.

Smith R. F., Dobson H. (1990). Effect of preslaughter experience on behaviour, plasma cortisol and muscle pH in farmed red deer. *Veterinary Record 126 (7)*, 155–158.

Smith M. A., Bush R. D., Thomson P., Hopkins D. L. (2015). Carcass traits and saleable meat yield of alpacas (*Vicugna pacos*) in Australia. *Meat Science 107*, 1–11.

Smith M. A., Bush R. D., van de Ven R. J., Hopkins D. L. (2017). The combined effects of grain supplementation and tenderstretching on alpaca (*Vicugna pacos*) meat quality. *Meat Science 125*, 53–60.

Soder K. J., Rotz C. A. (2001). Economic and environmental impact of four levels of concentrate supplementation in grazing dairy herds. *Journal of Dairy Science 84 (11)*, 2560–2572.

Sookhareea R., Taylor D. G., Woodford K. B., Dryden G. M., Shorthose R. (1995). The effect of slaughter age and sex type on meat quality of Javan rusa (*Cervus timorensis*) male deer. *Meat ´95 7B*, 17–20.

Sookhareea R., Taylor D. G., Dryden G. M., Woodford K. B. (2001). Primal joints and hind-leg cuts of entire and castrated Javan rusa (*Cervus timorensis russa*) stags. *Meat Science 58 (1)*, 9–15.

Sørheim O., Hildrum K. I. (2002). Muscle stretching techniques for improving meat tenderness. *Trends in Food Science & Technology 13 (4)*, 127–135.

Srebočan E., Pompe-Gotal J., Konjević D., Prevendar-Crnić A., Popović N., Kolić E. (2006). Cadmium in fallow deer tissue. *Veterinarski Arhiv 76*, 143–150. Retrieved from http://www.vef.unizg.hr/vetarhiv/papers/2006-76-7-17.pdf.

Srebočan E., Prevendar-Crnić A., Ekert-Kabalin A. M., Lazarus M., Jurasović J., Tomljanović K., Andreić D., Strunjak-Perović I., Čož-Rakovac R. (2011). Cadmium, lead, and mercury

concentrations in tissues of roe deer (*Capreolus capreolus* L.) and wild boar (*Sus scrofa* L.) from lowland Croatia. *Czech Journal of Food Sciences 29 (6),* 624–633.

Stachowicz J. B., Vannoni E., Pitcher B. J., Briefer E. F., Geffen E., McElligott A. G. (2014). Acoustic divergence in the rut vocalizations of Persian and European fallow deer. *Journal of Zoology 292 (1),* 1–9.

Stanisz M., Ludwiczak A., Buda P., Pietrzak M., Bykowska M., Kryza A., Ślósarz P. (2015). The effect of sex on the dressing percentage, carcass, and organ quality in the fallow deer (*Dama dama*). *Annals of Animal Science 15 (4),* 1055–1067.

Strazdina V., Jemeljanovs A., Sterna V., Ikauniece D. (2013). Nutrition value of deer, wild boar and beaver meat hunted in Latvia. *International Proceedings of Chemical, Biological and Environmental Engineering (IPCBEE) 53,* pp. 71–76.

Sullivan G. A., Calkins C. R. (2011). Ranking beef muscles for Warner–Bratzler shear force and trained sensory panel ratings from published literature. *Journal of Food Quality 34 (3),* 195–203.

Suttie J. (2012). Report to deer industry New Zealand: Estimation of deer population and productivity data 1990-2012. *Report SCL 12/2,* p. 91.

Suttie J. M., Webster J. R. (1998). Are arctic ungulates physiologically unique? *Rangifer 18 (3–4),* 99–118.

Tack D. M., Blanton J. D., Holman R. C., Longenberger A. H., Petersen B. W., Rupprecht C. E. (2013). Evaluation of knowledge, attitudes, and practices of deer owners following identification of a cluster of captive deer with rabies in Pennsylvania in July 2010. *Journal of the American Veterinary Medical Association 242 (9),* 1279–1285.

Tan G. Y., Fennessy P. F. (1981). The effect of castration on some muscles of red deer (*Cervus elaphus* L.). *New Zealand Journal of Agricultural Research 24 (1),* 1–3.

