



# Influence of driven hunts on selected game meat quality parameters in central Germany

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## Abstract

Common hunting practices in Germany include stand hunts and driven hunts. Unlike stand hunts, driven hunts involve setting game in motion. This could potentially induce stress in animals and consequently affect meat quality. In order to evaluate the potential impact of the “driven hunt” method on certain standard-relevant meat quality parameters, 150 roe deer (*Capreolus capreolus*), 57 wild boar (*Sus scrofa*) and 20 red deer (*Cervus elaphus*) tongues from areas in East Westphalia, North and East Hesse were examined using a new standardised method. A particular advantage of this study is the use of tongue tissue (*m. lingualis proprius*) as sample material. Tongues are usually discarded, leaving muscle parts preferred for consumption intact. To verify results, tongue and shoulder (*m. biceps brachii*) muscle samples from ten roe deer per hunting method were directly compared. The method evaluated sensory parameters such as meat texture, colour, cooking juice loss and drip loss. Chemical analyses included pH values as an indicator of meat maturation, as well as D-glucose content to assess individual stress levels. All parameters consistently indicated high quality of game meat, which was measured in both shoulder and tongue muscles, regardless of hunting method. The particularly low amount of elevated stress values measured shows that hunting can be a gentle method of acquiring meat. This highlights the strict adherence to ethical hunting practices and hygiene standards in Germany, ensuring production of a premium product.

**Keywords** Meat quality · Influence of stress · Hunting methods · Game meat · Driven Hunt

## Introduction

Global trends in developed countries indicate a partial decline or stagnation in meat consumption, alongside an increasing number of people following vegetarian or vegan diets. However, majority of the world’s population prefers to consume meat within limits of availability of luxury goods. Only a small proportion abstains from it consciously. In developed nations in particular, consumers are placing greater importance on sustainability, ethics and personal health. Traditional meat production and high meat consumption result in a high environmental impact and may increase the risk of lifestyle diseases such as cardiovascular disease or diabetes. Therefore, researching alternative methods of

acquiring meat is important in order to meet modern consumer demands (Corradini et al. 2022; Godfray et al. 2018; Parlasca and Qaim 2022; Strazdiņa et al. 2013).

Hunting is a controversial topic of discussion, with debates focusing on cultural, traditional, economic, ecological and ethical factors. Critics argue that hunting is no longer necessary in modern society as it was in past, when it served purposes, such as acquiring food and defending oneself. Nowadays, hunting is considered more of a recreational activity, and aspects such as trophy hunting are deemed unjustifiable. In Germany, however, hunting is mainly regulated by the German Animal Welfare Act and the Federal Hunting Act. These laws ensure that proper hunting practices adhere to principles of animal welfare. Furthermore, wild game meat can serve as a valuable alternative to conventionally farmed meat, as life in the wild is undoubtedly more species-appropriate. Nutritional benefits of game meat support its consumption. Compared to conventionally farmed livestock, game meat has several nutritional advantages: it is low in cholesterol and high in protein, and has a low-fat content and favourable fatty acid composition.

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It is also tender due to its short-fibre muscle. According to the German Hunting Association (Deutscher Jagdverband), demand for game meat is increasing in Germany. However, it is important to note that a significant proportion of game meat available on German market is imported from countries such as New Zealand. Game meat found in supermarkets is often sourced from game farms. In general, consumers can establish a regional connection when dealing with local hunters (Corradini et al. 2022; Krüger 2021; Needham et al. 2023; Rösener 2004; Strazdiņa et al. 2013).

A comparison of conventional slaughter methods with hunting reveals the latter to be a more animal-friendly form of meat acquisition (Marescotti et al. 2020). Game is not removed from its natural environment or transported to a slaughterhouse. Game meat is regarded as a high-quality food product if it is obtained in accordance with EU Regulation No. 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down hygienic rules for production and distribution of meat and meat products.

Extant research on quality of game meat from free-ranging game is grounded in a limited database. Literature is only available on nutritional physiology, chemical and physical properties of game meat (Needham et al. 2023; Onyango et al. 1998; Strazdiņa et al. 2013). A significant body of research concentrates predominantly on hygiene of meat and its contamination by environmental toxins, including heavy metals and radioactivity (Caridi et al. 2020; Gerofke et al. 2019; Nkosi et al. 2021).

Research on the influence of environmental factors that directly affect animal living conditions and behavior and subsequently impact meat quality is limited. For instance, a project at the HBLFA (Higher Federal Teaching and Research Institute for Agriculture and Nutrition as well as Food and Biotechnology in Tyrol, Austria) examined seasonal impact on quality and fatty acid composition of various game species (Kitzer et al. 2014; Velik et al. 2010).

It is well-established that stress, experienced by livestock shortly before slaughter, may affect meat quality. Common meat defects can be categorized as either PSE (pale, soft, exudative), often observed in stress-prone pigs, or DFD (dark, firm, dry), which is primarily seen in cattle. In this instance, glycogen content of muscle tissue may serve as an indicator of experienced stress levels. In situations of stress, process of glycogen metabolism is initiated, resulting in production of glucose. This glucose is then transported to muscular tissues via bloodstream, thereby supplying the necessary energy to facilitate escape reflexes. Consequently, elevated glucose levels in muscles are anticipated under protracted periods of stress. This results in depletion of glycogen stores, leading to a subsequent decrease in glucose levels within muscles (Belitz et al. 2007; Loudon et al. 2019; Trevisan and Brum 2020).

