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Effect of Gender and Muscle Type on Fatty Acid Profile, Sanogenic Indices, and Instrumental and Sensory Analysis of Flemish Giant Rabbit Meat

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Abstract: The aim of this study was to represent quality characterization, by gender and muscle type, of rabbit meat from the Flemish Giant (FG) breed, following the fatty acid profile, sanogenic indices, and instrumental (color and texture) and sensory analysis. The biological material comprised 40 rabbits (20 females and 20 males) whose *Longissimus dorsi* (LD) and *Semimembranosus* (SM) muscles were sampled. Compared to female samples, the meat from males was more qualitative in terms of higher ratios of polyunsaturated vs. saturated fatty acids and proportions (+42%) of Essential and Desirable Fatty Acids (+21.6% EFA; +6.7% DFA). Also, the Atherogenic Index (AI) and Thrombogenic Index (TI) were better in males (−37.1% AI; −34.3% TI), as were the ratio of hypocholesterolemic/Hypercholesterolemic fatty acids (+27.8%) and the Nutritive Value Index (NVI, +11.6%). The Polyunsaturation Index (PI) was higher for females (+57.5%), with the widest differences in hind leg muscles (SM muscles), while the omega-6/omega-3 fatty acid ratio was also better (+11.3%). Female meat was more tender due to lower shear force (−6.2%... 9.3%) in both muscles. Female meat was less pigmented than that of males, while the overall sensory attributes were better scored in male samples (+3.1%... +7.1%) ($p < 0.01$). The meat of males proved to be more sanogenic (richer in EFA and DFA, with a better h/H ratio and NVI, while AI and TI were lower). We would recommend slaughtering 3–4 weeks earlier in females vs. males to avoid excessive fat deposition and, consequently, the development of unfavorable sanogenic indices for consumer health.

Keywords: Flemish Giant breed rabbit; meat; fatty acids; instrumental and sensory analysis

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1. Introduction

The worldwide food crisis, the shortage of natural resources and climate change, the desertification of agricultural land, and the population increase—both in number and life expectancy—have led to the urgent need to find new sources of proteins with high biological value. The diseases associated with an abundant and unhealthy diet lead to metabolic syndromes, mostly in developed or developing countries, characterized by the following: hypercholesterolemia, type 2 diabetes, hyperuricemia/gout, and obesity. Rabbit meat can be a handy solution for solving food security problems (access to qualitative, healthy, and sufficient food). Rabbit meat meets the needs of consumers as a functional food [1] (rich in proteins balanced in essential amino acids, polyunsaturated fatty acids (PUFA), n-3 and n-6 fatty acids, easily bioavailable vitamins, and minerals) [1–6] for people who are increasingly concerned about health and nutrition.

Rabbit meat provides multiple advantages for consumer health: absence of uric acid; small amounts of saturated fatty acids (SFA) and cholesterol [7–14]; high content of monounsaturated fatty acids (MUFA) and PUFA, with a protective role against cardiovascular diseases; and low cholesterol values [15,16]. Rabbit meat is highly appreciated for its excellent nutritional features, with lower fat, fewer saturated fats, and lower cholesterol levels compared to other commonly consumed meats [1–14,17]. Rabbit meat is lower in fat (9.2 g/100 g) and cholesterol (56.4 mg/100 g) compared to chicken, beef, and pork [7,17]. Rabbits show a great variation in breed size, from dwarf (1 kg adult weight) to giant lines (7–8 kg adult weight). Out of the wide variety of rabbit breeds, commercial production uses average-sized breeds for reproduction due to their high prolificacy and large breeds as terminal sires due to their high growth rate. This lowers the maintenance cost, allowing the production of commercial rabbits with a high growth rate [18]. At the international level, the quality of rabbit meat from medium breeds is well documented [6,8,10–13,19,20]. Dietary supplementation of feed with various non-conventional ingredients seems to influence the final quality of the meat [21–29]. As far as we know, there are very few studies on large meat breeds. The quality (including chemical composition) of meat from Flemish Giant (FG) rabbits remains insufficiently investigated [30]. Although FG is the largest breed of rabbit (10–12 kg live weight as an adult), its farming for meat production is not a tradition. Usually, in the northeast of Romania, this breed is bred for participation in exhibitions, with a spectacular appearance and size. Unfortunately, raising rabbits is no longer a habit in traditional Romanian households, as it was during the communist period, and the consumption of their meat has severely declined throughout the last 15–20 years. The use of agroindustry by-products in rabbit diets allows the use of residues that are not fit for human consumption [3]. Also, rabbits are one of the most efficient cellulose-converter animal species, ensuring the high production of low-cost meat [31]. The fact that rabbits can be raised with grass, alfalfa, clover, and food scraps (such as cabbage spines, carrot peels, pieces of dry bread, etc.) could ease/facilitate meat production in a sustainable, circular, and inexpensive way in small households. Some studies also show the advantages of raising rabbits for meat in maintaining food security, especially in armed conflicts [32]. Within such a context, our study aimed to highlight the quality of meat (characterization by gender and muscle type) in the largest rabbit breed—Giant Flemish—as a potentially sustainable, valuable food resource in terms of dietary quality (palatable, suitable for diverse culinary uses, nutritious, healthy, and sanogenic) by approaching several measurable/scalable traits: the fatty acid profile, sanogenic indices, and the instrumental (color and texture of meat) and sensory analysis.