Taylor J. M., Hopkins D. L. (2011). Patents for stretching and shaping meats. Recent *Patents on Food, Nutrition & Agriculture 3 (2)*, 91–101.

Telfer E. S., Scotter G. W. (1975). Potential for Game Ranching in Boreal Aspen Forests of Western Canada. *Journal of Range Management 28 (3)*, 172–180.

Tešanović D., Kalenjuk B., Tešanović D., Psodorov Đ., Ristić Z., Marković V. (2011). Changes of biochemical and sensory characteristics in the *musculus longissimus dorsi* of the fallow deer in the early phase *post-mortem* and during maturation. *African Journal of Biotechnology 10 (55)*, 11668–11675.

Thompson J. M. (2002). Managing meat tenderness. *Meat Science 62 (3)*, 295–308.

Thompson J. M., Hopkins D. L., D´Souza D. N., Walker P. J., Baud S. R., Pethick D. W. (2005). The impact of processing on sensory and objective measurements of sheep meat eating quality. *Australian Journal of Experimental Agriculture 45 (5)*, 561–573.

Toman R., Massányi P. (1996). Cadmium in selected organs of fallow deer (*Dama dama*), sheep (*Ovis aries*), brown hare (*Lepus europaeus*) and rabbit (*Oryctolagus cuniculus*) in Slovakia. *Journal of Environmental Science and Health Part A – Environmental Science and Engineering & Toxic and Hazardous Substance Control 31 (5)*, 1043–1051.

Torrentera N., Carrasco R., Salinas-Chavira J., Plascencia A., Zinn R. A. (2017). Influence of methionine supplementation of growing diets enriched with lysine on feedlot performance and characteristics of digestion in Holstein steer calves. *Asian-Australasian Journal of Animal Sciences 30 (1)*, 42–50.

Toscas P. J., Shaw F. D., Beilken S. L. (1999). Partial least square (PLS) regression for the analysis of instrument measurements and sensory meat quality data. *Meat Science 52 (2)*, 173–178.

Tous N., Lizardo R., Vilà B., Gispert M., Font-i-Furnols M., Esteve-Garcia E. (2014). Effect of reducing dietary protein and lysine on growth performance, carcass characteristics, intramuscular fat, and fatty acid profile of finishing barrows. *Journal of Animal Science 92 (1)*, 129–140.

Tshabalala P. A., Strydom P. E., Webb E. C., De Kock H. L. (2003). Meat quality of designated South African indigenous goat and sheep breeds. *Meat Science 65 (1)*, 563–570.

Ulbricht T. L. V., Southgate D. A. T. (1991). Coronary heart disease – 7 dietary factors. *Lancet 338 (8773)*, 985–992.

Van Soest P. J., Robertson J. B., Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science 74 (10)*, 3583–3597.

de Vargas Junior F. M., Martins C. F., dos Santos Pinto G., Ferreira M. B., de Almeida Ricardo H., Leão A. G., Fernandes A. R. M., Teixeira A. (2014). The effect of sex and genotype on growth performance, feed efficiency, and carcass traits of local sheep group Pantaneiro and Texel or Santa Inês crossbred finished on feedlot. *Tropical Animal Health and Production 46 (5)*, 869–875.

Vengušt G., Vengušt, A. (2004). Some minerals as well as trace and toxic elements in livers of fallow deer (*Dama dama*) in Slovenia. *European Journal of Wildlife Research 50 (2)*, 59–61.

Vestergaard M., Oksbjerg N., Henckel P. (2000). Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of *semitendinosus*, *longissimus dorsi* and *supraspinatus* muscles of young bulls. *Meat Science 54 (2)*, 177–185.

Vodňanský M. (2007). Zvěřina – vysoce hodnotný přírodní produkt a cenná potravina. *Myslivost 55 (85)*, 32–33.

Volpelli L. A., Valusso R., Piasentier E. (2002a). Carcass quality in male fallow deer (*Dama dama*): Effects of age and supplementary feeding. *Meat Science 60 (4),* 427–432.