In Germany, there is a prevalent belief that game meat obtained through driven hunts is of substandard quality. While animals are driven during hunts, objective is not to stress or force them into a fleeing situation. Instead, objective is to induce a change in their location. Nevertheless, the risk of errant shots or pressured animals due to dogs is higher compared to stand hunts. In the context of driven hunts, it is optimal for game to remain undetected by the hunters (Paulsen 2012).

This prompts the investigation of impact of driven hunting on meat quality. One potential explanation for this phenomenon could be the heightened stress levels experienced by the game during a particularly intense pursuit. To investigate this, a method was developed that focused on glucose level measurement and sensory tests. This method was based on typical wildlife in study area, including roe deer, wild boar, and red deer.

## Methods

### Selection of sample

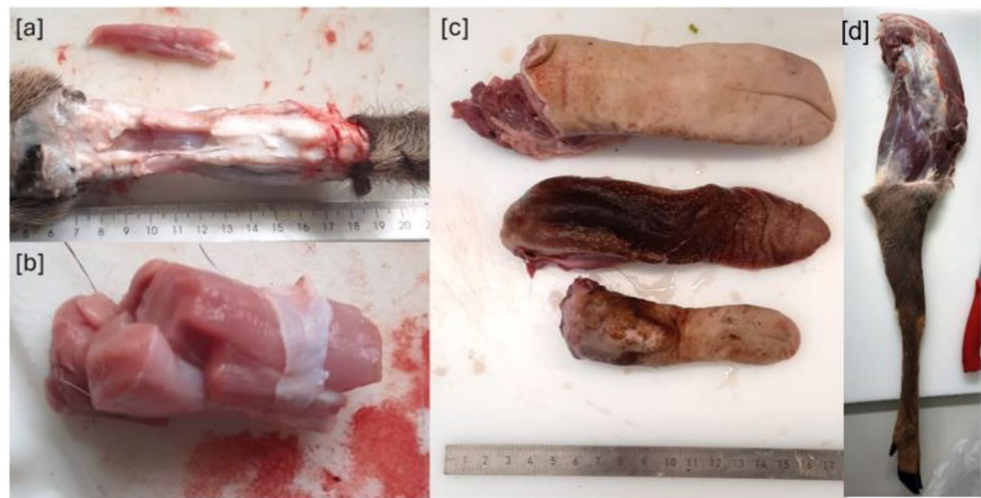
Selection of game meat samples is primarily influenced by methods of acquisition and sample size. Marketing of freshly hunted meat is primarily focused on its local and seasonal nature, with the inclusion of fur and bones as integral components. Consequently, employment of conventional meat cuts (e.g., haunch, back, or shoulder) becomes arduous, leading to a reduction in total sample number. Moreover, it is imperative to establish a comprehensive database containing information about individual animal. Consequently, collection of samples at the onset of food chain is advantageous in minimizing the impact of transportation and processing steps.

Comparability with conventional meat cuts can be achieved by using pure muscle tissue. The preliminary plan involved the utilization of forelimb muscles for trichinae sampling in a wild setting (Ophoven 2011). Furthermore, forelegs are a waste product and can be sampled directly after hunt. Striated skeletal muscle is highly vascularized, so influence of stress on muscle glucose levels will become readily apparent here.

Due to muscle structure in wild boar and quantity of foreleg muscle in roe deer, sampling these tissues appeared to be complicated. Quantity of muscle in forelegs of roe deer is insufficient for all tests (Fig. 1 [a]) and front leg muscles of a wild boar is composed of 3 muscle strands (Fig. 1 [b]), complicating sample cutting for texture analysis.

Due to its anatomical characteristics, the tongue was considered a viable alternative (Fig. 1 [c]). It is a striated skeletal muscle well-supplied with blood and various

**Fig. 1** Forelimb muscles of deer [a]; 3-bundle forelimb muscles of wild boar [b]; from top to bottom: Red deer tongue, wild boar tongue, roe deer tongue [c], roe deer shoulder/foreleg [d]



muscles appear as a single unit. This structure enables cutting of samples for texture analysis. Tongues are also used for *Trichinella* sampling due to its good blood circulation (Ophoven 2011) and red deer tongues are valued as special delicacies. While roe deer tongue is the smallest and therefore constitutes limiting factor in method development, an adaptation was possible. A direct comparison of shoulder and tongue muscle shows whether tongues are certainly suitable.

### Data collection

Collection of specific data on each individual animal is challenging in case of free-ranging wildlife. The available information does not include any details regarding animal's life circumstances prior to its current state. Typically, documentation includes details such as species, age, sex, and weight of game. In the context of the study, hunters were tasked with documenting temporal parameters of their shooting activities during a driven hunt. This approach was adopted to systematically record and analyze the temporal factors that influenced their actions. Animals harvested at the onset of driven hunts are likely to experience minimal to no stress, while the duration until evisceration is longest for this specimen. The game is subject to a prolonged stress situation subsequent to the conclusion of driven hunts. Samples are linked to data using the animal's tag number, and, in rare cases, hunters can provide additional information about an individual animal. Feasibility of data link during driven hunts has been hindered by high volume of samples generated.

In collaboration with forestry authorities, a schedule of sample collection has been established during 12 driven hunts between October and late November 2023 and November 2024. Obtaining samples from stand hunts can be challenging due to driven hunt season, as fewer hunters engage in this hunting method. A total of 150 roe deer,

including 30 obtained through stand hunt, 57 wild boar, including 2 obtained through stand hunt, and 20 red deer, including 1 obtained through stand hunt, were sampled.