2. Materials and Methods

2.1. Meat

The biological material was composed of 40 rabbits from the Flemish Giant breed (20 females and 20 males), slaughtered at 10 months old (via electrical stunning, respecting animal welfare and the specific technological stages), with average carcass weights of 9.45 kg. They were reared outdoors for farming purposes in a roofed pavilion with two individuals in wire mesh cages with a wood-slatted floor (length 140 cm × width 90 cm × height 70 cm), resulting in 0.63 sqm of floor surface per individual. Rabbits were fed, ad libitum, a complete commercial pelleted diet (crude protein, 16.90%; fat, 2.89%; crude fiber, 17.00%; ash, 7.57%; methionine, 0.30%; lysine, 0.65%; sodium, 0.16%; phosphorus, 0.77%; calcium, 1.00%; and Vitamin E, 45 mg/kg). The *Longissimus dorsi* (LD) and *Semimembranosus* (SM) muscles were used as actual biological material. The sampling was carried out right after slaughter, and the samples were kept at a temperature of 2–3 °C. The muscles were chosen due to their different physical–chemical properties, the different metabolic types, and to cover the main anatomical regions of the carcasses (episome—LD and hind leg—SM). The muscles from one half of each carcass were used for fatty acid analysis, and the ones from the other half were used for sensory and textural assessments. The color of the meat was measured on both sides of the carcass before sampling.

2.2. The Fatty Acids Content

To investigate the fatty acids profile, each analyzed muscle was sampled from the carcass and minced to homogenize the sample for analysis. The assessment of fatty acids content was performed using the FOSS 6500 NIR spectrophotometer (manufacturer FOSS Co., Denmark). Freshly ground samples were placed in sterile Petri dishes, weighed (90 ± 5 g), then lyophilized at −110 °C for 24 h, using the CoolSafe ScanVac freeze dryer (manufacturer LaboGene co., Denmark), weighed again (25 ± 1.5 g), then vacuumed and stored in a freezer at a temperature of −80 °C until their analysis. There were assessed the following saturated fatty acids (SFA): C14:0 (myristic acid), C15:0 (pentadecanoic acid), C16:0 (palmitic acid), C17:0 (heptadecanoic acid) and C18:0 (stearic acid). Among the monounsaturated fatty acids (MUFA, ω7, and ω9) there were analyzed: 16:1n-7 (palmitoleic acid, n-7 fatty acid), C18:1n-7 (vaccenic acid cis isomer of oleic acid) and C18:1n-9 (oleic acid); a total of nine polyunsaturated fatty acids (PUFA, ω3 and ω6) were also assessed: C18:2n-6 (linoleic), C18:3n-3 (linolenic/ALA), C20:2n-6 (eicosadienoic), C20:3n-6 (eicosatrienoic), C20:4n-6 (arachidonic/AA), C20:5n-3 (eicosapentaenoic/EPA), C22:4n-6 (docosatetraenoic), C22:5n-3 (docosapentaenoic/DPA) and C22:6n-3 (docosahexaenoic/DHA).

2.3. Health Lipid Indices Calculation

Rabbit meat sanogenic quality was assessed by calculating the amounts of SFA, MUFA, PUFA, the desirable fatty acids (DFA) (DFA = 18:0 + MUFA + PUFA), and the essential fatty acids (EFA) (EFA = C18:2n-6 + C18:3n-3 + C20:4n-6) according to Chen et al. [33]; the Polyunsaturation Index (PI) was calculated as described by Timmons [34]; the atherogenic (AI) and thrombogenic (TI) indices calculation was performed according to Ulbricht and Southgate [35]; the ratio between the hypocholesterolemic and Hypercholesterolemic fatty acids (h/H) was obtained according to Fernandez et al., adapted [36–38]; the Nutritive Value Index (NVI) [4] and the desirable fatty acids (DFA) after Wereńska et al. [39] using Equations (1)–(6):

$$PI = C18{:}2n\text{-}6 + (C18{:}3n\text{-}3 \times 2); \quad (1)$$

$$AI = [(4 \times C14{:}0) + C16{:}0 + C18{:}0]/MUFA + PUFA\ n\text{-}6 + PUFA\ n\text{-}3; \quad (2)$$

$$TI = (14{:}0 + 16{:}0 + 18{:}0)/[(0.5 \times MUFA) + (0.5 \times n\text{-}6\ PUFA) + (3 \times n\text{-}3\ PUFA) + (n\text{-}3\ PUFA/n\text{-}6\ PUFA)]; \quad (3)$$

$$h/H = (C18{:}1 + PUFA)/(C14{:}0 + C16{:}0); \quad (4)$$

$$NVI = (C18{:}0 + C18{:}1)/C16{:}0; \quad (5)$$

$$DFA = \sum MUFA + \sum PUFA + C18{:}0. \quad (6)$$

2.4. Instrumental and Sensory Analysis

For textural measurements, the muscles were individually packaged, vacuumed, and sealed on a vacuum device, then cooked for one hour at a constant temperature of 80 °C in a water bath, with a slight and continuous stirring of the content. Afterward, the samples were cooled to room temperature (20 ± 2 °C) for 30 mins and then kept at 4 °C for more than 30 mins prior to analysis. Between 4 (SD muscles) and 6 prisms (LD muscles) of 1 cm height × 1 cm width × 2 cm length were shaped, with the muscle fibers parallel on the longitudinal axis of the prism. The texture measurement was performed in a Warner–Bratzler cell applied to a Model TA-XT2I texturometer (Stable Micro System, Surrey, UK). The samples were sectioned perpendicularly to the direction of the muscle fibers with a cutting speed of 5 mm/second. The measured parameters were the total shear force (kg/cm^2), firmness ($kg/s \times cm^2$), and area ($kg \times s/cm^2$).

The color measurement of rabbit meat was performed on the Minolta CR3000 portable tristimulus colorimeter via the CIELAB system. Any color can be expressed as a mix of 3 primary colors: red, yellow, and blue. CIELAB is a coordinate system where L = brightness coordinate (gray tones), a = red index, and b = yellow index. The axis for red and green is projected for the term a*. When the value is positive, it shows the direction of the deviation of the yellow tone. When the value is negative, it shows the deviation from the direction of the blue tone. The brightness scale is placed in the center, perpendicularly to the a* and b* axes. Samples of 1.5–2.5 cm thickness were used to avoid the light passage through them and the possible errors that might occur. The samples were exposed to air for 30–40 mins to oxygenate for a more effective reading. The CIELAB system uses two light sources—C, which is equivalent to daylight, and D65, which includes part of the ultraviolet. The calibration was performed so the L, a*, and b* readings fit the values of the standardized palette (L = 98.19; a* = 0.0; b* = 1.93). After each reading, the surface of the device that came into contact with the analyzed pieces of meat was cleaned with ethyl alcohol to avoid possible errors that might occur.

