

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriScience



**Utilization of Alternative Protein Sources in Rabbit
Nutrition**

DISSERTATION

Author

MSc. Tolulope S. Aremu

Supervisor

doc. Tersia Kokošková, Ph.D.

Consultant

doc. Ing. Zdeněk Volek, PhD.

Prague 2026

Declaration

I, Tolulope Sabainah Aremu, hereby declare that I have finished this dissertation thesis entitled “*Utilization of Alternative Protein Sources in Rabbit Nutrition*” independently, except for the jointly authored publications that are included. In the case of such publication, my specific contributions have been clearly stated at the start of the relevant publication chapter. Furthermore, I confirm that proper acknowledgement has been provided within this thesis for any references made to the works of others, I also ensure that this work has not been, nor is it currently submitted for any other degree, to this or any other university. All information sources have been quoted and acknowledged by means of complete references. I declare that I have used AI tools in accordance with the university’s internal regulations and principles of academic integrity and ethics. Appropriate references to the use of those tools have been made in the thesis.

In Prague, September 2026

.....

Tolulope Sabainah Aremu

Acknowledgments

I express my utmost appreciation to God for this accomplishment. For being with me all the way from Nigeria to Prague, Czech Republic to attain this milestone. His love, mercy, and divine strength have sustained me throughout this challenging yet rewarding doctoral journey. I return all glory to Him.

I would like to express my sincere appreciation to the **Czech University of Life Sciences Prague**, and specifically to the **Faculty of Tropical AgriSciences**, for providing me with the opportunity to conduct my doctoral research. The resources provided during this research were instrumental to its success.

I am forever grateful to my supervisor, doc. **Tersia Kokošková**, Ph.D., your timely advice, guidance, invaluable contributions and insights were the foundation that directed this work. Aside from your academic guidance, I am extremely grateful for your support during moments of utmost difficulty; your belief in me often outweighs my own. You are one of a kind.

I wish to express my profound appreciation to doc. Ing. **Zdeněk Volek**, Ph.D., of the **Institute of Animal Science, Prague (IAS)**, whose invaluable collaboration, financial support, and facilitation made this research possible. I am equally grateful to the IAS for granting access to their research facilities. This academic journey was made possible through the generous support of **ČZU Prague- FTZ Internal Grant Agency (IGA: 20223107; 20233112; 20243112; 20253130)** and **Erasmus+ International Credit Mobility Program**. I also appreciate the research collaboration and network I had with Prof **Antonella Dalle Zotte** in the **University of Padova, Italy** for my 5 months internship program.

I would also like to extend my sincere gratitude to my academic mentors **Prof. Olajide Sogunle**, **Dr. Kolawole Safiyu**, **Dr. Yazavinder Singh** and **doc. Sadiq Musa** who guided me at critical phases during this journey. To my academic peers, **Dr Jerico Consolacion**, **Doc. Gospel Iyioku**, and **Ing. Thoniso Chitambala**, your collaboration, and combined input helped navigate the complexities of this endeavour successfully.

To my family members, whose love is the centre of my being, I remain grateful forever. To my amazing father **Dr. G. B. Aremu**, thank you for the academic foundation you showed me, and my wonderful mother **Mrs. E.O. Aremu**, your prayers and moral support went a long way. To my darling siblings, nieces and nephews, your continued prayers, love, words of encouragement, and unwavering support have been the source of immense joy and strength.

I also express my deep appreciation to my late uncle **Mr Okey Nnorom**, you made this journey possible by your financial and moral support from the beginning. Grateful to my boss **Amb. Adebowale Onafowora** for your ever-present support and guidance. I also want to thank my manager **Jan Rehak** and my team lead **Frantisek Vondra** for always cheering me on and making my journey a smooth one.

My sincere gratitude also goes to **Pastor Olayinka Ojo** and **Mr Gbenga Lawal** for your counsels, supports and prayers.

To my lovely friends, who were home away from home, **Mobola Oyesile**, **Ing. Isaac Ehovuomen**, **Ing Margaret Darko**, **Ing. Omolola Irere**, **Alamu Omobolanle**, **Amos Ogunola**, **Arogundade Temitayo**, and so, so many others; thank you for the laughter, late-night conversations, and for being pillars of strength for me.

Abstract

Three experiments were conducted to evaluate alternative feed ingredients for improving the performance and product quality of rabbits, as well as meat processing methods for novel products. Experiment 1 assessed using yellow mealworm meal (*Tenebrio molitor*, YMM) as a replacement for soybean meal (SBM) in diets for lactating does, and the effects of this maternal diet on their kits. Twenty-four crossbred does were allocated to either a 13% SBM- or 11% YMM-based diets from parturition to day 32 of lactation, with litters adjusted to 10 kits per doe. Feed intake, milk yield, feed conversion ratio, milk composition, litter weight, and average daily gain of rabbit does did not differ between treatments. Results indicate that the replacement of SBM with YMM as the primary dietary protein source is feasible for lactating does, without affecting milk production and quality, feed efficiency, nor the performance of their kits. Experiment 2 examined the effects of *Camelina sativa* oilseed cake (CSC) on meat quality and sensory traits of grower rabbits. A total of 168 crossbred Hyplus PS19 × PS40 rabbits of both sexes were weaned at 32 days and randomly assigned to three dietary treatments with 56 rabbits each (14 cages): a control diet with 10% rapeseed cake, and two diets where 5% or 10% of the rapeseed cake was replaced with CSC. At 74 days of age, 14 representative males per treatment were selected, weighed, and slaughtered, after which the right hind leg and both *longissimus lumborum* muscles were collected for meat quality analyses. Results revealed increasing CSC inclusion rates reduced yellowness and water content in *longissimus lumborum* and *biceps femoris* muscles, decreased saturated and monounsaturated fatty acids, and linearly increased polyunsaturated and omega-3 fatty acids, halving the n-6/n-3 ratio in the 10% CSC group. Although CS10 meat had higher fatty, rancid, and abnormal flavour intensity scores, overall consumer acceptance was unaffected. Experiment 3 evaluated the use of wet (n = 20) versus dry (n = 20) ageing for 7 or 14 days on the physicochemical and sensory properties of the *longissimus thoracis et lumborum* muscle from 90-day-old rabbits. Shear force declined from day 1 to day 7 regardless of method, but physicochemical and sensory properties differed with ageing method and period. On day 7, dry-aged meat scored higher for off-odours but overall acceptance was unaffected. After 14 days, dry-aged meat showed favourable flavour development and was preferred by panellists. In conclusion, yellow mealworm meal and *Camelina sativa* oilseed cake are viable dietary protein sources for sustainable rabbit production that support growth, lactation, and healthier meat fatty acid profiles without compromising product acceptability, while dry ageing rabbit meat for 14 days can be utilised to enhance flavour development, and to develop novel meat products for the modern consumer.

Keywords: *Hyplus rabbit; Yellow mealworm meal; Camelina sativa; Meat quality; Meat ageing*

Contents

<i>Declaration</i>	<i>i</i>
<i>Acknowledgments</i>	<i>ii</i>
<i>Abstract</i>	<i>iii</i>
<i>Contents</i>	<i>iv</i>
<i>List of tables</i>	<i>vii</i>
<i>List of figures</i>	<i>ix</i>
<i>List of abbreviations</i>	<i>x</i>

CHAPTER 1 – Introduction.....1

1.1. General introduction.....	1
1.2. Aims of the thesis.....	4
1.3. Research questions.....	4
1.4. Overview of the chapters.....	5

CHAPTER 2 – Literature review.....7

2.1 Introduction to current rabbit production.....	7
2.2 Sustainable small-scale rabbit production in developing countries.....	11
2.2.1 Constraints to rabbit production in developing countries.....	13
2.3 Challenges for animal feed production	15
2.4 Rabbit dietary protein requirements	17
2.4.1 Dietary protein requirements of rabbits.....	17
2.4.2 Amino acid requirements of rabbits.....	20
2.4.3 Microbial protein from cecotrophy.....	20
2.5 Emerging use of non-conventional protein sources (NCAP) in rabbit nutrition.....	21
2.6 Insect as a protein source for livestock nutrition	23
2.6.1 Nutritional value of insects.....	24
2.6.2 Yellow mealworm (<i>Tenebrio molitor</i>) and feeding value for livestock.....	33
2.7 <i>Camelina sativa</i> (L.) Crantz and feeding value for livestock	36
2.8 Consumer trends and perception of rabbit meat.....	39
2.8.1 Qualitative parameters of rabbit meat.....	42
2.8.2 Meat ageing – can we use it for rabbits?.....	44
2.9 Concluding remarks.....	46

CHAPTER 3 – General methodology.....47

3.1. Study area description	47
3.2 Animals and housing	47
3.3 Overview of experimental design and data collection	47

3.4 Data processing and statistical analysis	48
CHAPTER 4 – Effect of yellow mealworm meal (<i>Tenebrio molitor</i>) on the growth, milk yield, and milk composition of lactating rabbits, and their kit.....	50
4.1. Abstract.....	51
4.2. Introduction.....	52
4.3. Materials and methods.....	53
4.3.1. Experimental site	53
4.3.2. Experimental diets	53
4.3.3 Animals, experimental design, and lactation performance ...	58
4.3.4 Analytical methods	59
4.3.5 Statistical Analysis	60
4.4. Results.....	60
4.5. Discussion.....	64
4.6. Conclusion.....	66
CHAPTER 5 – Assessing the impact of dietary <i>Camelina sativa</i> (L.) Crantz inclusion on meat quality and sensory traits of growing rabbits	67
5.1 Abstract.....	68
5.2 Introduction.....	69
5.3. Materials and methods.....	71
5.3.1. Ethical statement	71
5.3.2. Experimental design	71
5.3.3. Physical analyses	72
5.3.4. Sample preparation and proximate composition	72
5.3.5 Fatty acid profile and contents	73
5.3.6. Sensory analysis	75
5.3.7 Statistical analysis	76
5.4. Results.....	77
5.5. Discussion.....	81
5.6. Conclusion.....	84
CHAPTER 6 – Effect of wet and dry post-mortem rabbit loin meat ageing on its physicochemical and sensory properties	85
6.1. Abstract.....	86
6.2. Introduction.....	87
6.3. Materials and methods.....	88
6.3.1 Animals and sampling	88
6.3.2 Physicochemical meat quality assessment	89
6.3.3 Descriptive sensory analysis	90

6.3.4 Statistical analysis	92
6.4. Results.....	92
6.5. Discussion.....	94
6.6. Conclusion.....	98
CHAPTER 7 – General discussion.....	99
CHAPTER 8 – General conclusions and recommendations.....	102
CHAPTER 9 – General references.....	103
CHAPTER 10 – Annexes.....	138
Annex 1. Supplementary Table 5.1.....	138
Annex 2. Curriculum vitae Tolulope Sabainah Aremu.....	139

List of tables

Table 2.1: Crude protein requirements of rabbits.....	19
Table 2.2: Proximate composition (%) of selected insect species.....	28
Table 2.3: Essential amino acid composition of different insect species.....	29
Table 2.5: Fatty acid composition of insect fats.....	30
Table 2.6: Vitamin composition of insects.....	31
Table 2.7: Mineral composition (mg/kg) of selected insects.....	32
Table 4.1: Ingredients and chemical composition of the experimental diets, as well as some chemical composition components of the <i>Tenebrio molitor</i> meal only (i.e., prior to feed-mixing). Data are presented as g/kg on an as feed basis, unless stated otherwise.....	55
Table 4.2: Fatty acid profiles of the diets and <i>Tenebrio molitor</i> (YMM) meal (% total fatty acids).....	56
Table 4.3: Ingredients and chemical composition (g/kg on as-fed basis unless otherwise stated) of the diet for growing rabbits.....	57
Table 4.4: Rabbit doe performance during the 32-day lactation experiment, fed either soybean (SBM) meal or insect meal (YMM) as a primary protein source. Data is presented as the LSMean $\pm$ SEM.....	61
Table 4.5: Rabbit doe milk composition after feeding either soybean (SBM) meal or yellow mealworm meal (YMM) as a primary protein source. Data is presented as the LSMean $\pm$ SEM.....	62
Table 4.6: Milk fatty acid composition (% of total fatty acids) from does fed lactation diets containing either soybean meal (SBM) or yellow mealworm meal (YMM). Data is presented as the LSMean $\pm$ SEM.....	63
Table 4.7: Litter performance parameters for rabbits from does fed either soybean meal (SBM) or yellow mealworm meal (YMM) as a protein source for the maternal diet. Twenty four does were included in the analyses, with litter size standardized to 10 kits per doe. Data is presented as the LSMean $\pm$ SEM.....	64
Table 5.1: Fatty acids profile (% Total Fatty Acids Methyl Esters - FAME) of the experimental diets.....	74
Table 5.2: Definition and scale of the attributes used in the meat sensory analysis...	76
Table 5.3: Effect of the dietary inclusion of camelina (<i>Camelina sativa</i>) cake (0 %, 5 %, 10 %) for growing rabbits on the physical properties of hind leg (HL), <i>biceps femoris</i> (BF), and <i>longissimus lumborum</i> (LL) muscles.....	77

Table 5.4: Effect of the dietary inclusion of camelina (<i>Camelina sativa</i>) cake (0 %, 5 %, 10%) for growing rabbits on the proximate composition (g/100 g meat) of hind leg meat.....	78
Table 5.5: Effect of the dietary inclusion of camelina (<i>Camelina sativa</i>) cake (0 %, 5 %, 10%) for growing rabbits on the fatty acids profile of hind leg meat.....	79
Table 5.6: Effect of the dietary inclusion of camelina (<i>Camelina sativa</i>) cake (0 %, 5 %, 10%) for growing rabbits on the fatty acids content of hind leg meat (mg/100 g meat).....	80
Table 5.7: Effect of the dietary inclusion of camelina (<i>Camelina sativa</i>) cake (0 %, 5 %, 10%) on the sensory traits of grilled rabbit <i>longissimus lumborum</i> meat.....	81
Table 6.1: Description of the scale of the sensory attributes for the evaluation of aged rabbit meat.....	91
Table 6.2: Effect of ageing on physicochemical characteristics of <i>longissimus thoracis et lumborum</i> muscle of rabbits.....	93
Table 6.3: Sensory properties of rabbit <i>longissimus lumborum</i> muscle after ageing for 7 days.....	94
Table 6.4: Sensory properties of rabbit <i>longissimus lumborum</i> muscle after ageing for 14 days.....	94
Supplementary Table 5.1 Chemical composition (g/kg, as fed) and energy content (MJ/kg) of camelina (<i>Camelina sativa</i>) cake and experimental diets.....	13

List of figures

Figure 2.1: The main global rabbit producing countries by share of global meat production (%) and share of global rabbits slaughtered (%).....	8
Figure 2.2: The main global exporters and importers of rabbit meat by share of the market (% of tonnage).....	8
Figure 2.3: Nutritional characteristics of edible insects.....	25
Figure 2.4: Life cycle of yellow mealworm.....	35
Figure 2.5: <i>Camelina sativa</i> (L.) Crantz.....	38
Figure 2.6: Amino acid profile of solvent-extracted (CamSol) and expelled (CamExp) camelina meals, solvent-extracted canola meal (Canola), and solvent-extracted soybean meal (SBM).....	39

List of the abbreviations used in the thesis

a^* – Redness

ADF - Acid detergent fiber

ADFI - Average daily feed intake

ADG - Average daily gain

b^* – Yellowness

BF - *biceps femoris*

BSFL - Black soldier fly larvae

CAGR - Compound annual growth rate

CIE - Commission Internationale de l'Éclairage

CP - Crude protein

CS - *Camelina sativa*

CSC - *Camelina sativa* oilseed cake

DE - Digestible energy

DNA - Deoxyribonucleic acid

EC - European Commission

EE - Ether extract

EEC - European Economic Community

FAME – Fatty acid methyl esters

FCR - Feed conversion ratio

GHG - Greenhouse gases

HL - Hind legs

IAS - Institute of Animal Science

ISO - International Organization for Standardization

L^* – Lightness

LL - *longissimus lumborum*

MDA - Malondialdehyde

MUFA - Monounsaturated fatty acids

NCFR - Non-conventional feed resources

NDF - Neutral detergent fiber

NZW - New Zealand White

PSF - Peak shear force
PUFA - Polyunsaturated fatty acids
RSC - Rapeseed cake
SBM - Soybean meal
SFA - Saturated fatty acids
SSRPM - Small-scale rabbit production model
UFA - Unsaturated fatty acids
WBSF - Warner-Bratzler Shear Force
WRSA - World Veterinary Rabbit Association
YMM - Yellow mealworm meal

CHAPTER 1

Introduction

1.1. General introduction

Global livestock populations are projected to reach 100 billion by 2050, driving a concurrent increase in global meat demand over the next two decades (Woods & Fearon, 2009; Yitbarek, 2019). Rabbits (*Oryctolagus cuniculus*) are highly prolific domesticated farm animals with short generation intervals, good mothering ability, and low management requirements (Malik et al., 2020; Onuoha et al., 2020). Rabbit meat stands out as a lean, high-protein food with high biological value, and it is also a good source of vitamins and minerals (Dalle Zotte, 2004; Etukudo et al., 2024). Its nutritional composition, however, is influenced by factors such as muscle type, its fat content, and diet (Dalle Zotte, 2002; Pla et al., 2004). With an average fat content of around 6.8%, rabbit meat has a lower energy density than most red meats (Dalle Zotte, 2004; Hernández & Gondret, 2006). In addition to its nutritional profile, rabbit meat is not subject to religious dietary restrictions, making it widely acceptable across different cultural and religious groups (Nistor et al., 2013). As a result, rabbit production presents a viable strategy for addressing the growing demand for protein-rich foods. It is particularly valuable for strengthening household-level food security in regions where small-scale livestock production, often managed by women, forms a key part of the local economy.

Commercial rabbit production relies heavily on formulated diets, with soybean meal (SBM) serving as the primary protein source due to its ability to supply adequate quantity and quality for optimal growth performance (Zwoliński et al., 2017). Despite its nutritional value, dependence on conventional feed ingredients like soybean presents major sustainability challenges. These include price instability, direct competition with human food supply, and environmental impacts associated with soybean cultivation and trade (Shaahu et al., 2014; Singh et al., 2023a). The challenge is particularly acute in regions such as many European countries, where soybean is not locally cultivated and production systems depend largely on imports (de Visser et al., 2014). This reliance increases production costs and exposes the industry to supply chain vulnerabilities. Consequently, there is an urgent need to identify sustainable and cost-effective alternatives to conventional feedstuffs to ensure the long-term viability of rabbit

farming and strengthen global food security. In response, a growing trend toward partial or complete replacement of soybean in livestock rations has emerged. This shift is driven by the desire to reduce dependence on imported feed, lower feed production costs, and address consumer concerns over genetically modified organisms in animal products (Tudisco et al., 2006; Zwoliński et al., 2017).

Several alternative protein sources to SBM have been evaluated in rabbit diets, with *Camelina sativa* (L.) Crantz emerging as a promising option. Commonly known as camelina, false flax, or gold of pleasure, it is frequently farmed in marginal, low-productivity, or drier areas where major commodity crops like soybeans struggle or cannot grow (Ahmad et al., 2023). Compared to other *Brassicaceae* crops, camelina's shorter life cycle allows for double-cropping and likely reduces nematode cysts due to its high glucosinolate content acting as a biofumigant, while its intercropping in maize and soybean systems also enhances biodiversity, reduces soil erosion and nutrient losses, and lowers cultivation costs without compromising the yield of primary crops (Zanetti et al., 2021). This annual dicotyledonous plant produces oil rich in polyunsaturated fatty acids (PUFAs), including α -linolenic acid (>35% of total fatty acids) and linoleic acid (>17%), as well as monounsaturated fatty acids (MUFAs) such as eicosenoic acid (>19%), oleic acid (>14%), and erucic acid (<4%) (Cullere et al., 2023). Camelina seeds also contain 24.5–30% protein by weight and provide a balanced profile of essential and non-essential amino acids (Singh et al., 2023a). However, they contain several anti-nutritional factors, including glucosinolates, condensed tannins, sinapine, phytic acid, and trypsin inhibitors, which can limit nutrient utilization if not properly managed (Juodka et al., 2022; Russo & Reggiani, 2017). The full utilization of camelina offers economic advantages, as both seeds and by-products can be valorized across multiple industries, including animal feed, biofuel, and biopolymer production (Righini et al., 2016; Zanetti et al., 2021). *Camelina sativa* is a source of bioactive compounds such as polyphenols and tocopherols, alongside significant levels of protein and fiber, further enhancing its value as a feed ingredient (Kurasiak-Popowska & Stuper-Szablewska, 2020).

Additionally, insect meals have been successfully incorporated into diets for fish, poultry, and pigs as substitutes for conventional protein sources (Renna et al., 2017; Biasato et al., 2018; Dabbou et al., 2018). The promotion of insect farming is driven by its resource efficiency and role in circular economies, coupled with strong European public support and willingness to pay for solutions that mitigate the environmental impacts of livestock production (Lisboa et al., 2024). Insect farming provides economic benefits through the production of feed

ingredients that can improve livestock diets in both developed and developing countries, while addressing sustainability and environmental challenges by efficiently converting organic waste into protein, reducing reliance on soy and fishmeal, lowering greenhouse gas emissions, and requiring less land and water compared to conventional feed crops (Lisboa et al., 2024). Regulations governing the production and use of insects and insect meal vary by country (Lahteenmaki-Uutela et al., 2017), with the European Union enforcing some of the strictest standards globally. Under Commission Regulation (EU) 2017/893, the EU initially approved seven insect species — black soldier fly (*Hermetia illucens*), common housefly (*Musca domestica*), yellow mealworm (*Tenebrio molitor*), lesser mealworm (*Alphitobius diaperinus*), house cricket (*Acheta domesticus*), banded cricket (*Grylloides sigillatus*), and field cricket (*Gryllus assimilis*) — for pet food and aquafeed in 2017, and later expanded this to poultry and pig feed in 2021 via Commission Regulation (EU) 2021/882 (Toviho & Bársony, 2022). Among these, larvae of the yellow mealworm (*Tenebrio molitor*) are particularly promising for rabbit nutrition due to their high protein content and favourable amino acid profile; furthermore, they are rich in lysine, sulfur-containing amino acids, threonine, and arginine (Makkar et al., 2014; Finke & Oonincx, 2017; Volek et al., 2021). According to Volek et al. (2021), yellow mealworm-based diets support the overall growth performance in rabbits comparable to SBM-based diets, with no adverse effects on mortality. They also improve nitrogen utilization and reduce urinary nitrogen losses, suggesting both nutritional and environmental benefits (Volek et al., 2021). Regarding rabbit nutrition, dietary inclusion of insect meals such as silkworm pupae (*Bombyx mori*), housefly maggot (*Musca domestica* larvae), and yellow mealworm larvae (*T. molitor*) did not adversely affect growth performance, feed efficiency, nutrient digestibility, nitrogen output, gastrointestinal function, or meat and carcass quality in rabbits (Volek et al., 2023).

Consumer reluctance to purchase rabbit meat is largely attributed to animal welfare concerns (Petracci et al., 2018); however, market limitations also play a role. In many Western countries, the rabbit meat market remains focused on whole carcasses and primal cuts intended for traditional, family-style cooking, with limited development of value-added products tailored to contemporary consumer preferences. The processing technology of rabbit meat products currently also has some challenges, such as variation in meat quality due to pre-mortem factor (Hao et al., 2023), as well as the use of improper thawing and processing methods that have adverse effects on the flavor of rabbit meat products, as well as water loss and color changes caused by production, transportation, and storage (Deng et al., 2024). Consequently, reorienting

marketing strategies toward “new products,” “new entries,” or functional foods that leverage rabbit meat’s high nutritive value may improve its market position (Petracci et al., 2018). Meat ageing originally served as a preservation method but its purpose has shifted toward improving the sensory and physicochemical properties of meat to meet consumer expectations (Alam et al., 2024), but it has not been explored in rabbit meat.

Thus, this study was designed to evaluate the potential of yellow mealworm (*Tenebrio molitor*) and *Camelina sativa* as sustainable, alternative protein sources in rabbit nutrition, with the goal of reducing reliance on conventional soybean meal while maintaining growth performance and meat quality. Furthermore, the use of meat ageing methods was explored, to determine its potential for diversifying rabbit meat products for the modern consumer.

1.2. Aims of the thesis

The thesis aimed to evaluate the effects of dietary inclusion of yellow mealworm meal and *Camelina sativa* cake as a replacement for conventional protein sources on the performance of commercial rabbits, as well as the use of meat ageing methods to improve the eating quality and diversity of rabbit meat products. The main objectives were:

- To assess the impacts of the complete replacement of soybean meal with yellow mealworm meal on lactating does’ milk yield and composition, and kit growth.
- To determine effects of different dietary inclusion rates of *Camelina sativa* cake meal on rabbit meat quality and sensory attributes.
- To compare the use of wet vs dry ageing for two ageing periods (7 vs 14 days) on the physicochemical and sensory properties of rabbit loin meat.

1.3. Research questions

The present research thesis seeks to answer the following questions:

- Can yellow mealworm be used as a complete replacement for soybean meal in the diet of rabbit does without negatively affecting milk yield and quality, and subsequently rabbit kit growth?
- Which inclusion level is suitable for the use of CSC in the diets of grower rabbits, without negatively affecting growth rate, meat production performance, meat nutritional value, and eating quality?

- How do different ageing techniques influence the organoleptic properties of rabbit meat, as a strategy for rabbit product diversification?

1.4. Overview of the chapters

This thesis comprises of eight chapters; the first three chapters present the General Introduction, Literature Review, and General Methodology. These provide the background of the research, motivation and aims, and common methodology for the experimental work. This is followed by three research chapters, of which the first is currently unpublished while the remaining two have been published in Web of Science-indexed, peer-reviewed journals. The published journals have been included in their published form, only minor formatting changes have been made to ensure uniformity throughout the thesis.

The first study (Chapter 4 – **Aremu et al., Unpublished Data**) of this thesis, entitled: “*Effect of yellow mealworm meal (*Tenebrio molitor*) on the growth, milk yield, and milk composition of lactating rabbits, and their kits*”, evaluates the inclusion of yellow mealworm meal as a dietary protein source in lactating rabbit diets. Here, effects on doe growth performance, milk production, milk composition, and the growth of their kits are assessed. Such information may serve as a basis for evaluating insect meal as a sustainable alternative protein source throughout various stages of the rabbit production cycle.

The second study (Chapter 5 – **“Kokošková, T., Pontalti, E., Aremu, T. S., Tůmová, E., Chodová, D., Bureš, D., Lebedová, N., Volek, Z., Singh, Y., Cullere, M., & Palumbo, B. (2025). Assessing the impact of dietary *Camelina sativa* (L.) Crantz inclusion on meat quality and sensory traits of growing rabbits. *Meat Science*, 219: 109679”**), evaluates the effects of replacing rapeseed oilseed cake with camelina oilseed cake in growing rabbit diets. One hundred sixty-eight crossbred rabbits were fed diets containing 0%, 5%, or 10% camelina oilseed cake, and meat from the *longissimus lumborum* and hind legs was analyzed for physical traits, proximate composition, fatty acid profile, and sensory attributes. The findings showed that camelina inclusion altered the fatty acid profile by increasing polyunsaturated and omega-3 fatty acids while reducing the n-6/n-3 ratio and affected flavour intensity without changing overall acceptance. Such information may serve as a basis for using camelina oilseed cake as a sustainable protein source in rabbit production for healthier meat. The study was published in *Meat Science* (<https://doi.org/10.1016/j.meatsci.2024.109679>).

The third study (Chapter 6 – “Aremu, T. S., Bureš, D., James, T. E., Lebedová, N., Urbanová, K., Dalle Zotte, A., Volek, Z., & Kokošková, T. (2025). Effect of wet and dry post-mortem rabbit loin meat ageing on its physicochemical and sensory properties. *Meat Science*, 229, 109901”), evaluates the impact of wet and dry ageing methods and ageing periods on the quality of rabbit *longissimus thoracis et lumborum* muscle. Fifty Hyplus rabbits were slaughtered and the muscles were assigned to wet ageing in vacuum packaging or dry ageing for 7 or 14 days, with analyses conducted on ageing losses, physicochemical quality, lipid oxidation, and sensory attributes. On day 14, wet-aged meat was lighter in colour, redder, and exhibited higher cooking losses. In contrast, dry-aged meat had lower moisture and higher ash content. Dry-aged samples also showed more off-odour on day 7, but by day 14 they developed a more favourable flavour profile.

Such information may serve as a basis for selecting appropriate ageing methods to improve the physicochemical and sensory properties of rabbit loin meat. The study was published in *Meat Science* (<https://doi.org/10.1016/j.meatsci.2025.109901>).

The last three Chapters 7, 8, and 9 consist of the General Discussion, Conclusions and Recommendations, and References utilised throughout the thesis.

CHAPTER 2

Literature review

2.1 Introduction to current rabbit production

Cuniculture, the practice of rearing rabbits for meat, originated in the Mediterranean and North America, where agricultural traditions later underwent industrialization in Europe during the 20th century (Olawale et al., 2025). This shift emphasized improved carcass characteristics and production efficiency through structured breeding programs (Olawale et al., 2025). Globally, rabbit production remains a substantial livestock sector, with approximately 570 million rabbits slaughtered worldwide in 2021, yielding 860,000 tons of meat valued at US\$ 1.5 billion (FAOSTAT, 2021). According to Samkol & Lukefahr (2008), European nations historically accounted for the highest rabbit production output, followed by China, in 2008. Between 2010 and 2020, rabbit meat production declined by 41.2% in Europe, while Africa saw an increase of 23.5%. Overall, global production fell by 24.1% during the same period (FAOSTAT, 2023). Production dropped from 919,978 tons in 2019 to 893,631 tons in 2020, with China as the leading producer, followed by North Korea and Egypt (Figure 2.1). It declined further to 572,210 tons in 2021, partly due to COVID-19 disruptions and meat supply challenges (FAOSTAT, 2023). This decline is likely driven by several factors: waning interest among traditional consumers, urbanization, a larger working population, higher disposable incomes, the availability of convenient ready-to-eat meat products, loss of traditional recipes and cooking skills, animal welfare concerns among both traditional and new consumers, and price parity issues at the production level (Kumar et al., 2025). In the same year, Spain, Hungary, China, and France emerged as the top exporters, driving the US\$ 136.7 million global rabbit meat trade that reached 29,900 tons (Figure 2.2).