### Method development

Instrumental standardized sensory and chemical methods were employed to ascertain the impact of hunting method on selected consumer-relevant parameters. Complete list of equipment and chemicals utilized is provided in Table 1. Concurrent with the section of game samples, method development process entailed a 6-fold series of all parameters, employing commercially available pork cutlets, beef roasts, and chicken breast fillets. Subsequently, adjustments were implemented to adapt the method to limited sample size of roe deer tongue, taking into account anticipated characteristics of game samples, which are analogous to those of conventional mammalian samples.

In addition to sensory parameters, two **chemical parameters** are considered. The optimal **pH** value for post-mortem meat after 24 h is between 5.3 and 5.7, beyond which an increase in pH is observed. pH values above 6.2 are generally considered indicative of meat quality issues and an accelerated spoilage process (Ebermann and Elmadfa 2011).

Furthermore, **glucose concentration** in muscle tissue is enzymatically determined, in accordance with manufacturer's instructions. Due to complexity inherent in preparation of meat samples, including their structural characteristics and additional components, the use of cooking juice obtained from process is employed as an alternative.

**Texture Analyser** (Table 1) provides instrumental force measurement for the purpose of comparing meat tenderness. A variety of parameters can be considered for purpose of evaluation, including force profile and maximum force, which reflect peak resistance during biting or chewing. Additionally, area under the curve, which includes a time course,

**Table 1** Materials and chemicals

Material	Type	From
Texture Analyzer	TA.HDplusC	WINOPAL Forschungsbedarf GmbH, Elze, Germany ( <a href="http://www.winopal.com">www.winopal.com</a> )
Cutting tools	– blunt blade guillotine – Warner Bratzler knife – Volodkevitch bite jaws	
Compression tools	– ø 75 mm compression plate – ø 10 mm delrin cylinder – ø 10 mm delrin cylinder with rounding – ø 10 mm stainless steel ball – ø 35 mm aluminium cylinder	
pH-Meter	mettler206-pH-3	Testo SE & Co. KGaA, Titisee-Neustadt, Germany ( <a href="http://www.testo.com">www.testo.com</a> )
Scale	JP2002G /M	Mettler-Toledo GmbH, Gießen, Germany ( <a href="http://www.mt.com">www.mt.com</a> )
Chroma Meter	CR-400	Konica Minolta Business Solutions Deutschland GmbH, Langenhagen, Germany ( <a href="http://www.konicaminolta.de">www.konicaminolta.de</a> )
Micro-literpipette (single channel)	Transferpette® S (Capacities: 10–100 µL, 100–1000 µL, 500–500 µL)	BRAND GMBH+CO KG, Wertheim, Germany ( <a href="http://www.brand.de">www.brand.de</a> )
Photometer	Pharma-Spec UV-1700, UV-Vis Spectrophotometer	Shimadzu Deutschland GmbH, Duisburg, Germany ( <a href="http://www.shimadzu.de">www.shimadzu.de</a> )
filter paper	MN 615 x Ø 125 mm	MACHEREY-NAGEL GmbH & Co. KG, Düren, Germany ( <a href="http://www.mn-net.com">www.mn-net.com</a> )
<b>Chemicals</b>	<b>Type</b>	<b>From</b>
Carrez solution I	36,0 g K <sub>4</sub> [Fe(CN) <sub>6</sub> ]/1 L	Feedstock from Th. Geyer GmbH & Co. KG, Renningen, Germany ( <a href="http://www.thgeyer.com">www.thgeyer.com</a> )
Carrez solution II	72,0 g ZnSO <sub>4</sub> × 7 H <sub>2</sub> O/1 L	
Pepsin/HCl cleaning solution	Chemsolute® Electrode Cleaning solution	Th. Geyer GmbH & Co. KG, Renningen, Germany ( <a href="http://www.thgeyer.com">www.thgeyer.com</a> )
1 N NaOH	-	Carl Roth GmbH+Co. KG, Karlsruhe, Germany ( <a href="http://www.carlroth.com">www.carlroth.com</a> )
Enzyme test kits	Enzytec™ Generic D-Glucose	R-Biopharm AG, Darmstadt, Germany ( <a href="http://www.r-biopharm.com">www.r-biopharm.com</a> )
	D-Glucose-HK Assay kit (K-GLUHK-220 A)	Megazyme Ltd., Bray, Ireland ( <a href="http://www.megazyme.com">www.megazyme.com</a> )

**Table 2** Texture analyser settings

ø 10 mm delrin cylinder with rounding	Guillotine with blunt blade
„simple standard test“, pre-speed: 1 mm/s, test-speed: 2 mm/s, return speed: 10 mm/s, test height at start: 15 mm, measuring points 200 pps	
Degree of deformation: 60%	Distance: 30 mm

can be taken into account. Compression test simulates the act of mastication, while cutting test emulates the force exerted during biting. To ensure repeatability and maximize variability for differentiation, various biting and cutting tools (Table 1), as well as test parameters such as test speed and deformation, were compared and selected (Table 2). Optimal configuration is a guillotine and a 10 mm diameter delrin cylinder with rounding. It has been demonstrated that both options are suitable for the use of used sample sizes. They are also characterized by ease of handling, and a differentiation between species has been demonstrated.