Sensory analysis of rabbit meat was performed after the samples were cooled. They were cut in the same manner and piece sizing and randomly assigned to 23 tasters, trained in advance. The panelists rinsed their mouths with water between the sampling of the meat. The room temperature was 21–22 °C, and ambiental white light was used. The assessment sheets of the sensory characteristics, adapted after Ariño et al., 2007 [40], were filled in using a five-point hedonic scale (scores from 1 to 5), in which 1 represented the not favorable features, while 5 points indicated the characteristics which fully satisfied the tasters (Table 1). For example, the extremely pale color was noted with 1 point, while the intense pink color was noted with 5 points; the global assessment was scored using 1 point for unacceptable meat, 2 points for acceptable meat, 3 points for good meat, 4 points for very good meat and 5 points for exceptional meat.

Table 1. Five-point hedonic scale for sensory characteristics of FG rabbit meat.

Sensory Parameters	Granted Scoring (Points)				
	1	**2**	**3**	**4**	**5**
Color	Extremely Pale	Pale	Pale Pink	Pink	Intense Pink
Fibrous appearance	Weakly highlighted	Lightly highlighted	Medium highlighted	Distinctly highlighted	Strongly highlighted
Smell/ odor	Imperceptible	Weakly perceptible	Medium perceptible	Distinct perceptible	Very perceptible
Taste	Slightly unpleasant	No taste	Tasty enough	Tasty	Very tasty
Flavor	Slightly unpleasant	No flavor	Pleasant	Very pleasant	Extremely pleasant
Intensity of the flavor	Undetectable	Poor	Sufficiently pleasant	Pleasant and strong	Intense pleasant
Juiciness	Dry	Insufficiently juicy	Sufficiently juicy	Juicy	Very juicy
Tenderness	Very stiff	Slightly stiff	Sufficiently soft	Soft	Very soft
Overall assessment	Unacceptable	Acceptable	Good	Very good	Exceptional

2.5. Data Analysis

The results were statistically processed to compute the main descriptors (Mean, SEM—standard error of the mean, CV—coefficient of variation). Data acquired from males and females were compared to assess the amplitude and significance of gender-related differences using the Student's (t) test incorporated within the GraphPad Prism 9.4.1. software (GraphPad Software, Boston, MA, USA).

3. Results

3.1. The Fatty Acids Content and Sanogenic Indices of Flemish Giant Rabbit Meat

Table 2 presents the fatty acids content in LD and SM muscles sampled from rabbits.

Table 2. The fatty acids content (mg/100 g) of Flemish Giant rabbit meat.

Fatty Acids		M/F	LD Mean	LD SEM	LD CV%	LD *p*-Value	SM Mean	SM SEM	SM CV%	SM *p*-Value
SFA	C14:0	M	21.12	0.76	16.1	0.035	18.87	0.81	19.15	1.367×10^{-5}
		F	38.63	1.37	15.9	n.s	56.95	1.92	15.11	***
	C15:0	M	3.97	0.13	15.1	0.046	4.97	0.15	13.16	1.525×10^{-6}
		F	7.02	0.15	9.3	n.s	11.02	0.23	9.49	***
	C16:0	M	220.11	3.91	7.95	0.057	272.32	9.16	15.04	6.317×10^{-5}
		F	409.37	5.14	5.61	n.s	614.17	23.48	17.1	***
	C17:0	M	4.91	0.22	19.8	0.021	8.21	0.20	11.08	2.127×10^{-7}
		F	7.96	0.14	7.67	*	13.04	0.12	4.12	***
	C18:0	M	71.49	0.98	6.1	0.037	82.13	1.67	9.07	2.213×10^{-6}
		F	95.58	1.45	6.78	*	141.02	2.64	8.36	***
MUFA	C16:1n-7	M	21.03	0.26	5.51	0.798	28.07	1.26	20.04	1.288×10^{-5}
		F	62.11	0.81	5.82	n.s.	106.04	4.30	18.15	***
	C18:1n-7	M	14.81	0.19	5.61	0.078	15.98	0.39	11.05	1.233×10^{-6}
		F	19.97	0.28	6.16	n.s.	34.16	0.69	9.08	***
	C18:1n-9	M	208.16	5.84	12.54	0.037	270.99	10.34	17.07	8.462×10^{-7}
		F	358.97	4.62	5.76	*	593.17	12.14	9.15	***
PUFA	C18:2n-6	M	180.92	6.24	15.43	0.043	243.19	7.00	12.87	5.235×10^{-6}
		F	256.83	4.01	6.98	*	394.02	6.29	7.14	***
	C18:3n-3	M	14.11	0.20	6.42	0.074	21.1	0.98	20.71	6.159×10^{-6}
		F	23.32	0.58	11.08	n.s	40.02	0.82	9.16	***
	C20:2n-6	M	2.92	0.06	9.54	0.294	3.19	0.06	7.82	1.213×10^{-4}
		F	3.37	0.06	8.26	n.s	5.07	0.11	9.67	***
	C20:3n-6	M	3.89	0.05	5.63	0.081	5.34	0.09	7.16	0.036
		F	3.51	0.04	5.29	n.s	5.11	0.07	6.27	*
	C20:4n-6	M	50.97	0.82	7.19	0.018	49.38	0.90	8.13	0.017
		F	54.93	1.77	14.4	*	55.42	0.84	6.79	*
	C20:5n-3	M	11.17	0.27	10.81	0.197	12.33	0.25	9.17	0.272
		F	8.98	0.25	12.22	n.s.	11.57	0.35	13.38	n.s.
	C22:4n-6	M	15.06	0.22	6.64	0.007	16.14	0.27	7.42	1.707^{-5}
		F	13.95	0.21	6.81	**	15.2	0.21	6.18	***
	C22:5n-3	M	7.79	0.18	10.33	0.637	7.11	0.11	7.06	0.035
		F	9.66	0.31	14.35	n.s	7.92	0.21	11.99	*
	C22:6n-3	M	24.11	0.56	10.38	0.923	22.06	0.48	9.73	0.223
		F	24.69	0.67	12.19	n.s	25.09	0.65	11.51	n.s

LD—*Longissimus dorsi*; SM—*Semimembranosus*, SEM—standard error of mean, CV—coefficient of variation; Student test: ns = not significant, $p > 0.05$; * significant for $p < 0.05$; ** significant for $p < 0.01$; *** significant for $p < 0.001$.