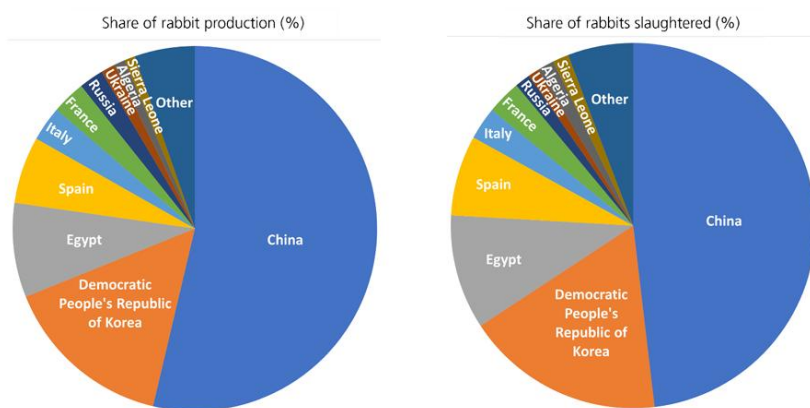


Figure 2.1: The main global rabbit producing countries by share of global meat production (%) and share of global rabbits slaughtered (%)
Source: FAOSTAT (2021)

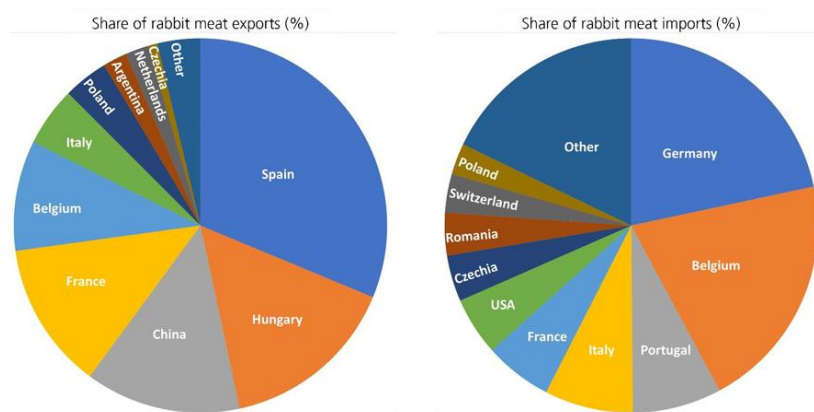


Figure 2.2: The main global exporters and importers of rabbit meat by share of the market (% of tonnage)
Source: FAOSTAT (2021)

The EU is the world's second-largest producer of meat rabbits after China, and accounts for 93% of global rabbit meat imports and exports. Within the EU27, Germany, Belgium, and Portugal are the main importers, while Spain, Hungary, France, and Belgium are the main exporters (Cullere & Dalle Zotte, 2018). Commercial rabbit production is concentrated in Spain, France, and Italy, which together produce 83% of EU output — 48.5 million rabbits in Spain, 29 million in France, and 24.5 million in Italy. Germany, the Netherlands, Poland,

Hungary, Belgium, Portugal, and Greece also have commercial farms, contributing another 14% of European rabbit meat. However, the number of commercial rabbit farms in the EU has declined over the past 20 years — by about 70% in the Netherlands and Belgium and 20% in Hungary — largely due to falling rabbit meat consumption among European consumers.

According to the European Commission, the EU produces 180 million meat rabbits annually. Of these, 66% (119 million rabbits) come from conventional farms and are slaughtered in approved slaughterhouses for human consumption, while 34% (61 million rabbits) are raised and sold through backyard farms and direct/local sales channels (European Commission, 2017). Conventional rabbit farms typically rely on family labour, with farm scale measured by the number of breeding does, which can range from several hundred to several thousand (EFSA, 2005). Approximately 600 breeding does are considered the minimum needed for one full-time farmer to achieve economic sustainability (AHAW et al., 2020). Over time, rabbit farms have also become increasingly professionalized and technically advanced. The EU has approximately 161,000 backyard rabbit farms and 4,500 commercial farms. Rabbit production can broadly be categorized into conventional large-scale systems and niche systems, including floor pens, organic, and outdoor production. Non-conventional systems remain limited and diverse in scale - for example, there are only about 50 organic rabbit farms in France and a few others across the EU (European Commission, 2017).

Most industrial rabbit production in Europe utilizes commercial crossbred ‘hybrid’ lines, with breeding females individually caged for 5–8 weeks pre-mating and lactating does housed individually with their litters (AHAW et al., 2020). These hybrids are developed by crossing lines from pure breeds selected by genetic suppliers. At weaning, either the doe remains and kits are moved, or the doe is moved and kits stay until slaughter in an all-in all-out system. Growing rabbits are mainly reared in dual-purpose cages, with growing use of enriched cages for 4–5 rabbits and, in some farms, elevated pens for groups of 32–36. Over the past decades, genetic selection in rabbits has primarily targeted traits that increase growth rate, muscle mass (Gondret et al., 2005; Hernandez et al., 2006), and in females, litter size and milk production. This intensive selection may have had unintended negative effects on robustness, defined as the ability to maintain high production and normal physiological function across diverse environmental, housing, and production conditions. In addition, breed or genetic line can predispose animals to certain diseases (Sanchez et al., 2012; Rosell & de la Fuente, 2018). However, selection for

reproductive longevity has proven effective in delaying senescence. These genetic lines show reduced sensitivity to external stressors, likely due to greater body mass and energy reserves (Pascual et al., 2013).

Under most production conditions, rabbits are fed complete pelleted diets formulated to meet their physiological and nutritional needs, thereby supporting health and productivity (de Blas & Mateos, 2010; Xiccato & Trocino, 2010; Gidenne et al., 2017). Nutrient requirements vary with genetics, housing conditions, and reproductive/rearing management, as well as interactions among these factors. Specific dietary components, particularly fiber fractions, also play a key role in preventing digestive disorders in growing rabbits (Trocino et al., 2014). For breeding females, feed is typically provided *ad libitum*. Does usually receive a single complete diet formulated to meet the nutritional needs of both the doe and the litter from one feeder. Once kits begin eating solids at 17–21 days of age, they consume the same lactation diet, which is formulated for the high nutrient demands of early lactation. In late lactation, from 24–35 days post-AI, kits may transition to a diet better suited to their developing digestive system (Xiccato et al., 2008; de Blas & Mateos, 2010). Feed restriction is not applied to reproducing does. However, young replacement does may be subjected to quantitative or qualitative feed restriction during rearing to prevent excess fat deposition, particularly when first insemination is delayed. For growing rabbits, feeding strategies vary. Some farms use multiple diets tailored to different growth stages, while others use only one or two diets. Feeding can be *ad libitum* or restricted. Intake is typically reduced by 15–30% relative to *ad libitum*, followed by a period of mild restriction or free access. This practice helps reduce post-weaning digestive disorders and improves feed efficiency (Gidenne et al., 2017).

Rabbit production presents notable environmental and socioeconomic advantages, characterized by low greenhouse gas (GHG) emissions, minimal land requirements, and efficient feed conversion (especially of lower quality feedstuffs and by-products), which collectively result in a small ecological footprint, aligned with sustainable food security objectives (Siddiqui et al., 2024). Although primarily raised for meat, skin, and fur, rabbits are also used as laboratory animals (Jiya et al., 2013). The species has gained attention as a tool for poverty alleviation in developing countries due to its potential to generate income, provide nutritious food, and promote sustainable agriculture (Lukefahr, 2008). Rabbits have a short gestation period of approximately 30 days, the ability to produce multiple litters annually, and low initial investment, making it well-suited for smallholder systems (Akinnusi et al., 2007). Ajala & Balogun (2004) identified rabbit production as a convenient strategy for addressing animal

protein deficiency in developing nations, particularly as rabbits efficiently convert feed, thrive on agricultural by-products and waste materials, and yield nutritious meat. The organic rabbit production sector offers opportunities for market expansion, where promoting rabbit meat as a healthful, natural product could enable small farms to capitalize on emerging demand while contributing to food security, poverty reduction, and sustainable agricultural practices (Samkol & Lukefahr, 2008; Fanatico & Green, 2012).

Production systems utilize both purebred and crossbred rabbits, including local indigenous breeds, though these traditional types may be less suited to modern intensive farming, except in organic systems which are gaining traction commercially (Dalle Zotte & Ragno, 2005; Dalle Zotte, 2007; Dalle Zotte & Paci, 2014). The New Zealand White (NZW) and Californian breeds dominate commercial meat production due to their white fur and favourable meat-to-bone ratio (Spencer, 2011), with the NZW valued for superior mothering ability and carcass quality, while crossbreeding with Californians can enhance litter size and fryer weight. Other meat breeds, such as English Spot and Flemish Giant, typically do not attract premium prices because of their coloured fur, whereas the Altex, a heat-tolerant hybrid of Flemish Giant, Champagne d'Argent, and Californian, is noted for rapid growth and mature weights of ~ 5–9 kg. Breeds are further diversified by purpose, including Angora for wool and meat, Dutch, English Spot, Himalayan, and Polish rabbits for laboratory use, and Holland Lop, Polish, Dutch, and Mini Lop as pet breeds, with many domestic rabbit breeds serving multiple roles across meat, show, laboratory, and fur/wool production (Fanatico & Green, 2012). Although pure breeds and their crossbreeds hold substantial economic importance, locally adapted indigenous genotypes are poorly suited to contemporary intensive rabbit farming (Lukefahr, 1998). However, organic production provides a viable alternative system of production for these genetic types (Dalle Zotte & Ragno, 2005; Dalle Zotte, 2007; Dalle Zotte & Paci, 2014). Hybrid rabbit lines such as Hyplus produced through crossbreeding are currently preferred for meat production, capitalising on the benefits of hybrid vigor (Sanad et al., 2023).

2.2 Sustainable small-scale rabbit production in developing countries

Small livestock systems, with rabbits as a prime example due to their significant economic potential, present a viable strategy for addressing global challenges of poverty eradication and malnutrition by supplying nutritious, low-cholesterol animal protein and increasing income for a growing population (Mukaila, 2022; Silva et al., 2021). Rabbits are microlivestock that can meet household demands, with a single rabbit doe capable of producing up to 47 kg of

meat per year, sufficient for a medium-sized family (Ugosor et al., 2016). They are suitable for both large-scale and small-scale production, requiring minimal space and causing limited environmental pollution. A key advantage of rabbits is their ability to feed on variety of food resources, including conventional feeds, cereals, and various plants (Lukefahr et al., 2010; Medenou et al., 2020; Moningkey et al., 2021). This is facilitated by caecal microbes that enable fibre-rich feed digestion during caecotrophy (Taiwo et al., 1999).

The small-scale rabbit production model proposed by Lukefahr (2004) emphasizes alternative and self-sustaining systems for small-scale rabbit production, where inputs are sourced within the farm, offering a viable approach to poverty alleviation, food security, and sustainable agriculture in developing countries. Smallholder rabbit units, characterized by few breeding rabbits, use of local materials for hutches and equipment, feeding of fresh forage and kitchen wastes, integration with other farm components, sharing of family labour, and consumption of rabbits by the household or through sale of excess stocks in the local market, are well-suited to this model (Finzi, 2000; Lukefahr, 2004). Despite limited economic resources, these units leverage family labour and traditional knowledge, providing a source of income and nutritious food for households, while promoting agroecological practices and contributing to sustainable rural development (Finzi, 2000; Mukaila, 2022; Leroy and Petracci, 2021).

Rabbit production is a significant contributor to the economy of some developing countries, particularly in Africa, where Lukefahr (2004) emphasizes alternative and self-sustaining systems for small-scale rabbit production, where inputs are sourced within the farm. Traditional farms, often oriented towards family consumption and based on renewable resources, dominate the sector, accounting for 64% and 58% of farms in Sub-Saharan Africa and North Africa, respectively (Colin & Lebas, 1996). These farms are typically characterized by small herd sizes, with 8-10 does, and contribute significantly to household food security and income (Colin & Lebas, 1996). Between 1990 and 2010, several African countries reported increases in national rabbit stocks, with some experiencing exponential growth, such as Kenya (145%), Madagascar (130%), Rwanda (172%), and Sierra-Leone (407%) (FAOSTAT, 2011). Rabbit production has also been utilized as a tool for poverty alleviation and community development, targeting vulnerable households, including young people, people living with HIV/AIDS, and recovery programmes from natural disasters (Kamel & Lukefahr, 1990; Kaplan-Pasternak, 2011; Kaplan-Pasternak & Lukefahr, 2011). The success of these initiatives highlights the potential of rabbit

production to contribute to sustainable rural development and improve the livelihoods of small-scale farmers.

The rabbit industry contributes significantly to social development, rural economic growth, and poverty reduction in many nations (Wu, 2022). Its benefits include job creation, easy management, and flexible investment, making it an attractive venture (Wu, 2022). Rabbit meat is a nutritious and culturally valued food source, recommended for patients with coronary heart conditions due to its low sodium and cholesterol content (Cullere & Zotte, 2018; Escribá-Pérez et al., 2019). It is rich in phosphorus, calcium, and vitamin B, making it a popular choice among consumers (Grădinaru, 2017; Nistor et al., 2013). Despite growing interest in rabbit farming, smallholder farmers in developing countries dominate the industry, with limited investment in management practices (e.g., housing, feeding) (Mukaila et al., 2023).

2.2.1 Constraints to rabbit production in developing countries

Despite their efficient digestive physiology, rabbits in developing tropical regions exhibit markedly slow growth rates, with average daily gain (ADG) values ranging from <10 to 21 g/d, in contrast to 35–40 g/d reported in temperate countries (Lukefahr & Cheeke, 1991a). However, direct comparison between temperate and (sub)tropical environments is complicated by the differences in factors such as differences in breed use, production systems, and nutrition, for example. For example, in Nigeria, pre-weaning ADG values as low as 7 g/d have been recorded (Odeyinka et al., 2008), while post-weaning ADG values of 13.8–21.2 g/d were reported for rabbits, depending on their diet (Onwudike et al., 1995). Similarly, Rashwan et al. (1997) observed pre-weaning ADG of 10.2–17.4 g/d and post-weaning ADG of 17.5–19.4 g/d across purebred and crossbred genotypes during hot summer months in Egypt. These suboptimal growth rates are primarily attributed to heat stress and nutritionally inadequate diets, underscoring the critical need for improved feeding strategies and thermal stress mitigation in tropical systems (Finzi, 2000). The challenge is compounded by high feed costs, which limit smallholders' ability to adopt balanced concentrate diets and often result in reliance on low-quality forages or unbalanced farm formulations (Cherwon et al., 2020).

Beyond biological and nutritional limitations, socioeconomic and institutional factors further constrain rabbit production in tropical regions. Cultural preferences can restrict demand, as the absence of a tradition of consuming rabbit meat in some Sub-Saharan African areas limits market development and producer incentives (Price & Regier, 1982; Oseni, 2010).

Disease and mortality are consistently ranked as the most severe barriers to production (Rosell & de la Fuente, 2016), a finding corroborated by other studies that identify pests and diseases as major constraints (Taiwo et al., 1999; El-Ashram et al., 2020). The emergence of myxomatosis in the 1950s caused a marked decline in rabbit population density and altered their distribution (Muñoz 1960). Populations subsequently recovered gradually until the late 1980s, when viral haemorrhagic disease (VHD) emerged (Calvete et al., 2002). VHD triggered a second major decline and led to the local extinction of numerous wild rabbit populations (Villafuerte et al., 1995). These health challenges directly reduce revenue and enterprise profitability. Although modern housing could mitigate heat stress and harsh weather, high construction costs render it unaffordable for most smallholders, a situation linked to poor access to credit facilities and limited government support. Inadequate credit is another severe barrier, restricting farmers' capacity to scale up or adopt improved technologies (Falola et al., 2022b). Compounding these issues, weak government and research institute support, together with poor extension services, limits farmers' access to modern management information and health interventions, thereby contributing to persistent mortality and disease outbreaks.

Climate change further exacerbates production challenges, with farmers reporting increasingly unfavourable weather conditions. Heat stress is a major environmental constraint in tropical and arid regions, causing reduced feed intake, impaired growth, infertility, and elevated mortality in both breeding and growing stock (Saviotto et al., 2012; Cherfaoui et al., 2013; Kumar et al., 2013; Sivakumar et al., 2013). Ambient temperatures exceeding 30 °C are particularly detrimental to reproduction, often leading to infertility in breeding rabbits (Lebas et al., 1986; Lukefahr & Cheeke, 1991b). El-Raffa (2004) ranked heat stress as the most significant challenge facing the rabbit industry in these regions, surpassing poor diet quality, diseases, and parasites, due to its direct effects on feed intake, growth, fertility, and kit survival. Field assessments of heat stress commonly rely on indicators such as animal posture, core body temperature, pulse, and respiration rates (Finzi et al., 1992). Despite these constraints, rabbits are still successfully raised in hot and humid climates, contributing to household nutrition and livelihoods. Therefore, mitigation strategies include enhanced housing designs that improve ventilation and provide shade, breeding schedules timed for cooler early morning hours, and other adaptive management practices that reduce thermal stress (Lukefahr & Cheeke, 1991b; Lebas et al., 1997; Finzi, 2000).

Institutional and policy limitations, coupled with critical environmental conditions, also pose significant challenges to the growth of sustainable smallholder rabbit production systems. A major constraint is the absence of appropriate policy frameworks supporting small stock development, particularly for backyard and smallholder rabbit units (Colin & Lebas, 1996). This gap is compounded by a dearth of strategic development plans that explicitly target rabbit production with a poverty alleviation focus (Lukefahr, 2004). Consequently, despite the documented contributions of rabbits to household nutrition, income generation, and food security (Adu et al., 2005), these benefits remain largely overlooked in national agricultural policies and development initiatives. Nevertheless, case studies of successful self-mobilization by rabbit farmers in Ciskei, South Africa (Zeising, 2000) and Guerrero State, Mexico (Clavel et al., 2004) demonstrate that economically viable, environment-friendly backyard systems can be developed with minimal capital investment and limited external technical assistance. These examples illustrate the potential for community-led models to deliver sustainable smallholder rabbit production that enhances livelihoods for poor families in marginal lands, even within weak institutional environments.

2.3 Challenges for animal feed production

The anticipated growth in global livestock populations is estimated to be 100 billion by 2050 (Yitbarek, 2019). This escalating global demand for animal products, projected to increase by 57% for meat and 48% for milk between 2005 and 2050 (Kirkpinar et al., 2025), poses significant challenges to the sustainability of livestock production systems. This will exert substantial pressure on natural resources, including land and water, and exacerbate climate change and variability if current agricultural practices remain. Livestock farming occupies approximately one-third of the world's ice-free land surface for grazing and one-quarter of cropland for feed production (Kirkpinar et al., 2025), with 33% of croplands dedicated to livestock feed and fodder production. Furthermore, about one-third of global cereal production is allocated to animal feed, competing with human food supply, and posing significant challenges for the sustainable growth of the animal feed industry to provide the necessary feed for the livestock industry to meet the increasing demand in animal products. Intensive cereal crop production is said to contribute towards environmental degradation through overgrazing, deforestation, and GHG emissions (Mottet et al., 2017; FAO, 2010), as natural pastures are cleared for growing crops, thereby decreasing the available grazing area and affecting the natural ecosystem. This underscores the urgent need for sustainable feed production strategies and resource management practices to mitigate these impacts.

Feed production is a pivotal driver of the environmental and economic impacts of livestock production systems globally, accounting for a significant portion of GHG emissions, water usage, and land degradation. Projections indicate a near doubling (1.8–2.3 times) of global feed demand between 2000 and 2050 (Pradhan et al., 2013), exacerbating these impacts. Livestock production systems rely heavily on unsustainable plant-based feedstuffs, such as soybean, maize, and wheat, competing directly with human food production for resources, driven by increasing demand for animal products, human population growth, and climate change impacts (FAO, 2018). Soybean production, a key feed component, has experienced significant growth, becoming one of the most widely grown crops globally, with 87% of output used for oil and meal production (Fraanje & Garnett, 2020). High-protein soybean meal accounts for approximately 70% of global protein meal production, driving growth in soybean production, which is projected to continue with a compound annual growth rate of 5.9% from 2025 to 2032 (Kırkpınar et al., 2025; Fraanje & Garnett, 2020). This growth underscores the urgent need for sustainable feed production strategies, alternative feed sources, such as insect-based proteins or utilisation of food by-products and waste, and efficient resource management to mitigate environmental degradation, ensure global food security, and address the increasing demand for animal products.

Although the global livestock feed industry maintained average annual growth of 3% over the past decade, and 3.7% over the past five years, total feed output (broiler, pig, layer, dairy, beef, aqua, pet, and equine feeds) declined marginally by 0.01% in 2023 to 1,295.28 million metric tonnes compared to 1,295.42 million metric tonnes in 2022 (Kırkpınar et al., 2025). This decline can be attributed to several factors, including the adoption of efficient production systems that optimize feed use, tight margins experienced by feed and animal protein companies, changing consumption patterns driven by inflation and dietary trends, higher production costs, and geopolitical tensions (Kırkpınar et al., 2025). The use of soybean in animal feed raises concerns about food security and sustainability, as it competes directly with human consumption and contributes to environmental degradation (Mottet et al., 2017). Climate change and price fluctuations have further impacted feed production, emphasizing the need for alternative feeds and protein supplements. The pressure on agricultural land is evident, with about 14% of global agricultural land (50% of arable land) under pressure to convert to cropland (Kim et al., 2019), highlighting the urgency for sustainable solutions. Non-conventional feeds, such as insect-based proteins, food by-products and waste, and locally sourced (underutilised) ingredients, can help bridge the feed supply gap, reduce food grain competition, lower costs, and

promote local nutrient self-sufficiency (Onte et al., 2019). Evaluating the environmental, economic, and social impacts of these alternatives is crucial to ensure efficacy, viability, and sustainability, while safeguarding food safety and human health (Muscat et al., 2020). The future of animal feed production depends on the adoption of sustainable and efficient feed production strategies, including the use of alternative feed sources, precision feeding, and reduced waste, to ensure global food security and mitigate environmental degradation.

2.4 Rabbit dietary protein requirements

Rabbits are small herbivores that exhibit selective feeding behaviours, prioritizing nutrient-dense plant components such as tender shoots and leaves over fibrous, older foliage (Olawale et al., 2025). This makes them concentrate selectors that prefer high-energy foods, a behaviour that in the wild facilitates rapid feed intake while minimizing predator exposure (Mayer, 2024). Specific feed ingredients and proportions vary with age, health status, and season (Olawale et al., 2025). The use of concentrate feed by rabbit farmers has increased over the years, particularly during dry seasons when vegetation is scarce. These all-in-one pellet or nugget formulations prevent selective feeding and supply essential nutrients in proportions required for optimum performance. As hindgut fermenters, rabbits digest plant-based feed in the cecum and colon through microbial fermentation, enabling efficient fiber utilization post-gastric digestion (Meredith, 2011). They practice cecotrophy, the reingestion of soft, nutrient-enriched feces produced via the caecum, a process that typically occurs at night and allows absorption of additional vitamins, volatile fatty acids, and microbial proteins synthesized in the cecum (Kohles, 2022). Adequate dietary fiber is critical for rabbits, as digestible fiber supports fermentation activity and cecal health, while indigestible fiber promotes gastrointestinal motility and dental wear (Mayer, 2024).

2.4.1 Dietary protein requirements of rabbits

Protein constitutes a fundamental component of animal physiology, playing a pivotal role in virtually every cellular function, and its synthesis is essential for life (Akande, 2015). As a critical constituent of animal tissues, hormones, and enzymes, protein is integral to the structure and function of living organisms (Halls, 2010). Proteins are involved in a wide array of cellular processes, including the maintenance of neural reactions (homeostasis), formation of the structural unit of protoplasm, synthesis of enzymes that catalyze metabolic reactions, production of antibodies that confer immune defense, and transport of essential compounds (Kerstetter et al., 2005; Akande, 2015).

Furthermore, dietary proteins serve as a primary source of amino acids, which are the building blocks of cellular proteins, highlighting the importance of adequate protein intake in animal nutrition. The synthesis of proteins is tightly regulated by nuclear DNA (deoxyribonucleic acid), which controls the expression of genes responsible for protein production, regardless of their function (Akande, 2015). This emphasizes the critical importance of dietary protein in providing the necessary amino acids for protein synthesis and underscores the need for a nuanced understanding of protein requirements in animal nutrition.

Rabbits require dietary protein to support growth, maintenance, and lactation, with optimal requirements varying by stage: 16% for growth, 18% for lactation (Pond et al., 1995), and 12%, 18%, 16%, and 17% for maintenance, pregnancy, growth, and lactation, respectively (Akande, 2015; Table 2.1). Notably, cecotrophs provide an additional source of microbial protein, contributing to the overall protein economy of the rabbit. However, dietary protein quality is particularly crucial for rapidly growing weanling rabbits, which may not have well-developed cecal fermentation. Studies suggest differing optimal protein levels, e.g., 18-22% for (Omole, 1982) vs. 15% (Adegbola, 1991), for rabbits adapted to tropical environment, likely due to breed, trial duration, protein quality, and location differences. For breeding does, 17-18% crude protein is optimal, while 21% increases milk production but may reduce weaning rate (FAO, 1997). Lactating does, especially those concurrently pregnant, require higher protein levels to avoid negative balance (de Blas & Wiseman, 2003), as protein levels below 18% can impair milk production and suckling rabbit growth if energy is inadequate (Church, 1991), highlighting the need for careful protein management in rabbit production systems. The protein requirements of rabbits vary by stage or production type, as illustrated in Table 2.1.

Table 2.1: Crude protein requirements for rabbits

Rabbit stage (production type)	Crude protein requirement (%)	Reference(s)
Fur (hair) producing	17	Church, 1991
	18	Pond et al., 1995
Lactating	17	NRC, 1977
	16	Pond et al., 1995
Growing (young) rabbits	16	NRC, 1977
	15	Adegbola et al., 1991
Gestation (pregnancy)	18	NRC, 1977
Breeding	17-18	FAO, 1997
Maintenance	12	NRC, 1977
Fattening	15-16	FAO, 1997

Source: Akande (2015)

Protein nutrition assumes particular significance in rabbits producing fur and hair, as these products are predominantly composed of nitrogen-containing compounds and sulphur-containing amino acids, thereby necessitating a dietary crude protein content of at least 17% and a minimum of 0.6% sulphur-containing amino acids (methionine and cystine) to support optimal production (Church, 1991).

Protein digestibility in rabbits declines from 5 weeks of age, shows a further drop following weaning, stabilizes around the 9th week, and then continues to decline gradually thereafter (de Blas & Wiseman, 2003). Excessive dietary protein can have deleterious effects on air quality in rabbit production facilities, as it leads to increased excretion of urea in the urine, which is subsequently converted to ammonia through bacterial action, promoting a cascade of adverse effects (Li et al., 2023). The high-water requirement and resultant urine excretion characteristic of rabbits, coupled with the typically confined and densely stocked nature of rabbit production facilities, contribute to elevated humidity levels, which in turn facilitate the dissolution of ammonia in water vapour, creating an environment conducive to respiratory problems (Pond et al., 1995). The inhalation of ammonia-laden air damages the cilia and mucous membranes in the nasal passages, thereby increasing susceptibility to infection by pathogens such as *Pasteurella multocida*, the causative agent of snuffles (Deeb, 2009). Consequently, controlling ammonia levels through optimal protein feeding strategies and ensuring adequate ventilation is crucial for maintaining the health and welfare of rabbits in production systems.

2.4.2 Amino acid requirements of rabbits

Proteins, the fundamental constituents of living organisms, are composed of amino acids, with growing rabbits requiring a dietary intake of specific amounts of 10 essential amino acids, in addition to two semi-essential amino acids that can partially replace two of the essentials (Akande, 2015; FAO, 1997). The essential amino acids for rabbits include arginine, histidine, leucine, isoleucine, lysine, phenylalanine plus tyrosine, methionine plus cystine, threonine, tryptophan, and valine, which are crucial for maintaining optimal physiological functions, growth, and reproduction (FAO, 1997). Extensive research has been conducted on the requirements of specific amino acids for rabbits, notably arginine, lysine, and the sulphur-containing amino acids (methionine and cystine), with recommended levels varying by stage of production. For example, the recommended dietary levels for grower rabbits (8–12 weeks of age) are 0.6% lysine and 0.7% sulphur-containing amino acids, while breeding does under intensive milk production require higher lysine intake (FAO, 1997). Arginine intake should be at least 0.8% for grower rabbits, with a slightly higher requirement for optimal growth (FAO, 1997). Notably, the margin between required and toxic levels of sulphur-containing amino acids is relatively narrow, whereas lysine and arginine exhibit a wider safety margin (FAO, 1997). For fattening rabbits, a dietary crude protein content of 15-16% should suffice if essential amino acids are balanced and supplied through dietary protein sources (Akande, 2015). Rabbits exhibit a preference for balanced feeds containing essential amino acids, and deficiencies in methionine and lysine can have deleterious effects on growth rate and reproduction (FAO, 1997; Halls, 2010). Cereal grains, commonly used in rabbit diets, are often limiting in methionine and lysine, emphasizing the need for strategic combination of protein sources to meet rabbit protein and amino acid requirements, which range from 12-17% crude protein, with 0.65% lysine and 0.60% methionine (Aduku & Olukosi, 1990). Consequently, a nuanced understanding of amino acid requirements and dietary protein sources is essential for optimizing rabbit production systems.

2.4.3 Microbial protein contribution from cecotrophy

Cecotrophy, the unique behavioural adaptation of rabbits wherein they consume soft faeces (cecotropes) directly from the anus, plays a vital role in their nutritional physiology, providing essential nutrients, including microbial protein, B-complex vitamins, and energy derived from volatile fatty acid production (Pond et al., 1995; FAO, 1997). This phenomenon allows rabbits to adapt to low-protein diets, as the microbial protein present in cecotropes significantly improves the amino acid balance, thereby mitigating the adverse effects of poor

dietary protein quality (Akande, 2015; Pond et al., 1995). The regulation of cecotrophy is a complex physiological process, primarily driven by the metabolic need for amino acids, with rabbits exhibiting a pronounced preference for consuming cecotropes when fed low-protein diets, while avoiding them when fed high-protein diets (Pond et al., 1995). This adaptive mechanism enables adult rabbits to derive approximately 10-20% of their total protein intake from cecotrophy, underscoring the significance of this process in maintaining nitrogen balance (Halls, 2010). Furthermore, cecotrophy has a profound impact on protein digestibility, with restriction of this behaviour resulting in a substantial reduction (up to 20%) in protein digestibility, highlighting the importance of this process in optimizing nutrient utilization (Halls, 2010). The consumption of cecotropes contributes significantly to the amino acid pool, with microorganisms in the caecum producing amino acids that are either absorbed directly through the caecum wall or subsequently absorbed by the small intestine (Halls, 2010; Akande, 2015). Notably, the contribution of microbial protein to the amino acid pool is markedly lower in young rabbits (4-8 weeks of age), emphasizing the critical need for high-quality dietary protein during this growth phase to support optimal growth and development (Akande, 2015).