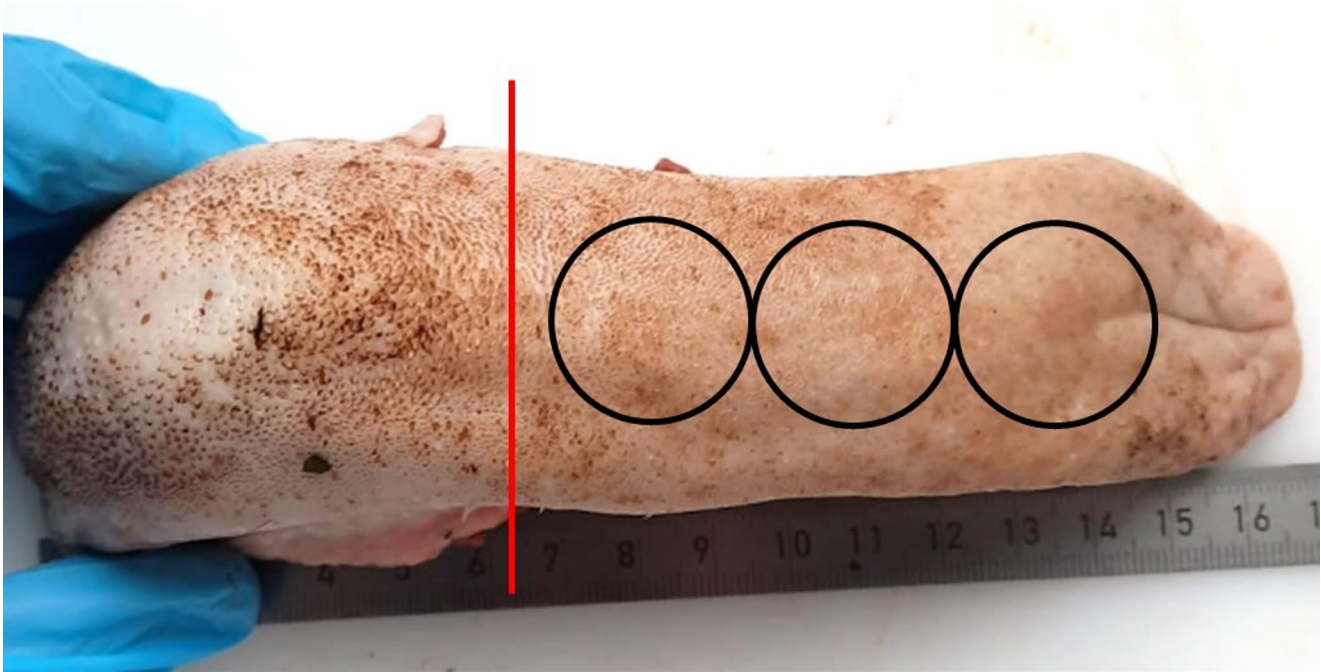
In addition to texture or tenderness of meat, factors such as cooking and drip loss, as well as color, are relevant parameters for consumers, as they directly influence purchasing decisions. In the context of this study, color is of particular importance, given its role as one of the initial impressions.

**Coloration of meat** is influenced by various factors, including species of animal, its living conditions, and processing steps involved in its production. To ensure reproducibility of results, all samples are subjected to identical conditions. The impact of hunting method on maturation of meat must be given primacy (Honikel et al. 1992).

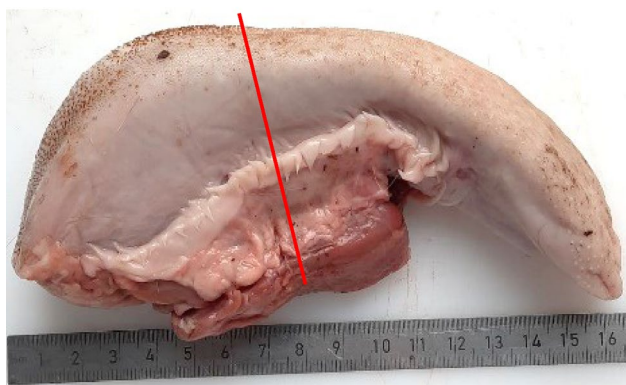
Process of **cooking juice loss** offers a valuable opportunity to gain insight into water-holding capacity of meat during heating process. A high cooking juice loss is considered to be a sensorially indicative sign of lower meat quality. This is often noticed by consumers as shrinkage during heating (Honikel et al. 2006).

**Drip loss** has been shown to be a reliable indicator of the presence of PSE (pale, soft, exudative) and of low meat quality. This phenomenon occurs as a result of post-mortem processes, which are influenced by various factors, including stress during slaughter (Belitz et al. 2007; Honikel et al. 1999).

Measurement of this parameters is based on the commonly described method of the Swiss Food Code “Schweizerisches Lebensmittelbuch”. Deviations and final procedures resulting from sample selection and quantity are outlined in “Experimental Procedure” section. Drip loss was excluded for game samples due to sample size, where drying outweighed drip loss effect. All tongues were tested within 3–5 days of shooting, the time at which meat is usually delivered to consumer, due to meat maturing process.



**Fig. 2** Example of colour measurement procedure - roe deer tongue (circles=chromameter measurement points, red line: Posterior portion of tongue shows anatomically lighter colour)



**Fig. 3** Onset of colour influence at the base of cervid tongue in posterior region - example: Roe deer tongue

This measurement time was chosen, because of consumers observation of decrease meat quality in drive-hunted meat. After shooting, samples were stored at 2 to 8 °C in freezer bags to allow maturation.