The highest amount of SFA was found in female SM muscles, out of which palmitic acid/C16:0 (614.17 mg/100 g) was the most present. In the MUFA category, the oleic acid/C18:1n-9 (593.17 mg/100 g) was better represented. The most occurring PUFA was the C18:2n-6 (394.02 mg/100 g)(compared to 243.18 mg/100 g in males), followed by the C20:4n-6 (55.42 mg/100 g), with closer values in males (49.38 mg/100 g). In LD muscles, C20:4n-6 reached 54.93 mg/100 g in females vs. 50.97 mg/100 g in males.

For all analyzed fatty acids, higher values were measured in females, especially in the SM muscles, which were richer in fat than in the LD muscles.

The statistical results predominantly highlighted significant differences between genders in SM muscles ($p < 0.001$), compared with LD muscles, where the values were significantly ($p < 0.05$) or even insignificantly different ($p > 0.05$), suggesting the predisposition of females to accumulate more fat in hind limbs, in comparison with the episome.

The sums of several categories of fatty acids and the sanogenic indices are presented in Table 3.

Table 3. Total fatty acids (mg/100 g meat) and sanogenic indices in FG rabbit meat.

Sanogenic Indices	Gender	LD	SM	Mean/Gender	Mean/Breed
Total SFA	M	321.60	386.50	354.05	525.72
	F	558.56	836.20	697.38	
Total MUFA	M	244.01	315.04	279.53	433.37
	F	441.05	733.37	587.21	
Total PUFA	M	310.94	379.84	345.39	412.36
	F	399.24	559.42	479.33	
ΣPUFA/ΣSFA	M	0.97	0.98	0.98	0.84
	F	0.71	0.67	0.69	
ΣPUFA n-6	M	253.76	317.24	285.50	344.61
	F	332.59	474.82	403.71	
ΣPUFA n-3	M	57.18	62.60	59.89	67.76
	F	66.65	84.60	75.63	
Σn6/n3	M	4.44	5.07	4.76	5.03
	F	4.99	5.61	5.30	
EFA	M	246.00	313.67	279.84	346.06
	F	335.08	489.46	412.27	
%EFA	M	28.06	29.01	28.54	26.01
	F	23.95	22.99	23.47	
DFA	M	626.43	777.01	701.72	943.28
	F	935.87	1433.81	1184.84	
%DFA	M	71.47	71.85	71.66	69.40
	F	66.90	67.35	67.13	
NVI	M	1.34	1.36	1.35	1.28
	F	1.16	1.25	1.21	
AI	M	0.31	0.38	0.35	0.42
	F	0.41	0.56	0.48	
TI	M	0.33	0.38	0.35	0.41
	F	0.40	0.54	0.47	
h/H	M	2.21	2.29	2.25	2.01
	F	1.74	1.77	1.76	
PI	M	2.09	2.85	2.47	3.18
	F	3.03	4.74	3.89	
Total fatty acids	M	876.54	1081.38	978.96	1371.44
	F	1398.85	2128.99	1763.92	

LD—*Longissimus dorsi;* SM—*Semimembranosus*; SFA = Saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; EFA = essential fatty acids; %EFA= EFA × 100/Σ Total fatty acids; DFA = desirable fatty acids; %DFA = DFA × 100/Σ Total fatty acids; AI =Atherogenic Index; TI = Thrombogenic Index; h/H =Ratio between the hypocholesterolemic and Hypercholesterolemic fatty acids; PI = Polyunsaturation Index; NVI = Nutritive Value Index.

The sum of SFA was higher in females for both muscles, with more than double the value in SM muscles (836.2 mg/100 g) compared to males (386.5 mg/100 g).

The sum of MUFA (mg/100 g) was higher in females vs. males, as average for both muscles (587.21 vs. 279.53) or in SM muscle (733.37 vs. 315.04) and LD muscles (441.05 vs. 244.01 in males). The sum of PUFA was also higher (on average) in females compared to males (479.33 vs. 345.39).

The total fatty acids were higher in females than in males, on average, for both muscles (1763.92 vs. 978.96 mg/100 g), as well as in SM muscles (2128.99 mg/100 g vs. 1081.38 mg/100 g) and LD muscles (1398.85 mg/100 g in females vs. 876.54 mg/100 g in males).

The Σ PUFA/Σ SFA ratio was higher in males (0.97/1 vs. 0.71/1 in LD and 0.98/1 vs. 0.67/1 in SM; 0.98/1 vs. 0.69/1, on average, for both muscles).

On the contrary, the Σn6/n3 ratio was higher in females (4.99/1 vs. 4.44/1 in LD and 5.61 vs. 5.07 in SM), with average values of 5.30/1 in females and 4.76/1 in males.

AI was higher in females (0.41 vs. 0.31 in LD muscles and 0.56 vs. 0.38 in SM muscles), while the TI also had higher values in females for both muscles (0.33 vs. 0.40 for LD

muscles and 0.38 vs. 0.54 for SM muscles). On average, the values of AI and TI were almost similar (0.35 for vs. 0.48 for AI, respectively, 0.35 vs. 0.47 for TI), depicting the healthier fat composition in male meat compared to females that had higher atherogenicity and thrombogenicity potential.