2.5 Emerging use of non-conventional protein sources (NCAP) in rabbit nutrition

The conventional protein sources utilized in animal agriculture, including soybean meal, fishmeal, and animal by-products, have been extensively employed as primary protein sources in livestock and aquaculture production systems. Notwithstanding their nutritional value, the production of these traditional feed ingredients is inextricably linked to a plethora of environmental challenges that compromise ecosystem integrity and sustainability. Specifically, soybean farming has been a major driver of deforestation, particularly in biodiversity-rich regions such as the Amazon rainforest, resulting in widespread habitat destruction, loss of biodiversity, and increased carbon emissions (Fearnside, 2001; Gibbs et al., 2015). Furthermore, the use of fishmeal, derived from small fish species such as anchovies and sardines, has contributed to overfishing, threatening the long-term viability of marine ecosystems and reducing the availability of fish for human consumption (Naylor et al., 2000; Tacon & Metian, 2015). Animal by-product use is often limited in livestock feed nowadays, due to disease-transfer risks (Saidin et al., 2022). In addition, the production of traditional protein sources is also associated with significant GHG emissions, primarily due to energy-intensive agricultural practices and land-use changes (Steinfeld et al., 2006; Gerber et al., 2013). Moreover, the cultivation of crops such as soybean and maize requires substantial

amounts of water, fertilizer, and pesticides, contributing to water pollution, soil degradation, and the depletion of natural resources (Tilman et al., 2001; Zhang et al., 2015). In light of these challenges, the exploration of alternative protein sources has become a critical research priority, with the aim of improving the sustainability of animal agriculture, ensuring food security, and meeting the nutritional needs of a growing global population (Masako, 2024).

Feed costs can be reduced through the strategic use of non-conventional feed resources (NCFRs). Examples include cassava peels, citrus pulp, palm kernel cake, brewers' grains, and watermelon rinds in tropical regions, and sugar beet pulp, apple pomace, brewers' spent grain, and wheat straw in temperate regions (Abiola-Olagunju & Olusoji, 2015). When properly processed, many NCFRs retain appreciable nutritive value and can be incorporated into rabbit diets to reduce feed–food competition and lower production costs (Jumare et al., 2024). The use of NCFRs, particularly those containing bioactive compounds, has been associated with improvements in meat quality. This suggests a dual role in reducing dietary costs and improving product functionality (Dalle Zotte & Szendrő, 2011). Beyond meat, Olawale et al. (2025) reported that NCFRs could replace 75%–100% of maize in weaned rabbit diets without compromising economic viability or profit margins, though results vary with the type of NCFR and diet formulation. However, when inclusion levels of fruit and vegetable peels exceed 30%, reductions in daily weight gain and feed conversion efficiency have been observed, suggesting that optimal inclusion rates must balance cost savings with growth performance (Haider et al., 2025).

Furthermore, non-conventional alternative protein sources (NCAPs) are gaining traction in livestock nutrition due to their high nutritional value and potential to reduce feed costs. It can be derived from insects, fish, and plant-based sources (Karim & Grace, 2023). Lupin seeds are valued for their high protein content and favorable levels of lysine and arginine. They also contain appreciable amounts of lipids, non-starch polysaccharides, raffinose family oligosaccharides, minerals, and vitamins (Petterson, 2000). Moreover, lupin extracts rich in alkaloids and lupin protein concentrates exhibit anti-inflammatory and antioxidant activities, supporting the potential use of lupin as a nutraceutical or therapeutic ingredient (Danowska-Oziewicz & Kurp, 2017; Magalhães et al., 2017). Black soldier fly larvae are a common high-protein NCAP that can substitute traditional ingredients such as soybean meal (Lu et al., 2022). Despite these benefits for sustainability and efficiency, several challenges limit NCAP adoption. Availability and cost vary by region and season, and regulatory barriers may restrict the use of some NCAP in animal feed (Ravindran & Blair, 1993).

However, given the livestock industry's pressures from disease outbreaks, environmental concerns, and rising demand for farm animal products, exploring alternative protein resources is increasingly important. Because protein is typically the most expensive and scarce dietary component, NCAP use is especially relevant for resource-limited farmers (Ncobela & Chimonyo, 2015). The protein content of NCAP sources ranges from 380 to 650 g/kg (Ravindran & Blair, 1993). Interest in NCAP has grown, partly due to market preferences. For example, chickens fed grasshoppers were reported to have preferred flavor and commanded higher market prices compared to those fed conventional protein sources (Khusro et al., 2012). This has encouraged the use of NCAP as non-conventional feed supplements for poultry. To support sustainable production at both small and large scales in other animals especially rabbits, reliance on seasonal NCAP supplies should be avoided (Ncobela & Chimonyo, 2015). NCAP must be produced, harvested, processed, and stored in sufficient, safe, and consistent quantities. Facilities for these processes should be accessible, hygienic, and affordable. Additionally, local production and recycling of NCAP can reduce waste and pollution while supporting household socio-economic status (Khusro et al., 2012). On a commercial scale, alternative dietary protein sources for rabbit nutrition, and livestock nutrition in general, has recently focused on sources which can be up-scaled, such as insects or alternative and underutilised local plant protein sources. Of particular interest in rabbit nutrition, the use of yellow mealworm (*Tenebrio molitor*) has been considered as an alternative insect protein source (Volek et al., 2021), whilst alternative oilseed crops, such as *Camelina sativa* (L.) Crantz (Volek et al., 2025), have been identified as potential plant protein sources for commercial meat rabbit production.

2.6 Insect as a protein source for livestock nutrition

Insect farming has emerged as a promising solution for alternative protein sources in animal diets, garnering significant attention for its potential to mitigate the environmental impacts associated with traditional protein sources (Hancz et al., 2024). Insects, such as black soldier fly larvae (BSFL) (*Hermetia illucens*), crickets (*Acheta domesticus*), and mealworms (*T. molitor*), are being extensively explored for their high protein content, efficient feed conversion, and low environmental footprint (Hancz et al., 2024). Insect protein is rich in essential amino acids, vitamins, and minerals, making it an excellent nutritional supplement for livestock (Zhou et al., 2022). The protein content of insects can rival that of traditional animal sources, providing a well-balanced nutrient

profile. For instance, BSFL are rich in lysine and methionine, essential amino acids that are often limiting in plant-based protein sources (Hancz et al., 2024).

The production of insect protein offers several environmental advantages. Insects require minimal resources, including land, water, and feed, making them an attractive alternative to resource-intensive crops like soybean and maize (van Huis, 2022). Furthermore, insects can be raised on organic waste products, including food scraps, agricultural by-products, and food waste, thereby reducing waste disposal issues and promoting a circular economy (Van Huis & Gasco, 2023). This approach not only reduces the pressure on natural resources but also contributes to waste management and reduction. Insect farming generates significantly lower GHG emissions compared to traditional livestock farming, making it a more sustainable option for aquaculture, poultry, and pig farming (Masako, 2024). A study by Oonincx et al. (2010) reported that relative to conventional livestock production, insect farming produces lower emissions of ammonia, nitrous oxide, and methane, contributing to a reduced carbon footprint. Conversely, according to Biteau et al. (2026), insect meal, including black soldier fly larvae, mealworms, and crickets, can produce higher carbon emissions than soybean meal. The study reports emissions of 2.8–11 kg CO₂e/kg DM, 21.1 kg CO₂e/kg WM, and 3.0–30.2 kg CO₂e/kg protein. The elevated emissions stem from intensive indoor climate control, specialized high-energy processing, and often high-quality feed inputs. However, insect meal production has sustainability advantages in terms of its reduced requirements for land-usage and water, compared to soybean meal (Biteau et al., 2026).

2.6.1 Nutritional value of insects

Insects boast an impressive nutritional profile (Figure 2.3), rich in proteins, oils, vitamins, minerals, and sugars essential for livestock growth and development (Dobermann et al., 2017). As animal-derived food, insects offer high levels of protein and fat, surpassing traditional livestock meat in energy, protein, fat, polyunsaturated fatty acids, and cholesterol content (Orkusz, 2021). Notably, insects contain a broader range of trace elements than meat, positioning them as a nutritious and healthier alternative (Orkusz, 2021); however, this also depends on the feed provided to the insects. The nutritional diversity of insects is striking, with some species exhibiting exceptional nutritional profiles. For instance, palm weevil larvae, a popular edible insect in Asia and Africa, contain up to 66.3% protein and 37.1% oil (Elemo et al., 2011). Rich in potassium and phosphorus, palm weevil larvae offer a valuable source of essential minerals (Elemo et al., 2011). Their nutritional content can vary depending on morphological type and growth conditions, but they remain a high-quality

protein, oil, and mineral source (Fogang Mba et al., 2018). While some insect species are high in energy due to their fat content, they can also serve as a valuable supplementary nutrient source for humans and livestock (Payne et al., 2016).

Zhou et al. (2022) reported considerable interspecific variation in insect proximate composition, with protein and fat as the primary dry matter components ranging from 6.25% to 80.26% and 2.2% to 58.80%, respectively, as presented in Table 2.2. Moisture content is highest in fresh insects, with an inverse relationship observed between moisture and fat content (Williams et al., 2016). Notably, insects generally exhibit a low ash content, attributable to the absence of calcified skeletons, except for *Musca autumnalis*, which displays an exceptionally high ash content of 63% dry weight, in contrast to 1.2% in *Oxya chinensis* (Finke, 2002). This variability underscores the importance of species-specific analysis for accurate nutritional evaluation and highlights the potential for targeted exploitation of insect nutritional profiles. Furthermore, studying the nutritional value of different insect species under controlled conditions (e.g., farmed under controlled conditions and feed sources) will also provide important representative information.

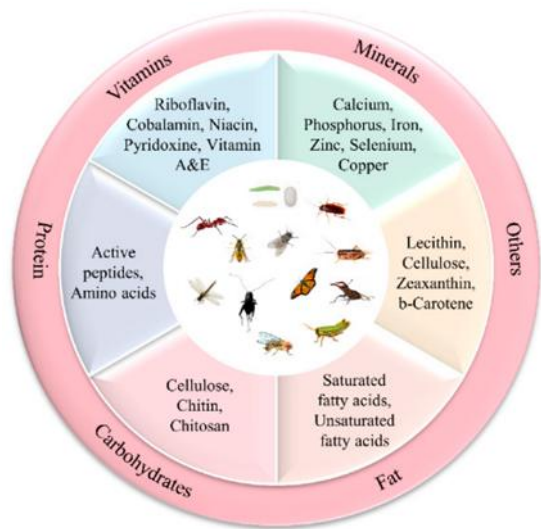


Figure 2.3: Nutritional characteristics of edible insects
Source: Zhou et al. (2022)

Insect proteins emerge as a valuable source of essential amino acids, with a protein content ranging from 35% to 60% dry weight, surpassing that of cereals and legumes, and exhibiting notable variability across species, with *Orthoptera* species such as crickets and locusts demonstrating particularly high protein levels (Rumpold & Schlüter, 2013; Schlüter et al., 2017). Notably, insect proteins contain all eight essential amino acids, which are indispensable for livestock nutrition, thereby positioning insects as a feasible and necessary protein source, capable of supporting immune function, enzymatic activity, and energy production (Chen et al., 2010; Liceaga, 2022). The presence of these essential amino acids in insect proteins (Table 2.3) underscores their potential to address protein deficiencies, warranting further exploration of their nutritional and therapeutic applications.

Insect fats are a valuable energy source and contain essential fatty acids, including linoleic acid and α -linolenic acid (Paul et al., 2017; Ramos-Elorduy, 2008). The fat content of insects varies significantly, ranging up to 43% of dry weight, with notable differences between species, such as 33.40% in Coleoptera and 13.41% in Orthoptera (Rumpold & Schlüter, 2013; Siulapwa et al., 2014). Fatty acid composition (Table 2.4), including saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids, determines the nutritional quality of insect fats, with most insects being rich in beneficial unsaturated fatty acids (Roos, 2018; Zielinska et al., 2014). Insects generally exhibit a fatty acid profile similar to poultry and fish, but with higher levels of unsaturated fatty acids, particularly PUFAs (de Castro et al., 2018). However, exceptions exist, such as *Imbrasia ertli* caterpillars, which contain high levels of saturated arachidic acid (38%). Insects which are high in fat can also be problematic for animal feed, such as rancidity and spoilage (and thus poor shelf-life), milling and pelleting issues, difficulty balancing the nutritional composition of the feed, and animal health and product quality issues (Paul et al., 2017). These issues are addressed by defatting insect-based feed ingredients that are high in fat. Despite their potential, insect fats remain understudied compared to proteins, highlighting the need for further research (Paul et al., 2017).

Insects are a rich and diverse source of essential vitamins (Table 2.5), with levels influenced by species, growing environment, food source, and developmental stage (Finke, 2013; Rumpold & Schlüter, 2013; Mlcek et al., 2014). The vitamin B12 content varies significantly across species, ranging from 0.84 $\mu\text{g}/100\text{ g}$ in grasshoppers to 13.2 $\mu\text{g}/100\text{ g}$ in cockroaches, with some species like diving beetles and crickets exhibiting exceptionally high levels, up to 89.5 $\mu\text{g}/100\text{ g}$ (Schmidt et al., 2019; Okamoto et al., 2021). House crickets are also a good source of B vitamins, including thiamin, riboflavin, and folic acid

(Kinyuru et al., 2015; Payne et al., 2016). In addition to vitamins, insects are rich in essential minerals, particularly iron and zinc, making them a valuable resource for addressing micronutrient deficiencies, which affect 2 billion people globally (Mwangi et al., 2018; Bhutta et al., 2013). Crickets and termites, commonly consumed in Nigeria, are high in iron and zinc, while cricket powders can provide up to 22% of the recommended dietary calcium intake (Christensen et al., 2006; Montowska et al., 2019). Compared to beef, insects like grasshoppers, crickets, and mealworms contain higher levels of bioavailable calcium, copper, magnesium, manganese, and zinc, with crickets exhibiting particularly high iron bioavailability (Jantzen da Silva Lucas et al., 2021).

Furthermore, insects constitute a significant reservoir of minerals (Table 2.6), accumulating these micronutrients through ingestion and serving as a valuable resource for human and animal nutrition (Kinyuru et al., 2015). The presence of these micronutrients is crucial, as deficiencies can precipitate adverse health effects, including growth retardation, anaemia, and inflammatory bowel disease, contributing to approximately one million premature human deaths annually (Fritz et al., 2019; Rempel et al., 2021; Haddad et al., 2016). Notably, micronutrient deficiencies are a pervasive global health issue, underscoring the imperative to enhance food nutrition and explore alternative sources of essential vitamins and minerals. In this context, insects offer a promising solution, providing a wide range of essential micronutrients, and positioning them as a viable alternative to traditional sources, such as fisheries resources, which have been shown to address micronutrient deficiencies (Hicks et al., 2017; Kinyuru et al., 2015).

Table 2.2: Proximate composition (%) of selected insect species

Scientific Name	Moisture	Protein	Fat	Ash	Fiber
<i>Antheraea pernyi</i>	7.6	71.9	20.1	4	NA
<i>Clanis bilineata tsingtaica</i>	NA	65.5	23.68	2.17	3.77
<i>Oxya chinensis</i>	NA	20.8	2.2	1.2	1.2
<i>Schistocerca piceifrons piceifrons</i>	NA	80.26	6.21	3.25	12.56
<i>Gryllus bimaculatus</i>	NA	58.32	11.88	9.69	9.53
<i>Gonimbrasia belina</i>	5.68	46.7	14.04	11.38	NA
<i>Hermetia illucens</i>	5.76	34.9	27.93	7.5	NA
<i>Macrotermes subhylanus</i>	6.40	52.74	6.36	6.41	NA
<i>Macrotermes bellicosus</i>	2.82	20.4	NA	2.9	2.7
<i>Macrotermes notalensis</i>	2.98	22.1	NA	1.9	2.2
<i>Brachytrypes spp.</i>	3.41	6.25	NA	1.82	1.01
<i>Cytacanthacris aeruginosus unicolour</i>	2.56	12.1	NA	2.1	1.5
<i>Zonocerus variegatus</i>	2.61	26.8	NA	1.2	2.4
<i>Analeptes trifasciata</i>	2.19	29.62	NA	4.21	1.96
<i>Anaphe infracta</i>	2.73	20	NA	1.6	2.4
<i>Anaphe recticulata</i>	3.21	23	NA	2.5	3.1
<i>Anaphe spp.</i>	2.52	18.9	NA	4.1	1.68
<i>Anaphe venata</i>	3.34	25.7	NA	3.2	2.3
<i>Cirina forda</i>	4.40	20.2	NA	1.5	1.8
<i>Apis mellifera</i>	3.82	21	14.5	2.2	2
<i>Analeptes trifasciata</i>	2.65	20.1	NA	1.5	3.3
<i>Oryctes boas</i>	1.91	26	NA	1.5	3.4
<i>Rhynchophorus phoenicis</i>	2.74	28.42	NA	2.7	2.82
<i>Gynanisa maja</i>	9.2	55.92	12.1	7.4	NA
<i>Macrotermes falciger</i>	4.1	43.26	43.0	7.3	NA
<i>Ruspolia differens</i>	NA	44.3	46.2	2.6	4.9
<i>Imbrasia belina</i>	NA	56.8	12.9	10.4	NA
<i>Gryllodes sigillatus</i>	NA	70	18.23	4.74	3.65
<i>Schidtocerca gregaria</i>	NA	76	12.97	3.33	2.53
<i>Locusta migratoria</i>	4.2	48.7	38.1	2.3	8.8
<i>Alphitobius diaperinus</i>	2.74	58.76	25.9	3.5	6.08
<i>Rhynchophorus ferrugineus</i>	67.9	18.0	58.8	2.4	NA
<i>Hermetia illucens</i>	61.2	17.5	14	NA	6.8
<i>Chilecomadia moorei</i>	60.2	15.5	29.4	NA	4
<i>Blatta lateralis</i>	69.1	19	10	NA	5
<i>Musca domestica</i>	74.8	19.7	1.9	NA	6.5
<i>Zophobas morio</i>	57.90	19.70	17.70	1.00	6.60
<i>Tenebrio molitor</i>	61.00	18.40	16.80	1.20	5.40
<i>Galleria mellonella</i>	58.50	14.10	24.90	0.60	12.50
<i>Bombyx mori</i>	82.70	9.3	1.40	1.10	2.20
<i>Acheta domesticus</i>	69.20	20.50	6.80	1.10	10.00
<i>Oecyphylla smaragdina</i>	59.50	10.80	10.80	NA	NA

NA: not available, Source: Zhou et al. (2022)

Table 2.3: Essential amino acid composition of different insect species

Scientific Name	Isoleucine (g/kg)	Leucine (g/kg)	Lysine (g/kg)	Methionine (g/kg)	Phenylalanine (g/kg)	Threonine (g/kg)	Tryptophan (g/kg)	Valine (g/kg)	Histidine (g/kg)
<i>Antheraea pernyi</i>	79.5	32.4	45.4	14.7	81	46.4	40.5	66.3	29.4
<i>Bombyx mori</i>	57	83	75	46	51	54	6	56	25
<i>Gryllodes sigillatus</i>	25.6	57.8	38.4	15.9	22.0	36.8	NA	47.0	17.2
<i>Schistocerca gregaria</i>	28.2	77.7	35.1	8.2	18.7	35.5	NA	56.6	20.6
<i>Hermetia illucens</i>	7.62	12.1	11.9	3.37	7.56	6.82	3.00	12.9	5.94
<i>Chilecomadia moorei</i>	6.51	10.1	8.72	2.49	5.47	5.74	1.56	9.71	4.08
<i>Blatta lateralis</i>	7.73	12	12.8	3.35	7.67	7.89	1.66	12.3	5.49
<i>Musca domestica</i>	8.1	12.4	12.6	5.84	7.91	7.54	2.4	11	5.71
<i>Zophobas morio</i>	9.3	19.1	10.3	2.1	6.8	7.8	1.8	10.3	6.0
<i>Tenebrio molitor</i>	8.6	14.3	11.2	2.6	7.5	6.4	1.7	12.2	6.5
<i>Galleria mellonella</i>	6.3	12.4	7.9	2.2	5.3	5.9	1.2	6.8	3.3
<i>Acheta domesticus</i>	9.4	20.5	11.0	3.0	6.5	7.4	1.3	10.7	4.8
<i>Gryllus bimaculatus</i>	9.2	16.5	11.4	3.5	7.4	8.1	2.2	13.6	5.2
<i>Gonimbrasia belina</i>	13.0	18.3	25.6	4.1	13.5	18.4	4.8	19.1	18.4
<i>Gynanisa maja</i>	18.8	27.2	40.2	8.2	19.8	22.6	7.5	20.9	25.3
<i>Ruspolia differens</i>	26.1	26.7	57.4	4.3	26.1	28.6	0.3	16.4	44.1
<i>Macrotermes falciger</i>	18.9	31.6	37.2	8.2	19.7	19.5	3.5	21.7	26.5
<i>Imbrasia belina</i>	22.0	35.0	36.0	9.0	25.0	27.0	7.0	NA	17.0
<i>Apis mellifera</i>	16.0	25.0	19.0	NA	2.0	16.0	NA	17.0	7.0
<i>Rhynchophorus ferrugineus</i>	8	12	11	2	7	8	1	10	4

NA: not available, Source: Zhou et al. (2022)

Table 2.4: Fatty acid composition of insect fats

Scientific Name	C10:0	C12:0	C14:0	C15:0	C16:0	C17:0	C18:0	C20:0	SFA	C14:1	C16:1	C17:1	C18:1	C20:1	MUFA	C18:2	C18:3	PUFA
<i>Zophobas morio</i>	NA	<0.2	1.7	0.4	52.8	0.7	12.6	0.4	68.6	NA	0.7	0.6	66.0	NA	67.3	32.9	1.1	34.0
<i>Tenebrio molitor</i>	NA	0.6	5.2	0.2	25.5	0.2	4.0	0.2	35.9	NA	4.8	0.2	66.4	NA	71.4	49.0	2.2	51.2
<i>Galleria mellonella</i>	NA	<0.2	0.4	<0.2	79.6	<0.2	3.4	0.3	83.7	NA	5.1	0.3	124.0	NA	129.4	15.2	1.1	16.3
<i>Bombyx mori</i>	NA	<0.2	<0.3	<0.4	1.7	<0.2	1.2	0.1	3.0	NA	0.1	<0.2	3.2	NA	3.3	3.5	1.4	4.9
<i>Acheta domesticus</i>	NA	<0.2	0.4	<0.2	15.6	0.2	5.8	0.4	22.4	NA	0.9	<0.1	15.4	NA	16.3	22.9	0.6	23.5
<i>Hermetia illucens</i>	0.69	52.1	12.0	0.12	16.1	0.20	2.45	0.16	83.82	0.12	4.96	<0.08	15.6	<0.08	20.68	16.9	0.65	17.55
<i>Chilecomadia moorei</i>	<0.10	0.93	0.95	<0.10	69.3	<0.10	2.19	0.24	73.61	<0.10	14.7	<0.10	149.0	0.19	163.89	6.99	0.45	7.44
<i>Blatta lateralis</i>	<0.20	<0.20	0.48	<0.20	17.4	<0.20	4.22	<0.20	22.1	<0.20	1.21	<0.20	40.9	<0.25	42.11	21.6	0.71	22.31
<i>Musca domestica</i>	<0.01	0.02	0.32	0.17	3.72	0.10	0.40	0.04	4.77	0.02	1.96	<0.01	2.89	0.01	4.97	4.15	0.45	4.6
<i>Imbrasia belina</i>	NA	<0.1	<0.1	NA	3.0	NA	1.7	<0.1	4.9	NA	0.1	NA	1.8	NA	1.7	1.6	3.7	5.4
<i>Ruspolia differens</i>	NA	NA	NA	NA	32.1	NA	5.9	NA	39.1	NA	1.4	NA	24.9	NA	26.3	29.5	4.2	33.8
<i>Gryllodes sigillatus</i>	NA	0.10	1.65	0.24	23.5	0.32	7.35	0.40	33.74	0.09	3.78	0.29	29.14	1.03	34.33	29.78	2.13	31.91
<i>Schistocerca gregaria</i>	0.07	0.23	1.68	0.09	23.26	0.24	9.27	0.40	35.3	NA	1.80	0.20	36.22	0.14	38.35	14.04	11.35	26.28
<i>Polyrhachis vicina</i>	NA	0.7	0.6	0.1	17.5	0.2	4.3	0.3	23.9	NA	8.2	0.4	63.0	0.7	72.4	2.1	0.2	2.5
<i>Oecophylla smaragdina</i>	NA	0.9	2.1	0.2	20.8	0.3	5.8	1.0	31.9	NA	4.3	0.5	52.1	1.6	58.7	7.0	1.0	8.4
<i>Apis mellifera</i>	NA	0.3	2.4	NA	37.3	NA	11.8	NA	51.8	NA	0.7	NA	47.5	NA	48.2	NA	NA	NA
<i>Rhynchophorus ferrugineus</i>	NA	1	1.6	NA	49.4	NA	0.1	NA	53	NA	NA	NA	46.9	NA	46.9	0.8	0.5	1.3

NA: not available, Source: Zhou et al. (2022)

Table 2.5: Vitamin composition of insect species

Scientific Name	A (IU/kg)	B ₁ (mg/kg)	B ₂ (mg/kg)	B ₆ (mg/kg)	B ₁₂ (µg/kg)	C (mg/kg)	E (IU/kg)	PP (mg/kg)
<i>Hermetia illucens</i>	<1000	7.7	16.2	6.01	55.8	<10.0	6.2	71.0
<i>Chilecomadia moorei</i>	<1000	<0.01	64.5	3.29	5.1	23.0	13.0	33.6
<i>Blatta lateralis</i>	<1000	0.9	15.6	3.10	237	<10.0	<3.3	43.8
<i>Musca domestica</i>	<1000	11.3	77.2	1.72	6.0	<10.0	29.7	90.5
<i>Zophobas morio</i>	<1000	0.6	7.5	3.2	NA	12.0	7.7	32.3
<i>Tenebrio molitor</i>	<1000	1.2	16.1	5.8	NA	24.0	<5.0	41.3
<i>Galleria mellonella</i>	<1000	2.3	7.3	1.3	NA	<10.0	13.3	37.5
<i>Bombyx mori</i>	1580	3.3	9.4	1.6	NA	<10.0	8.9	26.3
<i>Acheta domesticus</i>	<1000	0.4	34.1	2.3	NA	30.0	19.7	38.4
<i>Ruspolia differens</i>	<1000	NA	14	4.4	NA	6.2	22.6	36.1
<i>Macrotermessubhyllanus</i>	<1000	NA	41.8	2.7	NA	7.3	NA	28.0
<i>Oecyphylla smaragdina</i>	NA	2.25	6.75	NA	NA	20.0	NA	NA
<i>Rhynchophorus ferrugineus</i>	NA	NA	NA	NA	NA	NA	18.8	NA

NA: not available, Source: Zhou et al. (2022)

Table 2.6: Mineral composition (mg/kg) of selected insect species

Scientific Name	Ca	P	Mg	Na	K	Cl	Fe	Zn	Cu	Mn	I	Se
<i>Apis mellifera</i>	849	7825	1770	584	18,719	NA	133	116	36	12	NA	NA
<i>Gryllodes sigillatus</i>	1300	NA	1010	3330	11,900	NA	42.3	139	47.9	NA	NA	NA
<i>Schistocerca gregaria</i>	700	NA	820	1730	7490	NA	83.8	186	63.2	NA	NA	NA
<i>Ruspolia differens</i>	245	NA	331	1210	2597	NA	2297	130	25	124	NA	5
<i>Gonimbrasia belina</i>	1278	NA	697	412	102	NA	267	NA	3	15	NA	NA
<i>Gynanisa maja</i>	1664	NA	1000	324	655	NA	136	NA	3	14	NA	NA
<i>Macrotermes falciger</i>	780	NA	490	127	127	NA	248	NA	7	15	NA	NA
<i>Imbrasia belina</i>	570	240	NA	2670	110	NA	1160	NA	NA	NA	NA	NA
<i>Gryllus bimaculatus</i>	2402	11,696	1467	4530	10,799	NA	97	224	46	104	NA	NA
<i>Allomyrina dichotoma</i>	1234	8607	2836	1484	12,491	NA	143	103	14	86	NA	NA
<i>Teleogryllus emma</i>	1935	10,854	1525	2782	8955	NA	108	185	22	59	NA	NA
<i>Rhynchophorus ferrugineus</i>	380	2390	1200	380	5680	NA	10	80	11	6	NA	NA
<i>Hermetia illucens</i>	9340	3560	1740	887	4530	1160	66.60	56.20	4.03	61.80	0.26	0.32
<i>Chilecomadia moorei</i>	125	2250	278	198	2590	1160	14	37.70	2.95	0.71	0.10	0.03
<i>Blatta lateralis</i>	385	1760	250	744	2240	1600	14.80	32.70	7.93	2.64	0.30	0.30
<i>Musca domestica</i>	765	3720	806	1380	3030	1760	125	85.80	12.90	26.60	0.10	0.15
<i>Zophobas morio</i>	177	2370	498	475	3160	1520	16.5	30.7	3.6	4.3	<0.1	0.14
<i>Tenebrio molitor</i>	184	2720	864	489	2970	1750	21.5	44.5	6.4	3.6	<0.1	0.13
<i>Galleria mellonella</i>	234	1950	316	165	2210	640	20.9	25.4	3.8	1.3	<0.1	0.11
<i>Bombyx mori</i>	177	2370	498	475	3160	620	16.5	30.7	3.6	4.3	<0.1	0.14
<i>Acheta domesticus</i>	407	2950	337	1340	3470	2270	19.3	67.1	6.2	11.5	0.21	0.19

NA: not available, Source: Zhou et al. (2022)

2.6.2 Yellow mealworm (*Tenebrio molitor*) and feeding value for livestock

The rules governing the production and use of insects and insect meal differ across countries (Lahteenmaki-Uutela et al., 2017), with the EU having some of the most stringent standards. The EU first authorized seven insect species for use in pet food and aquafeed in 2017 under Commission Regulation (EU) 2017/893, and later extended approval to include poultry and pig feed in 2021 through Commission Regulation (EU) 2021/882 (Toviho & Bársony, 2022). The yellow mealworm, *Tenebrio molitor*, is one of the few insect species well-suited for commercial production at scale (Heckmann et al., 2018). The life cycle of *T. molitor*, illustrated in Figure 2.5, progresses through the egg, larva, pupa, and adult stages, with a total duration varying widely from 280 to 630 days due largely to the larval stage (Makkar et al., 2014). It is the most commonly farmed and traded insect in Europe (Bordiean et al., 2020). In rearing systems, mealworms are typically fed wheat flour or bran, though they are omnivorous by nature (Grau et al., 2017). This species grows quickly, requires minimal inputs for breeding, and is easy to manage (Sankian et al., 2018). It can be reared on a range of low-grade organic substrates, such as agricultural by-products (Van Broekhoven et al., 2015; Zhang et al., 2019; Ruschioni et al., 2020), making it a viable feed ingredient for livestock, especially monogastric animals (Veldkamp & Bosch, 2015; Hong et al., 2020). Notably, *T. molitor* is currently the only one of the seven approved insect species authorized for sale as a novel food under Commission Regulation (EU) 2021/1372 (Toviho & Bársony, 2022).

