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The influence of hunting region and deer species on the content of volatile compounds in deer meat

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ABSTRACT

The aim of this study was to assess the effect of region (lowland vs. mountain region) on the content of volatile compounds of red deer (Cervus elaphus), fallow deer (Dama dama) and roe deer (Capreolus capreolus). A total of forty eight female carcasses of three species (16 red deer, 16 fallow deer, and 16 roe deer) were collected from lowland and a mountain region, so from each region, 8 red deer, 8 fallow deer, and 8 roe deer were collected. In our study, higher contents of the aldehydes, ketones, and alcohols responsible for off-flavours of meat were found in our fallow deer meat than in red deer and roe deer meat. Moreover, in our study, region affected most of the content of aldehydes, heterocyclic and phenolic compounds, aromatic hydrocarbons, and some ketones, alcohols, and esters. Higher content of volatile compounds responsible for off-flavours was detected in mountain deer meat than in deer meat from the lowland region.

1. Introduction

During the last few decades, the meat of deer has been regularly consumed in European countries with predominant species being red deer, roe deer, and fallow deer (*Sorriano et al*., 2020). According to the Food and Agriculture Organization of the United Nations, annual game meat production has increased worldwide from approximately 1.89 million tons in 2010 to more than 2.03 million tons in 2022, and the increase is related to enhanced consumer interest in game meat (*FAOSTAT*, 2022). In Serbia, the number of deer was 6.127 in 2013 and 8.928 in 2021, while the number of roe deer in the same period ranged from 120.000 to 145.000. The number of hunting deer was 1.052 in 2013 and 1.172 in 2021, while the hunting of roe deer in the same period ranged from 9.000 to 11.000 animals (*www.stat.gov.rs*). One of the reasons for higher interest of consumers for game meat lies in the fact that game meat is generally considered as „healthy“ due to its high content of proteins (more than 22%), minerals, vitamins, and lower lipid content than 3% (*Costa et al.*, 2016). Moreover, game meat is a good source of unsaturated fatty acids, long chain n-3 polyunsaturated fatty acids, and conjugated linoleic acid (CLA) and it is regarded as „natural meat“, since animals mainly feed on pasture free of hormones, antibiotics, and other substances (*Soriano et al*., 2020). Game meat consumption differs among European countries and it is the highest in France (5.7 kg of game/person/year) and the lowest in Slovenia (0.56 kg of game/person/year) (*Mesinger et al*., 2023). Moreover, it is assessed that only 2–4% of the population consumes game meat and the reason for lower representation in the diet of Europeans could be ascribed to its high price, low availability, eating habits that not include game meat, and lack

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of recepies using game meat (*Soriano et al*., 2020). Game meat is generally regarded as expensive and exotic, and it is not often available on the market (*Hoffman and Wiklund*, 2006).

Consumer's attitude toward the use of game meat in diet depends on sensory characteristics of meat such as colour, tenderness, and specific flavour (*Soriano et al*., 2020). The sensory characteristics of meat could be affected by many factors such as diet, gender, age, body condition, season, and climate (*Dannenberger et al*., 2013; *Kudrnáčová et al*., 2018; *Soriano et al*., 2020). Aroma is one of the most important attribute when consumer is making a decision to purchase meat (*Bosse et al*., 2017). During processing of meat different volatile organic compounds are formed that give meat characteristic flavour and their precursors significantly affect the final aroma of cooked meat (*Wojtasik-Kalinowska et al.,* 2023).

To the best of our knowledge, there are insufficient data in the published literature that evaluate the effect of region, with respect to altitude/terrain, on the content of volatile compounds in deer meat. Therefore, the aim of this study was to assess the effect of region (lowland vs. mountain region) on the content of volatile compounds of red deer (*Cervus elaphus*), fallow deer (*Dama dama*), and roe deer (*Capreolus capreolus*).