The h/H indices were lower for females for both muscle groups (1.74/1 vs. 2.21/1 in male LD samples and 1.77 vs. 2.29/1 in male SM samples). The average values (both muscles calculated together) revealed a lower h/H ratio in females, as well (1.76 vs. 2.25 in males), suggesting a stronger hypocholesteremic effect when consumers opt out of male meat in the diet.

The NVI was also smaller in females (1.16 vs. 1.34 in males for LD; 1.25 vs. 1.36 in males for SM). The average values varied between 1.21 (females) and 1.35 (males).

The DFA (mg/100 g) was higher in females (935.87 vs. 626.43 in males for LD and 1433.81 vs. 777.01 in males for SM), with averages of 1184.84 (females) vs. 701. 72 (males). However, when the %DFA was calculated, better proportions were found in males vs. females (71.47 vs. 66.90 in LD muscles and 71.85 vs. 67.35 in SM muscles).

The absolute value of EFA (mg/100 g) was higher in females vs. males (412.27 vs. 279.84), while the relative proportion (%EFA) was higher in males (28.06% in LD and 29.01% in SM muscles) compared with the females (23.95% in LD and 22.99% in SM muscles).

On the other hand, PI was better in females (on average 3.89 vs. 2.47 in males), with wider differences (almost double values) in SM muscles (4.74 vs. 2.85 in males).

3.2. The Instrumental Assessment of Rabbit Meat

3.2.1. The Texture Parameters of Rabbit Meat

The texture analysis data (maximum strength, firmness (consistency)) and the total mechanical work performed to cut the sample (the area under the obtained curve) by applying the Warner–Bratzler test for both muscle groups from rabbits are presented in Table 4.

Table 4. The texture parameters of FG rabbit meat.

Muscles	Parameters	Gender	Mean ± SEM	CV%	*p*-Value
L.D.	Shear force (kg/cm^2)	M	5.62 ± 0.15	11.97	0.0342
		F	5.14 ± 0.15	12.65	*
	Firmness (kg/s × cm^2)	M	2.71 ±0.10	17.14	0.0011
		F	2.11 ± 0.07	14.98	**
	Area (kg × s/cm^2)	M	10.89 ± 0.27	10.95	0.1003
		F	9.49 ± 0.34	15.82	ns
S.M.	Shear force (kg/cm^2)	M	5.48 ± 0.26	20.99	0.4017
		F	5.16 ± 0.22	18.74	ns
	Firmness (kg/s × cm^2)	M	2.37 ± 0.07	12.96	0.2030
		F	2.19 ± 0.08	16.31	ns
	Area (kg × s/cm^2)	M	9.31 ± 0.27	12.92	0.3286
		F	8.57 ± 0.28	14.79	ns

LD—*Longissimus dorsi*; SM—*Semimembranosus*, SEM—standard error of mean; CV—coefficient of variation. Student test: ns = not significant, $p > 0.05$; * significant for $p < 0.05$; ** significant for $p < 0.01$.

The highest average value of total shear force was measured in male LD muscles (5.62 kg/cm^2), while in female samples, it reached 5.14 kg/cm^2. In the SM samples, males also required higher shear force (5.48 kg/cm^2), while in females it reached 5.16 kg/cm^2 ($p < 0.05$).

These data induced the same pattern in the firmness analysis, with the highest values in male LD samples (2.71 kg/s × cm^2) versus 2.11 kg/s × cm^2 in females ($p < 0.01$). In the hindleg, the muscles were also firmer in males (2.37 kg/s × cm^2) than in females (2.19 kg/s × cm^2).

The area recorded by the texturometer (the total mechanical work required to cut the samples) was the highest in LD male muscles (10.89 kg × s/cm^2). In females, it had an

average value of 9.49 kg × s/cm^2. The same dynamics were noticed in SM muscles, with higher values in males (9.31 kg × s/cm^2) than in females (8.57 kg × s/cm^2).

3.2.2. The Color Parameters of Flemish Giant Rabbit Meat

The color parameters of rabbit meat are presented in Table 5. In LD muscles, relatively close average values can be observed for L*/lightness in males (59.12) and females (58.32). The red index (a*) had average values of 2.87 in females and 3.12 in males ($p < 0.05$). The yellow index (b*) was higher in males (3.01) than in females (2.12) ($p < 0.001$).

Table 5. The color parameters of FG rabbit meat.

Muscles	Parameters	Gender	Mean ± SEM	CV	*p*-Value
L.D.	L*	M	59.12 ± 0.95	7.21	0.9912
		F	58.32 ± 0.88	6.77	ns
	a*	M	3.12 ± 0.08	6.82	0.0138
		F	2.87 ± 0.04	5.68	*
	b*	M	3.01 ± 0.03	4.94	0.000002
		F	2.12 ± 0.03	5.83	***
S.M.	L*	M	55.49 ± 0.54	4.28	0.7384
		F	56.16 ± 0.52	4.14	ns
	a*	M	3.21 ± 0.03	4.39	0.8296
		F	3.31 ± 0.03	4.25	ns
	b*	M	2.75 ± 0.03	5.02	0.1268
		F	2.81 ± 0.02	4.41	ns

LD—*Longissimus dorsi*; SM—*Semimembranosus*; SEM—standard error of mean; CV—coefficient of variation. Student test: ns = not significant, $p > 0.05$; * significant for $p < 0.05$; *** significant for $p < 0.001$.

In SM muscles, gender did not significantly affect meat coloring, regardless of the investigated parameter, such as lightness (L* = 56.16 in females vs. L* = 55.49 in males), red color (a* = 3.31 in males vs. 3.21 in females) and yellow color (b* = 2.81 in males vs. 2.75 in females).

In all analyzed situations, the coefficient of variation was calculated within the 4 and 8% range, suggesting good homogeneity in all analyzed traits.