### Experimental procedure

The superficial layer of chilled tongue is meticulously removed using a sharp knife, exposing underlying muscle tissue (*m. lingualis proprius*). Color is measured in triplicate from the tip of tongue using a chromameter (see Table 1). The base of cervid tongue is anatomically lighter in color; therefore, measurement is taken as illustrated in Figs. 2 and 3 to ensure comparability.

A total of two square muscle pieces measuring 20 mm × 20 mm are obtained from the anterior tongue region for the purpose of textural analysis. The height of pieces ranges from approximately 0.8 to 1 cm. Orientation of muscle fibers is perpendicular to cutting edges, and the pieces are composed exclusively of muscle tissue, devoid of connective tissue or skin. In scenarios involving numerous samples, it is imperative to temporarily suspend the cutting process to ensure prioritization of texture analysis. This will ensure that any deviations in cut samples, such as drying or heat-induced changes, are prevented. Compression and cutting tests are both conducted for each individual sample with texture analyzer settings described in Table 2.

pH value of tissues is measured at three points in the lower part of muscle. It is imperative that pH meter electrode (see Table 1) does not come into contact with any skin or connective tissue. The electrode is then subjected to a cleaning procedure, employing a cleaning solution (Table 1), to remove any residual proteins.

Subsequently, 30 mg of muscle tissue is meticulously minced into cubes measuring approximately 0.8 × 0.8 mm and placed in a 1 L freezer bag. The actual weight of each sample is meticulously documented, and sample bags are subjected to a cooking process at a temperature of 75 °C for a duration of 20 min. Thereafter, bags are allowed to cool to room temperature for a period of 60 min. Subsequently, bags are reweighed to ascertain the final weight.

Resulting cooking juice is used for enzymatic analysis. For this, 2 mL of cooking juice, 2 mL of Carrez solution

I, 2 mL of Carrez solution II, 0.250 mL of 1 N NaOH, and 2 mL of distilled water (Table 1) are successively pipetted into beakers with swirling between each addition. Mixture is clarified with filter paper (Table 1) and a funnel, first 3–5 drops are discarded. Both enzyme kits work by converting D-glucose via hexokinase and measuring absorbance at 340 nm using a photometer (Table 1).

Settings of texture analysis are described in Table 2. After calibration, samples are placed centred for both tools. For guillotine, muscle fibres are oriented orthogonally to tool. Both compression and cutting test are conducted for each individual.

Shoulder muscles examined in preliminary tests are sampled in the same way as tongue muscles, after fur has been removed.

### Preliminary experiments for method validation

To assess the suitability of tongue muscle as an alternative sample material to commonly used back muscle (*M. longissimus dorsi*) or leg muscles (used for trichinella testing), a direct comparison of chemical parameters was conducted. A comparison of tongue muscle is conducted at the earliest possible point following animal's demise with shoulder muscle of same species of deer to assess stress levels, independent of meat maturation process. At this juncture, modest dispersion is anticipated, thereby facilitating a more precise comparison between muscle groups. A total of 10 roe deer, each from both stand and driven hunts, are examined approximately 4 h postmortem. Analysis of shoulder muscle is conducted in a manner consistent with the methodology employed for tongue muscle analysis (see Experimental Procedure). Due to adequate blood circulation in both muscles, similar values are anticipated.

During maturation process, there is a shift in glucose concentration, as evidenced by the breakdown of glycogen into glucose and subsequent anaerobic metabolism into lactate. This phenomenon can be likened to fluctuations in pH value. However, implementation of a time-series measurement of glucose concentration for tongue muscle proved to be unfeasible, owing to limitations in available sample size. Therefore, measurements were conducted on the 20 shoulder muscle samples at 4-, 12-, 24-, 72- and 96-hours postmortem to determine whether glucose levels after maturation could provide insights into animal's stress level at time of death.

It is imperative to measure glucose levels post-maturation, as immediate post-mortem sampling is impractical for driven hunts due to the challenges associated with sample acquisition. Furthermore, consumers have reported qualitative differences in meat quality when purchasing meat from mature animals. Findings derived from roe deer are

anticipated to be applicable to other wild species that are the subject of study.