Volpelli L. A., Valusso R., Morgante M., Piasentier E. (2002b). Produzione di carne di daino. *Zootecnia 5*, 47–50.

Volpelli L. A., Valusso R., Morgante M., Pittia P., Piasentier E. (2003). Meat quality in male fallow deer (*Dama dama*): Effects of age and supplementary feeding. *Meat Science 65 (1),* 555–562.

Volpelli L. A., Failla S., Sepulcri A., Piasentier E. (2005). Calpain system *in vitro* activity and myofibril fragmentation index in fallow deer (*Dama dama*): Effects of age and supplementary feeding. *Meat Science 69 (3),* 579–582.

Wang T., Crenshaw M. A., Regmi N., Armstrong T., Blanton J. R., Liao, S. F. (2015). Effect of dietary lysine fed to pigs at late finishing stage on the market-value associated carcass characteristics. *Journal of Animal and Veterinary Advances 14 (8),* 232–236.

Warner R. D. (2014). Measurements of water-holding capacity and color: objective and subjective. In: Devine C., Dikeman M. (Eds.). *Encyclopedia of Meat Sciences.* Oxford: Academic Press, pp. 164–171. ISBN: 9780123847348.

Warriss P. D. (2010). *Meat science: An introductory text*. Cambridge, UK: Cambridge University Press, p. 248. ISBN: 978-1-84593-593-1.

WHO, FAO. (2003). Diet, nutrition and the prevention of chronic diseases. *World Health Organization Technical Report Series 916*, p. 149.

Wiklund E., Andersson A., Malmfors G., Lundström K., Danell Ö. (1995). Ultimate pH values in reindeer meat with particular regard to animal sex and age, muscle and transport distance. *Rangifer 15 (2),* 47–54.

Wiklund E., Stevenson-Barry J., Cummings T. (2000). Sensory meat quality in red deer (*Cervus elaphus*) grazed on pasture or fed a commercial feed mixture. *Proceedings: 46th International Congress of Meat Science and Technology (ICoMST), 27 August – 1 September 2000. Argentina: Buenos Aires*, pp. 192–193.

Wiklund E., Manley T., Littlejohn R., Stevenson-Barry J. (2003a). Fatty acid composition and sensory quality of *Musculus longissimus* and carcass parameters in red deer (*Cervus elaphus*) grazed on natural pasture or fed a commercial feed mixture. *Journal of the Science of Food and Agriculture 83 (5)*, 419–424.

Wiklund E., Johansson L., Malmfors G. (2003b). Sensory meat quality, ultimate pH values, blood parameters and carcass characteristics in reindeer (*Rangifer tarandus tarandus* L.) grazed on natural pastures or fed a commercial feed mixture. *Food Quality and Preference 14 (7)*, 573–581.

Wiklund E., Mulley R. C., Hutchison C. L., Littlejohn R. P. (2004a). Effect of carcass suspension method on water holding capacity of *M. longissiumus* from fallow deer (*Dama dama*) and lamb. *Proceedings: 50th International Congress of Meat Science and Technology (ICoMST), 8–13 August 2004. Finland: Helsinki*, pp. 559–562. ISBN: 9521019603.

Wiklund E., Manley T., Littlejohn R. (2004b). Glycolytic potential and ultimate muscle pH values in red deer (*Cervus elaphus*) and fallow deer (*Dama dama*). *Rangifer 24 (2)*, 87–94.

Wiklund E., Hutchison C. L., Flesch J. S., Mulley R. C., Littlejohn R. (2005). Colour stability and water-holding capacity of *M. longissimus* and carcass characteristics in fallow deer (*Dama dama*) grazed on natural pasture or fed barley. *Rangifer 25 (2)*, 97–106.

Wiklund E., Sampels S., Manley T., Picková J., Littlejohn R. (2006). Effects of feeding regimen and chilled storage on water-holding capacity, colour stability, pigment content and oxidation in red deer (*Cervus elaphus*) meat. *Journal of the Science of Food and Agriculture 86 (1)*, 98–106.

Wiklund E., Finstad G., Worker S., Bechtel P. (2008a). Effects of early castration on carcass composition, yield and quality characteristics of meat from young reindeer (*Rangifer tarandus tarandus*) bulls and steers. *Rangifer 28 (1)*, 1–8.