From an environmental sustainability perspective, the life cycle assessment of *T. molitor* can be compared to conventional protein sources such as meat, milk, fishmeal, and soy, though high energy consumption is required to maintain optimal rearing temperatures (van Huis & Oonincx, 2017). Nevertheless, in terms of direct emissions, insects such as *T. molitor* are more efficient than conventional livestock, producing GHG emissions roughly 100 times lower than the 18% attributed to the livestock sector and significantly lower CO₂ equivalents per unit of edible protein than broiler chickens and beef (Oonincx & Boer, 2012). According to Biteau et al. (2026), insect meal; including mealworms can produce higher carbon emissions than soybean meal. The study reports emissions of 2.8–11 kg CO₂e/kg DM, 21.1 kg CO₂e/kg WM, and 3.0–30.2 kg CO₂e/kg protein. Land use for insect production is also significantly lower than for traditional feed materials (Oonincx et al., 2010) and livestock farming. Producing 1 kg of edible protein from *T. molitor* requires only ~10% of the land needed for beef production (van Huis et al., 2013). Water use is similarly lower compared to traditional livestock (Dobermann et al., 2017; van Huis & Oonincx, 2017). Embracing the circular economy, *T. molitor* can be fed waste raw materials, effectively converting them into high-nutritional-value food through bioconversion (van Huis, 2022). Their ability to thrive on waste further strengthens their role in a circular economy by reducing competition with human food and

valorizing organic waste. In addition, compared to conventional protein sources such as soybean meal and rapeseed meal, *T. molitor* products are currently less cost-competitive in most markets (Mu et al., 2026). Despite energy costs for rearing, the practical application of *T. molitor* products is limited by several factors. These include safety concerns related to allergens, microbial contamination, heavy metal accumulation, and inconsistent quality control during processing and storage (Mu et al., 2026). The lack of harmonized standards and regulatory frameworks also poses a challenge. However, the overall benefits make insect farming compelling for food security, environmental sustainability, and economic viability.

The nutritional composition of *T. molitor* larvae closely resembles that of conventional protein sources, positioning them as a promising alternative source of nutrients for both human and animal diets. *T. molitor* larvae contain high levels of protein and lipids on a dry matter (DM) basis. Crude protein typically ranges from 47–53%, and lipids from 25–35%, depending on diet and developmental stage – this is significantly higher in fat than soybean meal. They supply most essential amino acids and are a good source of minerals, except calcium, though calcium levels can be enhanced through diet and are also a valuable source of vitamins including B₁₂ (Nowak et al., 2016). Despite its high protein content, yellow mealworm faces several key challenges, including poor digestibility, nutritional limitations, and safety concerns. These issues undermine its competitiveness relative to conventional protein sources in commercial livestock production (Lu et al., 2026). The lipid profile includes beneficial fatty acids such as oleic acid (C18:1), linoleic acid (C18:2), and palmitic acid (C16:0) (Kröncke et al., 2019; Trukhanova et al., 2022). Their lipid profile includes a significant proportion of unsaturated fatty acids, notably oleic acid (C18:1) and linoleic acid (C18:2), as well as saturated fatty acids such as palmitic acid (C16:0) (Kröncke et al., 2019; Trukhanova et al., 2022). The favourable nutritive profile is reinforced by the ease of breeding and the reduced environmental impact of *T. molitor* production compared to livestock (van Huis et al., 2013). Given these advantages, *T. molitor* larvae serve as both a promising alternative to conventional feeds and a practical replacement for fishmeal and soybean meal in animal feed formulations (Makkar et al., 2014). Fishmeal, which is widely used in aquaculture, pig, and poultry diets and typically produced from small wild-caught marine fish unsuitable for human consumption, has become less available and more expensive due to overexploitation of wild fish stocks and other factors (FAO, 2016; van Huis & Oonincx, 2017).

LIFECYCLE OF A MEALWORM

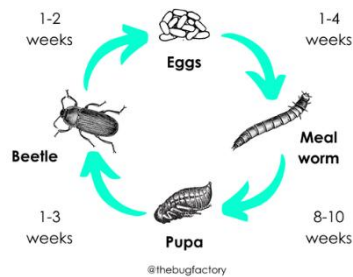


Figure 2.4: Life cycle of yellow mealworm
Source: Shah, A. A. (2021).

Although most studies on *T. molitor* as a feed ingredient have focused on poultry, its use is also being explored in other livestock, such as rabbits. Kowalska et al. (2020) found that adding 4% full-fat *T. molitor* meal to the diet of NZW rabbits improved final body weight and carcass yield. The fatty acid profile was unaffected, but the amino acid composition shifted, with increased levels of isoleucine and methionine in rabbits fed *T. molitor* meal. In a follow-up study, Kowalska et al. (2021) reported that replacing 4% of soybean meal with full-fat *T. molitor* meal similarly increased body weight and muscle fat content, suggesting that partial substitution of soybean meal is feasible in rabbit diets. Strychalski et al. (2021) also observed that 4% full-fat *T. molitor* meal improved apparent total tract digestibility of ether extract, acid detergent fiber, and acid detergent lignin, and enhanced caecal and colonic bacterial N-acetyl- β -D-glucosaminidase activity. However, at this inclusion level, enzyme activity and short-chain fatty acid concentrations in the hindgut were reduced. Complete replacement of soybean meal with 30 g/kg *T. molitor* meal maintained rabbit performance without negative effects (Volek et al., 2021). Rabbits fed *T. molitor* meal also showed lower urinary nitrogen losses and reduced total nitrogen excretion. These results were confirmed in a later study, which found no adverse impacts on growth performance or nitrogen output (Volek et al., 2023). Studies examining the use of *T. molitor* larval fat in rabbit diets, mainly as a replacement for soybean oil, have shown positive outcomes. Replacing 50% or 100% of soybean oil with *T. molitor* fat did not adversely affect growth performance, apparent digestibility, gut morphometric measurements, or organ histopathology. The substitution also had no negative impact on consumer acceptance of the meat and actually decreased its susceptibility to lipid oxidation (Gasco et al., 2019).

2.7 *Camelina sativa* (L.) Crantz and feeding value for livestock

Over the past decade, *Camelina sativa* (L.) Crantz (Figure 2.6) has attracted increasing interest as an oilseed crop due to its environmental adaptability and nutritional composition comparable to conventional oilseeds. It can be cultivated under drought and dryland or rainfed conditions and demonstrates great tolerance to pests and diseases (Waraich et al., 2013). As an annual member of the *Brassicaceae* family, camelina is also referred to as false flax or gold of pleasure. The crop can be grown as either a spring or winter type and has potential as a low-input cover crop in the semiarid Great Plains in the United States (Obour et al., 2015). Previous research in Montana, Wyoming, and Oregon indicates that camelina is well-adapted to the semi-arid conditions of the Northern Great Plains and the Pacific Northwest (Schillinger et al., 2012; Wysocki et al., 2013). In Montana, camelina seed yields range from 700 to 2,000 kg ha⁻¹ with oil concentrations of 290 to 400 g kg⁻¹, depending on precipitation and planting date (McVay & Lamb, 2008). In U.S. trials, winter camelina produced grain yields of 743 kg ha⁻¹ (Zanetti et al., 2020). In Russia and several European countries, Camelina was cultivated as an agricultural crop from before the Second World War through the 1950s and now holds promise as a source of both human food and animal feed (Waraich et al., 2013). In Europe, camelina is currently used commercially mainly as food-grade oil and as feed cake, and is cultivated on an estimated >10,000 ha annually with a significant organic share, although official cultivation data are not publicly available (Zanetti et al., 2021). The *Camelina sativa* advanced breeding line 787–08 outperformed all other entries across Greece, Italy, Poland, and Canada, producing 30% larger seeds and high, stable yields of 1.1–2.7 Mg DM ha⁻¹ (Zanetti et al., 2017).

Camelina's short growth cycle makes it compatible with double-cropping systems involving soybean and maize, while its cold and drought tolerance support its use in wheat-fallow rotations (Veljković et al., 2022). The production of camelina has decreased in the US from 2009 to 2017 (Obour et al., 2015), with 937 acres planted in 2017 (USDA, 2017). This reduction has been attributed largely to lower seed prices associated with declining crude oil prices (Obour et al., 2015). Despite the decrease in planted area, interest in camelina has grown, particularly in relation to expanding biofuel production (Sydor et al., 2022). The seeds contain 38–43% oil, which is utilized for human consumption and biofuel (Veljković et al., 2022). Camelina oil is rich in linoleic and alpha-linolenic acids, giving it value as an edible oil (Moloney et al., 1998). Recent studies have also examined its potential for biofuel production, including aviation fuel (Obour et al., 2015). Expanding camelina and biofuel production is expected to increase camelina meal availability, creating opportunities for its use in animal feeds. Camelina meal is high in crude protein and omega-3 fatty acids, particularly alpha-linolenic acid, making it a promising feed

ingredient, although the presence of anti-nutritional factors may constrain its level of inclusion in livestock diets (Riaz et al., 2022).

Oilseed meals are widely incorporated into livestock diets due to their high crude protein (CP) content. Canola and soybean meals are established protein sources for both ruminant and monogastric species, whereas the use of camelina meal remains less documented (Paula et al., 2019). Camelina meal (or cake) is generally lower in price or competes at a discount compared to mainstream regional oilseed co-products like rapeseed cake (Li & Mupondwa, 2016). Camelina seeds contain substantial oil, but following extraction the residual meal consists primarily of CP and fiber (Colombini et al., 2014).

The nutrient composition of camelina meal is generally comparable to that of canola meal, although it varies with the oil extraction method, with solvent extraction typically producing a meal with reduced fat and elevated CP concentrations (Paula et al., 2019). Given its CP content, camelina meal is most suitable as a protein supplement. Its CP level is similar to canola meal but lower than soybean meal, both of which are routinely used as protein sources in animal feeds (Riaz et al., 2022). Colombini et al. (2014) reported that among 10 camelina varieties, ruminal protein degradation rates ranged from 0.123 to 0.191 h⁻¹ and rumen-unavailable protein (RUP) ranged from 255 to 332 g CP/kg. For comparison, the same study found a canola meal with a degradation rate of 0.156 h⁻¹ and RUP of 275 g CP/kg. Three camelina varieties exceeded the canola meal in RUP, with a mean value of 356 g CP/kg, which is consistent with the recommendation of 350 g CP/kg for ruminant diets (National Academies of Sciences, Engineering, and Medicine, 2016). It should be noted that both the camelina and canola meals in that study were solvent-extracted using a Soxhlet apparatus without heat treatment, a condition that may increase RUP.

In swine, the ileal standardized digestibility of CP was greater for solvent-extracted camelina meal than for expelled meal, 0.67 versus 0.58, even though the solvent-extracted meal had undergone heat treatment, which typically reduces CP and amino acid digestibility (Cerisuelo et al., 2023). Cerisuelo et al. (2023) attributed this result to lower glucosinolate and soluble fiber content in the solvent-extracted meal. The authors concluded that the digestibility of individual amino acids in camelina meal is comparable to that in canola and soybean meals. The amino acid profile of camelina meal also resembles that of canola and soybean meals (Figure 2.6). Glutamate, aspartate, arginine, and leucine are the most abundant amino acids in both camelina and soybean meals, though canola and soybean meals contain higher proportions of lysine (Delver et al., 2024). Processing method does not appear to alter the profile, as no differences were observed between solvent-extracted and expelled camelina meals from the same source (Cerisuelo et al., 2023).

Peiretti et al. (2007) investigated graded levels of *Camelina sativa* seed in rabbit diets and their effects on growth performance, carcass traits, and fatty acid composition of meat and fat. Inclusion of camelina seed up to 15% of the diet (whilst decreasing the corn, barley, and alfalfa meal contents of the diets) did not affect growth performance or carcass characteristics. Although meat chemical composition remained largely unchanged, camelina significantly increased polyunsaturated fatty acids in the *longissimus dorsi* muscle and perirenal fat while reducing saturated fatty acids. This dietary level also decreased the saturation, atherogenic, and thrombogenic indices of rabbit meat. Prola et al. (2011) further confirmed that 15% camelina seed did not increase lipid oxidation in meat or live animals. Together, these studies indicate that oilseeds rich in polyunsaturated fatty acids and antioxidants, such as camelina seed, can improve the nutritional quality of rabbit meat through changes in fatty acid composition.

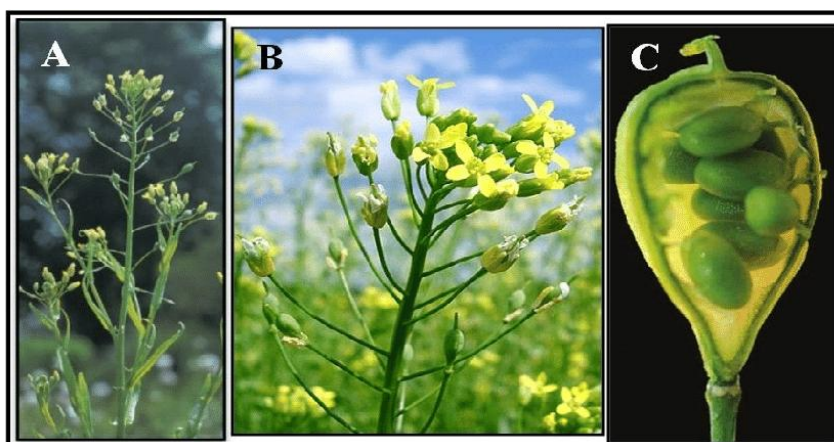


Figure 2.5: *Camelina sativa* (L.) Crantz:
A) camelina branches, B) camelina inflorescences and C) camelina seed pod.
Source: Guendouz *et al.* (2022)

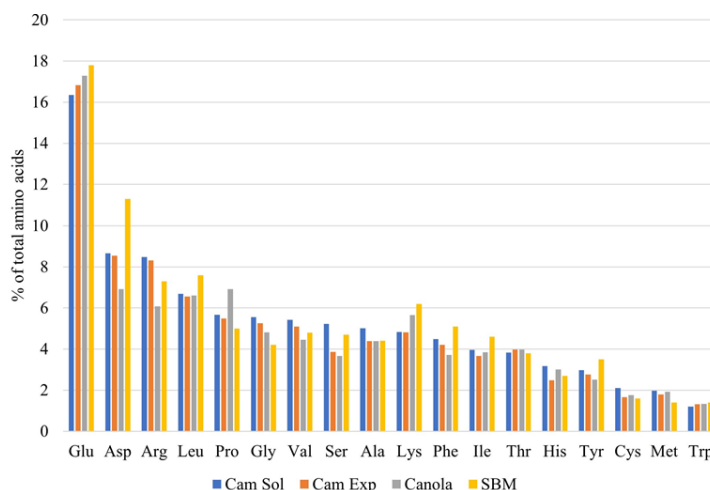


Figure 2.6: Amino acid profile of solvent-extracted (CamSol) and expelled (CamExp) camelina meals, solvent-extracted canola meal (Canola), and solvent-extracted soybean meal (SBM). Glu: Glutamic acid, Asp: Aspartic acid, Arg: Arginine, Leu: Leucine, Pro: Proline, Gly: Glycine, Val: Valine, Ser: Serine, Ala: Alanine, Lys: Lysine, Phe: Phenylalanine, Ile: Isoleucine, Thr: Threonine, His: Histidine, Tyr: Tyrosine, Cys: Cysteine, Met: Methionine, Trp: Tryptophan
Source: Delver et al. (2024)

2.8 Consumer trends and perception of rabbit meat

Rabbit meat production and consumption are expanding in China and Mexico, but have declined in traditional markets such as Italy, Poland, France, and Spain (FAOSTAT, 2020). This shows that consumer attitude is a strong predictor of rabbit meat consumption. Attitude refers to a positive or negative evaluation of a behavior (Cullere & Dalle Zotte, 2018; Szendro et al., 2020), and it is shaped by consumers' beliefs and perceptions about eating rabbit meat (Sanchez-Sabate & Sabaté, 2019). Examining these beliefs and attitudes is therefore essential for understanding consumption trends across countries. Positive beliefs about rabbit meat strengthen positive attitudes, which in turn increase consumption. Key beliefs and perceptions influencing attitude include sensory characteristics, perceived healthiness, convenience, ethical concerns, production methods, and price (Cullere & Dalle Zotte, 2018). Rabbit meat is valued for its high-quality protein content, approximately 20-25% crude protein, containing all essential amino acids with high biological value, including lysine and tryptophan, particularly in breeds such as NZW and Californian (Etukudo et al., 2021). Nutritionally, rabbit meat compares favourably to chicken, beef, and pork, with higher levels of calcium (21.4 mg/100 g) and phosphorus (347 mg/100 g), and lower levels of fat (9.2 g/100 g) and cholesterol (56.4 mg/100 g) (Nistor et al., 2013; Grădinaru, 2017). The meat is exceptionally lean with 1-3% fat (*longissimus thoracis et lumborum* muscle), contains unsaturated fatty acids and low cholesterol that position it as a so-called heart-healthy protein source,

and is also rich in micronutrients such as B vitamins (B3, B6, B12), selenium, zinc, potassium, and phosphorus, enhancing its nutritional profile (Etukudo et al., 2021). Additionally, rabbit meat is versatile, with a mild flavour and suitable for diverse cooking methods (ARBA, 2023) and offers favourable returns on investment especially in developing countries (Narita, 2026). Consumer preferences for meat are largely driven by physical attributes followed by nutritional and chemical qualities, including colour, texture, and taste (Akhigbe & Akaeze, 2023).

Findings on the sensory characteristics of rabbit meat are mixed. Consumers who eat rabbit meat describe it as having a pleasant, delicate flavor, and a tender texture (Adanguidi, 2020; Sanah et al., 2020). In contrast, non-consumers often report an unpleasant taste (González-Redondo et al., 2010). Appearance is also a barrier, especially for younger consumers, who perceive whole rabbit carcasses sold with the head as unappetizing (González-Redondo et al., 2010; Petracci et al., 2018). Regarding healthiness, consumer beliefs about rabbit meat's nutritional value are inconsistent. Some consumers view rabbit meat as healthier than other meats and fish (Petrescu & Petrescu-Mag, 2018), particularly because of its low fat and cholesterol content (Kallas & Gil, 2012). However, most consumers are unaware of its broader dietary benefits (Szendrő, 2016; Sanah et al., 2020). Providing information on the nutritional and health properties of rabbit meat could therefore improve consumer attitudes toward the product (Dalle Zotte & Szendrő, 2011; Escriba-Perez et al., 2017).

Despite these benefits, global acceptance remains limited due to cultural beliefs and food preferences that vary across regions (Petracci et al., 2018). Understanding consumer expectations is therefore important for developing new rabbit meat products effectively (Grunert et al., 2004). Consumer behaviour and meat acceptability are shaped by a combination of internal and external factors that can either encourage or hinder the consumption of specific foods (Popescu et al., 2015). Growing health awareness among consumers has been a key driver of food choice, with Verbeke (2005) finding that acceptance of functional foods is highest among health-conscious groups. Socio-cultural factors also play a role, as consumption patterns for these foods vary across different socio-cultural and ethnic groups (Hasnah Hassan, 2011). Recent social and economic changes have increased consumer interest in convenient food products (Contini et al., 2018). Convenience refers to characteristics that reduce the time and effort required in food preparation and consumption (Brunner et al., 2010). While a wide range of ready-to-cook and ready-to-eat alternatives such as beef and chicken are available, rabbit meat products with convenience features remain limited (Cullere & Dalle Zotte, 2018; Li et al., 2018). Rabbit meat is typically sold as a whole carcass and is associated with traditional recipes that require considerable time and cooking skills (Baviera-Puig et al., 2017). Bone structure also affects ease of consumption. The small size and

fragility of rabbit bones are seen as a barrier, particularly by younger consumers, who find eating rabbit meat difficult (González-Redondo et al., 2010).

Attitudes toward rabbit meat consumption are also influenced by beliefs about production methods, particularly origin and feeding practices. Consumers value local origin both as an indicator of quality and as a way to support the local economy (Szendro et al., 2020). In some parts of Africa, prohibitions still prevent rabbit consumption (Sonandi et al., 1996). For example, Hoffman et al. (2004) reported that in the Western Cape of South Africa, 79% of rabbit meat consumers disliked whole carcass presentation because it resembled a cat or a human infant. Despite Egypt being the leading rabbit producer, rabbit meat accounted for only 3.3% of total household meat consumption (Alboghdady & Alashry, 2010). A similar pattern occurred in Kenya, where consumption frequency remains low even among rabbit farmers (Mailu et al., 2017). Additional barriers relate to animal welfare and consumer perception. Concerns about housing and welfare practices influence purchasing decisions (Petracci et al., 2018), and many consumers now view rabbits primarily as pets rather than as livestock (Leroy & Petracci, 2021). The use of natural feed is also perceived as important for ensuring the healthiness of the meat (Adanguidi, 2020; Szendro et al., 2020). Price perceptions also shape attitudes toward consumption (Hartmann & Siegrist, 2017). Consumer views on rabbit meat pricing are divided. Some perceive it as more expensive than other meats, while others consider it to offer good value for money due to its health benefits (Kallas & Gil, 2012; Adanguidi, 2020). Because production costs are high, lowering the price would reduce profit margins. These factors help explain the downward trend in consumption in established markets. Therefore, improving price perceptions may depend less on price reductions and more on information campaigns that highlight the health benefits of rabbit meat (Adanguidi, 2020). Consumer acceptance of meat from insect-fed animals remains mixed. Many consumers express reluctance to eat meat or fish derived from insect-fed animals, even while they are willing to pay premiums for free-range products that may themselves contain insect-derived feed ingredients (Szendrő et al., 2020). In a study by Laureati et al. (2016), participants were categorized as accepting (53%), uncertain (25%), or disagreeing (22%) with insect inclusion in animal diets, yet all three groups indicated willingness to consume meat from livestock fed insects. Similarly, de Domingues et al. (2020) reported moderate acceptance scores (~3 on a 1–5 scale) for insect-based feeds, with highest acceptance for aquaculture and lowest for cattle. Paradoxically, some of the lowest acceptance rates have been reported in Brazil, despite a tradition of entomophagy (Schardong et al., 2019).

The global industry has also been slow to adopt new processing methods or product innovations that would make rabbit meat more appealing to modern consumers. Given its nutritional profile, there is scope to reposition rabbit meat

through novel products, market entry strategies, and functional foods (Petracci et al., 2018). Meat and meat products are generally regarded as functional foods because they contain multiple compounds with health-promoting properties (Dalle Zotte & Szendrő, 2011). The International Organization for Standardization (ISO) offers one of the most widely used definitions of quality as “the degree to which a set of inherent characteristics fulfills requirements” (International Organization for Standardization, 2015). In the food sector, meat quality has traditionally referred to properties that determine suitability for consumption, further processing, storage, and retail display (Andersen et al., 2005). Although multiple definitions of meat quality exist and are variably accepted, it remains clear that perceptions of quality are largely shaped by socio-economic and cultural factors, including ethics, religious beliefs, and traditions (Font-i-Furnols & Guerrero, 2014). This also applies to rabbit meat (Dalle Zotte, 2002). The quality of meat and meat products is determined by both intrinsic and extrinsic factors, which can be adjusted to make a product more appealing to consumers (Font-i-Furnols & Guerrero, 2014). In highly competitive markets, this is essential, since competitive advantage generally depends on the ability to create differentiated products that align with consumer preferences (Grunert et al., 2004). Therefore, developing new rabbit meat products that meet modern consumer expectations requires a clear understanding of the basic quality parameters of rabbit meat and how potential innovations might influence them.

2.8.1 Qualitative parameters of rabbit meat

Although perceptions of meat quality are relative and terminology varies, a consistent aspect of rabbit meat quality is its nutritional composition (Dalle Zotte & Szendrő, 2011). Fresh, unprocessed rabbit meat contains approximately 119 kcal per 100 g, along with 6.8 g of fat, 1.05 g of saturated fatty acids, 0.96 g of monounsaturated fatty acids, 0.68 g of polyunsaturated fatty acids, 53 mg of cholesterol, 1.34 mg of iron, and 47 mg of sodium (Mačanga et al., 2011). These characteristics make rabbit meat an attractive option for consumers seeking low-fat meat with a high proportion of unsaturated fatty acids and low levels of cholesterol and sodium. As a result, the World Health Organization recommends rabbit meat for children based on its nutritional and dietary profile (Vergara et al., 2005). Nevertheless, a comprehensive evaluation of meat quality requires consideration of not only chemical composition but also physical and sensory, or organoleptic, properties.

Meat typically consists of about 75% water, though this proportion varies with cut size, muscle type, and physical factors such as pH. In rabbit meat, the ultimate pH₂₄ usually falls between 5.6 and 5.85 (Blasco & Piles, 1990). Other quality attributes, including meat colour, water-holding capacity measured by purge, drip, or cooking losses, flavour, tenderness, and shelf life, are also strongly influenced by pH

(Lawrie, 1985). Protein is the second most abundant component of meat. According to Kim & Fagan (2014), average protein content is 11.9% in pork, 15.75% in lamb, 16.3% in beef, 18% in veal, 20% in chicken, 20.1% in turkey, and 20.8% in rabbit meat. Combined with its low-fat content, this high protein level makes rabbit meat a relatively lean source of meat compared to other livestock. The relatively high proportions of polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) in rabbit meat also make it appealing to health-conscious consumers (Leiber et al., 2008). Since the fatty acid composition of meat from monogastric animals depends on both *de novo* synthesis and dietary intake (Dinh et al., 2018; Bravo-Lamas et al., 2018), the fatty acid profile of rabbit meat is shaped by nutrition as well as by genotype, age, and physical activity (Peiretti, 2012). The oxidation of these fatty acids during processing and storage is an important consideration in developing novel rabbit meat products, as it can affect aroma, flavour, and ultimately consumer acceptance (Peiretti, 2012).

Among the physical quality parameters of rabbit meat, colour and appearance are decisive factors in whether consumers accept or reject a product at the point of purchase (Boles & Pegg, 2001). For this reason, colour evaluation is a fundamental component of meat product development research. Meat colour is influenced by multiple factors, including animal species, nutrition, genetics, pre-slaughter handling, post-mortem changes in muscle associated with pH and temperature decline, storage time after slaughter, and processing methods (Cavani et al., 2000). Rabbit meat is typically light in colour, similar to pork, turkey, and chicken, which also display lighter surface colours but are distinguished by a pinkish-gray tone (Goli et al., 2025). Meat tenderness affects how easily meat can be chewed and is regarded as one of the most important eating quality attributes, directly influencing whether consumers repurchase a product (Grunert et al., 2004). Compared to other meat types, rabbit meat ranks highest for tenderness, with low coarseness and a notable level of juiciness (Rødbotten et al., 2004). Instrumentally, tenderness is measured by determining the peak shear force (PSF) required to cut through a cooked meat sample. This method correlates more closely with sensory evaluations of tenderness than compression tests, which are better suited for texture profile analysis (Perry et al., 2001). Huffman et al. (1996) reported that meat with a PSF of ≤ 41 N achieves 98–99% consumer acceptance, while a PSF below 30 N yields near 100% acceptability. Ongoing efforts to improve tenderness are applied throughout commercial meat production, from pre-slaughter husbandry and handling to post-mortem techniques such as carcass suspension methods and meat ageing (Ahnström et al., 2012).

Beyond tenderness, consumers also evaluate other organoleptic properties when judging meat quality, with aroma and flavour standing out as key characteristics. These attributes are shaped by the processing and storage conditions of meat products (Lambert et al., 1991; Shahidi & Zhong, 2010). Many factors

influence aroma, but lipids have been shown to play a particularly strong role in its development (Rabe et al., 2003). The overall flavour of meat, which combines taste and aroma, influences consumer purchasing decisions, preferences, and behaviour (Jayasena et al., 2013). Studies by Gerencsér et al. (2014) and Li et al. (2016) found that while rabbit meat is similar to poultry and other “white” meats in colour and shelf life, it differs notably in flavour. Because of this, identifying the compounds responsible for the flavour of different rabbit meat products is important for understanding and predicting consumer acceptance (Fischer et al., 2014).

Rabbit meat storage requires careful control because of its high moisture, low fat, and high protein composition, which makes it prone to microbial growth, lipid oxidation, and rapid quality loss (Vissio et al., 2024). In terms of packaging, conventional materials like polyethylene and polypropylene offer poor barriers to oxygen and moisture, accelerating oxidation and microbial growth (Dhiman et al., 2025). Furthermore, traditional post-harvest techniques such as drying including air-drying and dehydration, reduces water activity and inhibits microbial proliferation, yielding shelf-stable products, though it can affect texture and lead to nutrient losses if not properly controlled (Sultana et al., 2022). Ageing, or holding carcasses under refrigerated conditions for several days, allows endogenous enzymes to tenderize the meat and develop flavor, but requires strict temperature and hygiene management to prevent spoilage (Racewicz et al., 2023). Vacuum and modified atmosphere packaging are more effective at preserving sensory and nutritional quality by limiting oxygen, but may cause discoloration, textural changes, and require specialized equipment (Wyrwicz et al., 2025). Synthetic preservatives can further extend shelf life, yet raise concerns over endocrine disruption and allergenicity (Shah et al., 2025). Overall, an integrated approach combining appropriate drying, controlled ageing, and advanced packaging is needed to maintain rabbit meat quality while minimizing economic losses.