## Results

### Preliminary experiments

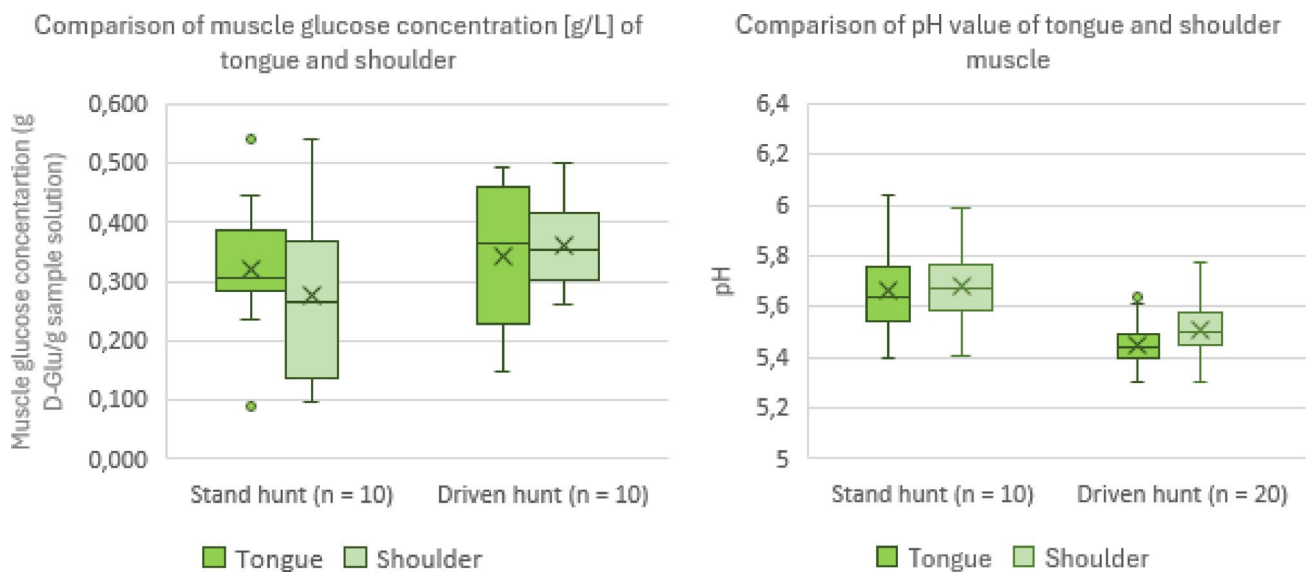
An analysis of the adequacy of tongue as a sample material reveals discrepancies in muscle glucose concentration when compared to shoulder muscle of roe deer four hours after death. No variation between hunting methods is observed. Range of muscle glucose values is from 0.1 to 0.6 g D-glucose per liter of sample solution. A comparison of pH values reveals identical values in both tissues (see Fig. 4). These values are consistent with literature benchmarks for high meat quality (Ebermann and Elmadfa 2011)

Influence of measurement time of glucose concentration after maturation exhibited nearly identical trends for the two types of hunting. Following maturation process, glucose value of muscle tissue exhibited the widest distribution after 96 h, ranging from 0.1 to 1.6 g of D-glucose per liter of sample solution (see Fig. 5). pH value during maturation of meat from both hunting methods (i.e., from a stand and driven hunting) did not differ significantly. This finding corresponds to pH values reported in literature for meat of good quality (Ebermann and Elmadfa 2011).

### Main experiments

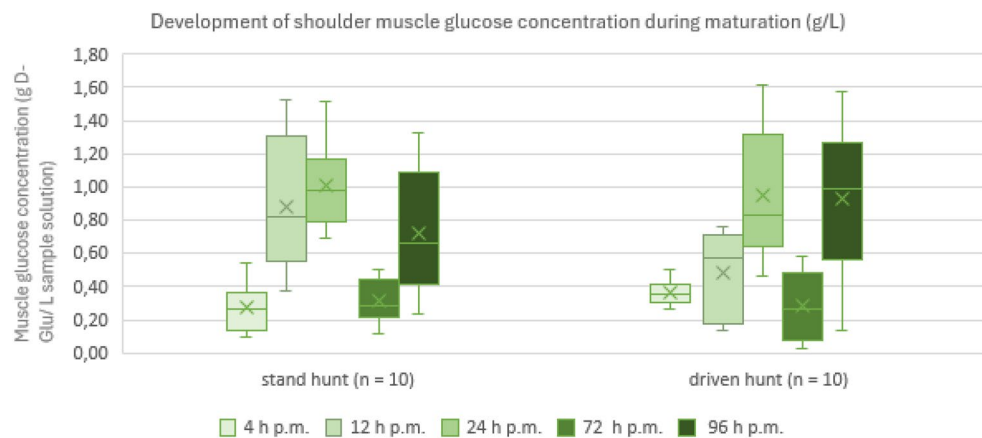
Direct observation of individual animals allows for a more precise interpretation of glucose concentrations. As illustrated in Fig. 7, data reveals that four red deer individuals exhibited elevated glucose concentrations (dark green columns). A similar trend was observed in roe deer and wild boar. Individual RedD-SH-4 is harvested during a stand hunt session, with an approximate interval of 40 min between shooting and death. This phenomenon is evidenced by an elevated glucose concentration, and no state of exhaustion has been observed after approximately 40 min in a stressful situation. Other elevated glucose values (RedD-DH-1/18/20) may also serve as indicators of elevated stress levels in individuals; however, no information is available regarding the harvest.

Figure 8 presents pH values of examined species. According to extant literature, the critical pH level is 6.2. Values of pH that are at or above this threshold have been shown to be associated with a reduction in meat quality (Ebermann and Elmadfa 2011). Some individuals of wild boar have been observed to have elevated pH levels, which are often accompanied by an unpleasant odor. Absence of correlation with other parameters suggests that the cause is likely not



**Fig. 4** Comparison of glucose concentration [g/L] (left) and pH (right) of shoulder and tongue muscle of the same roe deer individual 4 h postmortem ( $n=20$  roe deer, 10x driven hunt and 10 x stand hunt)

**Fig. 5** Development of shoulder muscle glucose concentration [g/L] during meat maturation of 10 roe deer of each hunting type



stress-related. Potential for a microbial ethology is considered, with possibility arising from either heating or injury to gastrointestinal tract.

Results of color, cooking juice loss, and tenderness measurements revealed no significant deviations in meat quality in shoulder and tongue muscles. A thorough examination reveals no discernible correlation among the parameters that have been identified.