Wiklund E., Asher G. W., Archer J., Ward J., Littlejohn R. (2008b). Carcass and meat quality characteristics in young red deer stags of different growth rates. *Proceedings of the New Zealand Society of Animal Production (NZSAP) 68*, pp. 174–177.

Wiklund E., Farouk M., Stuart A., Dobbie P. (2009). Consumer evaluation of chilled never-frozen versus chilled-frozen-thawed beef and venison. *Proceedings: 55th International Congress of Meat Science and Technology (ICoMST), 16–21 August 2009. Denmark: Copenhagen*, pp. 1206–1209.

Wiklund E., Dobbie P., Stuart A., Littlejohn R. (2010). Seasonal variation in red deer (*Cervus elaphus*) venison (*M. longissimus dorsi*) drip loss, calpain activity, colour and tenderness. *Meat Science 86 (3)*, 720–727.

Wiklund E., Finstad G., Aguiar G., Bechtel P. J. (2012). Does carcass suspension technique influence reindeer (*Rangifer tarandus tarandus*) meat quality attributes? *Animal Production Science 52 (8)*, 731–734.

Wiklund E., Farouk M., Finstad, G. (2014). Venison: Meat from red deer (*Cervus elaphus*) and reindeer (*Rangifer tarandus tarandus*). *Animal Frontiers 4 (4)*, 55–61.

Williams V., Pearson A., Jeffrey G., Mackenzie R., Ward L., Fisher M. (2015). A snapshot of New Zealand farmers' awareness of, and self-reported compliance with, animal welfare requirements. *Proceedings of the New Zealand Society of Animal Production (NZSAP), 28 June – 1 July 2015, New Zealand: Dunedin*, pp. 200–204.

Wilson P. R., Grace N. D. (2001). A review of tissue reference values used to assess the trace element status of farmed red deer (*Cervus elaphus*). *New Zealand Veterinary Journal 49 (4)*, 126–132.

Wójcik K., Sobczak M., Żochowska-Kujawska J., Zieliński K. (2010). Porównanie tekstury i struktury oraz podatności na proces masowania mięśni danieli (*Dama dama*) w zależności od płci i wieku. *Żywność. Nauka. Technologia. Jakość/Food. Science Technology. Quality 1 (68)*, 93–104.

Wood J. D., Richardson R. I., Nute G. R., Fisher A. V., Campo M. M., Kasapidou, E., Sheard P. R., Enser M. (2003). Effects of fatty acids on meat quality: A review. *Meat Science 66 (1)*, 21–32.

Wu G., Bazer F. W., Burghardt R. C., Johnson G. A., Kim S. W., Knabe D. A., Li P., Li X., McKnight J. R., Satterfield M. C., Spencer T. E. (2010). Proline and hydroxyproline metabolism: Implications for animal and human nutrition. *Amino Acids 40 (4)*, 1053–1063.

Xue F., Zhou Z., Ren L., Meng Q. (2011). Influence of rumen-protected lysine supplementation on growth performance and plasma amino acid concentrations in growing cattle offered the maize stalk silage/maize grain-based diet. *Animal Feed Science and Technology 169 (1)*, 61–67.

Yamada H., Moriya H., Tsugita A. (1991). Development of an acid hydrolysis method with high recoveries of tryptophan and cysteine for microquantities of protein. *Analytical Biochemistry 198 (1)*, 1–5.

Yancey E. J., Grobbel J. P., Dikeman M. E., Smith J. S., Hachmeister K. A., Chambers E. C. 4$^{th}$, Gadgil P., Milliken G. A., Dressler E. A. (2006). Effects of total iron, myoglobin, hemoglobin, and lipid oxidation of uncooked muscles on livery flavor development and volatiles of cooked beef steaks. *Meat Science 73 (4)*, 680–686.

Young O., Priolo A., Lane G., Frazer K., Knight T. (1999). Causes of pastoral flavour in ruminant fat. *Proceedings: 45$^{th}$ International Congress of Meat Science and Technology (ICoMST), 1–6 August 1999. Japan: Yokohama*, pp. 420–421.