2. Materials and Methods

A total of forty eight female carcasses of three species (16 red deer (*Cervus elaphus*), 16 fallow deer (*Dama dama*), and 16 roe deer (*Capreolus capreolus*)) were collected during the hunting season in October of 2019. Animals were approximately two years old as estimated by tooth eruption (*England & Wales Best Practise Guide*, 2019). Free-roaming deer of the three species were shot in two hunting districts, one a lowland and one a mountain region, so from each region, 8 red deer, 8 fallow deer, and 8 roe deer were collected. The lowland region is Karadjordjevo in Vojvodina (112 m above sea level, with average daily temperature of 14.6°C) and the mountain region is Deli Jovan in Eastern Serbia (from 700 to 1150 m above sea level, with average daily temperature of 13.0°C). The animals in the lowland region had access to 4120 hectares of free roaming area, consisting of oak (*Quercus robur*), ash (*Fraxinus excelsior*), elm (*Ulmus campestris*), poplar (*Populus alba*), and willow (*Salix babylonica*) forest and pastures. The mountain region hunting area comprises approximately 13000 ha, with predominantly beech (*Fagus silvatica*), oak (*Quercus robur*), acacia (*Robinia pseudoacacia*), and hornbeam (*Carpinus betulus*) forest. From December to March, deer were provided with the same additional feed that consisted of roughage feed (65% fodder beet and 35% alfalfa hay) and concentrate feed (whole kernel corn) placed in separated troughs. From March to December, deer were provided with additional concentrate feed (whole kernel corn) in order to provide all the necessary macro- and micronutrients that enable animals to maintain satisfactory health and achieve good performance results. The free-roaming animals had access to salt blocks during the whole year. Considering the differences in deer species (red deer, fallow deer, and roe deer) and hunting region (lowland and mountain region), six experimental groups were formed, each containing 8 carcasses.

Animals were shot from hunting stands and approximately in the head and neck region, immediately exsanguinated on the ground, hung onto the side of the truck, transported to the facility and then eviscerated and skinned within 1 h. Carcasses were held in chilled storage at 4°C for 24 h prior to sampling. At 24 h post mortem, meat samples (M. *longissimus lumborum*) were taken from the right side of each carcass behind the last rib, packed in polyethylene bags, and kept at –18°C in a thin layer for no longer than 10 days until analyses of the content of volatile organic compounds.

The day before analysis of the content of volatile organic compounds, meat samples were defrosted overnight at 4°C. Volatile compounds were analysed according to the procedure described by *Ivanović et al*. (2020).

Statistical analysis of the results was conducted with GraphPad Prism software version 6.00 for Windows (GraphPad Software, San Diego, CA, USA, www.graphpad.com). Two-way analysis of variance (ANOVA) with Tukey's multiple comparison test was performed to test the effect of region (mountain region vs. lowland) and game species (fallow deer, red deer, and roe deer) as the main effects, and their interactions on the volatile content of deer meat. All parameters were described by means and standard error of means (SEM). Values of $p<0.05$ were considered significant.

3. Results

The effects of region (lowland vs. mountain region) and game species (fallow deer, red deer, and roe deer) on specific volatile substances in M. *longissimus lumborum* of our fallow deer, red deer, and roe deer are shown in Table 1.

Table 1. The effect of region (lowland vs. mountain region) and game species (fallow deer, red deer, and roe deer) on the content of volatile organic compounds in deer meat (n=8).