2.8.2 Meat ageing – can we use it for rabbit meat?

Meat ageing refers to the period meat is held after slaughter, ranging from a few days to several weeks or months, and can be carried out using different methods such as wet ageing in vacuum packaging or dry ageing without packaging. In wet ageing, primal cuts or individual muscles are stored in vacuum-sealed bags under controlled low temperatures to improve tenderness and extend shelf life (Frank et al., 2019). This method is widely used in the meat industry because it is cost-effective, reducing weight loss and trimming waste, requires less storage space, and provides a longer shelf life without negatively affecting eating quality (Kim et al., 2018). Dry ageing, by contrast, involves storing unpackaged meat in chambers where humidity, temperature, and airflow are carefully controlled. The process of ageing influences tenderness as it contributes to the duration period for lipid oxidization and enzymatic

activities, primarily the calpain protease system (Hopkins & Thompson 2002; Herrera-Mendez et al. 2006; Ouali et al. 2013).

Ageing methods can enhance the aroma, texture, and flavour of meat to varying degrees. In beef, extending the ageing period generally improves characteristics associated with flavour, tenderness, and juiciness (Huff-Lonergan & Lonergan, 2005; Kemp et al., 2010; Kristensen & Purslow, 2001). During post-mortem ageing, chemical compounds that influence meat flavour and aroma are also formed, with the specific profile depending on the ageing technique used (Spanier et al., 1990). Wet ageing is intended to produce meat with a flavour profile comparable to that achieved through traditional dry ageing. It typically yields higher market returns than dry ageing due to lower moisture loss (Berger et al., 2018). However, dry-aged meat tends to develop more desirable and distinctive flavours, which has contributed to its popularity and higher premium price (Dikeman et al., 2013; Lee et al., 2019). Dry-aged beef is commonly described as having “broth,” “roasted nut,” “sweet,” “beefy,” and “nutty” flavours, which are generally well received (Warren & Kastner, 1992; Dikeman et al., 2013; Corbin et al., 2015). In contrast, wet-aged beef is often associated with sour, metallic, and bloody notes (Jiang et al., 2010; Terjung et al., 2021), attributes that are less favourable and can reduce consumer acceptance.

During dry ageing, the exposed surface of the meat dries out due to moisture evaporation, making it more vulnerable to mold and yeast growth (Dashdorj et al., 2016; Khan et al., 2016; Lee et al., 2017; Lee et al., 2019). Studies comparing dry and wet ageing report varying levels of moisture loss, largely depending on the specific ageing conditions. Other researchers have also reported higher moisture content in wet-aged meat compared to dry-aged meat (Dikeman et al., 2013; Li et al., 2014; Sitz et al., 2006). As a result, dry-aged meat often shows higher concentrations of protein, ash, and fat relative to wet-aged meat due to this moisture loss. Despite the economic drawbacks of weight and trimming losses associated with dry ageing, the product continues to gain popularity in the red meat industry and commands a premium price because of its distinctive sensory attributes (Ribeiro et al., 2025). Given the distinct physical and sensory properties of rabbit meat compared to beef, the impact of ageing and the specific method used on its quality attributes, as well as on the acceptability of the aged product, should be examined before recommending its use. By initially evaluating key factors that drive changes in sensory characteristics—such as lipid oxidation and volatile compounds—it becomes possible to understand how ageing and different ageing methods influence the eating quality of rabbit meat and its potential role in product development.

In summary, while meat ageing through wet and dry methods has proven effective in improving tenderness, flavour, and shelf life of beef and other red meats, its application to rabbit meat remains largely unexplored. Given the unique physical

characteristics, low fat content, and distinct sensory profile of rabbit meat compared to beef, the effects of ageing duration and method on lipid oxidation, enzymatic activity, and volatile compound formation cannot be directly extrapolated. Wet ageing may offer practical advantages for rabbit meat in terms of cost, yield, and shelf life, but dry ageing could potentially enhance flavour complexity and market value despite higher moisture and trimming losses. In rabbits, trimming losses are inversely related to carcass and muscle size, as smaller animals exhibit a higher proportion of bone and surface area relative to meat, resulting in increased relative waste during cutting and deboning (Ribeiro et al., 2025). Therefore, systematic evaluation of how different ageing methods influence the tenderness, flavour, juiciness, and consumer acceptability of rabbit meat is essential before recommendations can be made. Future research should focus on optimizing ageing conditions specific to rabbit meat to determine whether this post-mortem process can be leveraged to improve product quality and expand its appeal in modern markets.

2.9 Concluding remarks

Rising global demand for sustainable, high-quality animal protein highlights the need for efficient livestock production systems that reduce reliance on conventional feed resources while maintaining product quality. Rabbits represent an attractive species for meeting this demand because of their high reproductive potential, efficient feed conversion, and production of nutritious, lean meat. However, the sustainability of rabbit production is challenged by dependence on imported soybean meal as the primary dietary protein source, while limited product innovation constrains consumer acceptance of rabbit meat. These challenges have driven interest in alternative feed ingredients, such as *Camelina sativa* cake and yellow mealworm (*Tenebrio molitor*) meal, as well as post-slaughter processing strategies such as meat ageing to enhance eating quality. Accordingly, this research sought to investigate the potential of these alternative nutritional and processing approaches to contribute towards the improvement of the sustainability of rabbit production.

CHAPTER 3

General methodology

3.1. Study area description

The studies were carried out at the Institute of Animal Science (IAS), Prague, Czech Republic. Ethical clearance was obtained from the Ethics Committee of the IAS (PPE 1/2023; PPE 2/2022; PPE 3/2023), and the experiment was conducted in accordance with the EC Directive 86/ 609/EEC (EEC, 1986) regarding the protection of animals used for scientific purposes and the guidelines of Act No. 246/1992 (FAO, 1992), protecting the animals against cruelty. All animals slaughtered were done so at the accredited facilities of the IAS.

3.2 Animals and housing

Three separate trials used Hyplus crossbred rabbits under controlled environmental conditions, according to the following summary:

- **Experiment 1 - Lactation trial:** 24 rabbit does were stratified by body weight and parity, then allocated to 2 dietary groups. Does were housed individually in wire-net cages ($50 \times 40 \times 42.5$ cm) with nesting boxes, at 16–18°C, 65% relative humidity, and a 12h light:12h dark photoperiod. Litter size was standardized to 10 kits per doe via cross-fostering. Kits had access to does during controlled nursing from 08:00–10:00 daily.
- **Experiment 2 - Fattening trial:** 168 weaned rabbits (32 days old, both sexes in equal number per sex) obtained from the breeding facility at the IAS (and unrelated to Experiment 1) were randomly assigned to 3 dietary groups, 56 rabbits per group. Rabbits were housed in groups of 4 in wire-net cages ($80 \times 64 \times 45$ cm; $0.12 \text{ m}^2/\text{rabbit}$) at 18–20°C, 65% relative humidity, and 12h light:12h dark.
- **Experiment 3 - Meat ageing trial:** 50 male rabbits raised under the same housing conditions as the fattening trial but fed a standard commercial diet, were slaughtered at 90 days-old and at an average live weight of 3270 ± 321.2 g, following standard commercial protocol.

3.3 Overview of experimental design and data collection

Experiment 1 (**Chapter 4**) - Twenty-four crossbred rabbit does were assigned to 2 dietary groups for 32 days of lactation: 13 does received a soybean meal-based diet, 11 received a yellow mealworm-based meal diet at parturition and without adaptation (complete replacement). The diets were formulated to be isoenergetic and isoprotein. Doe and litter weights were recorded at parturition (after cross-fostering)

and weekly; feed intake was recorded daily to calculate ADG, ADFI, and feed efficiency for does, while litter growth was tracked per litter. Milk yield was measured daily by weighing does pre- and post-nursing. Does did not eat or drink during the nursing period, which lasted only a few minutes (maximum 10 minutes). Milk samples were collected on day 32 of lactation from selected does (five does from each treatment) and chilled for proximate and fatty acid analyses.

Experiment 2 (**Chapter 5**) - One hundred sixty-eight crossbred rabbits of both sexes were weaned at 32 days and randomly assigned to 3 dietary groups with 56 rabbits each, housed 4 per cage. For 42 days, rabbits received isoenergetic, isoprotein pelleted diets differing only in protein source: Control = 10% rapeseed cake; CS5 = 5% rapeseed + 5% camelina cake; CS10 = 10% camelina cake. Housing was under constant conditions: 18-20°C, 65% RH, 12h light/dark, with 0.12 m² floor space per rabbit. Live weight was recorded weekly and feed intake, morbidity, and mortality daily per cage to calculate ADG, ADFI, and FCR. At 74 days of age, 14 rabbits per group were slaughtered without fasting. Carcasses were chilled 24 h at 4 °C, then right hind legs and *longissimus lumborum* muscles were collected for physical and sensory analyses.

Experiment 3 (**Chapter 6**) - Fifty 90-day-old male hybrid rabbits were slaughtered and carcasses chilled 24 h at ~4 °C. At 24h post-mortem, 10 carcasses were sampled for baseline physicochemical analysis of the *longissimus thoracis et lumborum* muscle. The remaining 40 carcasses were assigned to 4 ageing treatments: wet or dry ageing for 7 or 14 days, n=10 per treatment. Wet-aged LTL muscles were removed, weighed, and vacuum-packed; dry-aged carcasses were hung whole in an ageing chamber to reduce moisture loss. All samples were aged under identical conditions: 2°C, 85% RH, 10% air exchange/hour, using beef protocols due to lack of rabbit-specific standards. At days 7 and 14, samples were removed, weighed, and evaluated for physicochemical and sensory traits.

3.4 Data processing and statistical analysis

Experiment 1 (**Chapter 4**): Data were analyzed in Statistica 13 using restricted maximum likelihood method, after confirming residual normality. Diet was the fixed effect; doe nested in diet was the random effect in the models utilised. For repeated measures, day of trial was added as a fixed effect. Initial weights were used as covariates: doe start weight for doe performance, litter d1 weight for litter performance. Means were compared using Fisher's LSD at $P \leq 0.05$. Results are reported as LSMeans $\pm$ SEM.

Experiment 2 (**Chapter 5**): Physical traits, proximate composition, and fatty acid profile/quantity data were analysed by one-way ANOVA using GLM procedure in SAS OnDemand for Academics, with diet as fixed effect. Least square means were

compared using Bonferroni post-hoc test. Sensory data were analysed in SAS 9.4 with a mixed model: diet as fixed effect, day of assessment and assessor as random effects. Physical properties data used a mixed model with diet as fixed and day of assessment as random effect. Tukey's test assessed significance at $P \leq 0.05$.

Experiment 3 (**Chapter 6**): Physicochemical data were analysed in SAS 9.4. Data were tested for normality and homogeneity of variance and met both assumptions. A mixed linear model with GLM procedure was used, with ageing method, ageing period, and their interaction as fixed effects for physicochemical data. For sensory data, ageing method was fixed and assessor was random using MIXED procedure. Treatment means were separated using Tukey's Range Test at $P \leq 0.05$, and results are presented as least square means $\pm$ SEM.

CHAPTER 4

Effect of yellow mealworm meal (*Tenebrio molitor*) on the growth, milk yield, and milk composition of lactating rabbits, and their kits

Unpublished manuscript.

Contributing authors: Aremu, T., Kokošková, T., Volek, Z.

CRedit authorship contribution statement: **Tolulope Aremu:** Writing – original draft, Investigation, Formal analysis. **Tersia Kokošková:** Writing – original draft, Formal analysis, Data curation, Supervision, Funding acquisition. **Zdeněk Volek:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization, Resources, Funding Acquisition, Supervision.

4.1 Abstract

This study evaluated the growth, milk yield, and milk composition of lactating rabbits, and their kits, fed yellow mealworm meal (*Tenebrio molitor*) as a replacement for soybean meal during lactation and kit fattening. A total of 24 crossbred rabbit does were divided into two treatment groups upon parturition, and were fed one of two diets during the lactation period, which lasted 32 days. One treatment group was fed a pelleted soybean-based diet (SBM) while the other group was fed a diet containing yellow mealworm, fully replacing SBM. Litter size was corrected to 10 kits per doe utilizing cross-fostering. Litters from each doe also received creep feed based on a local dietary protein source, white lupine, from 18 – 32 days of age. Data was collected on doe performance (milk yield, milk composition, body weight) during lactation, as well as kit performance (body weight, creep feed intake) throughout the experimental period. Results revealed average daily feed intake, daily milk production, and feed efficiency for the periods from D1-32, D1-21, and D22-32 did not differ between dietary treatments. No significant differences were recorded in chemical, mineral, and vitamin composition of rabbit milk between the two diets. There were also no differences between the dietary treatments for litter weight and ADG per kit over the experimental period. In conclusion, the utilization of 11 g of yellow mealworm diet per kg was equally as effective as the soybean meal in promoting growth performance of lactating does and their kits as well as supporting milk production.

Keywords: Rabbits, *Tenebrio molitor*, Growth, Milk yield, Milk composition

4.2 Introduction

Rabbits (*Oryctolagus cuniculus*) are highly prolific domesticated farm animals with short generation intervals, good mothering ability, and low management requirements (Malik et al., 2020; Onuoha et al., 2020). Rabbit meat is also nutritious, and low in fat and cholesterol, which can positively impact human health (Etukudo et al., 2024). The feeding of rabbits for commercial production requires formulated diets often containing soybean meal (SBM) as the basic protein source, supplied in adequate quantity and quality for their optimal growth rate (Zwoliński et al., 2017). However, the use of SBM as a protein source in livestock feed is increasingly unsustainable, due to its associated costs, the rise in demands by humans for its use as food in various forms and for other industrial purposes, and its environmental footprint (Shaahu et al., 2014). In certain areas of the world, such as many European countries, a huge dependency on the import of soybean exists, particularly since soybean is not cultivated in such areas. A trend has emerged for the partial and/or total omission of soybean from feed rations for most livestock, which is due to the willingness to become independent from imported feed, reduce cost of feed production, and the consumer fear of products containing genetically modified organisms (Tudisco et al., 2006; Zwoliński et al., 2017). Various dietary protein alternatives for SBM have been investigated in the feed of rabbits, including lupins (*Lupinus albus* L.) (Volek et al., 2011; 2018; 2020) and camelina (*Camelina sativa* (L.) Cranz) (Kokošková et al., 2025; Volek et al. 2025). Furthermore, the use of insect protein in animal feeds has also gained interest in the livestock sector, and insect meals have been used to replace conventional protein sources (mainly fishmeal and soybean meals) in fish, poultry and pig feeds (Renna et al., 2017; Biasato et al., 2018; Dabbou et al., 2018). Whilst yellow mealworm meal (YMM) is increasingly produced in Europe for feed and food following EU authorizations, it remains an emerging niche market rather than a fully mature bulk commodity. This also has cost implications, and it is currently more expensive than soybean meal (Biteau et al., 2026). Whilst insect production has advantages compared to livestock production regarding greenhouse gas emissions, its production currently has a greater carbon footprint than SBM (Biteau et al., 2026). However, insect meal production has numerous other advantages regarding sustainability; particularly, the reduced land-usage and water requirements (Cadinu et al., 2020). Furthermore, the production system utilised for insect meal needs to be considered, because if food waste or by-products are utilised in their feeding, then using insect meal as an animal feed supports circular bioeconomy (Jagtap et al., 2021). If insects are fed with diets based on food-grade materials, however, this does not support environmentally friendly approaches.

The potential of insect protein sources, like YMM, in rabbit diets is evident from existing research. Additionally, consumer acceptance of animals fed insect-based diets appears to be positive (Sogari et al., 2019). Studies have shown that rabbits can effectively utilize diets containing various insect meals such as silkworm pupae meal (*Bombyx mori*), maggot meal (*Musca domestica*, larvae), and yellow mealworm larvae (*Tenebrio molitor*) without negatively impacting growth performance (Duwa et al., 2014; Gugolek et al., 2019; 2021; Kowalska et al., 2020; 2021; Strychalski et al., 2021; Volek et al., 2021), feed efficiency (Gugolek et al., 2019; Volek et al., 2021), nutrient digestibility and nitrogen output (Strychalski et al., 2021; Volek et al., 2021), gastrointestinal function (Strychalski et al., 2021), and rabbit meat and carcass quality (Kowalska et al., 2020). These studies suggest that insect protein may be a viable option for enhancing the sustainability of rabbit production, contributing to the further development of circular bioeconomy within industry.

The larvae of the yellow mealworm (YM) are a promising feed option for rabbits due to their high protein content, rich in essential amino acids like lysine, and sulfur-containing amino acids, threonine, and arginine (Makkar et al., 2014; Finke & Oonincx, 2017; Volek et al., 2021). The use of YM-based diets have supported growth performance in rabbits, with improved nitrogen utilization and no adverse effects on mortality, compared to a soybean meal-based diet (Volek et al., 2021). Rabbits fed YM diets showed comparable average daily weight gain, feed conversion ratio, and final live weight to those fed soybean meal (SBM) diets, with reduced urinary nitrogen losses (Volek et al., 2021). Although research on YM in rabbit feed is limited, it has thus shown that it can effectively replace soybean meal (SBM) in the diet of fattening rabbits (Volek et al., 2021). However, its use in lactating does, and the subsequent effect of the maternal lactation diet on their offspring, remains unexplored. Therefore, this study aims to evaluate the effect of the dietary inclusion of yellow mealworm meal on the growth, milk yield, and milk composition of lactating rabbits, and the performance of their kits.

4.3 Materials and methods

4.3.1 Experimental site and diets

This experiment was carried out at the Institute of Animal Science (IAS), Prague, Czech Republic. Ethical clearance was obtained from the Ethics Committee of the IAS (PPE 1/2023), and the experiment was conducted in accordance with the EC Directive 86/ 609/EEC (EEC, 1986) regarding the protection of animals used for scientific purposes and the guidelines of Act No. 246/1992 (FAO, 1992), protecting the animals against cruelty.

4.3.2 Experimental diets

The experimental diets were given to the does at parturition, without prior adaptation. Prior to this, the does received a standard commercial reproduction diet. Two experimental diets (Table 4.1 and 4.2) were formulated to meet the requirements of lactating rabbit does. Both diets had the same basal mixture of ingredients and only varied in the crude protein source; soybean meal (SBM) and insect yellow mealworm meal (YMM). The YMM (full-fat) used was obtained from Underground Food s.r.o. (Brno, Czech Republic). Diets were offered to lactating does in pelleted form (3 mm in diameter and 5–10 mm in length). A pre-milling system with a vertical hammer mill was used for the feed manufacturing process. The diets had similar crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and digestible energy (DE) contents and met the nutrient requirements of lactating rabbits. The YMM diet was higher in ether extract (EE), due to a generally high EE content of YMM. No medication was included in the feed or drinking water throughout the study. The kits were provided with the same standard creep feed based on white lupin seeds, available *ad libitum* (Table 4.3).

Table 4.1: Ingredients and chemical composition of the experimental diets, as well as some chemical composition components of the *Tenebrio molitor* meal only (i.e., prior to feed-mixing). Data are presented as g/kg on an as feed basis, unless stated otherwise.

Ingredient (g/kg, as feed basis)	SBM diet	YMM diet	YMM only
Alfalfa meal	300	300	-
Soybean meal	130	-	-
Sunflower meal	50	65	-
Insect yellow mealworm meal	-	105	-
Wheat bran	80	110	-
Sugar beet pulp	20	20	-
Oats	160	160	-
Barley	220	200	-
Rapeseed oil	10	10	-
Vitamin, mineral and amino acid supplement ¹	10	10	-
Dicalcium phosphate	7	7	-
Limestone	10	10	-
Salt	3	3	-
Chemical composition			
Dry matter ²	895.4	885.9	966.9
Crude protein ³	168	169	521
NDF ⁴	318	317	-
ADF ⁵	188	185	99
ADL ⁶	53	54	-
Ether extract ⁷	28	50	269
Starch	194	183	-
Ash ⁸	66.2	64.4	41.2
Amino acids ⁹			
<i>Asparagine</i>	15.2	14.2	41.5
<i>Threonine</i>	6.3	6.4	20.2
<i>Serine</i>	7.2	7.1	22.9
<i>Glutamine</i>	30.3	28.3	64.9
<i>Proline</i>	10.3	10.9	37.4
<i>Glycine</i>	7.2	7.8	26.5
<i>Alanine</i>	7.4	8.7	37.8
<i>Valine</i>	7.5	7.9	29.4
<i>Isoleucine</i>	6.6	7.4	35.4
<i>Leucine</i>	11	11.2	38.5
<i>Tyrosine</i>	3.9	4.3	32.8
<i>Phenylalanine</i>	7.6	7.2	18.2
<i>Histidine</i>	3.6	3.9	15.5
<i>Lysine</i>	7.7	7.5	26.7
<i>Arginine</i>	9.3	8.7	26.9
<i>Cysteine</i>	2.8	2.6	4.9
<i>Methionine</i>	3.5	3.6	6.9
<i>Tryptophane</i>	19.69	18.41	48.8
Vitamins and minerals ¹⁰			
Ca	10.87	10.13	0.29
P	5.27	5.64	13.99
Mg			2.60
Na			1.82
Vitamin E (mg/kg)			
<i>α-tocopherol</i>	36.3	30.7	ND
<i>γ-tocopherol</i>	4.18	2.93	ND
<i>δ-tocopherol</i>	2.83	0.57	ND
Vitamin A (mg/kg)	2.75	2.56	ND
β-carotene (mg/kg)	2.86	2.64	0.199
Lutein (mg/kg)	11.89	11.18	0.109
Zeaxanthin (mg/kg)	3.59	3.16	0.055
Gross Energy (MJ/kg)	120	118	
Digestible Energy (MJ/kg)	10.3	10.4	

SBM = soybean meal; YMM = insect meal; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin. ¹Included per kg of feed: vitamin A, 12000 IU; vitamin D₃ 2000 IU; vitamin E 50 mg; vitamin K₃ 2 mg; vitamin B₁ 3 mg; vitamin B₂ 7 mg; vitamin B₆ 4 mg; niacinamide 50 mg; Ca-pantothenate 20 mg; folic acid 1.7 mg; biotin 0.2 mg; vitamin B₁₂ 0.02 mg; choline chloride 600 mg; Co 1 mg; Cu 20 mg; Fe 50 mg; I 1.2 mg; Mn 47 mg; Zn 50 mg; Se

0.15 mg,^{2,3,7,8}AOAC International (2005), ⁴Mertens (2002), ⁵AOAC International (2000; Method 973.18), ⁶Robertson and Van Soest (1981), ⁹Volek et al. (2020, 2023), ¹⁰Froescheis et al. (2000).

Table 4.2. Fatty acid profiles of the diets and *Tenebrio molitor* (YMM) meal (% total fatty acids).

Fatty acid	SBM diet	YMM diet	YMM only
C 6:0	0.00	0.00	0.00
C 8:0	0.01	0.02	0.00
C 10:0	0.01	0.04	0.01
C 12:0	0.06	0.22	0.38
C 13:0	0.01	0.02	0.06
C 14:0	0.25	1.55	3.75
C 15:0	0.10	0.14	0.13
C 16:0	15.47	17.88	17.68
C 17:0	0.12	0.20	0.16
C 18:0	2.22	3.45	3.30
C 20:0	0.37	0.32	0.03
C 21:0	0.02	0.02	0.00
C 22:0	0.01	0.01	0.00
C 23:0	0.02	0.02	0.00
C 24:0	0.02	0.03	0.01
Total SFA	18.69	23.92	25.51
C 14:1-n5	0.01	0.02	0.03
C 15:1-n5	0.00	0.00	0.05
C 16:1-n7	0.22	0.71	2.07
C 18:1-n9	29.00	30.71	47.06
C 18:1-n7	1.68	0.95	0.72
C 20:1-n9	0.74	0.43	0.10
C 24:1-n9	0.05	0.07	0.05
C 22:1-n9	0.01	0.05	0.00
Total MUFA	31.71	32.94	50.08
C 18:2-n6	40.79	35.58	23.54
C 18:3-n6	0.10	0.12	0.02
C 18:3-n3	7.63	5.44	0.74
C 20:2-n6	0.06	0.09	0.00
C 20:3-n6	0.01	0.05	0.03
C 20:4-n6	0.05	0.02	0.01
C 20:3-n3	0.02	0.03	0.01
C 20:4-n3	0.00	0.00	0.00
C 20:5-n3	0.22	0.20	0.01
C 22:4-n6	0.09	0.05	0.01
C 22:5-n3	0.61	1.56	0.04
Total PUFA	49.58	43.14	24.41
<i>Total n-3</i>	8.48	7.22	0.79
<i>Total n-6</i>	41.11	35.91	23.61
<i>n-6/n-3</i>	4.85	4.98	29.92
Total UFA	81.29	76.08	74.49
UFA/SFA	4.35	3.18	2.92

SBM = soybean meal; YMM = insect meal; TMM = *Tenebrio molitor* meal; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids.

Table 4.3: Ingredients and chemical composition (g/kg on as-fed basis unless otherwise stated) in the diet for growing rabbits.

Ingredients	g/kg, as feed basis
Alfalfa meal	270
White lupine seeds (cv Zulika)	100
Sugar beet pulp	100
Wheat bran	320
Oat	120
Barley	60
Vitamin and mineral premix ¹	10
Dicalcium phosphate	5
Limestone	10
Salt	5
Chemical Composition	
Dry matter ²	882
Crude protein ³	163
Ether extract ⁴	39
Neutral detergent fibre (NDF) ⁵	402
Acid detergent fibre (ADF) ⁶	200
Acid detergent lignin (ADL) ⁷	44
Starch ⁸	158
Ash ⁹	71
Lysine ¹⁰	7.4
Sulphur amino acids ¹¹	5.7
Threonine ¹²	6.1
Gross energy (MJ/kg)	16.5

¹ Included per kg of feed: vitamin A, 12,000 IU; vitamin D₃, 2000 IU; vitamin E, 50 mg; vitamin K₃, 2mg; vitamin B₁, 3 mg; vitamin B₂, 7 mg; vitamin B₆, 4 mg; niacinamide, 50 mg; Ca-pantothenate, 20 mg; folic acid, 1.7 mg; biotin, 0.2 mg; vitamin B₁₂, 0.02 mg; choline chloride, 600 mg; Co, 1mg; Cu, 20 mg; Fe, 50 mg; I, 1.2 mg; Mn, 47 mg; Zn, 50 mg; Se, 0.15 mg. ^{2, 3, 4, 8, 9}AOAC International (2005), ⁵Mertens (2002), ⁶AOAC International (2000; Method 973.18), ⁷Robertson and Van Soest (1981), ^{10, 11, 12}Volek et al. (2020, 2023), ¹³Adiabatic calorimeter

4.3.3 Animals, experimental design, and lactation performance

A total of 24 crossbred rabbit does (Hyplus PS 19 × Hyplus PS 40) were divided into two dietary treatment groups. Does were stratified according to body weight (4th parity does), with one group consisting of 13 rabbit does fed a pelleted soybean-based diet (SBM) while the other consisted of 11 rabbit does, which were fed a diet containing yellow mealworm meal (YMM) as the main dietary protein source (Table 4.1), for a duration of 32 days during lactation. Litter size was standardized to 10 kits per doe, utilizing cross-fostering at parturition, and without adaptation. Prior to this, the does received a commercial reproduction diet. Parturition occurred on 31 days of pregnancy for all does included in the experiment.

Litters were housed with their mothers in modified cages (92 × 72 × 45 cm) equipped with two feeders, allowing separate distribution of solid feed to rabbit does and kits (Fortun-Lamothe et al., 2000; Volek et al., 2014, 2018). The cage was divided into two sections by a wire mesh partition positioned in the middle of the cage, while the nest box remained inside the cage. The nest box was equipped with two entrances, one facing the doe section and the other facing the litter section. Access from the doe side remained closed except during nursing. The doe entrance was opened once daily in the morning at a fixed time (09:00 h) for a maximum of 10 min, as rabbit does typically nurse their litters only once per day for a few minutes (Xiccato et al., 2004; Maertens et al., 2006). Environmental conditions were controlled throughout the experiment, including room temperature (16–18 °C), relative humidity (65%), and a photoperiod of 12 h light and 12 h dark.

The initial weights of all rabbit does and their litters were measured at parturition, after crossfostering. Body weights (BW) of does and kits were recorded weekly, whereas feed intake was recorded daily. Until weaning, the growth performance (weight and creep feed intake) of the litters was monitored on a per-litter-basis and not individually. Milk production was recorded on a daily basis and was estimated from the difference in doe body weight measured immediately before and after nursing (Lebas, 1968). Doe feed efficiency was calculated as the litter weight gain from d1 to d21 of lactation (g) divided by the feed intake of the does from d1 to d21 of lactation (g).

Five does from each of the two lactation diets were used to evaluate milk composition, including dry matter (DM), crude protein, fat, ash, and fatty acid (FA) profile. Milk samples (25–35 mL) were collected on day 21 of lactation, as kits rely exclusively on maternal milk during the first three weeks of life. In addition, milk composition remains relatively stable throughout lactation until the end of the third week (Maertens et al. 2006).

All litters (of both maternal dietary treatment groups) were fed the same diet based on a local protein source – white lupine seeds – (Table 4.2) for growing-fattening rabbits, *ad libitum* from d 17 to 32 (weaning) of age. Litter BW were recorded weekly from birth to d 32 of age. The litters were weighed before suckling. The solid feed intake of litters was recorded daily from d 18 to 32 of age, and the health status of litters were checked daily.

4.3.4 Analytical methods

Chemical analyses of the YMM itself (i.e., prior to feed mixing) and both experimental diets, as well as the milk samples, were performed following official procedures of the AOAC International (2005) for ether extract (EE) (920.39) using a Soxtec 1043 (FOSS Tecator AB, Höganäs, Sweden), starch (920.40), dry matter (DM) (934.01) and crude protein (CP) (954.01) via calculation after nitrogen content analyses using a Kjeltac Auto 1030 Analyser (FOSS Tecator AB, Höganäs, Sweden). Gross energy (GE) was determined by combustion in an adiabatic calorimeter (C5000 control, IKA-Werke, Staufen, Germany). Neutral detergent fibre (NDF) was determined following the methodology of Mertens (2002), with heat-stable amylase and corrected for residual ash, ash-free acid detergent fibre (ADF) content was determined following the AOAC International (2000; Method 973.18), and acid detergent lignin (ADL) content was quantified following Robertson and Van Soest (1981).