3.3. The Sensory Parameters of Flemish Giant Rabbit Meat

Hedonic scoring of LD muscles revealed higher grades in males than in females for color (2.45 vs. 2.2), fibrous appearance (2.60 vs. 2.53) ($p < 0.001$), smell (3.40 vs. 3.35) ($p < 0.001$), taste (3.65 vs. 3.40) ($p < 0.01$) and flavor (3.40 vs. 3.25). On the contrary, female LD muscles scored better in terms of the intensity of flavor ($p < 0.001$), tenderness ($p < 0.001$), and juiciness ($p < 0.001$) (Figure 1 and Table 6). Overall appreciation resulted in slightly higher scores in males vs. females (3.35 vs. 3.25) ($p < 0.01$).

Table 6. The statistical differences of sensory analysis, by gender, of FG rabbit meat.

Sensory Descriptor	Sensory *p* Values (Males vs. Females)	
	LD	SM
Color	0.8480/ns	0.000105/***
Fibrous appearance	0.000014/***	0.000003/***
Smell	5.9×10^{-8}/***	$1E\times10^{-9}$/***
Taste	0.0028/**	0.0033/**
Flavor	0.1553/ns	0.3088/ns
Flavor intensity	6×10^{-7}/***	0.0004/***
Tenderness	3×10^{-10}/***	2.93×10^{-6}/***
Juiciness	1.55×10^{-6}/***	1×10^{-9}/***
Overall appreciation	0.0019/**	0.0033/**

Student test: ns = not significant, $p > 0.05$; ** significant for $p < 0.01$; *** significant for $p < 0.001$.

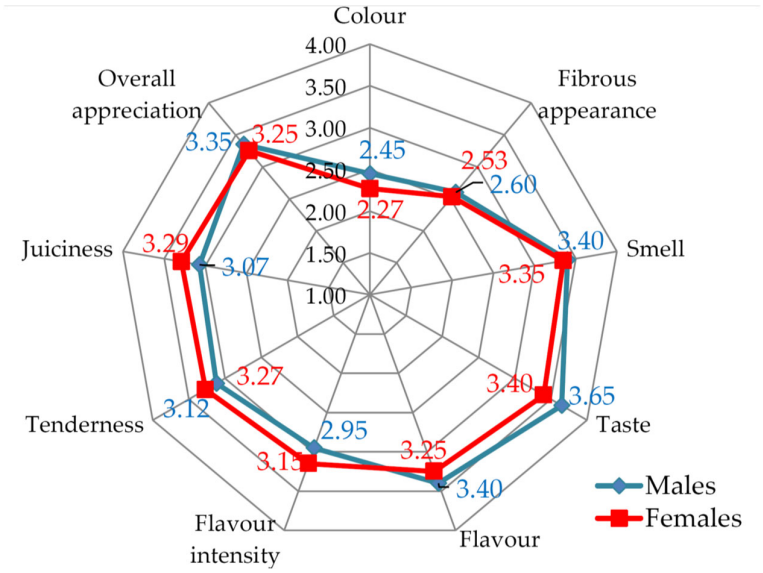

Figure 1. The sensory appreciation of LD muscles.

In SM samples (Figure 2, Table 6), females were better scored for color (3.42 vs. 3.11) ($p < 0.001$), tenderness (2.89 vs. 2.56) ($p < 0.001$), flavor (3.18 vs. 3.11) and juiciness (3.33 vs. 2.78) ($p < 0.001$), while males received better grades for the fibrous appearance (3.01 vs. 2.67) ($p < 0.001$), smell (3.33 vs. 2.78) ($p < 0.001$), taste (3.33 vs. 3.11) ($p < 0.01$), the intensity of flavor (3.56 vs. 3.27) ($p < 0.001$) and overall appreciation (3.33 vs. 3.11) ($p < 0.01$).

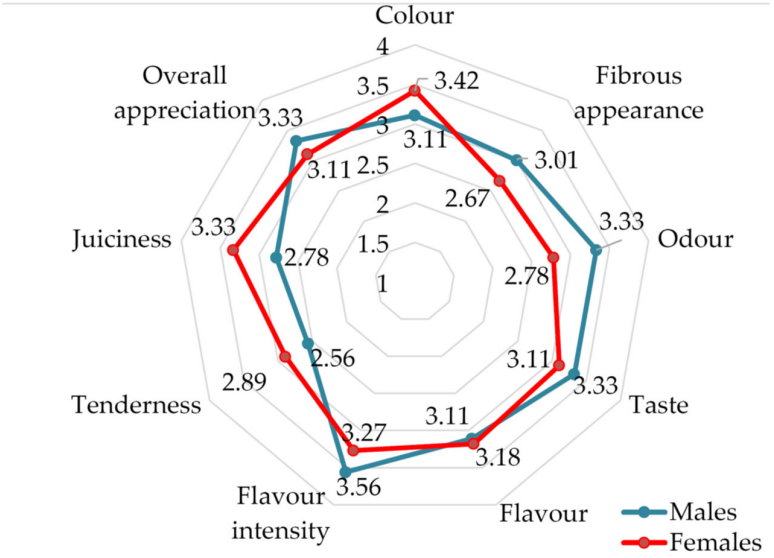

Figure 2. The sensory appreciation of SM muscles.

4. Discussion

4.1. The Fatty Acids Content and Sanogenic Indices of FG Rabbit Meat

The level and quality of dietary nutrients are primordial factors that count toward maintaining a healthy status in human consumers [41].

A dietary PUFA/SFA ratio of 0.45 or higher is recommended for preventing cardiovascular diseases [42]. A better PUFA/SFA ratio was reported in New Zealand rabbit meat (0.9–1.1) [43], Grimaud breeds (0.61–1.03) [44], and gray-colored rabbit breeds (0.92–0.94) [45].

The sanogenity of any dietary fat source can also be measured by the cholesterol neogenesis potential in consumer hepatocytes and is expressed as a ratio of hypocholesterolemic/hypercholesterolemic (h/H) fatty acids. In this respect, the New Zealand White breed had approximately 1.54–1.78 [46].

In our original findings, the PUFA/SFA ratio was 0.84, higher in males (+49%) than in females. However, the n6/n3 ratio was higher for females (+11.3%) vs. males. The h/H was, on average, 2.01, with 27.8% better in males than in females.