	Fallow deer		Red deer		Roe deer			p value (ANOVA)		
VOC (µg/kg)	**Mountain**	**Lowland**	**Mountain**	**Lowland**	**Mountain**	**Lowland**	**SEM**	**R**	**S**	**R×S**
Aldehydes										
Hexanal	2.9^{6a}	3.0^{4a}	Nd	Nd	1.6^{9b}	1.7^{0b}	0.375	ns	***	ns
Furfural	nd	Nd	0.02	0.016	nd	nd	0.004	ns	***	ns
Heptanal	0.3^{2a}	0.0^{7b}	0.0^{8b}	0.0^{8b}	0.5^{9c}	0.5^{3c}	0.091	**	***	**
Octanal	0.5^{8a}	0.0^{4b}	0.5^{6a}	0.6^{0}a	0.6^{9}a	0.6^{9}a	0.081	***	***	***
Phenylacetaldehyde	0.1^{2a}	0.0^{7ab}	0.1^{4a}	0.1^{0a}	0.0^{1b}	0.0^{9ab}	0.050	**	ns	**
Benzaldehyde	nd	Nd	Nd	Nd	0.02	0.02	0.006	ns	***	ns
Ketones										
2-butanone	12.0^{5a}	$21.^{7c}$	6.6^{3ab}	4.9^{1b}	1.9^{1b}	4.0^{3b}	4.111	*	***	**
2,3-butanedione	0.6^{4a}	1.2^{2a}	0.5^{6a}	0.7^{8a}	2.2^{4b}	1.6^{2b}	0.447	***	ns	**
2-heptanone	0.1^{7a}	0.2^{4a}	1.3^{1b}	1.1^{8b}	0.0^{5a}	0.0^{3a}	0.280	ns	***	ns
3-methyl-2(5H)-furanone	0.7^{2a}	0.9^{2a}	0.2^{9b}	0.3^{5b}	0.2^{4b}	0.1^{8b}	0.148	ns	***	ns
Heterocyclic compounds										
Furan	0.0^{8a}	2.1^{0b}	1.1^{2c}	1.3^{0c}	3.0^{8d}	3.3^{2d}	0.232	***	***	***
β-butyrolactone	3.1^{9a}	0.5^{3b}	4.1^{5c}	1.2^{3d}	0.0^{9b}	0.0^{9b}	0.257	***	***	***
2-pentylfuran	nd	0.30^{0a}	Nd	Nd	0.02^{1b}	0.02^{3b}	0.021	***	***	***
2-methyl pyrazine	3.2^{4a}	3.2^{4a}	Nd	Nd	0.6^{0b}	1.1^{9c}	0.198	**	***	***
2,5-dimethyl pyrazine	2.2^{5a}	0.9^{0b}	1.1^{9c}	1.3^{2c}	0.0^{8d}	0.0^{9d}	0.115	***	***	***
2,6-dimethyl pyrazine	1.4^{3a}	1.4^{8a}	1.0^{4b}	1.0^{4b}	0.0^{8c}	0.0^{8c}	0.163	ns	***	ns
Thiophene	nd	Nd	Nd	Nd	nd	nd	0.000	ns	ns	ns
Phenolic compounds										
Guaiacol	0.2^{7a}	0.3^{0a}	Nd	Nd	0.7^{4b}	0.5^{9c}	0.057	*	***	**
Aromatic hydrocarbons										
1,2-dimethoxybenzene	0.3^{4a}	Nd	0.9^{8b}	1.0^{4b}	0.2^{0ac}	0.0^{5c}	0.147	**	***	**
Sulphuric compounds										
2,5-dimethyl thiophene	0.11	0.02	0.07	0.07	0.03	0.03	0.050	ns	ns	ns
2-methyl thiophene	1.3^{2a}	1.3^{9a}	3.5^{1b}	3.8^{3b}	0.0^{8c}	0.0^{8c}	0.309	ns	**	ns
2-buthanethiol	0.5^{0a}	0.4^{7a}	1.0^{5b}	0.9^{9b}	0.3^{4a}	0.3^{5a}	0.127	ns	***	ns
2-methyl-3-furanthiol	nd	Nd	0.4^{2a}	0.4^{3a}	nd	nd	0.072	ns	***	ns
Alcohols										
2-butanol	10.4^{4a}	13.2^{0b}	3.2^{1c}	3.3^{5c}	5.1^{8d}	5.4^{1d}	0.523	***	***	***
2-pentanol	0.0^{5a}	0.05	Nd	Nd	0.0^{6a}	0.0^{6a}	0.010	ns	***	ns
3-methyl-1-butanol	38.5^{7a}	37.8^{3a}	28.5^{9b}	26.5^{1c}	30.2^{6d}	31.3^{6d}	0.582	**	***	***
2,3-butanediol	1.4^{7a}	1.7^{0a}	3.3^{7b}	3.3^{5b}	7.5^{5c}	6.6^{4c}	0.559	ns	***	*
1-octen-3-ol	0.8^{5a}	1.0^{2b}	0.6^{8c}	0.5^{9c}	0.3^{5d}	0.4^{0d}	0.087	ns	***	**