To determine the amino acid content of the feed and milk samples, they were hydrolyzed in 6 M hydrochloric acid at 110 °C for 23h and analyzed using an Amino Acid Analyzer AAA-400 (INGOS Ltd., Prague, Czech Republic) equipped with an ion exchange column, as described by Volek et al. (2020, 2023). Fatty acid composition was determined after chloroform-methanol extraction of total lipids (Folch et al., 1957).

α -tocopherol, δ -tocopherol, γ -tocopherol, and β -carotene contents were determined using high-performance liquid chromatography, fitted with a diode-array detector (VP series) (Shimadzu, Kyoto, Japan), according to the following European standards: EN 12822 (2000) and EN 12823-2 (2000). Furthermore, the same equipment was utilised to analyse lutein and zeaxanthin contents, according to Froescheis et al. (2000).

The chemical composition of the experimental diets, and the YMM alone, can be found in Table 4.1, and the dietary fatty acid compositions are provided in Table 4.3.

4.3.5 Statistical Analysis

Data was analyzed using Statistica 13 (StatSoft Inc.). Normality of the residuals were confirmed and the restricted maximum likelihood method was utilized to evaluate the treatment effects. Fixed effects included the effect of diet (soybean meal vs insect meal) whilst random effects included doe nested in diet. When data was analyzed over the trial period, day of the trial was included as a fixed effect. When doe performance data was analyzed, initial weight at the start of the study was utilized as a covariate. When litter performance data was analyzed, initial litter weight on d 1 was utilized as a covariate. Means were compared using Fisher's Least Significant Difference post-hoc tests. All results are reported as the Least Square Mean (LSMean) $\pm$ standard error of the mean (SEM). A significance level of 5% was used throughout.

4.4. Results

4.4.1. Performance of lactating rabbit does

There were no differences between the diet treatments for doe body weight, milk yield, and feed intake over the trial period. Whilst these parameters changed over the lactation period (i.e., the main effect of day was significant; $P < 0.001$), there were no significant interactions between dietary treatment and day of lactation, thus following the same pattern of change for both dietary treatments. Additionally, the average daily feed intake and daily milk production for the periods from D1-32, D1-21, and D22-32 did not differ between the dietary treatments (Table 4.4). There tended ($P = 0.090$) to be differences for the ADFI between d 22 to 32 of the trial, where does fed the insect meal diet had lower ADFIs than those fed the soybean meal diet. However, differences ($P = 0.009$) were found for doe feed efficiency from d1 to d21 of lactation, where those does fed the insect meal diet had a higher feed efficiency (Table 4.4).

Table 4.4: Rabbit doe performance during the 32-day lactation experiment, fed either soybean (SBM) meal or insect meal (YMM) as a primary protein source. Data is presented as the LSMean $\pm$ SEM.

Parameter	SBM diet	YMM diet	P-value
Rabbit doe body weight (g)			
immediately after parturition	4173.0 $\pm$ 314.02	4152.0 $\pm$ 285.96	0.389
at D21	5027.7 $\pm$ 67.39	5110.8 $\pm$ 73.37	0.417
at weaning (D32)	5149.9 $\pm$ 161.42	4950.3 $\pm$ 127.43	0.709
Average daily feed intake (g/day)			
D1–D21	466.9 $\pm$ 18.07	430.4 $\pm$ 18.67	0.300
D22–D32	542.8 $\pm$ 17.03	492.5 $\pm$ 17.9	0.090
D22–D32	493 $\pm$ 17.19	451.9 $\pm$ 13.32	0.131
Daily milk production (g/day)			
D1–D21	284.9 $\pm$ 11.52	273.3 $\pm$ 12.03	0.755
D22–D32	296.4 $\pm$ 16.84	282.5 $\pm$ 15.47	0.872
D22–D32	288.8 $\pm$ 12.44	276.7 $\pm$ 11.87	0.794
Feed efficiency¹			
D1–D21	0.3 $\pm$ 0.01	0.4 $\pm$ 0.02	0.009

SBM = soybean meal; YMM = insect meal

¹Litter weight gain from d1 to d21 of lactation (g)/ feed intake of the does from d1 to d21 of lactation (g)

4.4.2. Milk composition

No significant differences were found for the chemical composition, mineral composition, and vitamin composition of the milk from the does fed the two different diets (Table 4.5). However, several differences were found in the fatty acid composition of the milk (Table 4.6). Milk from rabbit does fed SBM had significantly higher percentages ($P = 0.001$) of total saturated fatty acids compared to those fed YMM, primarily attributed to increased levels of C8:0, C10:0, and C12:0, despite YMM-fed does having milk with higher C13:0, C14:0, and C20:0. Conversely, milk from YMM-fed does exhibited higher percentages ($P < 0.001$) of total monounsaturated fatty acids, driven by elevated levels of C18:1-n7. Furthermore, YMM-fed does produced milk with greater percentages ($P = 0.036$) of polyunsaturated fatty acids (PUFA), particularly n-6 ($P = 0.015$) fatty acids, including C18:2-n6 and C22:4-n6. As a result, milk from YMM-fed does had increased n-6/n-3 and UFA/SFA ratios.

Table 4.5: Rabbit doe milk composition after feeding either soybean (SBM) meal or yellow mealworm meal (YMM) as a primary protein source. Data is presented as the LSMean $\pm$ SEM.

Parameter	SBM diet	YMM diet	P-value
Chemical composition (g/kg)			
Dry matter	24.1 $\pm$ 1.19	25.0 $\pm$ 1.34	0.911
Crude fat	10.8 $\pm$ 1.03	11.7 $\pm$ 1.11	0.597
Crude protein	9.6 $\pm$ 0.40	9.6 $\pm$ 0.24	0.630
Ash	2.0 $\pm$ 0.07	2.0 $\pm$ 0.03	0.331
Minerals			
Ca (g/kg)	5.4 $\pm$ 0.28	4.9 $\pm$ 0.14	0.142
P (g/kg)	3.1 $\pm$ 0.17	3 $\pm$ 0.07	0.712
Mg (g/kg)	0.4 $\pm$ 0.02	0.4 $\pm$ 0.01	0.172
Na (g/kg)	1.3 $\pm$ 0.1	1.2 $\pm$ 0.14	0.418
K (g/kg)	1.3 $\pm$ 0.19	1.5 $\pm$ 0.18	0.558
Fe (mg/kg)	4.4 $\pm$ 0.32	4.4 $\pm$ 0.44	0.919
Cu (mg/kg)	1.4 $\pm$ 0.1	1.5 $\pm$ 0.15	0.879
Zn (mg/kg)	15.9 $\pm$ 1.48	15.3 $\pm$ 0.59	0.699
Mn (mg/kg)	0.4 $\pm$ 0.1	0.4 $\pm$ 0.06	0.966
Vitamins (mg/kg)			
α -tocopherol	3.8 $\pm$ 0.55	3.7 $\pm$ 0.23	0.788
γ -tocopherol	0.2 $\pm$ 0.02	0.2 $\pm$ 0.02	0.809
Vitamin A	1.7 $\pm$ 0.15	1.9 $\pm$ 0.17	0.513

Table 4.6: Milk fatty acid composition (% of total fatty acids) from does fed lactation diets containing either soybean meal (SBM) or yellow mealworm meal (YMM). Data is presented as the LSMean $\pm$ SEM.

	SBM diet	YMM diet	P-value
Fatty acids (% of total fatty acids)			
C 4:0	0.112 $\pm$ 0.0082	0.115 $\pm$ 0.0102	0.813
C 6:0	0.415 $\pm$ 0.0081	0.354 $\pm$ 0.0294	0.082
C 8:0	29.712 $\pm$ 0.8280	24.311 $\pm$ 1.1645	0.005
C 10:0	25.103 $\pm$ 0.7224	20.617 $\pm$ 0.7237	0.002
C 11:0	0.014 $\pm$ 0.0009	0.014 $\pm$ 0.0012	0.908
C 12:0	3.255 $\pm$ 0.1735	2.638 $\pm$ 0.1952	0.046
C 13:0	0.009 $\pm$ 0.0007	0.017 $\pm$ 0.0017	0.003
C 14:0	1.337 $\pm$ 0.1159	1.657 $\pm$ 0.0321	0.029
C 15:0	0.223 $\pm$ 0.0087	0.226 $\pm$ 0.0099	0.795
C 16:0	10.059 $\pm$ 0.5994	11.004 $\pm$ 0.5473	0.278
C 17:0	0.222 $\pm$ 0.0124	0.235 $\pm$ 0.0118	0.448
C 18:0	2.181 $\pm$ 0.1427	2.514 $\pm$ 0.1628	0.163
C 20:0	0.050 $\pm$ 0.0030	0.069 $\pm$ 0.0073	0.041
C 21:0	0.026 $\pm$ 0.0007	0.026 $\pm$ 0.0013	0.77
C 22:0	0.004 $\pm$ 0.0005	0.005 $\pm$ 0.0002	0.086
Total SFA	72.73 $\pm$ 1.283	63.81 $\pm$ 1.007	0.001
C 14:1-n5	0.117 $\pm$ 0.0103	0.118 $\pm$ 0.011	0.921
C 16:1-n7	0.728 $\pm$ 0.1647	0.999 $\pm$ 0.1222	0.224
C 18:1-n9 t	0.056 $\pm$ 0.005	0.057 $\pm$ 0.0053	0.838
C 18:1-n11t	0.062 $\pm$ 0.0033	0.071 $\pm$ 0.0125	0.465
C 18:1-n9	12.059 $\pm$ 0.4587	18.725 $\pm$ 0.4097	< 0.001
C 18:1-n7	0.58 $\pm$ 0.0464	0.54 $\pm$ 0.0406	0.537
C 20:1-n9	0.161 $\pm$ 0.0055	0.155 $\pm$ 0.0088	0.606
C 22:1-n9	0.014 $\pm$ 0.0007	0.013 $\pm$ 0.0018	0.664
Total MUFA	13.8 $\pm$ 0.676	20.7 $\pm$ 0.55	< 0.001
C 18:2-n6 t	0.016 $\pm$ 0.0005	0.021 $\pm$ 0.0024	0.116
C 18:2-n6	10.888 $\pm$ 0.5484	12.919 $\pm$ 0.3781	0.016
C 18:3-n6	0.117 $\pm$ 0.0283	0.224 $\pm$ 0.0469	0.086
C 18:3-n3	1.896 $\pm$ 0.0839	1.731 $\pm$ 0.0538	0.137
C 18:2 (9,11)	0.043 $\pm$ 0.0069	0.053 $\pm$ 0.0084	0.395
C 18:2 (10,12)	0.004 $\pm$ 0.0004	0.004 $\pm$ 0.0003	0.742
C 20:2-n6	0.084 $\pm$ 0.0051	0.089 $\pm$ 0.0112	0.702
C 20:3-n6	0.05 $\pm$ 0.0072	0.041 $\pm$ 0.0035	0.332
C 20:4-n6	0.223 $\pm$ 0.0346	0.237 $\pm$ 0.021	0.730
C 20:3-n3	0.009 $\pm$ 0.0004	0.009 $\pm$ 0.0008	0.712
C 20:4-n3	0.007 $\pm$ 0.0005	0.007 $\pm$ 0.0005	0.880
C 20:5-n3	0.04 $\pm$ 0.0054	0.03 $\pm$ 0.0031	0.127
C 22:4-n6	0.044 $\pm$ 0.0024	0.031 $\pm$ 0.0024	0.006
Total PUFA	13.47 $\pm$ 0.65	15.48 $\pm$ 0.465	0.036
<i>Total n-3</i>	2.005 $\pm$ 0.0826	1.864 $\pm$ 0.0538	0.189
<i>Total n-6</i>	11.422 $\pm$ 0.568	13.563 $\pm$ 0.4059	0.015
<i>n-6/n-3</i>	5.693 $\pm$ 0.1112	7.277 $\pm$ 0.0532	< 0.001
Total UFA	27.27 $\pm$ 1.283	36.19 $\pm$ 1.007	0.001
UFA/SFA	0.38 $\pm$ 0.025	0.57 $\pm$ 0.025	0.001

SBM = soybean meal; YMM = yellow mealworm meal; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids

4.4.3 Kit performance until weaning

Regarding the litter weight and ADG (g/kit/day) over the experimental period, there were no significant diet effects. These parameters changed over the lactation period (i.e., the main effect of day was significant; $P < 0.001$), but there were no significant interactions between dietary treatment and week of the experiment, and thus kits followed the same growth pattern for both maternal dietary treatments. Additionally, the litter weight at d 1, 21, and 32 as well as the ADG (g/kit/day) for the periods from d 1-32, d 1-21, and d 22-32 did not differ between the maternal dietary treatments (Table 4.7). Only the ADFI of the pellets (g/kit/day) tended to differ ($P = 0.066$), being marginally lower in kits from does fed YMM-based feed (Table 4.6). No morbidities or mortalities were reported during the experimental period before weaning.

Table 4.7: Litter performance parameters for rabbits from does fed either soybean meal (SBM) or yellow mealworm meal (YMM) as a protein source for the maternal diet. 24 does were included in the analyses, with litter size standardized to 10 kits per doe. Data is presented as the LSMean $\pm$ SEM.

Parameter	SBM diet	YMM diet	P-value
Rabbit litter weight (g)			
immediately after parturition	656.9 $\pm$ 18.23	681.1 $\pm$ 27.19	0.456
d 21	3569.7 $\pm$ 137.42	3551.1 $\pm$ 147.02	0.927
at weaning (d 32)	7368 $\pm$ 223.33	7270.8 $\pm$ 236.3	0.768
Average daily gain (g/day)			
d 1 - d 21 (Week 1 – 3)	13.7 $\pm$ 0.66	13.8 $\pm$ 0.76	0.717
d 22 - d 32 (Week 3-5)	34.2 $\pm$ 1.44	34.2 $\pm$ 1.2	0.860
d 1 to d 32 (Week 1-5)	20.8 $\pm$ 0.68	20.8 $\pm$ 0.82	0.730
Milk Efficiency¹	0.34 $\pm$ 0.015	0.35 $\pm$ 0.014	0.606
Average daily feed intake (g pellets/kit/day)			
d 18 - d 32	16.0 $\pm$ 0.16	15.9 $\pm$ 0.14	0.066

SBM = soybean meal; YMM = yellow mealworm meal

¹Litter weight gain from d 1 to d 21 of lactation (g/kit/day) / milk intake (g/kit/day)

4.5. Discussion

The lactation diets in this study exhibited comparable chemical compositions, including amino acid profiles, indicating that protein quality and quantity were likely not limiting factors. This suggests that YMM-based diets have great potential as a suitable alternative to conventional soybean, given its high-quality proteins with adequate amino acid scores for livestock nutrition (Nasir et al., 2024). However, the YMM-based diet had a higher ether extract content, potentially influencing energy density and fatty acid metabolism. The high fat content in insect meals can lead to an excess dietary lipid supply (Veldkamp and Vernooij, 2021). The YMM diet's fatty acid profile was characterized by elevated total saturated fatty acids and reduced polyunsaturated fatty acids and total unsaturated fatty acids compared to

SBM-based diets, consistent with reports on mealworm fatty acid profiles (Palupi et al., 2025). The balance between PUFA and SFA is influenced by feed and fat sources (Chaves et al., 2019; Simopoulos, 2016), with animal fat sources typically having higher SFA content and plant fat sources being richer in PUFA (Chaves et al., 2019). Additionally, the YMM diet had lower vitamin E levels than the SBM diet, likely due to plants' higher vitamin E production through photosynthesis (Mène-Saffrané, 2018). However, the current study revealed that doe weight, milk yield and feed intake, and feed efficiency were statistically similar between lactating rabbit does fed SBM- and YMM-based diets, implying that the inclusion of *T. molitor* in the diet had no detrimental effect on the performance of lactating rabbits. This may be due to the similar chemical composition of the experimental diets, being almost identical in their energy, starch and fiber fractions. Typically, feed intake of rabbits is affected by dietary fiber content (De Blas et al., 1981) and dietary digestible energy content to some extent (Xiccato and Trocino, 2020). In earlier studies of Volek et al. (2021; 2023), the effect of feeding *T. molitor* to broiler rabbits was investigated. In the first study, two diets were formulated, namely 60 g/kg SBM or 30 g/kg YMM as the main crude protein source (Volek et al., 2021). Whilst a lower ADG was recorded between 32 and 53 day of age, lower ADFI between 32 and 79 days of age, and a lower live weight at 53 days for rabbits fed YMM compared to SBM, the overall ADG, FCR, and final live weight of the rabbits, and the total tract apparent digestibility (CTTAD) of the diets, were not affected by the treatments (Volek et al., 2021). Nitrogen excretion was affected by feeding YMM, with a higher nitrogen retention coefficient for rabbits fed the YMM-diet. Similar results were reported by Volek et al. (2023), feeding diets with 60.00 g/kg SBM and 38.50 g/kg YMM to fattening rabbits.

The present study found that the chemical, mineral and vitamin composition of milk samples collected from rabbit does fed SBM- and YMM-diets were comparable. The slight differences are likely due to genotype differences. The current study showed that the fatty acid profile of rabbit milk is significantly affected by the dietary protein source, consistent with previous research (Pascual et al., 2003; Maertens et al., 2006). Despite YMM-based diet having a higher total SFA content (23.92%) compared to SBM-based diet (18.69%), milk from does fed SBM exhibited higher total SFA, C8:0, C10:0, and C12:0, suggesting other factors such as hindgut fermentation, metabolic processes, or selective absorption may be influencing the results. A significantly greater MUFA content was observed in the milk of rabbits fed the YMM diet, likely associated with the high proportion of MUFA in YMM. The elevated n-6/n-3 ratio in milk from YMM-fed does may have implications for the nutritional quality of rabbit milk and potentially impact the health and development of suckling kits (Ulbricht & Southgate, 1991). Volek & Marounek (2011) have also reported that replacing conventional protein sources with whole white lupin seeds

affects rabbit milk fatty acid profiles, improving saturation, atherogenic and thrombogenic indexes in rabbit products from does fed whole white lupine seeds.

The similarities between body weights of kits from does fed SBM- and YMM-dietary treatments monitored at different intervals of this study supports the suitability of YMM in replacing SBM in rabbit doe nutrition without negatively affecting the growth of their kits. The ADG was also unaffected by the maternal dietary treatment. Whilst no other information regarding feeding YMM to does and the effects on the kits exists, Volek et al. (2021) recorded lower growth rates in growing rabbits during the first 3 weeks after weaning and lower feed consumption during the entire fattening period in rabbits fed *T. molitor*-based diet when compared to those fed the SBM-based diet. The authors attributed the lower growth rate and feed intake to the lower CP content in their *T. molitor*-based diet. The absence of morbidities or mortalities during the current trial indicates that all diets were well-tolerated and supported the health and well-being of the rabbits.

4.6. Conclusion

It could be concluded that the utilization of yellow mealworm was equally as effective as the soybean meal in promoting growth performance of lactating does and their kits as well as supporting milk production in rabbit does. It can be assumed that the dietary requirements of lactating rabbit does were likely met by the YMM-based diet, due to comparable feed intakes, weight maintenance, and milk yields. However, the differences in milk fatty acid composition observed between diets suggest that yellow mealworm altered the lipid profile transferred to milk. Therefore, further investigation into the long-term effects of YMM on milk FA profiles is warranted to fully assess its suitability as a sustainable protein alternative.

Chapter 5

Assessing the impact of dietary *Camelina sativa* (L.) Crantz inclusion on meat quality and sensory traits of growing rabbits

Published as: Kokošková, T., Pontalti, E., Aremu, T. S., Tůmová, E., Chodová, D., Bureš, D., Lebedová, N., Volek, Z., Singh, Y., Cullere, M., & Palumbo, B. (2025). Assessing the impact of dietary *Camelina sativa* (L.) Crantz inclusion on meat quality and sensory traits of growing rabbits. *Meat Science*, 219: 109679. <https://doi.org/10.1016/j.meatsci.2024.109679>

This chapter is a literal copy of the published article, only formatting changes have been included to align the manuscript with the overall thesis.

CRedit authorship contribution statement: Tersia Kokošková: Writing – review & editing, Formal analysis, Supervision; Emanuele Pontalti: Writing – original draft, Formal analysis; Tolulope Sabainah Aremu: Writing – original draft, Formal analysis; Eva Tůmová: Writing – review & editing, Formal analysis; Darina Chodová: Writing – review & editing, Formal analysis; Daniel Bureš: Writing – review & editing, Formal analysis; Nicole Lebedová: Formal analysis; Zdeněk Volek: Resources, Project administration, Conceptualization; Yazavinder Singh: Formal analysis, Data curation, Software; Marco Cullere: Writing – review & editing, Data curation; Bianca Palumbo: Formal analysis; Incoronata Galasso: Resources; Antonella Dalle Zotte: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

5.1. Abstract

This study investigated the effects of dietary *Camelina sativa* oilseed cake (CSC) inclusion on the meat quality and sensory traits of growing rabbits. A total of 168 crossbred 32-day-old rabbits (both sexes) were randomly allocated into three experimental groups: a Control diet (10 % rapeseed oilseed cake as main crude protein source), CS5 diet (5 % rapeseed oilseed cake and 5 % CSC), and CS10 diet (10 % CSC). After slaughter (74 days of age), *longissimus lumborum* (LL) muscles and hind legs (HL) were dissected and their meat were evaluated for physical traits (LL and *biceps femoris*; BF), sensory attributes (LL), proximate composition and fatty acid (FA) profile (whole HL). The CSC inclusion did not significantly affect physical meat traits, except for yellowness, which decreased ($P < 0.05$) in both BF and LL muscles. Meat water content decreased linearly with CSC inclusion ($P < 0.05$). The FA profile of the HL meat was modified in rabbits fed CSC-containing diet: decreased saturated FA ($P < 0.001$) and monounsaturated FA ($P < 0.001$) and increased polyunsaturated FA ($P < 0.001$). Omega-3 FA content linearly increased with the CSC inclusion level ($P < 0.001$) and, consequently, the n-6/n-3 ratio decreased (halved ratio in CS10 compared to Control; $P < 0.001$). The CS10 treatment had the highest fatty flavour, rancid flavour, abnormal flavour intensity, and overall flavour intensity. However, overall acceptance was not affected. These findings suggest that CSC can be a viable protein source for sustainable rabbit production and healthy meat for consumers.

Keywords: *False flax, Fatty acids, Meat quality, Oryctolagus cuniculus, Proximate composition, Sensory analysis*

5.2. Introduction

The global meat demand is projected to increase over the next 20 years, driven by population growth (Woods & Fearon, 2009). The availability of meat and other food animal protein is therefore required to meet human nutrient requirements. Rabbit meat is a lean, protein-rich food source with high biological value, rich in vitamins and minerals (Dalle Zotte, 2004). Its chemical composition varies depending on fat content, carcass portion, and feeding factors (Dalle Zotte, 2002; Pla, Pascual, & Ariño, 2004). With an average fat content of 6.8 %, rabbit meat has a lower energy value compared to red meats (Dalle Zotte, 2004; Hernández & Gondret, 2006). Moreover, rabbit meat consumption is not restricted by religious beliefs (Nistor et al., 2013). Rabbit production offers a promising solution to meet the increasing demand for protein-rich food, in particular to help improve food security in countries where part of the economy is supported at the household level, especially by women. However, rabbit production faces sustainability challenges due to reliance on conventional feedstuffs like sunflower and soybean, responsible for price volatility, feed-food competition, and environmental impacts (Singh, Cullere, & Dalle Zotte, 2023). The need to identify sustainable and economically viable alternatives to conventional feedstuffs is urgent, to ensure the long-term viability of rabbit production and contribute to global food security.

Camelina sativa (L.) Crantz, a member of the Brassicaceae family, is a promising crop due to its rich nutrient composition. It is an annual dicotyledonous plant species that is commonly known as camelina, false flax, or gold of pleasure and serves as a source of edible oil rich in polyunsaturated fatty acids (PUFA), like α -linolenic acid (>35 % total fatty acids, FA) and linoleic acid (>17 % total FA), and MUFA, like eicosenoic acid (>19 % total FA), oleic acid (>14 % total FA), and erucic acid (<4 % total FA) (Cullere et al., 2023). The potential to utilise camelina in its entirety offers economic advantages (Righini, Zanetti, & Monti, 2016), as its by-products can be valorised in various industries, including animal feed, biofuel production, and biopolymer manufacturing (Zanetti et al., 2021). Moreover, *Camelina sativa* contains bioactive compounds like polyphenols and tocopherols, as well as good amounts of protein, and fibre, making it a valuable resource (Kurasiak-Popowska & Stuper-Szablewska, 2020). The presence of these bioactive compounds, combined with its fatty acid profile, makes camelina a promising crop for various applications. Camelina seeds are also a protein-rich source (24.5–30 % of their weight), containing essential and non-essential amino acids (Singh, Cullere, Tůmová, & Dalle Zotte, 2023). These seeds however contain anti-nutritional compounds, including glucosinolates, condensed tannins, sinapine, phytic acid, and trypsin inhibitors (Juodka et al., 2022; Russo & Reggiani, 2017). Thus, further research is needed to fully understand the nutritive potential of *Camelina sativa* and its by-products, as well as its suitability for livestock feeding.

Camelina seed oil, accounting for 36.8 % of the seed's weight, is distinguished by its unique fatty acid composition, featuring a high content of n-3 PUFA, α -linolenic acid (ALA; C18:3 n-3) (Juodka et al., 2022). The oil extraction process yields significant amounts of by-products, including camelina seed oil cake (CSC), approved as a feedstuff only in 2008 by the European Commission (EC), which concluded that its glucosinolates content has not particular effect on both animal and consumer welfare (European Commission [EC], 2008). Since its approval, CSC has gained interest as a cost-effective alternative protein feedstuff and valuable resource in animal nutrition (Zanetti et al., 2021). While its crude protein content is comparable to rapeseed cake (RSC), it is lower than soybean meal (Ja' skiewicz, Sagan, & Puzio, 2014; Pekel, Kim, Chapple, & Adeola, 2015). However, CSC contains higher crude fat and crude fibre contents than soybean and RSC (Ciurescu, Ropota, Toncea, & Habeanu, 2016; Juodka et al., 2022). Previous research has extensively investigated the use of CSC in poultry diets to optimise performance and meat quality. Lolli et al. (2020) and Cullere et al. (2023) explored the effects of CSC on performance and meat quality of broiler chicken and quails, respectively, whereas Aziza, Panda, Quezada, & Cherian (2013) examined the effects of CSC on laying hen performance and egg quality. A 15 % inclusion level of CSC impaired quail performance, as reported by Cullere et al. (2023), but carcass yield and meat quality results were inconsistent across studies. Some research found no significant effects on broiler chicken carcass traits with 2.5–10 % CSC inclusion (Aziza, Quezada, & Cherian, 2010; Orczewska-Dudek & Pietras, 2019), whereas Pekel et al. (2009) reported negative effects on carcass traits at a 10 % inclusion level. In ducks, Juodka et al. (2018) found that 15 % or 20 % CSC inclusion altered carcass weight. Camelina cake inclusion had a positive effect on muscle SFA content in chickens, with significant reductions in breast and leg meat (Nain, Oryschak, Betti, & Beltranena, 2015). Additionally, CSC inclusion decreased MUFA content in breast and leg meat, and in liver (Juodka et al., 2018; Nain et al., 2015; Orczewska-Dudek & Pietras, 2019). Despite these findings, literature on CSC inclusion in rabbit diets and its impact on rabbit meat quality is still limiting, pivoting the need for this study. This study therefore investigated the inclusion of CSC in rabbit diets, leveraging the aforementioned nutritional benefits to promote sustainable and efficient feed formulation, aiming also to further enhance rabbit meat healthiness.

5.3. Materials and Methods

5.3.1 Ethical statement

The welfare and well-being of the rabbits utilised were carefully considered for the entire period of the experiment. Animals had access to water and feed ad libitum. As to the protection of rabbits used in this experiment, the rules stated in EC Directives 86/606/EE (European Economic Community [EEC], 1986), and guidelines of Act No. 246/1992 protecting animals against cruelty, were followed. The study was carried out upon approval of the Ethics Committee of the Institute of Animals Science (the code of the approval is E3/2023, Prague, Czech Republic).

5.3.2. Experimental design

The study was carried out in a rabbit facility located at the Institute of Animal Science (IAS, Přátelství 815, Prague, Czech Republic). A total of 168 crossbred rabbits (line Hyplus PS 19 x Hyplus PS 40) of both sexes were selected and, after weaning (at 32 days old), randomly allocated to one of the three experimental groups (56 animals per group; 14 replicated cages/treatment). During fattening, rabbits were reared in groups of four inside wire-net cages ($80 \times 64 \times 45$ cm), thus having 0.12 m^2 floor space for each rabbit. Environmental conditions were maintained constant for the entire period of the trial using a forced ventilation system. Room temperature was set to between 18°C and 20°C , with a mean relative humidity of 65 %. The photoperiod was set to 12 h of light and 12 h of dark. From weaning up to slaughter (42-days period), rabbits were fed with three experimental diets offered as pellets (3.5 mm in diameter $\times$ 5–10 mm long) and formulated to be isoenergy, isoprotein, and to have similar dietary levels of crude fibre (CF), neutral-detergent fibre (NDF), acid-detergent fibre (ADF), and acid-detergent lignin (ADL), differing only in the main crude protein source. The control diet (Control) contained 10 % rapeseed (*Brassica napus*) cake as the main crude protein source. The CS5 diet contained 5 % rapeseed cake and 5 % camelina cake, while the main protein source of CS10 diet was camelina cake at 10 %. The experimental diets were also formulated to comply with the dietary recommendations for growing-fattening rabbits (de Blas & Mateos, 2020). No additional dietary fat sources and synthetic amino acids were included. The detailed chemical composition of the CSC and the three experimental diets can be found in the first part of the Supplementary Table 5.1.