Young O. A., West J. (2001). Meat color. In: Hui H., Nip W. K., Rogers R., Young O. A. (Eds.). *Meat science and applications*. New York, NY: Marcel Dekker, Inc., pp. 39–69. ISBN: 0-8247-0548-3.

Zhao T., Luo H., Zhang Y., Liu K., Jia H., Chang Y., Jiao L., Gao W. (2013). Effect of vitamin E supplementation on growth performance, carcass characteristics and intramuscular fatty acid composition of *Longissimus dorsi* muscle in "Tan' sheep. *Chilean Journal of Agricultural Research 73 (4),* 358–365.

Żochowska-Kujawska J., Sobczak M., Lachowicz K. (2009). Comparison of the texture, rheological properties and myofibre characteristics of SM (*semimembranosus*) muscle of selected species of game animals. *Polish Journal of Food and Nutrition Sciences 59 (3),* 243–246.

Żochowska-Kujawska J., Lachowicz K., Sobczak M. (2012). Effects of fibre type and kefir, wine lemon, and pineapple marinades on texture and sensory properties of wild boar and deer *longissimus* muscle. *Meat Science 92 (4),* 675–680.

Żochowska-Kujawska J., Kotowicz M., Sobczak M., Lachowicz K., Wójcik J. (2019). Age-related changes in the carcass composition and meat quality of fallow deer (*Dama dama* L.). *Meat Science 147,* 37–43.

Zomborszky Z., Szentmihályi G., Sarudi I., Horn P., Szabó C. (1996). Nutrient composition of muscles in deer and boar. *Journal of Food Science 61 (3),* 625–627.

Zomborszky Z., Husvéth F. (2000). Liver total lipids and fatty acid composition of shot red and fallow deer males in various reproduction periods. *Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology 126 (1),* 107–114.

## INTERNET RESOURCES

Deer Industry New Zealand. (2018). About the deer industry. The NZ Deer Industry [online]. Retrieved July 25, 2018 from: <https://deernz.org/about-deer-industry/nz-deerindustry#.WosLyreWzL8>.

FAOSTAT. (2017). Food and Agriculture Organization of the United Nations [online]. Retrieved July 25, 2018 from: <http://www.fao.org/faostat/en/#data/QL/visualize>.

Jedlička M. (2015). Chov jelenů má perspektivu [online]. Retrieved July 25, 2018 from: <https://naschov.cz/chov-jelenu-ma-perspektivu>

Masseti M., Mertzanidou D. (2008). *Dama dama* [online]. The IUCN Red List of Threatened Species 2008: e.T42188A10656554. Retrieved July 25, 2018 from: <http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T42188A10656554.en>.

Pařízek V. (2013). Farmové chovy jelenovitých. Sborník referátů z Myslivecké konference 2013 [online]. Okresní myslivecký spolek Česká Lípa. Retrieved July 25, 2018 from: <http://zivotni-prostredi.kraj-lbc.cz/getFile/case:show/id:215089>.

Zákon č. 166/1999 Sb., o veterinární péči a o změně některých souvisejících zákonů (veterinární zákon), ze dne 13. 7. 1999. In: *Sbírka zákonů* 30. 7. 1999, částka 57. pp. 3122–3168 [online]. Retrieved July 25, 2018 from: <www.mvcr.cz/soubor/sbirka-zakonu-castka-57.aspx>.