VOC (µg/kg)	Fallow deer		Red deer		Roe deer		SEM	p value (ANOVA)		
	Mountain	Lowland	Mountain	Lowland	Mountain	Lowland		R	S	R×S
Organic acids										
Propionic acid	2.6^{6a}	0.6^{3b}	1.3^{2c}	1.2^{2c}	0.6^{3b}	0.6^{0b}	0.401	***	***	***
3-methylbutanoic acid	1.2^{5a}	1.5^{3a}	2.5^{2b}	2.5^{5b}	0.2^{8c}	0.7^{2ac}	0.390	ns	***	ns
Hexanoic acid	nd	nd	0.0^{7a}	0.0^{7a}	nd	nd	0.012	ns	***	ns
Nonanoic acid	0.1^{3ab}	0.1^{5a}	0.1^{1ab}	0.1^{2ab}	0.0^{8b}	0.0^{8b}	0.027	ns	***	ns
Esters										
Isopropenyl acetate	nd	nd	0.01	0.02	nd	nd	0.005	ns	***	ns
Ethyl acetate	nd	0.04	Nd	Nd	nd	nd	0.014	**	**	**
Isobutyl acetate	0.2^{0a}	1.5^{0b}	1.1^{4c}	1.2^{0c}	0.8^{3d}	0.9^{2d}	0.072	***	***	***
Butyl acetate	5.4^{4a}	5.6^{3a}	Nd	Nd	0.9^{4b}	0.9^{0b}	0.091	ns	***	**
2-methylbutyl acetate	9.1^{3a}	8.7^{9a}	6.5^{2b}	6.4^{1b}	4.2^{7c}	4.5^{1c}	0.242	ns	***	*
3-methylbutyl acetate	0.0^{8a}	0.1^{1a}	0.0^{2b}	0.0^{2b}	0.0^{2b}	0.0^{1b}	0.019	ns	***	ns
Hexyl acetate	0.6^{4a}	0.5^{9a}	0.2^{3b}	0.3^{3c}	0.4^{2d}	0.3^{7dc}	0.049	ns	***	***
Ethyl butanoate	12.9^{6a}	13.7^{6a}	10.3^{0b}	11.2^{9c}	9.2^{1d}	7.8^{5e}	0.474	ns	***	ns
Ethyl isovalerate	nd	nd	Nd	Nd	nd	nd	0.000	ns	ns	ns
Ethyl 2-methylbutanoate	1.1^{5a}	1.2^{6a}	0.3^{3b}	0.2^{0bc}	0.0^{9cd}	0.0^{6d}	0.076	ns	***	**
Ethyl octanoate	1.34	1.42	0.09	0.11	1.07	1.19	0.067	**	***	ns
Alkanes										
Heptane	0.1^{1a}	0.0^{8a}	2.2^{6b}	3.2^{7c}	3.7^{0d}	3.9^{0d}	0.17	***	***	***

Data are means and standard error of means (SEM); R – Region; S – species; R×S – interaction between region and species; VOC – volatile organic compounds; nd – not detected; Within a row, means with a different superscript letter differ (a, b, c, d, e – $p < 0.05$); ns – not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