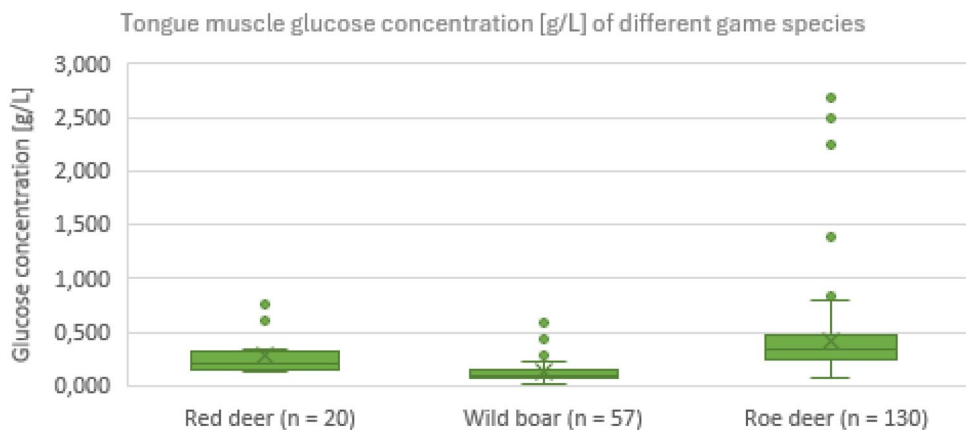
## Discussion

Increase in glucose concentration in shoulder muscle can be attributed to postmortem breakdown of glycogen into glucose, followed by its anaerobic conversion to lactate. Analysis of shoulder muscle, principally *biceps brachii*, revealed a predominant composition of type II muscle fibers. These fibers are known to be adapted for brief periods of

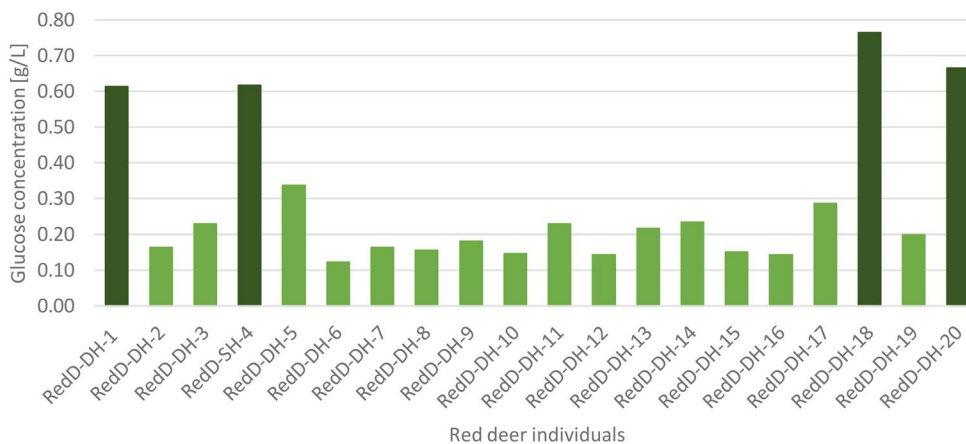
high-intensity activity, such as escape reactions. These fibers have been shown to store substantial amounts of glycogen and rapidly generate energy (Micheau et al. 2019; Rheinländer 2023). Since maturation process is closely linked to ATP levels - particularly the development of rigor mortis - and thus to postmortem glycogen breakdown, observed concentration pattern can be adequately explained (Belitz et al. 2007).

Conversely, glucose concentration in tongue increases marginally during maturation (Fig. 6). This finding indicates that tongue muscle is predominantly composed of type I muscle fibers. These fibers are well-suited for sustained contractions and possess reduced glycogen stores, rendering them less susceptible to effects of maturation processes (Rheinländer 2023). Observations made during sampling and subsequent analysis further corroborate this finding, as rigor mortis observed in tongues was less pronounced or of a shorter duration.

**Fig. 6** Measured muscle glucose concentration [g/L] of tongues, comparison of analyzed game species after maturation (72–96 h p.m.)



**Fig. 7** Table displays measured glucose concentrations [g/L] of tongues in red deer individuals. Dark green columns show red deer individuals with a high glucose concentration (72–96 h p.m.)



Characteristics of tongue make it a suitable tissue sample for stress assessment. Its abundant blood supply and minimal glycogen stores suggest that elevated glucose levels are predominantly attributable to heightened blood glucose concentrations resulting from stress. Anatomical evidence corroborates this hypothesis, as the presence of a high connective tissue content and a low muscle mass suggests minimal glycogen storage, slower muscular metabolic processes, and a reduced influence of meat maturation. Further research is necessary to determine the full scope of the phenomenon.

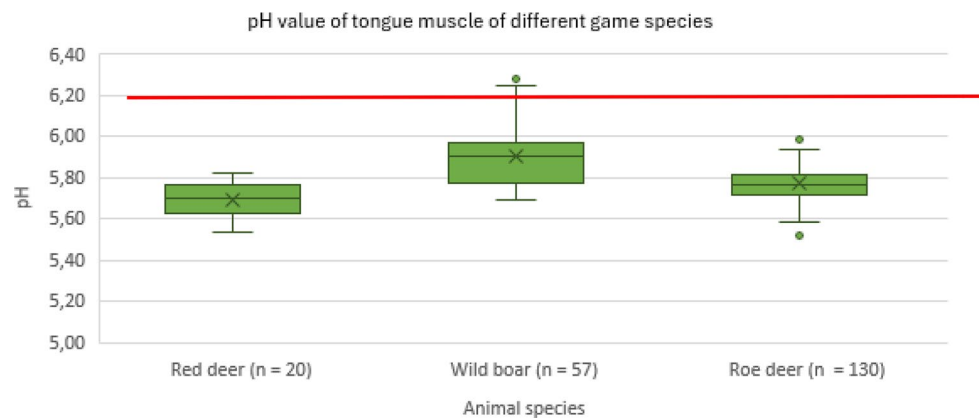
The findings suggest that Red Deer RedD-SH-4 model can serve as a reliable indicator of efficacy of method, as animal exhibited heightened stress levels prior to death, a phenomenon associated with elevated glucose concentrations (Fig. 7). It can be posited that other individuals with elevated measured glucose levels also experienced stress. However, there is a paucity of information regarding the conditions under which wildlife existed prior to advent of hunting. An increased incidence of stress has been observed in both stand and driven hunts. Potential contributing factors may include the act of hunting itself, as well as other environmental elements, such as encounters with joggers, individuals walking their dogs, or crossing a road. Hypothesis