# 9. LIST OF FIGURES, GRAPHS AND TABLES

# 10. LIST OF APPENDICES

## Appendix 1: Fallow deer – a survey of published studies and parameters observed.

| Reference | Production system | Effect studied | Parameters observed |
|---|---|---|---|
| Krzywiński et al. (1984) | F[a] | Sex, nutrition | Growth |
| Asher et al. (1987) | F | Sex, nutrition | Growth |
| Hogg et al. (1990) | F | Age, sex | Growth, carcass characteristics |
| Mulley and English (1992) | F | Sex | Carcass characteristics |
| Toman and Massányi (1996) | W[b] | - | Cd content in body tissues |
| Zomborszky et al. (1996) | W | Muscles, wild deer x cattle | Meat chemical composition |
| Zomborszky and Husvéth (2000) | W | Rut | Liver lipids, FA[c] |
| Volpelli et al. (2002a) | F | Age, nutrition | Carcass characteristics, meat chemical composition, FA |
| Morgante et al. (2003) | F | Nutrition | Meat chemical composition, FA |
| Volpelli et al. (2003) | F | Age, nutrition | Meat chemical composition and physical parameters, FA |
| Hutchison et al. (2004) | F | Sex, body condition | Meat chemical composition and physical parameters |
| Vengušt and Vengušt (2004) | W | - | Content of minerals and toxic elements in the liver |
| Wiklund et al. (2004) | F | - | Meat physical parameters, glycolytic potential |
| Ru et al. (2005) | F | Salt intake | Growth |
| Volpelli et al. (2005) | F | Nutrition, age | Myofibril fragmentation index |
| Wiklund et al. (2005) | F | Nutrition | Meat physical parameters, carcass characteristics |
| Mulley et al. (2006) | F | Slaughter and handling, carcass suspension | Carcass characteristics, meat physical parameters and sensory evaluation |
| | F | Body condition, nutrition, carcass suspension | Meat physical parameters and sensory evaluation |
| Srebočan et al. (2006) | W | - | Cd content in body tissues |
| Dahlan and Norfarizan-Hanoon (2007) | F | Nutrition | FA |
| Čelechovská et al. (2008) | W | - | Cd, Pb and Hg contents in body tissues |

| | | | |
|---|---|---|---|
| Dahlan and Norfarizan-Hanoon (2008) | F | Muscles | Meat chemical composition, physical parameters and sensory evaluation |
| Janiszewski et al. (2008) | F | Season | Growth |
| Pinto et al. (2009) | F | Age | Carcass characteristics, meat chemical composition and physical parameters, FA |
| Żochowska-Kujawska et al. (2009) | W | - | Textural parameters of meat, muscle fibres |
| Hutchison et al. (2010) | F | Sex, body condition, carcass suspension | Meat sensory evaluation |
| Mulley et al. (2010) | F | Stunning, slaughtering method | Ecchymosis prevalence |
| Wójcik et al. (2010) | F | Sex, age | Textural and structural parameters of meat, muscle fibres |
| Tešanović et al. (2011) | W | Ageing | Meat physical parameters and sensory evaluation |
| Curry et al. (2012) | F | - | Muscle fibres |
| Hutchison et al. (2012) | F | Body condition, nutrition | Meat physical parameters and sensory evaluation |
| Bovolenta et al. (2013) | F | Nutrition | Growth |
| Florek and Drozd (2013) | F | Sex | Meat chemical composition, FA |
| Cifuni et al. (2014) | W | Slaughter and handling | Carcass characteristics, meat physical parameters |
| Hutchison et al. (2014) | F | Carcass suspension | Meat physical parameters |
| Lazarus et al. (2014) | W | - | Cd, Pb and Hg contents in body tissues |
| Bureš et al. (2015) | F | Farmed deer x cattle | Meat chemical composition, sensory evaluation and physical parameters, FA |
| Daszkiewicz et al. (2015) | W, F | Production system | Meat chemical composition, sensory evaluation and physical parameters, FA |
| Janiszewski et al. (2015) | F | Housing | Carcass characteristics |

| | | | |
|---|---|---|---|
| Piaskowska et al. (2015) | W | Sex | Meat chemical composition, physical parameters and sensory evaluation, FA |
| Stanisz et al. (2015) | F | Sex | Carcass characteristics, meat physical parameters |
| Piaskowska et al. (2016) | W | Storage time and method | Meat physical parameters, chemical composition and sensory evaluation |
| Chakanya et al. (2017) | F | Storage conditions | Colour and oxidative stability of meat |
| Daszkiewicz et al. (2017a) | W | Carcass cuts | Meat physical parameters and chemical composition |
| Daszkiewicz et al. (2017b) | W | Storage conditions | Meat physical parameters and chemical composition |
| Ludwiczak et al. (2017) | F | Sex | Meat physical parameters and chemical composition |
| Bykowska et al. (2018a) | F | Ageing | Meat physical parameters and chemical composition |
| Bykowska et al. (2018b) | F | Sex, ageing, muscles | Meat physical parameters, chemical composition and sensory evaluation |
| Cawthorn et al. (2018) | W | Sex, muscles | Meat physical parameters |
| Neethling et al. (2018) | F | Sex, muscles, storage time | Meat physical parameter (colour) |
| Żochowska-Kujawska et al. (2019) | F | Age | Carcass characteristics, muscle fibres |