In our deer meat, aldehydes and ketones were found only in small quantities (aldehydes ranged from 0 to 3.04 µg/kg, and ketones ranged from 0 to 21.70 µg/kg). On the other hand, the most abundant compounds determined in our study were alcohols (ranged from 0 to 38.65 µg/kg). In our study, species affected all examined compounds ($p<0.01$), except for phenylacetaldehyde, 2,3-butanedione, thiophene, 2,5-dimethyl thio-phene, and ethyl isovalerate. Higher contents of the most abundant compounds among the aldehydes (hexanal), ketones (2-butanone), and alcohols (2-butanol and 3-methyl-1-butanol) were found in our fallow deer meat than in red deer and roe deer meat ($p<0.001$). Moreover, in our study, region affected most of the content of aldehydes, heterocyclic and phenolic compounds, aromatic hydrocarbons, and some ketones, alcohols, and esters ($p<0.05$).

4. Discussion

Some volatile compounds from the aldehydes and heterocyclic compound groups were not detected in the deer meat. The main precursors of these particular volatile compounds are unsaturated fatty acids, as the main constituent of phospholipids (*Martin et al*., 2002). Products of lipid oxidation and degradation are aldehydes, ketones, alcohols, hydrocarbons, and furans, while during the Maillard reaction, sulphuric and heterocyclic compounds are formed (*Neethling et al.,* 2016). *Bhadury et al.* (2021) has shown that many volatile compounds that were assumed to be created during thermal processes are also detected in raw meat. Packaging systems for meat and storage time may also affect lipid oxidation processes and, thus, formation of volatile compounds (*Wojtasik-Kalinowska*,2023).

During the storage of meat and meat products, lipid oxidation of mainly phospholipids may occur, and this phenomenon, known as warmed-over flavour (WOF), negatively affects meat quality. Meat with those changes has "rancid" and "metallic" tastes that are a consequence of many synthesized volatile compounds, such as hexanal, 2,3-octanedione, and trans-4,5-epoxy-(E)-2-decenal (*Kosowska et al.,* 2017). Although aldehydes and ketones are the predominant compounds in meat of domestic ruminants (*Villa Lobos- Del Gado et al*., 2014, *Moran et al*., 2022), in our deer meat those groups of volatiles substances were found only in small quantities likely due to the short period of storage before the analysis. The most abundant volatile compounds in our deer meat were alcohols and esters. Many factors affect volatile compounds in meat, such as breed, age, sex, rearing conditions, diet, and supplementation (*Wojtasik-Kalinowska*, 2023). Diet affects the volatile compounds in ruminant meat, and thus, a grain-based diet leads to a higher content of aldehydes and lactones, while the meat of grass-fed animals has higher contents of various phenols, terpenes, indoles, and sulphur compounds (*Bleicher et al*., 2022). The total fatty acid composition and fatty acid ratios in meat are characteristic of the animal species (*Neethling et al*., 2016). Thus, the content of PUFAs in deer meat, as the main precursors for volatile compound formation, depends on species. In our study, species affected all examined compounds, except for phenylacetaldehyde, 2,3-butanedione, thiophene, 2,5-dimethyl thiophene, and ethyl isovalerate. Higher contents of the most abundant compounds among the aldehydes (hexanal), ketones (2-butanone), and alcohols (2-butanol and 3-methyl-1-butanol) were found in our fallow deer meat than in red deer and roe deer meat.

Moreover, in our study, region affected most of the content of aldehydes, heterocyclic and phenolic compounds, aromatic hydrocarbons, and some ketones, alcohols, and esters. Higher contents of aldehydes, phenolic compounds, aromatic hydrocarbons, or-ganic acids, and 3-methyl-1-butanol were found in mountain deer than in deer from the lowland region. Discrepancies were observed for ketones (2-butanone, 2,3-butanedione), furan, 2-pentylfuran, 2-methyl pyrazine, 2-butanol, esters, and heptane, where higher levels were found in lowland deer than in deer from the mountain region. Higher content of volatile compounds found in deer from mountain region than in lowland region could be due to the fact that our lowland deer primarily grazed. Deer from lowland region had access to pastures, while mountain deer grazed to a lesser extent and primarily consumed concentrate feed. Pasture diets are richer in n-3 PUFA, as protective compounds for lipid oxidation and fat-soluble antioxidants like carotene and tocopherol that prevent lipid oxidation and formation of volatile compounds (*Neethling et al.,* 2016).