During the fattening period, rabbit live weight was recorded each week, whereas feed intake, morbidity, and mortality rates were recorded daily for each cage. The average daily weight gain, feed intake, and feed conversion ratio (FCR) were calculated afterwards. Moreover, the digestive health of rabbits was also recorded daily according to the definitions of the European Group on Rabbit Nutrition (Fernández-Carmona et al., 2005). However, the latter data will be reported elsewhere, and only general results will be indicated in the results section. At the end

of the fattening period (74 days of age), 14 rabbits per group (one male from each cage, representative in terms of average group weight) were selected, weighed, and slaughtered without previous fasting in an authorised experimental slaughterhouse of the IAS, in accordance with the recommendations of the World Rabbit Science Association (Blasco & Ouhayoun, 1996). After electro-stunning, rabbits were slaughtered by cutting the carotid arteries and jugular veins. The fresh carcasses were then chilled at +4 °C for 24 h in a ventilated room, following the harmonizing criteria of Blasco & Ouhayoun (1996). After chilling, the right hind legs (HL) and both *longissimus lumborum* (LL) muscles were separated from each carcass to perform the physical analyses, which were conducted at the Czech University of Life Sciences Prague. LL muscles were used also for sensory analysis at the sensory laboratory of the IAS.

5.3.3. Physical analyses

The chilled HL were individually weighed and then used to measure meat ultimate pH (pHu) and L*a*b* colour, specifically at the level of the *biceps femoris* (BF) muscle. The same measurements of pHu and colour were also done on the LL muscles, according to Krunt et al. (2022). pHu was measured using a calibrated spear-type probe pH-meter with thermal compensation (pH 70 Vio, XS Instruments, Carpi, Italy), while colour data were taken using the CIE L*a*b* system (Commission Internationale de l'Éclairage [CIE], 1976) with a portable calibrated spectrophotometer (CM-700d, Konica Minolta, Osaka, Japan; 8 mm aperture diameter size, 0 % UV; D-65/10° illuminant/observer angle). After the measurements, the HL were dissected into muscles and bones to calculate the meat-to-bone ratio. Once weighed, the HL meat was coarsely ground (Grindomix GM 300, Retsch GmbH, Germany) freeze-dried, properly packed, and then sent to the Laboratory “LabCNX” of the Animal Medicine, Production and Health (MAPS) Department of the University of Padova (Italy), together with CS cake, and diets samples in order to conduct chemical analyses.

5.3.4. Sample preparation and proximate composition

After their arrival at MAPS Department, samples were prepared for the respective analysis. The samples of the experimental diets were finely ground to determine their chemical composition and FA profile. Meanwhile, freeze-dried HL meat samples were ground again with a Retsch (Retsch Italia, Verder Scientific S.r.l., Torre Boldone, BG, Italy) Grindomix GM 200 (4000 g for 8 s). The obtained fine powder was used to determine proximate composition following the Association of Official Analytical Chemists (AOAC, 2012) methods for water (method no. 934.01), crude protein (CP; method no. 2001.11) and ash (method no. 967.05). Ether extract (EE) was determined after acidic hydrolysis (European Commission [EC], 1998)

5.3.5 Fatty acid profile and contents

Lipid extraction was performed using modified accelerated solvent extraction. Lipids of the experimental diets were extracted from 2.5 g ground samples, by using petroleum ether as the solvent, whereas for rabbit meat (0.75 g freeze-dried sample) a binary solvent mixture of chloroform/methanol at a 1:2 ratio was used, following the method suggested by Lee, Trevino, & Chaiyawat (1996). Samples' fat content was then determined gravimetrically after vacuum evaporation under nitrogen stream. Diet and meat samples were trans-methylated using a methanolic solution of H₂SO₄ at 4 % to determine FA methyl esters (FAME). Subsequently, to quantify the latter, 0.5 ml of distilled water and 1.5 ml of n-heptane was added to each extracted sample to obtain a biphasic separation that allowed FAMES quantification through gas chromatography (Shimadzu GC17A), which was equipped with an Omegawax (Sigma-Aldrich Co. LLC., Saint Louis, USA) 250 column (30 m × 0.25 µm × 0.25 µm) and a flame ionization detector. Helium was used as the carrier gas at a constant flow rate of 0.8 ml/min, whereas both injector and detector temperatures were set at 260 °C. For identification, commercially available FAME mixtures (37-Component FAME Mix; Supelco Inc., Bellefonte, PA, USA) were used. The obtained results were expressed as a % of the total detected FAMES. Finally, the quantitative determination (w/w) of FA was obtained by exploiting the total lipid content of the samples and the chromatographic peak area, as according to the internal standard (C19:0) method. The atherogenic (AI), thrombogenic (TI), peroxidability (PI), and hypocholesterolemic/hypercholesterolemic (hH) indices of rabbit meat samples were determined following the same formulae used by Dalle Zotte et al. (2018).

The FA profiles (expressed as % of total FAME) of the experimental diets (Control, CS5, and CS10) are presented in Table 5.1. Replacing RSC with CSC increased PUFA content to the detriment of MUFA, leading to a 2.9-fold increase in total n-3 FA and a 2.4-fold reduction in the n-6/n-3 ratio in the CS10 diet.

Table 5.1: Fatty acids profile (% total fatty acid methyl esters - FAME) of the experimental diets.

	Experimental diets		
	Control	CS5	CS10
C10:0	0.08	0.00	0.00
C12:0	0.08	0.08	0.07
C14:0	0.42	0.16	0.26
C15:0	0.11	0.24	0.08
C16:0	14.1	11.6	11.5
C17:0	0.13	0.14	0.09
C18:0	2.05	1.72	1.92
C20:0	0.51	0.58	0.86
C23:0	0.15	0.11	0.10
ΣSFA	17.7	14.7	14.9
C14:1	0.11	0.10	0.12
C15:1	0.09	0.12	0.07
C16:1	0.41	0.24	0.19
C17:1	0.09	0.00	0.07
C18:1 n-9	34.4	25.3	19.5
C18:1 n-7	2.73	1.71	1.06
C20:1 n-9	1.84	3.10	6.31
C22:1 n-9	0.27	0.60	1.31
C24:1 n-9	0.48	0.00	0.35
ΣMUFA	40.4	31.2	29.0
C18:2 n-6	26.8	34.4	30.9
C20:2 n-6	0.11	0.27	0.66
C22:2 n-6	0.13	0.24	0.19
C18:3 n-6	0.10	0.00	0.07
C20:3 n-6	0.00	0.00	0.14
C20:4 n-6	0.00	0.13	0.42
C18:3 n-3	4.51	9.32	14.3
C20:5 n-3	0.44	0.32	0.34
C22:6 n-3	0.16	0.16	0.07
ΣPUFA	32.3	44.9	47.0
ΣUFA	72.7	76.0	76.0
UFA/SFA	4.11	5.19	5.11
Σn-6	27.2	35.1	32.4
Σn-3	5.11	9.79	14.7
n-6/n-3	5.32	3.58	2.21
Identified	90.3	90.7	90.9

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids;

UFA: Unsaturated fatty acids.

5.3.6. Sensory analysis

A further 42 animals (14 per treatment) were included in the evaluation. Both *longissimus lumborum* muscles were removed from the carcass, weighed, vacuum-packed, and frozen at 20 °C until sensory analysis (~ 3 months). Sample preparation followed the methodology described in Volek, Bureš & Uhlířová (2018). The day before each sensory evaluation session, the samples were removed from the freezer and left inside the packaging to thaw at room temperature. Subsequently, the samples were removed, weighed to determine freezing losses, and grilled on a double-sided glass-ceramic grill tempered to 200 °C. From the weight differences before and after freezing and before and after grilling the samples, the percentage of weight loss was determined. The grilled muscles were removed when the internal temperature reached 70 °C as measured with a thermoprobe (AD14TH, AmaDigit, Kreuzwertheim, Germany). The samples were weighed again to determine grill loss and then cut into 15 mm long strips. Approximately half of the right LL muscle was taken for shear force determination. The remaining strips were placed in a glass container labelled with a three-digit randomly assigned code. The samples were kept at 50 °C until the actual assessment. The assessment took place in the standardised IAS sensory laboratory, equipped with individual boxes preventing visual contact between panellists, staff providing the samples, and the general environment around the panellists (International Organization for Standardization [ISO], 2012). Six trained and experienced assessors judged a total of 12 descriptors, the characteristics and method of assessment of which are shown in Table 5.2. A 100 mm long unstructured scale used, with the description of the edge points provided for each descriptor (i.e., 0 and 100), which was then transformed to continuous values between 0 and 100 for statistical purposes. The assessors were simultaneously presented with three sets of samples that differed in the way the rabbits were fed (i.e., dietary treatment). A total of 12 samples (4 sets) were assessed on the first day of the evaluation (session), and a total of 15 samples in 5 sets were assessed on the second and third days of the evaluation. The individual sample sets were presented to the assessors in random order. Red lighting was used during the evaluation, making it impossible to judge the samples by their colour. Bread and water were provided as palate cleansers.

Shear force (WBSF) was measured with a Warner-Bratzler knife fitted to an Instron (Instron Universal Texture Analyzer 3365, Canton, MA, USA). Cooled samples were used, and were cut into six cubes (1 ×1 ×1 cm) for shearing perpendicular to the direction of the muscle fibres. The crosshead speed was set at 100 mm/min. The peak force (N) measured was calculated as an average of the six measures per muscle sample.

Table 5.2: Definition and scale of the attributes used in the meat sensory analysis

Attribute	Scale	Definition
Overall aroma intensity	0 = very low 100 = very high	The strength of overall aroma, evaluation before eating sample
Rabbit aroma intensity	0 = very low 100 = very high	The strength of aroma typical for rabbit meat, evaluation before eating sample
Abnormal odour intensity	0 = very low 100 = very high	The strength or richness of an unnatural odour evaluation before eating sample
Tenderness	0 = very tough 100 = very tender	The force required to bite through the sample with molars, evaluation after first 2–3 chews
Juiciness	0 = very low 100 = very high	The amount of moisture released by the sample, evaluation after first 3–5 chews
Fineness	0 = very coarse 100 = very fine	Fineness or coarseness of fibres, evaluation after first 5–10 chews
Chewability	0 = scarcely chewable 100 = easily chewable	The amount of residual tissue after most of sample has been masticated, evaluation after 15–20 chews
Overall flavour intensity	0 = very low 100 = very high	The presence of overall flavour typical for cooked meat, evaluation after 5–10 chews
Rabbit flavour intensity	0 = very low 100 = very high	The presence of a flavour typical for cooked rabbit meat, evaluation after 5–10 chews
Abnormal flavour intensity	0 = very low 100 = very high	The strength or richness of an unnatural flavour, evaluation after 5–10 chews
Fatty flavour	0 = very low 100 = very high	The presence of a flavour apparent when fat is consumed, evaluation after 5–10 chews
Rancid flavour	0 = very low 100 = very high	The appearance of a flavour apparent in rancid butter, evaluation after 5–10 chews
Overall acceptance	0 = very low 100 = very high	Preference of assessors between samples presented, after completion of the sample evaluation

5.3.7 Statistical analysis

The results of rabbit meat physical traits, proximate composition and FA profile and quantity presented in the current study were subjected to a one-way ANOVA, with the three different diets (Control, CS5, and CS10) set as fixed effects, according to the general linear model (GLM) procedures of the SAS (SAS® OnDemand for Academics-3.81 Enterprise Edition, SAS Institute Inc., Cary, NC, USA). Least squares means were obtained and corrected through post-hoc pairwise comparisons performed with Bonferroni test. Data for sensory analysis were evaluated using SAS statistical software (version 9.4). Data were assessed using a mixed linear model (MIXED procedure) by including a fixed effect of diet (treatment) and the random effects of day of assessment and assessor in the model equation. For the physical properties data (thawing loss, grilling loss, and WBSF), a model equation including the fixed effect of diet and the random effect of day of assessment (sensory session) was used. Statistical significance of differences between the groups was assessed by Tukey's post hoc test. A significance level of 5 % was used throughout.

5.4. Results

5.4.1 Dissection yield of the HL, and physical analysis of the fresh BF and LL muscles

Replacing RSC with CSC in the diet of growing rabbits did not alter the physical properties of HL meat and the BF (Table 5.3). The sole exception remained yellowness (b*), which changed in both BF ($P = 0.036$) and LL ($P = 0.025$) muscles, following similar trends. Rabbits fed the CS5 diet had less yellow BF muscles than those fed the CS10 diet; additionally, the LL muscles from the CS5-fed rabbits were less yellow than those from the Control treatment. There were no significant differences between the dietary treatments for the thawing loss, grilling loss, and WBSF for the LL muscles ($P > 0.05$).

5.4.2 Proximate composition of rabbit HL meat

As it was observed in physical traits, the inclusion effect of CSC was also negligible on the proximate composition of the HL (Table 5.4). Water content was the only variable affected by the CSC inclusion, showing a decrease in CS10 meat compared to Control one, while CS5 was intermediate ($P = 0.0359$).

Table 5.3. Effect of the dietary inclusion of camelina (*Camelina sativa*) cake (0 %, 5 %, 10%) for growing rabbits on the physical properties of hind leg (HL), *biceps femoris* (BF), and *longissimus lumborum* (LL) muscles.

	Treatments			SEM ¹	P-value
	Control	CS5	CS10		
N.	14	14	14		
HL weight, g	232	232	226	3.52	0.3774
HL meat, g	188	191	185	3.48	0.4776
HL bone, g	40.8	39.9	39.3	1.41	0.7492
HL meat to bone ratio	4.72	4.83	4.98	0.72	0.6443
BF pH	5.76	5.74	5.74	0.03	0.6982
BF L*	55.2	54.6	54.2	0.68	0.6136
BF a*	−0.99	−1.33	−0.83	0.23	0.3093
BF b*	6.57 ^{ab}	5.65 ^b	6.66 ^a	0.29	0.0361
LL pH	5.61	5.59	5.57	0.02	0.3626
LL L*	59.0	57.7	58.3	0.45	0.1435
LL a*	−1.24	−1.27	−1.48	0.16	0.5208
LL b*	10.1 ^a	9.41 ^b	9.58 ^{ab}	0.19	0.0246
LL:					
Thawing loss, %	9.41	10.54	9.18	0.41	0.0520
Grilling loss, %	13.0	11.5	12.2	0.90	0.2950
WBSF, N	13.9	15.0	14.2	0.57	0.3540

^{a-b} Mean values with different superscripts within a row differ significantly $P < 0.05$.

¹ SEM: Standard error of the mean.

Table 5.4: Effect of the dietary inclusion of camelina (*Camelina sativa*) cake (0 %, 5 %, 10%) for growing rabbits on the proximate composition (g/100 g meat) of hind leg meat.

	Treatments			SEM ¹	P-value
	Control	CS5	CS10		
N.	14	14	14		
Water	72.7 ^a	71.9 ^{ab}	71.8 ^b	0.26	0.0359
Protein	20.2	20.6	20.5	0.12	0.0582
Lipids	5.63	6.00	6.39	0.26	0.1430
Ash	1.09	1.11	1.20	0.03	0.1380

^{a-b} Mean values with different superscripts within a row differ significantly $P < 0.05$.

¹ SEM: Standard error of the mean.

5.4.3 Fatty acid profile of rabbit HL meat

Considering the FA profile (Table 5.5), the main FA classes, namely saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA), were significantly affected by the dietary incorporation of CSC ($P < 0.0001$) to the detriment of both SFA ($P < 0.0001$). Single individual SFA, such as myristic acid (C14:0), pentadecylic acid (C15:0), palmitic acid (C16:0), and docosanoic acid (C22:0) were lower in the CS10 group compared to the Control group ($P < 0.05$). Furthermore, consequently to the PUFA increment, the peroxidability index (PI) increased linearly with the inclusion level of camelina meal ($P < 0.0001$).

Considering the FA content (Table 5.6), the observed outcomes differed to some extent to the ones obtained for FA profile. Except for total PUFA ($P 0.05$). Furthermore, the quantitative data of several individual FAs did not coincide with their respective percentage data. As example, FAs like C14:0, C15:0, C16:0, C14:1, C16:1, C18:1 n-9, C18:1 n-7, C20:3 n-6, and C20:4 n-6 were found in comparable amounts in all the dietary treatments ($P > 0.05$), though the significance difference in their fraction. Conversely, for other FAs, including C20:0, C22:0, C20:1 n-9, C22:1 n-9, and all the individual PUFA (except for C20:3 n-6 and C20:4 n-6), the treatment effect was the same in both percentage and quantitative data ($P < 0.05$).

5.4.4 Sensory analysis of rabbit LL

The overall flavour intensity of the LL muscles from rabbits fed the CS10 diet was scored significantly higher than the other two dietary treatments (Table 5.7). In particular, abnormal flavour intensity and rancid flavour was scored highest in the CS10-fed rabbits' LL muscles. Fatty flavour was also evaluated as higher (i.e., more intense) for the CS10 treatment than the Control. Despite this, overall acceptance scores did not differ between the treatments.

Table 5.5: Effect of the dietary inclusion of camelina (*Camelina sativa*) cake (0%, 5%, 10%) for growing rabbits on the fatty acids profile of hind leg meat.

	Treatments			SEM ¹	P-value
	Control	CS5	CS10		
C10:0	0.33	0.31	0.30	0.02	0.6650
C12:0	0.34	0.34	0.32	0.02	0.5912
C14:0	2.55 ^A	2.56 ^A	2.33 ^B	0.04	0.0006
C15:0	0.51 ^a	0.47 ^{ab}	0.47 ^b	0.01	0.0116
C16:0	24.4 ^a	24.4 ^a	23.3 ^b	0.25	0.0048
C17:0	0.47	0.45	0.46	0.01	0.3117
C18:0	5.45	5.41	5.34	0.09	0.7099
C20:0	0.13 ^B	0.14 ^B	0.16 ^A	0.01	<0.0001
C22:0	0.05 ^B	0.17 ^A	0.06 ^B	0.02	0.0004
ΣSFA	34.3 ^A	32.3 ^A	32.8 ^B	0.28	0.0005
C14:1	0.19 ^a	0.18 ^{ab}	0.10 ^b	0.03	0.0433
C15:1	0.15	0.18	0.21	0.02	0.0571
C16:1	3.85 ^A	3.56 ^{AB}	2.98 ^B	0.17	0.0023
C17:1	0.23	0.21	0.22	0.02	0.7622
C18:1 n-9	28.9 ^A	26.4 ^B	24.1 ^C	0.24	<0.0001
C18:1 n-7	1.91 ^A	1.69 ^B	1.46 ^C	0.02	<0.0001
C20:1 n-9	0.69 ^C	1.11 ^B	2.12 ^A	0.03	<0.0001
C22:1 n-9	0.07 ^{Bb}	0.10 ^{Ba}	0.19 ^A	0.01	<0.0001
C24:1 n-9	0.05	0.07	0.10	0.02	0.1018
ΣMUFA	36.1 ^A	33.5 ^B	31.5 ^C	0.33	<0.0001
C18:2 n-6	19.0 ^B	20.1 ^A	20.3 ^A	0.26	0.0015
C18:3 n-6	0.18	0.16	0.17	0.01	0.3483
C20:3 n-6	0.19 ^a	0.17 ^b	0.17 ^b	0.01	0.0119
C20:2 n-6	0.21 ^C	0.27 ^B	0.39 ^A	0.01	<0.0001
C20:4 n-6	1.07 ^a	0.96 ^{ab}	0.93 ^b	0.04	0.0488
C22:2 n-6	0.06 ^A	0.04 ^B	0.02 ^B	0.01	<0.0001
C18:3 n-3	3.69 ^C	5.09 ^B	8.18 ^A	0.10	<0.0001
C20:3 n-3	0.09 ^C	0.16 ^B	0.29 ^A	0.01	<0.0001
C20:5 n-3	0.07 ^{ABb}	0.06 ^B	0.10 ^{Aa}	0.01	0.0042
C22:6 n-3	0.06	0.08	0.08	0.01	0.1171
ΣPUFA	24.6 ^C	27.1 ^B	30.6 ^A	0.38	<0.0001
Σn-6	20.7 ^{Bb}	21.7 ^{Aba}	22.0 ^A	0.30	0.0088
Σn-3	3.91 ^C	5.40 ^B	8.64 ^A	0.12	<0.0001
ΣUFA	60.7 ^A	60.6 ^B	62.1 ^A	0.28	0.0006
UFA/SFA	1.77 ^B	1.77 ^B	1.90 ^A	0.02	<0.0001
n-6/n-3	5.29 ^A	4.04 ^B	2.55 ^C	0.05	<0.0001
AI ²	0.58 ^A	0.58 ^A	0.53 ^B	0.01	<0.0001
TI ³	1.12	1.14	1.11	0.01	0.2007
PI ⁴	33.6 ^C	37.4 ^B	44.0 ^A	0.55	<0.0001
hH ⁵	1.96 ^B	1.97 ^B	2.11 ^A	0.03	0.0007
Identified	94.9	94.8	94.9		

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids.

a-b Mean values with different superscripts within a row differ significantly $P < 0.05$.

A-C Mean values with different superscripts within a row differ significantly $P < 0.01$ or $P < 0.001$.

¹ SEM: Standard error of the mean.

² AI: Atherogenicity index = $(C12:0 + 4 \times C14:0 + C16:0) / [\Sigma MUFA + (\Sigma n-6) + (\Sigma n-3)]$.

³ TI: Thrombogenicity index = $(C14:0 + C16:0 + C18:0) / [(0.5 \times \Sigma MUFA) + 0.5 \times (\Sigma n-6) + 3 \times (n-3/n-6)]$.

⁴ PI: Peroxidability index = $(\% \text{ monoenoic} \times 0.025) + (\% \text{ dienoic} \times 1) + (\% \text{ trienoic} \times 2) + (\% \text{ tetraenoic} \times 4) + (\% \text{ pentaenoic} \times 6) + (\% \text{ hexaenoic} \times 8)$.

⁵ hH: Hypocholesterolemic/Hypercholesterolemic index = $(C18:1 \text{ n-9} + C18:2 \text{ n-6} + C20:4 \text{ n-6} + C18:3 \text{ n-3} + C20:5 \text{ n-3} + C22:5 \text{ n-3} + C22:6 \text{ n-3}) / (C14:0 + C16:0)$.

Table 5.6. Effect of the dietary inclusion of camelina (*Camelina sativa*) cake (0 %, 5 %, 10%) for growing rabbits on the fatty acids content of hind leg meat (mg/100 g meat).

	Treatments			SEM ¹	P-value
	Control	CS5	CS10		
C10:0	19.1	18.4	19.5	1.71	0.8944
C12:0	19.5	20.4	20.6	1.37	0.8309
C14:0	145	155	150	7.72	0.6957
C15:0	28.6	28.5	30.0	1.10	0.5870
C16:0	1390	1476	1500	70.8	0.5205
C17:0	26.4	27.3	29.1	1.15	0.2445
C18:0	308	326	343	14.6	0.2674
C20:0	7.28 ^B	8.34 ^B	10.4 ^A	0.42	<0.0001
C22:0	2.75 ^B	10.7 ^A	3.55 ^B	1.45	0.0006
ΣSFA	1947	2062	2105	96.2	0.4924
C14:1	10.3	10.5	6.27	1.49	0.0873
C15:1	8.38 ^B	10.5 ^{AB}	13.3 ^A	1.06	0.0089
C16:1	219	217	193	15.1	0.4037
C17:1	12.7	12.8	14.0	1.39	0.7790
C18:1 n-9	1641	1595	1552	77.7	0.7214
C18:1 n-7	108	102	93.8	4.75	0.1308
C20:1 n-9	38.9 ^C	67.0 ^B	136 ^A	3.94	<0.0001
C22:1 n-9	3.98 ^{Bb}	6.25 ^{Ba}	12.4 ^A	0.57	<0.0001
C24:1 n-9	2.80 ^b	4.03 ^{ab}	6.39 ^a	0.92	0.0274
ΣMUFA	2044	2026	2026	98.6	0.9887
C18:2 n-6	1065 ^B	1212 ^{AB}	1299 ^A	44.8	0.0025
C18:3 n-6	9.83	9.67	10.9	0.50	0.1759
C20:3 n-6	10.8	10.0	10.5	0.42	0.4771
C20:2 n-6	11.9 ^C	16.2 ^B	24.9 ^A	0.76	<0.0001
C20:4 n-6	59.4	57.5	58.7	1.98	0.7774
C22:2 n-6	3.79 ^{Aa}	2.23 ^{ABb}	1.39 ^B	0.41	0.0007
C18:3 n-3	208 ^C	307 ^B	525 ^A	16.1	<0.0001
C20:3 n-3	5.22 ^C	9.39 ^B	18.9 ^A	0.64	<0.0001
C20:5 n-3	3.90 ^B	3.74 ^B	6.09 ^A	0.38	<0.0001
C22:6 n-3	3.06	5.15	5.25	0.76	0.0808
ΣPUFA	1380 ^{Bb}	1639 ^{Aba}	1961 ^A	63.2	<0.0001
ΣUFA	3424 ^b	3659 ^{ab}	3987 ^a	158	0.0495
Σn-6	1160 ^B	1308 ^{AB}	1406 ^A	47.1	0.0028
Σn-3	220 ^C	331 ^B	555 ^A	17.3	<0.0001

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids.

^{a-b} Mean values with different superscripts within a row differ significantly $P < 0.05$.

^{A-C} Mean values with different superscripts within a row differ significantly for $P < 0.01$ or $P < 0.001$.

¹ SEM: Standard error of the mean.

Table 5.7. Effect of the dietary inclusion of camelina (*Camelina sativa*) cake (0 %, 5 %, 10%) on the sensory traits of grilled rabbit *longissimus lumborum* meat.

	Treatments			SEM ¹	P-value
	Control	CS5	CS10		
Overall aroma intensity	61.1	62.7	61.8	4.59	0.740
Rabbit aroma intensity	56.8	56.7	58.4	4.91	0.722
Abnormal odour intensity	24.1	27.5	27.6	8.17	0.104
Tenderness	71.4	76.4	76.9	3.19	0.046
Juiciness	62.0	64.0	63.0	3.26	0.712
Fineness	71.4	73.2	75.9	3.90	0.159
Chewability	74.1	76.7	79.3	2.58	0.060
Overall flavour intensity	64.9 ^b	65.9 ^b	70.9 ^a	5.75	0.008
Rabbit flavour intensity	57.9	59.5	57.5	5.24	0.697
Abnormal flavour intensity	28.2 ^b	28.3 ^b	33.1 ^a	8.19	0.016
Fatty flavour	21.0 ^b	21.9 ^{ab}	26.3 ^a	3.20	0.030
Rancid flavour	13.8 ^b	12.3 ^b	17.9 ^a	2.25	0.002
Overall acceptance	58.5	58.4	55.8	3.92	0.465

^{a-b} Mean values with different superscripts within a row differ significantly P < 0.05.

¹ SEM: Standard error of the mean.

5.5. Discussion

Camelina sativa is considered one of the most promising novel feedstuffs in the context to provide an alternative and sustainable protein source to food-producing animals, including rabbits. In the last decades, numerous scientific studies assessing the dietary inclusion of camelina by-products have been carried out using different animal species, including swine (Smit & Beltranena, 2017), fish (Hixson et al., 2014), lamb (Cieslak et al., 2013), and several poultry species (Cullere et al., 2023; Singh et al., 2023a;b). Despite this, data concerning the incorporation of *Camelina sativa* in the diet of fattening rabbits are quite scarce. To date, in fact, only one scientific trial has been conducted so far on growing rabbits by Peiretti et al. (2007). They observed that providing fattening rabbits with inclusion levels of 10 % or 15 % of camelina seeds did not significantly change their growing performances, carcass traits, and meat chemical composition. Nonetheless, the incorporation of camelina seeds significantly changed the FA contents of the *longissimus thoracis et lumborum* (LTL) muscle, specifically by increasing PUFA concentration to the detriment of SFA, thus improving the overall nutritional quality of rabbit meat.

The present study represents the first attempt to assess the impact of replacing a common protein source, such as rapeseed cake (RSC), with *Camelina sativa* cake (CSC) in the diet of growing rabbits. Authors therefore point out that the direct comparison of the proposed results with other papers is not yet feasible.

Replacing RSC with CSC could represent a valuable solution to improve the dietary benefits that animals receive, in addition to enhancing the final product's

quality destined to human consumption. The two Brassicaceae indeed present almost the same CP (both with a good and similar AA composition) and crude fibre contents. CSC provides more crude fats compared to RSC, the first however provides a valuable FA profile composed of an increased fraction of total PUFA and a reduced proportion of total SFA and MUFA. The RSC replacement with CSC could be further beneficial to the animals due to the higher amounts of antioxidants compounds, as well as the lower content of anti-nutritional factors found in the CSC (Juodka et al., 2022). Data concerning live performance, digestibility of nutrients, and carcass traits are discussed in the first part of this scientific study (unpublished data), where it is highlighted that the production efficiency of CSC-fed rabbits was similar to that of the Control diet, thus suggesting the economic feasibility of the tested replacement. Here, the results obtained from the gradual replacement of RSC by CSC in rabbit diets on meat quality traits are reported. Briefly, the obtained results showed that replacing RSC with CSC predominantly changed both the FA profile and content of rabbit HL meat, with only minor changes in the physicochemical properties and proximate composition. The changes in FA profile are also reflected in the sensory traits of the meat. Meat quality is heavily influenced by its pH, which affects numerous technological and quality traits, such as water holding capacity (WHC), tenderness, colour, and preservability. In this study, CSC did not affect the pH of both the *biceps femoris* (BF) and *longissimus lumborum* (LL) muscles. A similar trend was observed by Nowakowicz-Dębek et al. (2021) who fed crossbred rabbits with different inclusion levels (4 %, 8 %, and 12 %) of fermented RSC. The ultimate pH (pHu) of BF muscle in fact was not significantly affected by the RSC incorporation, showing a similar pHu range (5.74–5.79) compared to that obtained in the current trial, but increasing RSC inclusion levels negatively affected the pHu of rabbit LTL muscle (Nowakowicz-Dębek et al., 2021). Nonetheless, CSC has apparently no effect on either the pHu of LL or BF muscles of growing rabbits. Singh et al. (2023b) further corroborated the current findings by stating that different *Camelina sativa* by-products were unable to affect the meat pH of several broiler poultry species. Besides pH, meat colour represents another important factor intimately connected to meat quality. Introducing CSC into rabbit diets while replacing RSC has showed to affect only the yellowness (b^*) of both the BF and LL muscles. Nowakowicz-Dębek et al. (2021) published similar findings concerning the $L^*a^*b^*$ colour of the BF muscle, specifically yellowness, which was significantly decreased by an 8 % inclusion level of fermented RSC. Given its intrinsic link with meat colour, pH could have played a role in determining it. However, in this trial significant differences in meat pHu were not found. It was therefore hypothesised that the antioxidants compounds contained in the CSC compared to the RSC were mainly responsible for affecting meat yellowness, even if the observed variation is not appreciable by the human eye. To date, data concerning the impact of CSC on rabbit meat pHu and colour are not yet available, whereas data of other trials are rather inconsistent.