[a] Farm-raised. Deer under some of the following interventions: supplementary feeding, availability of housing during winter, medication of animals for welfare reasons, frequent handling and movement among multiple enclosures, separation of young (weaning) and sexes, selection of breeding stock.

[b] Wild.

[c] Fatty acids.

**Appendix 2: Fallow deer buck at the age of 16 months.**

(Photo: author).

**Appendix 3: Encapsulated RPAA lysine.**

(Photo: author).

**Appendix 4: Carcass suspension by Achilles tendon (right carcass half; see on the left) and through aitchbone (pelivc suspension or tender stretch; left carcass half; see on the right).**

(Photo: author).

**Appendix 5: Sample of the LL muscle intended for sensory analyses grilled on a double sided glass-ceramic plate grill.**

(Photo: author).

**Appendix 6: Fallow deer questionnaire used by trained sensory panel for assessment of MLL sample during descriptive sensory analyses.**

| Sensory analysis **"fallow deer meat 2016"** | | **Booth no.:** |
|---|---|---|
| Assessor no.: | Date: | **Set no.:** |

**Aroma intensity**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

**Game meat aroma intensity**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

**Tenderness**

| | | |
|---|---|---|
| **very tough** | ——— | **very tender** |

**Juiciness**

| | | |
|---|---|---|
| **very dry** | ——— | **very juicy** |

**Flavour intensity**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

**Game meat flavour intensity**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

**Grassy flavour**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

**Astringency flavour**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

**Liver flavour**

| | | |
|---|---|---|
| **very low** | ——— | **very high** |

## PUBLICATIONS

Bureš D., Čítek J., Bartoň L., Lebedová N., Zadinová K., **Kudrnáčová E.**, Stupka R. (2016). The effect of feeding Jerusalem artichoke on sensory properties of meat from *mutulus longissimus lumborum* of entire male pigs. EuroSense 2016: A Sense of Time. 7th European Conference on Sensory and Consumer Research. 11–14th September 2016, Dijon, France, p136.

**Kudrnáčová E.**, Bureš D., Bartoň L., Kotrba R. (2016). The influence of diet on carcass composition and meat quality attributes in cervids. Deer nutrition and feeding. 30th March 2016, Jablonné nad Orlicí, Czech Republic, p26.

Bureš D., Bartoň L., Kotrba R., **Kudrnáčová E.** (2017). Kvalita masa farmově chovaných jelenů a daňků. *Náš chov 76 (1)*, 72–74.

Bureš D., Bartoň L., Kotrba R., **Kudrnáčová E.**, Ceacero Herrador E. F. (2017). Vliv výživy na intenzitu růstu, složení jatečného těla a kvalitu masa daňků evropských z farmového chovu. *Maso 6*, 4–8.

Bureš D., Bartoň L., **Kudrnáčová E.**, Panovská Z., Kouřimská L. (2018). Maso divokých zvířat a jeho role v lidské výživě. *Výživa a potraviny 1*, 5–9.

**Kudrnáčová E.**, Bartoň L., Bureš D., Hoffman L. C. (2018). Carcass and meat characteristics from farm-raised and wild fallow deer (*Dama dama*) and red deer (*Cervus elaphus*): A review. *Meat Science 141,* 9–27.

**Kudrnáčová E.**, Bureš D., Bartoň L., Kotrba R., Ceacero Herrador E. F., Hoffman L. C., Kouřimská L. (2019). The effect of barley and lysine supplementation of pasture-based diet on growth, carcass composition and physical quality attributes of meat from farmed fallow deer (*Dama dama*). *Animals 9 (2),* pii: E33.