Unsaturated aldehydes and ketones are most responsible for off-flavours because of their low threshold (*Neethling et al.,* 2016). Since low levels of aldehydes and ketones were detected, the studied deer meat likely would have a low level of off-flavours. The most abundant aldehyde determined in our study was hexanal, originating from linoleic and arachidonic acid and having a rancid fragrance and grassy or green aroma (*Martin et al.,* 2002). In other studies, hexanal was the most abundant aldehyde (*Moran et al*., 2022, *Wei et al*., 2014), while *Ivanović et al*., 2020. did not detect hexanal in fallow and roe deer meat. It is important to note that during meat storage, the abundance of aldehydes in raw meat varies due to increased lipid oxidation, leading to rancid odour notes (*Dominguez et al.,* 2019). Although our meat samples were not stored for a long period, during long storage durations, long-chain aldehydes could degrade to short-chain aldehydes, such as hexanal (*Moran et al.,* 2022). In our study the most abundant ketone compound was 2-butanone, characterized by acetone-like odour. Ketones in meat are usually derived from the oxidation of free fatty acids (*Moran et al.,* 2022). In the group of alcohols, 3-methyl-1-butanol, with its pungent fragrance and associated with off-flavour, was detected as being the most abundant. Alcohols found in deer meat are mainly secondary products from aldehydes and likely generated from lipid oxidation (*Bueno et al.,* 2019).

Fallow deer had higher content of hexanal, 2-butanone, and 3-methyl-1-butanol than red deer and roe deer, indicating the potential lower sensory acceptability of fallow deer meat. Furthermore, the content of hexanal was similar in deer meat from the two regions. Moreover, 2-butanone was more abundant in lowland deer than in deer from the mountain region, while a higher level of 3-methyl-1-butanol was found in mountain deer than in lowland deer. These discrepancies in the amounts of the above-mentioned compounds that contribute to off-flavours made it difficult to conclude how region could affect the acceptability of deer meat.

5. Conclusions

With regard to volatile compounds responsible for off-flavours of meat, we detetcted higher volatile levels in fallow deer meat than in red deer and roe deer meat, as well as in mountain deer meat than in deer meat from the lowland region. Overall, considering the results of our study, we found that hunting region and deer species affects the volatile compounds responsible for off-flavours of meat.

Uticaj regiona lovišta i vrste jelenske divljači na sadržaj isparljivih jedinjenja u mesu jelena

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APSTRAKT

Cilj ovog istraživanja bio je da se proceni uticaj regiona lovišta (ravničarski, odnosno planinski region) na sadržaj isparljivih jedinjenja u mesu evropskog jelena (Cervus elaphus), jelena lopatara (Dama dama) i srndaća (Capreolus capreolus). Sakupljeno je ukupno četrdeset osam trupova ženki tri vrste (po 16 trupova evropskog jelena, jelena lopatara i srndaća), tako da je iz ravničarskog i planinskog kraja prikupljeno po 8 trupova evropskog jelena, jelena lopatara i srnadaća. U našem istraživanju u mesu jelena lopatara utvrđen je veći sadržaj aldehida, ketona i alkohola odgovornih za neprijatan ukus mesa u poređenju sa mesom evropskog jelena i srndaća. Pored toga, region lovišta uticao je na sadržaj većine aldehida, heterocikličnih i fenolnih jedinjenja i estara. Veći sadržaj isparljivih jedinjenja odgovornih za neprijatan ukus utvrđen je u mesu jelenske divljači iz planinskog kraja nego iz ravničarskog kraja.

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