that wild animals exhibit enhanced resilience to stress is predicated on the premise that their living conditions are a contributing factor. A comprehensive consideration of factors influencing meat quality is imperative, encompassing aspects such as nutrition, health status, and genetics. Generally, proportion of individuals with elevated glucose levels compared to total number of individuals examined is relatively low (Fig. 6), which supports hunting as an animal-friendly method of meat acquisition.

The presence of exhaustion, which would have been indicated by a non-existent or particularly low glucose level, was not detected. Overall, data indicate the presence of low glucose levels, with all animals exhibiting comparable levels within a certain range of variation (Fig. 6). The absence of any discernible effect on meat quality suggests that these animals may be unstressed individuals with a naturally occurring baseline concentration of glucose in their muscle tissue. The study found no association between glucose content and meat quality. Additionally, no correlation was observed between glucose values and other parameters under examination.

A comparison of results from multiple driven hunts conducted in disparate regions revealed no significant disparities, suggesting a consistent methodology. Furthermore,

**Fig. 8** pH values of tongues of the different species after maturation (72–96 h p.m.)



quality of meat is not influenced by animal's sex. The influence of age cannot be determined directly in this study, as driven hunts predominantly harvest young animals. Life expectancy of wild roe deer in their natural habitat is relatively low, averaging 2 to 3 years (Stubbe 2008). Despite harvesting of adult red deer, sample size for this demographic is constrained. Further research is necessary to substantiate these claims.

Elevated pH values observed in wild boar samples, particularly in cases where pH values were found to be above standard values, cannot be attributed to maturation of meat, its quality, or its glucose concentration (Fig. 8). However, an olfactory impression of mustiness is frequently reported, coinciding with elevated pH levels, particularly in wild boar. This phenomenon could potentially be attributed to a microbial cause, suggesting an initial stage of spoilage. Furthermore, the implementation of olfactory and gustatory experiments could offer additional insights. A comprehensive investigation into etiology of condition should consider the potential role of heat exposure or injuries to gastrointestinal tract. A notable distinction between wild boars and cervids, particularly during winter, is the former's thicker layer of fat and more compact physique. Consequently, larger animals exhibit a faster rate of spoilage in comparison to smaller animals. However, dataset indicates that younger animals are primarily targeted during driven hunts, which delays effects of heat due to their smaller size. Given the limited number of cases of critical pH, it is probable that etiology is associated with injuries to gastrointestinal tract. In omnivorous species such as wild boar, these effects may be more pronounced than in cervids. The early evisceration and generous removal or disposal of affected meat could further reduce the proportion of affected individuals. Narrower pH range observed in red deer may be indicative of reduced susceptibility to pH changes and a prolonged shelf life.

Absence of correlation between sensory and chemical parameters suggests that observed consistency in meat quality is not merely an artefact of sensory perception. The

findings of study suggest that tongues may exhibit a reduced propensity for PSE meat defects, attributable to diminished influence of maturation resulting from diminished glycogen stores. In contrast, no indications of PSE and DFD were identified in shoulder muscles. Low glucose concentrations observed in tongues of wild boars are likely attributable to inherent baseline levels rather than to a state of exhaustion.

Meat quality of shoulder muscles, akin to that of tongue muscles, is indicative of optimal quality, devoid of any indications of stress or dependency on the method of hunting. A lack of statistically significant variation in glucose concentration was identified four hours postmortem between stand and driven hunt groups. pH value ranged within the optimal range of reference values documented in extant literature, and sensory evaluation indicated the absence of qualitative deficiencies in meat. Consequently, data pertaining to muscles of shoulder support the conclusions derived from analysis of tongue, thereby refuting the initial hypothesis that elevated stress levels and diminished meat quality are associated with driven hunts.

In summary, the initial hypothesis proposing that wild game from driven hunts exhibits lower meat quality compared to stand hunts has been refuted. Tongue and shoulder muscle do not provide any indication that hunting method causes increased stress or impacts meat quality. A small number of isolated cases, not associated with hunting, may have various aetiologies. This underscores the significance of adhering to ethical hunting practices and hygienic standards in Germany. When executed with meticulous planning and strategic execution, driven hunts have the potential to yield high-quality products. These products can then be made available to consumers in a sustainable and local manner, ensuring the procurement of goods from trusted hunters.

**Author contributions** The acquisition of data, as well as the creation of all graphs and figures, in the laboratory, was carried out by S.K. M.B.-M., F.E. and S.K. were involved in the conception and design of the study, as well as in drafting the manuscript and approving the final version. M.B.-M., F.E. and S.K. participated in data interpretation.

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**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Ethical approval** Not applicable.

**Animal ethics** No tests have been conducted on live animals.

**Competing interests** The authors declare no competing interests.

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