The AI and thrombogenicity index (TI) should be lower than 1.0 in foods to prevent atherosclerosis and thrombosis through a healthy diet and lifestyle, respectively [42]. Grimaud breed had better AI (0.52–0.72); however, TI (0.59–1.14) exceeded the recommended level [44]. The AI and TI values obtained in our original study were lower and, consequently, more favorable for consumer health (on average, they reached 0.42). However, if we compare meat origin by gender, female muscles had higher values (+35%) of AI and TI than male ones, suggesting that male meat is healthier. In our research, for all analyzed fatty acids, higher values were found in females, especially in SM muscles, which are usually richer in lipids than LD muscles. Females tend to accumulate more fat than males, with more body fat at any chronological age [47,48].

The biological value of rabbit meat relies on the fatty acids involved in consumer cardiovascular health reinforcement. Rabbit meat is considered a healthy dietary fat source and is recommended for patients with hypertension, hyperlipidemia, and cardiovascular and cerebrovascular diseases [49,50].

The high PUFA/SFA ratio and the presence of essential fatty acids in rabbit meat are favorable for human health [51–54]. The α-linolenic acid (C18:3n-3/ALA) and PUFAs C20:5n-3/EPA, C22:5n-3/DPA, C22:6-n3/DHA received the most attention due to their importance for human health and nutrition [55], as being effective in reducing triacylglycerol in blood and preventing cardiovascular diseases. EPA and DHA reduce inflammation and play a role in decreasing the incidence of childhood allergic diseases. EPA and DHA have biological activities that might influence tumoral cell proliferation and viability; DHA can promote tumor cell apoptosis, possibly by inducing oxidative stress [56,57].

In Western diets, the ratio of n-6/n-3 essential fatty acids is 15/1–16.7/1. Western diets are deficient in n-3 fatty acids and have excessive amounts of n-6 fatty acids compared with the diet on which humans evolved, which had established genetic patterns. Excessive amounts of n-6 PUFA and a very high n-6/n-3 ratio (15/1–16.7/1) promote the pathogenesis of many diseases, including cardiovascular disease, cancer, and inflammatory and autoimmune diseases, whereas increased levels of n-3 PUFA (therefore, low n-6/n-3 ratio) exert suppressive effects. In the secondary prevention of cardiovascular disease, a ratio of 4/1 was associated with a 70% decrease in total mortality. A ratio of 2.5/1 reduced rectal cell proliferation in patients with colorectal cancer, whereas a ratio of 4/1 with the same amount of n-3 PUFA had no effect. The lower n-6/n-3 dietary ratio in women with breast cancer was associated with decreased risk. A ratio of 2–3/1 suppressed inflammation in patients with rheumatoid arthritis, and a ratio of 5/1 had a beneficial effect on patients with asthma, whereas a ratio of 10/1 had adverse consequences [58]. In our study, the n-6/n-3 ratio was, on average, 5.03, falling, therefore, within the beneficial range.

Rabbit females, in the optimal period for mating, deposit more lipid reserves to provide raw matter for fetal tissue development throughout gestation, then for lactation and offspring viability (based on the metabolism and hormonal equipment specific to females). Health implications should be considered if only female carcasses were sold, but this is not the case in the breeding and sale of rabbit meat. Nevertheless, we would recommend slaughtering females at least 3–4 weeks earlier than males to avoid excessive fat deposition and the development of unfavorable sanogenic indices in meat.

4.2. The Instrumental Assessment of FG Rabbit Meat

4.2.1. The Texture Parameters of FG Rabbit Meat

In the present study, the highest average value of shear force was observed for males vs. females in LD (+9.3%) and SM muscles (+6.2%) (Table 4). The average values for total shear force corresponded to those reported in studies that examined rabbit meat from medium-sized breeds [9,59–63]. The maximum force of 3.41–3.76 kg/cm^2 was measured for rabbits slaughtered at 9 weeks old in Spain [60] in breeds selected multigenerational for meat quality traits. Other traits, such as firmness, were reported from 10.85 kg × s/cm^2 to 14.84 kg/s × cm^2, while the total effort area was reported, on average, at 5.95 kg × s/cm^2 [9,60–62].

Other authors [51] obtained an average value of shear forces that varied, depending on the feed quality, from 3.92 kg/cm^2 to 4.92 kg/cm^2 (slaughtering age: 12 weeks).

In a wider study [9] on the quality of rabbit meat issued from conventional and organic farming systems, an average shear force of 4.58 kg/cm^2 was found in rabbits slaughtered at 90 days (organic farming) and of 3.64 kg/cm^2 in rabbits slaughtered at 63 days (conventional farming). Therefore, the age at slaughter plays an important influence on the texture of rabbit meat. In another study from Spain [62], the shear force reached 3.6 kg/cm^2 in LD muscles (age 4 to 9 weeks), values close to those reported by other authors [60–63]. Also, in other species, shear force was measured between 3.2 and 3.7 kg/cm^2 (lamb) [64], 5.2 kg/cm^2 (pork) [65] and 5.4 kg/cm^2 (beef) [66]. In our findings, rabbit meat had better tenderness than pork and beef and was close to that measured for lamb. However, it is a little forced to compare such findings, knowing that the texture is influenced by multiple factors, such as the genetic origin, age at slaughter, dietary specificity, artificial selection, environmental microclimate, preparation of sample for analysis, and the chosen instrumental method.

4.2.2. The Color Parameters of FG Rabbit Meat

The color parameters of LD muscles (Table 5) had relatively close values for L*/lightness in males (59.12) and females (58.32); the red index (a*) varied between 2.87 (females) and 3.12 (males). Also, a higher yellow index (b*) was observed in males than in females. In SM muscles, the color parameters were very close (females vs. males): L* was 56.16 vs. 55.49; a* was 3.31 vs. 3.21, and b* was 2.81 vs. 2.75. Other authors measured average values of L* for rabbit meat from medium bread, similar to those observed in the present study [5,10–12]. In another study on the conventionally and organically produced rabbit meat, L* varied from 57 to 60, a* index from 2.92 to 3.70, and smaller values were observed for the b* index (0.58 to −1.13) [9].

The mean value of L* of different rabbit breeds ranges from 41.78 to 65.68 [42]. Czech White and Moravian White rabbit breeds had the highest L* of *Biceps femoris* (BF) muscles than Czech gold breeds. Still, the Hyplus rabbits had intermediary L* values compared to other breeds [67], with differences given by the farming system. Another study [68] found meat color differences between the *Longissimus lumborum* and *Biceps femoris* muscles of three rabbit genotypes. The highest L* was reported in the Hyla breed (59.96–63.16). The higher proportion of myoglobin content and the type of myocytes might contribute to more redness a* value, even though it could be affected by many other factors such as exercise, diet, and genetic and environmental conditions [42,69].

In general, the brightness values determined for domestic rabbit meat are relatively close to those determined for turkey meat.

4.3. The Sensory Parameters of Flemish Giant Rabbit Meat

The mean values of sensory analysis parameters of LD muscles and SM muscles from FG rabbit meat are presented in Figures 1 and 2. Overall appreciation has 3–7% higher values for males vs. females (3.35 vs. 3.25 in LD and 3.33 vs. 3.11 for SM muscles). The potential reasons or the significance of these variations relied on the better taste and more

pleasant odor detected in male samples, compared to females, whose muscles were richer in total lipids and probably had a more pronounced flavor of rabbit meat.

Rabbit meat from giant and intermediary size breeds sensory analysis, which is very scarce [40]. A difficulty for sensory analysis of rabbit meat is the small muscle sample size in this type of meat. Moreover, the scoring of panel tests is difficult to interpret in terms of meat quality; for example, a difference of one point for flavor between two persons does not indicate whether this difference is relevant or not. Also, slaughtering parameters can severely affect meat texture and sensory traits due to stunning types of bleeding, extreme voltages, and frequencies that could be preferable to medium voltage and frequency levels (for improving sensory qualities, such as tenderness and juiciness) [70]. The sensory analysis presented in the literature is uneven, with studies pursuing the application of growth, nutrition, slaughter, or cooking strategies to improve the sensory quality of rabbit meat [4,23,40,70].

In our study, as the shear force and firmness measurements had increased values, the fibrous appearance of muscles increased while the tenderness and juiciness decreased (observed through the sensory analysis with trained specialists) on the hedonic scale.

4.4. Recommendation of Rabbit Breeding and Meat Consumption

The biological nutritional value of rabbit meat should be popularized globally, especially in Romania (and in other countries), where a drastic decline in farming and consumption is observed.

In comparison for sanogenic indices, in goose breast muscles, the AI was 0.37, and the TI was 0.69 [71], therefore lower than those calculated for other kinds of meat such as rabbit from medium breeds, whose AI was 0.90 and TI was 1.19 [72]. In chicken, AI was 0.49, and TI was 1.14 [73]. In turkey, the AI was 0.47, and TI was 0.91 [74]. In other mammals, the sanogenic indices varied from beef (AI = 0.60 and TI = 1.86) [75] to pork (AI = 0.47 and TI = 1.12) [76] and to lamb (AI = 0.90 and TI = 0.87) [77].

To ensure the sustainability of rabbit production and protect the global rabbit industry, cost-effective and practical strategies for improving rabbit production and meat quality must be developed. Recently, rabbit farming, like other animal farming, has faced feed shortages due to the impact of climate change, high competition between livestock species, and war conditions [31]. In general, and in Romania, chicken meat is now the most appreciated by consumers [78], at the expense of rabbit meat, which is also much rarer and harder to find. In European countries, the mean market price of rabbit meat at butcheries ranges from 5 to 10 EUR/kg, while broiler is normally priced between 2.50 and 6 EUR/kg. As a result, rabbit meat consumption has gradually decreased, particularly among low-income households. The most common difficulty is the absence of rabbit meat in butcher shops [79], which means that urban inhabitants who enjoy rabbit meat can only purchase it in a few places [80]. This species can efficiently transform the residues of agricultural nature into a product of high nutritional–biological value meat [81]. Regarding the global sustainability in agriculture, agri-food by-products can be added to a variety of foods to increase their bioactive profile, fiber content, and antioxidant capacity [82–85] while maintaining good sensory acceptability, with applicability for rabbit meat, eventually for ready to eat products, like sausages, etc.

Consumers today are encouraged to seek out alternative meat types due to the changes in their eating habits and the increased disease risk associated with conventional meat products [48]. A limited range of innovative, experimental rabbit meat alternative products to raw carcasses are available in the market, including smoked, canned, frozen, cured, sauce-picked, dried, and roasted products, as well as rabbit meat sausages and hamburgers [80], but territorially limited to certain Southern European countries and in China and not on a permanent availability basis.

5. Conclusions

Meat sanogenity was better in males than in females, with higher ratios of unsaturated vs. saturated fatty acids and lower values of the atherogenic and thrombogenic indices. The instrumental analysis of texture revealed less tender meat with better pigmentary properties in males. In thigh muscles, colorimetric investigation revealed closer results between genders. On the sensory overall acceptance, males achieved better scoring than females. However, the latter ones appeared to be better scored when tenderness and juiciness were assessed independently, suggesting less connective tissue in muscle stroma and, possibly, thinner myocytes.

The meat from males showed superior quality characteristics (both sanogenic and sensorial). We would recommend slaughtering females at least 3–4 weeks earlier than males (around 8 months old) to prevent excessive fat deposition in their carcasses and the development of unfavorable sanogenic indices.

As research follow-up, the instrumental data should be completed with structural histological analysis to assess the real composition of the connective tissue in the muscle marbling (is it predominantly collagenic or lipidic?). Also, the data could be refined using more samples and more homogenous carcasses in terms of age, physiological status, and gender repartition.

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