Considering the meat proximate composition, the decrease of water content caused by the dietary inclusion of CSC, yet biologically negligible, represents an exception compared to other reference findings. Peiretti et al. (2007), in fact, found no significant effects in the proximate composition of the LTL muscle, even with a 15 % inclusion level of camelina seeds, as well as Nowakowicz-Dębek et al. (2021) with a 12 % incorporation of fermented RSC. The same outcomes were found also in many broiler poultry species fed with different inclusion levels of *Camelina sativa* by-product (Singh et al., 2023b). Nonetheless, a study conducted by Cullere et al. (2023) showed that feeding broiler quails (*Coturnix japonica*) with three different *Camelina sativa* cultivars at a 15 % inclusion level interestingly affected their breast meat proximate composition. These outcomes were however not consistent with the present findings, since the CSC increased meat water content to the detriment of lipids, apparently due to a low crude fat digestibility (Cullere et al., 2023).

In agreement with past research on feeding *Camelina sativa* as a main protein source to food-producing animals (Hixson et al., 2014; Peiretti et al., 2007; Singh et al., 2023b; Smit & Bel tranena, 2017), significant differences in both FA profile and content were detected in the present study. The residual lipid fraction left by oil-extracting procedures of CSC has been so far acknowledged as an interesting opportunity to positively affect the meat FA profile and content of different reared species (Hixson et al., 2014; Singh et al., 2023b; Smit & Beltranena, 2017), except in rabbits. The rabbit is a monogastric animal, thus it is capable of efficiently incorporating dietary FA at both the muscular and adipose level (Dalle Zotte, 2002). The rabbit metabolism in fact allowed the HL meat to resemble the same FA profile and content of the three individual experimental diets. As expected, CSC gradually increased the meat's degree of fat unsaturation, with meat of CS5 and CS10 treatments presenting intermediate and the highest values, compared to the Control treatment. This can be attributed to an improved content of both LA and ALA in the CS10 diet compared to the Control one. Furthermore, the notable ALA content of CSC significantly increased both the fraction and content of total n-3 FA, thus reducing the meat n-6/n-3 ratio in the CS5 treatment, as well as halving the ratio within the CS10 meat. Additionally, the high CSC ALA content allowed the meat from both CSC-fed rabbit treatments to achieve the dietary claim of a “source of omega-3 fatty acids”, set by the European Commission (2010), by meeting the threshold of 300 mg ALA/100 g. The overall product healthiness was further improved by an increased hH index, especially in the CS10 treatment where the AI decreased as well. However, the increase in unsaturated fatty acids likely impacted the sensory quality of the meat obtained from the CS10 treatment, where higher scores of fatty, rancid, abnormal, and overall flavour intensities were noted by the trained panel. Typically, such flavours are the results of oxidation of unsaturated fatty acids, and thus this change in FA profile should also be considered regarding product

shelf-life, which could be negatively affected by higher inclusion levels of CSC. Nonetheless, the overall acceptance scores of the different treatments were unaffected when considering a 5 and 10 % inclusion level. In the present trial, meat oxidative status was not assessed given the results of a previous experiment on broiler quails, where a 15 % dietary inclusion of camelina cake did not alter the oxidative stability of breast meat (Cullere et al., 2023). Overall, feeding growing rabbits with CSC has therefore proved to be an interesting opportunity to promoting meat's health benefits and thus consumer's wellness, without significantly affecting the physicochemical characteristics and overall sensory acceptance of the final product.

5.6. Conclusion

The outcomes of this experimental trial indicated that the partial and total replacement of rapeseed meal with *Camelina sativa* cake in the diet of fattening rabbits effectively changed the FA profile and content of rabbit meat, without posing any drawbacks on its physicochemical characteristics but affecting the flavour profile of rabbit meat at a 10 % inclusion level. This study showed that even a partial replacement (5 %) of RSC with CSC was enough to obtain the “source of omega-3 fatty acids” claim for rabbit meat, making *Camelina sativa* of pivotal importance to enhance the dietary benefits of the meat of different monogastric animals, including rabbits. In addition, promoting the use of camelina by-products as feedstuffs for different food-producing animals could be essential for optimizing feed formulations in the near future. Nonetheless, further research on the impact of the dietary inclusion of CSC in rabbits is needed, especially when different feeding plans are considered. As an example, CSC could be incorporated during the animal finishing period solely to obtain the “source of omega-3 fatty acids” claim in rabbit meat. In this way, this emerging feedstuff could serve as a sustainable solution to dilute farmer's economic burden, in addition to improve the food product's overall healthiness.

CHAPTER 6

Effect of wet and dry post-mortem rabbit loin meat ageing on its physicochemical and sensory properties

Published as: Aremu, T. S., Bureš, D., James, T. E., Lebedová, N., Urbanová, K., Dalle Zotte, A., Volek, Z., & Kokošková, T. (2025). Effect of wet and dry post-mortem rabbit loin meat ageing on its physicochemical and sensory properties. *Meat Science*, 229, 109901. <https://doi.org/10.1016/j.meatsci.2025.109901>

This chapter is a literal copy of the published article, only formatting changes have been included to align the manuscript with the overall thesis.

CRedit authorship contribution statement: **T. Aremu:** writing original draft; **D. Bureš:** conceptualization, methodology, investigation, formal analysis, writing – review & editing, supervision. **T.E Omogbemi:** investigation, writing – review & editing; **N. Lebedová:** investigation, writing – review & editing; **K. Urbanová:** formal analysis, writing – review & editing; **A. Dalle Zotte:** writing – review & editing; **Z. Volek:** formal analysis, writing – review & editing; **T. Kokošková:** conceptualization, methodology, investigation, formal analysis, writing – original draft, supervision.

6.1. Abstract

Fifty male 90-day-old Hyplus rabbits (PS19 × PS40) were slaughtered (carcass weight: 2126 ± 316.1 g) to determine the effect of post-mortem ageing methods (wet vs dry) and ageing period (7 or 14 days) on the physicochemical characteristics and sensory properties of the *longissimus thoracis et lumborum* (LTL) muscle. Of the 50 carcasses, 10 were used for physicochemical meat quality assessment on 24h post-mortem (D1). The remaining carcasses were assigned to either wet ageing (deboned muscles in vacuum-packaging) or dry ageing (whole carcass), for 7 “D7” or 14 “D14” days (n = 10 per treatment combination). Physicochemical and sensory analyses were performed after each ageing period. Results revealed that wet-aged LTLs were lighter in colour (L^*) than the dry-aged LTLs, regardless of the ageing period. The wet-aged samples also had the highest a^* values (redness) on D14 than all other treatments. Cooking loss percentages were greater in wet- than dry-aged meat on D14, but did not differ on D1 and D7 of wet ageing. Shear force decreased from D1 to D7 of ageing, regardless of the method used, and then stabilised. The dry-aged meat on D14 exhibited the lowest moisture content and the highest ash content, whilst the greatest malondialdehyde concentration was reported on D7 for dry-aged meat corresponding with its higher scores for off-odour intensity by the sensory panel. Whilst no significant differences were noted for overall acceptance on D7, the positive flavour development during dry ageing after 14 days was favourably evaluated by the panellists.

Keywords: Ageing duration; Descriptive sensory evaluation; *Longissimus thoracis et lumborum* muscle; Physical meat quality; Chemical composition

6.2. Introduction

Rabbit meat production has shown potential to contribute towards food security, motivated by high fecundity rate, early age of maturity, rapid growth rate, efficient feed conversion rate, excellent space utilization with respect to land use, and the high nutritional quality of its meat (Dalle Zotte & Cullere, 2024). Additionally, rabbit meat fits well with the contemporary consumer's demand for a low-fat meat with a high degree of unsaturated fatty acids, and low cholesterol and sodium levels (Cavani et al., 2009). Compared to other meat types (chicken, beef, and pork), it was found that rabbit meat is rich in calcium (21.4 mg/100 g) and phosphorus (347 mg/100 g), and low in fat (9.2 g/100 g) and cholesterol (56.4 mg/100 g) (Nistor et al., 2013; Grădinaru, 2017).

Negative consumer attitudes towards rabbit meat consumption appear to largely be due to welfare concerns (Petracci et al., 2018). However, rabbit meat is also typically sold as a whole carcass or primal cuts suitable for family-style cooking, without the development of new products that meet modern consumer expectations, which may also influence the consumer's willingness to purchase rabbit meat products. Furthermore, little innovation or modern processing techniques to improve rabbit meat quality and produce products that are attractive to the modern consumer have been implemented in the rabbit meat industry. Thus, the marketing strategy of rabbit meat and rabbit meat products can be reoriented by developing "new products", "new entry", or functional foods (Petracci et al., 2018) as attributed to its high nutritive value.

Initially, meat ageing was a preservation technique using methods like drying, smoking, and salting. But with the advent of refrigerators and freezers, ageing focused on tenderizing tough meats from animal species which were not well-received by consumers to enhance their physicochemical and sensory qualities, expanding its purpose beyond preservation and tenderization (Hedrick, Stringer & Clarke, 1993). During post-mortem ageing, a variety of biochemical and physiological changes occur throughout the conversion of muscle to meat impacting colour, taste, juiciness, and tenderness (Sosin-Bzducha & Puchala, 2017). Moreover, depending on the technique used during post-mortem ageing, compounds that influence meat flavour and aroma are also produced (Spanier, McMillin & Miller, 1990), which is nowadays also an important goal of meat ageing. The meat ageing methods currently used are usually of two types; wet and dry ageing (Lee et al., 2017). Wet ageing involves the storage of fresh meat placed in vacuum-packed bags at temperature below 5°C to enhance the tenderness and improve shelf life (Laster et al., 2008; Frank et al., 2019). Wet ageing is an economically viable option for meat industries because it requires less space, reduces product moisture and trim losses compared to dry ageing, and possess a longer shelf life without diminishing palatability (Kim et al., 2018). During dry ageing, meat is placed under controlled

airflow, temperature, and relative humidity conditions without packaging, and in beef, it creates more intense beefy and brown/roasted flavours than that of wet-aged beef (Laster et al., 2008).

Whilst ageing has primarily been used in the beef industry to improve meat tenderness and flavour, in rabbit meat, it may enhance the flavour profile, allowing for the development of new products that could appeal to the modern consumer. Due to the unique physical and sensory properties of rabbit meat compared to beef, the effects of ageing method and duration on the quality parameters of rabbit meat, as well as the acceptability of the aged products, should be considered. Thus, this study aimed to investigate the effects of two ageing methods (wet vs dry) over two ageing periods (7 or 14 days) on the physicochemical and sensory properties of rabbit meat.

6.3. Materials and Methods

6.3.1 Animals and Sampling

A total of 50 male 90-day-old hybrid (Hyplus PS19 × PS40) were slaughtered (average slaughter weight: 3270 ± 321.2 g). The slaughter protocol was according to standard commercial protocol, and the carcasses were cooled for 24 hours at ± 4 °C. The day after slaughter (24-h post-mortem), ten carcasses were randomly selected and both the left and right *longissimus thoracis et lumborum* muscles (LTL) were removed, weighed, and the lumbar section (LL) was utilised for evaluating the physicochemical traits according to standard protocols (Honikel, 1998). The remaining 40 carcasses were assigned to either wet or dry ageing, for 7 or 14 days ($n = 10$ per treatment combination). In the case of wet ageing, the left and right LTLs were removed from the carcasses, then weighed, and vacuum-packed (VAC-STAR (PE/PA) 80 µm VAC-STAR CZ, Pardubice, Czech Republic). The carcasses assigned for dry ageing were hung in an ageing chamber (Friulinox AS-EN2-VTR, Friulinox, Italy) by the hindlegs, without removal of the LTL muscles, in an attempt to decrease moisture losses. Both the dry-aged and wet-aged meats were stored in the same ageing chamber to maintain the same storage conditions for the whole study period (2°C, 85% relative humidity, and 10% of air exchange per hour). As no information exists as to the commercial procedures for ageing rabbit meat, nor does data exist on the effects of different procedures followed during different ageing protocols, the commercial protocols used for beef were adopted. At days 7 and 14 post-mortem, the respective samples were removed from the ageing chamber, blotted with clean paper towel, weighed, and the physicochemical and sensory quality traits of the LTL muscles were evaluated.

6.3.2 Physicochemical meat quality assessment

The pH was measured in the left LL using a calibrated pH probe with automatic temperature adjustment (InoLab pH 730 set, WTW, Weilheim, Germany). The CIE Lab colour measurement was then carried out on the cut surface of each sample from the LL after 45 minutes of blooming (Krunit et al., 2022), using a calibrated portable spectrophotometer (CM-700d, Konica Minolta, Osaka, Japan; 8 mm aperture diameter size, 0% UV; D-65/10° illuminant/observer angle). Colour data (L^* , lightness; a^* , redness and b^* yellowness) were determined at three locations in duplicate (i.e., six measurements) on each muscle sample, and averaged. The chroma and hue angle were calculated according to Volek, Bureš, and Uhlířová (2018): chroma (C^* , saturation index) = $(a^{*2} + b^{*2})^{1/2}$ and hue angle ($^\circ$) = $\tan^{-1}(b^*/a^*)$. Steaks from the LL (approximately 4cm), weighed, placed in a transparent plastic bag, and into a pre-heated water bath (80°C) until an internal temperature of 75°C was reached. Thermoprobes (AD14TH, Ama-Digit, Kreuzwertheim, Germany) were used to monitor and measure the temperature of the samples in the water bath. Once the desired internal temperature was achieved, samples were removed from the water bath and left to cool at room temperature. Samples were removed from the bags, blotted with clean paper towel, and their weights were taken again to determine the percentage of moisture lost during the cooking process. The cooked samples were cut into six 1 cm × 1 cm × 1 cm subsamples, and shear force was measured following similar methodology to that of Volek et al. (2018). The Warner-Bratzler shear force was measured using the Warner-Bratzler blade fitted to an Instron Universal Texture Analyzer 3365 (Canton, MA, US), best-placing the cross blade perpendicular to the direction of the muscle fibres at a speed of 100 mm/min. The average peak shear force was determined for the six subsamples.

Meat chemical composition was determined using the thoracic section (LT) of both of the LTL muscles (left and right) according to the procedures of AOAC (2003). Muscle samples were homogenized prior to chemical analysis. Moisture content of the meat samples was determined by oven-drying 2 g of meat at 105°C for hours until a constant weight. The nitrogen content was determined by the Kjeldahl procedure (Kjeltec 2400, FOSS Tecator AB, Höganäs, Sweden), and the protein content was calculated by multiplying the nitrogen content by a factor of 6.25. Intramuscular fat content was determined using the Soxhlet extraction method (Soxtex Avanti 2055, FOSS Tecator AB, Höganäs, Sweden), with petroleum ether. Ash content was obtained by igniting 2 g of meat samples in a muffle furnace (LAC L15/12, LAC, Židlochovice, Czech Republic) set at 570°C for 4-6 h. While the same carcasses used for chemical analyses on D1 could not be used for the ageing treatments due to the small size of rabbit LTL muscles, the chemical composition of the LT muscles on D1 were similar to those reported for Hyplus rabbits by Tůmová et al. (2014).

Malondialdehyde (MDA) concentrations in the homogenized LT muscle samples were determined using high-performance liquid chromatography (HPLC–MS-MS TSQ Fortis II, Thermo Fisher Scientific, San Jose, CA). Samples were saponified with 1 ml of 1 M potassium hydroxide and 10 µl of 0.02 M butylated hydroxytoluene in methanol. This mixture was then placed in an enclosed tube and then placed in a water bath at 60°C for 1 h, while continuously shaking, in the dark. Afterwards, the solution was cooled down and then acidified using concentrated hydrochloric acid (HCl) to ~ pH 2. The sample was centrifuged at $15,000 \times g$ for 5 min, at approximately 5°C. To 200 µl of the supernatant, 300 µl of 0.1 M HCl and 50 µl of 2,4-dinitrophenylhydrazine solution were added. The resulting mixture was vigorously mixed and kept at 50°C for 1 h in the dark. At the end of the derivatisation procedure, if necessary, the sample was allowed to cool down and then once again centrifuged at $15,000 \times g$ for 5 min at approximately 5°C. The solution was then placed in a vial, where 10-45 µl of the solution was taken, and injected for chromatographic analysis, according to Czauderna et al. (2011). Liquid chromatography was performed using a chromatograph equipped with a Nova-Pak C-18 column (Waters Corporation, USA, obtained from Chromservis Ltd., Prague, Czech Republic).

6.3.3 Descriptive sensory analysis

For the descriptive sensory analysis, the methodology of Volek et al. (2018) was followed. The remaining muscle samples from the LL sections of both the left and right LTL were weighed and then grilled on a double-sided glass ceramic contact grill preheated to 200°C (VCR 6 l TL, Fiamma, Aveiro, Portugal) until an internal temperature of 70°C, as measured by a thermoprobe (AD14TH, AmaDigit, Kreuzwertheim, Germany). After cooking, the samples were weighed again to determine the moisture percentage lost during grilling. Samples were cut into 15 mm long strips, placed in a sealed glass container, and then into an oven at a regulated temperature of 50°C to keep it warm until being provided to the trained panellists. The sample containers were randomly labelled with codes to eliminate biases from panellists, and the room was lit with a red light (ISO 8589:2007) to remove colour discrepancies in individual samples.

A total number of six trained panellists (ISO 8586:2023) with previous experience in evaluating rabbit meat were involved in the sensory analysis. Participants in the sensory panel are long-standing informed volunteers, trained in sensory analyses and with numerous previous experiences tasting rabbit meat. Their participation is anonymized during the analyses, and they can withdraw from the study at any point in time. The sensory analyses were performed during two sessions, on day 7 and 14 of ageing for the respective treatments. Samples were presented to each panellist, seated in individual cubicles, as a set (each set consisted of a wet- and

dry-aged sample and was presented to the panellists in a randomised order), and they analysed each sample consecutively using the parameters provided in Table 6.1, on a continuous line scale (0-100). The sample sets were presented to the evaluators in a random order. At both 7 and 14 days after slaughter, 20 samples in ten sets were submitted to the evaluators per day (session). The sensory analysis thus involved the evaluation of a total of 40 samples. Bread and water were provided to cleanse the palate after the tasting of the previous sample.

Table 6.1. Description of the scale of the sensory attributes for the evaluation of aged rabbit meat.

Attributes	Evaluation	Definition	Scale
Aroma intensity	Before eating	Intensity of overall aroma	0 = cannot be identified 100 =extremely strong
Rabbit odour intensity		The strength of aroma typical for cooked rabbit meat	
Off-odour intensity		The strength or richness of unnatural odour	
Tenderness	After first 2 or 3 chews	The force required to bit through the sample with molars	0 = very tough 100 = very tender
Juiciness	After first 3 to 5 chews	The amount of moisture released by the sample	0 = very low 100 = very high
Fineness	After first 5 to 10 chews	Fineness or coarseness of fibres	0 = very coarse 100 = very fine
Chewiness	After 10 to 25 chews	The amount of residual tissue after most of the sample has been masticated.	0 = scarcely chewable 100 = easily chewable
Flavour intensity	After first 5 to 15 chews	Intensity of overall flavour	0 = cannot be identified 100 =extremely strong
Rabbit flavour intensity		The presence of flavour typical to cooked rabbit meat	
Off-flavour intensity		The strength or richness of unnatural flavour	
Nutty flavour		Flavour reminiscent of hazelnuts	
Roasted flavour		Flavour associated with roasted meat	
Overall acceptance	After completion of evaluation	Total acceptability of the sample	0 = not acceptable 100 = highly acceptable

6.3.4 Statistical analysis

Data collected for the physicochemical analyses were analysed using SAS (Statistical Analysis Software; Version 9.4, SAS Institute Inc., United States). The data were first tested for normality (UNIVARIATE procedure) followed by the homogeneity of variance tests (Levene's test, GLM procedure), and all data were normally distributed and homoscedastic. Evaluation of the data was done using mixed linear models (GLM procedure), in which the fixed effects of ageing method (wet or dry) and period (control of 1 day post-mortem, 7, and 14 days post-mortem) were included, as well as their interaction (for the physicochemical data only). For the sensory evaluation data, only ageing method was included as a fixed effect and assessor was included as a random effect (MIXED procedure). Tukey's Range Test was used to compare treatment means. A 5% significant level was used throughout the analyses. The data are presented as least square means (LSM) and standard errors of the mean (SEM).

6.4. Results

6.4.1 Physicochemical characteristics of the *longissimus thoracis et lumborum* (LTL) muscle of rabbits after ageing

The effect of post-mortem storage on the physicochemical characteristics of the LTL muscle of rabbits is presented in Table 6.2. Muscle weight and pH were not significantly affected by post-mortem ageing methods or time. Several significant interactions between ageing method and time were found for the physicochemical data; the L^* values increased ($P < 0.001$) with wet ageing, regardless of the time period used, but were not affected by dry ageing. The wet-aged meat at D14 had the highest a^* and b^* values ($P < 0.001$). A similar trend was observed for Chroma values, with wet-aged meat at day 14 having the highest values ($P < 0.001$), with all other treatments not differing from each other. In contrast, hue angle values decreased ($P < 0.001$) across ageing treatments on D14 compared to D1, whilst D7 showed no difference compared to D1. WB shear force decreased ($P < 0.001$) with ageing, compared to D1, regardless of the ageing method and period used. Cooking loss was higher in wet-aged meat at D14 ($P = 0.013$) compared to both dry-aged meat on D7 and 14. The dry-aged meat exhibited the lowest moisture content (D7 and D14), and the highest ash content (on D14 only). Protein content was greatest ($P < 0.001$) with dry ageing at D14. The intramuscular fat differed ($P = 0.019$) between the dry-aged meat on D7 (10.4 g/kg muscle) and the wet-aged meat on D14 (6.5 g/kg muscle). As expected, MDA content was lowest on D1 (0.36 mg/kg muscle), and it increased significantly ($P < 0.001$) on D14 for both ageing methods (0.53 and 0.58 mg/kg muscle, for wet and dry-aged meat, respectively); however, on D7, it increased for dry-aged meat only (0.81 mg/kg muscle).

Table 6.2. Effect of ageing on physicochemical characteristics of *longissimus thoracis et lumborum* muscle of rabbits.

	Day 1	Day 7		Day 14		SEM	P-value
		Wet ageing	Dry ageing	Wet ageing	Dry ageing		
Muscle weight [#] (g)	100.7	103.3	102.5	95.2	91.6	4.25	0.248
pH	5.6	5.6	5.7	5.6	5.7	0.04	0.223
Colour <i>L</i> *	60.1 ^b	63.7 ^a	60.2 ^b	65.6 ^a	58.9 ^b	0.76	<0.001
<i>a</i> *	-0.9 ^c	-0.4 ^{bc}	-0.3 ^{bc}	1.4 ^a	0.7 ^{ab}	0.27	<0.001
<i>b</i> *	10.9 ^{bc}	11.0 ^{bc}	10.2 ^c	13.8 ^a	11.7 ^b	0.34	<0.001
Chroma	10.9 ^b	11.0 ^b	10.2 ^b	13.9 ^a	11.8 ^b	0.35	<0.001
Hue angle	94.6 ^a	92.0 ^{ab}	91.7 ^{ab}	84.3 ^c	87.1 ^{bc}	1.26	<0.001
WB shear force (N)	24.5 ^a	16.7 ^b	18.1 ^b	14.8 ^b	15.9 ^b	1.40	<0.001
Cooking loss (%)	17.8 ^{ab}	16.0 ^{ab}	12.1 ^b	19.3 ^a	12.7 ^b	1.64	0.013
Moisture (g/kg muscle)	743.3 ^a	739.3 ^{ab}	727.0 ^{bc}	740.3 ^{ab}	717.6 ^c	8.56	<0.001
Protein (g/kg muscle)	231.2 ^b	227.8 ^b	230.6 ^b	228.9 ^b	262.7 ^a	2.63	<0.001
IMF (g/kg muscle)	7.6 ^{ab}	8.9 ^{ab}	10.4 ^a	6.5 ^b	9.2 ^{ab}	0.83	0.019
Ash (g/kg muscle)	11.9 ^b	12.1 ^b	12.2 ^b	12.3 ^b	14.2 ^a	0.179	<0.001
MDA (mg/kg)	0.36 ^d	0.41 ^{cd}	0.81 ^a	0.53 ^{bc}	0.58 ^b	0.035	<0.001

[#]muscle weight was obtained by weighing both *longissimus thoracis et lumborum* muscle pairs for a given treatment on 1, 7 or 14 days after slaughter, and dividing the weight by two to obtain the average weight per muscle; ^{a,b,c} Values with different superscripts within the same row (i.e., for all ageing times and methods) differ at $P < 0.05$; IMF: intramuscular fat; MDA: Malondialdehyde

6.4.2 Sensory properties of the *longissimus thoracis et lumborum* (LTL) muscle of rabbits after ageing

In Table 6.3, the sensory properties of the LTL muscle of rabbits under post-mortem ageing for 7 days are presented. No differences were found for sensory parameters such as aroma intensity, rabbit odour intensity, juiciness, fineness, chewiness, off-flavour intensity, nutty flavour, roasted flavour, and overall acceptance. However, abnormal off-odour intensity ($P = 0.018$) and tenderness ($P = 0.035$) were scored higher for dry-aged meat, while flavour intensity ($P = 0.020$) and rabbit flavour intensity ($P = 0.008$) were scored higher for wet-aged meat.

The sensory properties of the LTL muscle after post-mortem ageing for 14 days are illustrated in Table 6.4. Juiciness ($P = 0.013$) and abnormal flavour intensity ($P = 0.027$) was scored higher in wet-aged meat on D14 than dry-aged meat, whilst dry-aged meat scored higher for roasted flavour ($P = 0.011$) and overall acceptance ($P = 0.037$).

Table 6.3: Sensory properties of rabbit *longissimus lumborum* muscle after ageing for 7 days.

	Ageing method		SEM	P -value
	Wet	Dry		
Aroma intensity	54.1	53.5	3.93	0.872
Rabbit odour intensity	48.2	43.9	3.99	0.150
Off-odour intensity	22.6	31.4	5.62	0.018
Tenderness	53.7	64.9	5.30	0.035
Juiciness	47.6	42.3	4.58	0.292
Fineness	51.9	58.1	5.18	0.088
Chewiness	54.8	59.4	5.38	0.265
Flavour intensity	55.0	46.8	2.43	0.020
Rabbit flavour intensity	50.2	41.9	2.41	0.008
Off-flavour intensity	22.2	26.1	5.22	0.223
Nutty flavour	16.8	15.4	5.00	0.549
Roasted flavour	37.3	36.6	4.30	0.867
Overall acceptance	53.0	48.3	4.29	0.329

Table 6.4: Sensory properties of rabbit *longissimus lumborum* muscle after ageing for 14 days.

	Ageing method		SEM	P -value
	Wet	Dry		
Aroma intensity	51.5	53.3	3.66	0.680
Rabbit odour intensity	45.1	46.9	2.77	0.540
Off-odour intensity	25.2	30.4	6.29	0.128
Tenderness	57.0	58.1	4.67	0.791
Juiciness	49.1	39.8	3.54	0.013
Fineness	61.1	56.8	4.99	0.127
Chewiness	59.2	54.5	4.93	0.122
Flavour intensity	55.8	54.6	4.32	0.762
Rabbit flavour intensity	47.8	45.9	3.57	0.560
Off-flavour intensity	29.9	21.9	5.73	0.027
Nutty flavour	22.0	23.7	8.23	0.418
Roasted flavour	40.0	48.4	5.25	0.011
Overall acceptance	46.4	55.6	3.26	0.037

6.5. Discussion

The findings presented in this study provide information on how to maximise the sensory properties of rabbit meat, and potentially to increase the shelf life and marketability of different rabbit meat products. Typically, fresh rabbit meat is bright pink in colour, with high tenderness and fineness, and mild flavour traits, and often considered to have a similar appearance and tenderness to chicken (Spencer, 2013). However, most research on dry ageing has been done on beef, limiting the direct comparison of the present results with similar rabbit meat studies.

The current study found that post-mortem ageing had no influence on the pH of the LTL muscle, the values of which fell between the normal range of 5.6 to 5.7 for rabbit LTL at 24 hours post-mortem, as reviewed by Bízková & Tůmová (2010), and similarly reported by Dutra et al. (2024) for the *longissimus lumborum* muscle processed after 24-hr postmortem from both male and female Botucatu rabbits. A similar ultimate pH range of 5.8 to 5.9 for rabbit meat was reported by Sanah et al. (2024). Moreover, the pH of rabbit meat after both wet and dry ageing for 7 and 14

days can be considered suitable for storage, as the pH values did not exceed 6. This is important, as pH values above 6 can foster the growth of proteolytic microorganisms, leading to decreased quality as well as spoilage. Thus, ageing may have a positive impact on the shelf life of rabbit meat. This result was consistent with the study of Kim et al. (2019) where the pH was not influenced by the ageing method of beef cuts. Koziół et al. (2015) observed significant differences in pH levels in the LTL and *biceps femoris* muscles of rabbits after 7 and 24 hours post-mortem; however, the impact of prolonged ageing in rabbit muscles was not evaluated. Furthermore, the pH results in the present study are similar to those reported in the rabbit LTL meat shelf-life study of Cullere et al. (2018), after 4 (pH 5.69) and 10 days (pH 5.73) of storage in vacuum packaging.

Colour is another important quality attribute that influences the consumer acceptance of meat. Meat colour, and its stability during storage, plays a vital role in consumers' decision in meat selection at the point of purchase (Neethling et al., 2016). The present study's findings indicate that wet-aged rabbit meat had higher lightness (L^*) and redness (a^*) when compared to dry-aged meat, as this method enables the retainment of moisture resulting in a lighter appearance. Cullere et al. (2018) found no significant differences in rabbit LTL colour traits evaluated at 4 and 10 days of storage under different packaging conditions, including vacuum-packaging. They reported slightly lower L^* values, significantly lower a^* values, and similar b^* values for vacuum-packaged rabbit meat on D4 and D10 of storage, compared to the wet-aged meat in the present study. However, differences can already be seen on the D1 samples regarding colour values between these two studies, which may be influenced by factors such as diet and breed. The L^* and a^* values reported by Koziół et al. (2015) in the rabbit LTL after 24 hrs were 55.43 and 5.16, respectively. Pałka et al. (2021) reported L^* values ranging from 55.97 to 60.56, with a^* values from 0.25 to 4.88, at 45 minutes and 24 hours post-mortem, respectively. Similar trends for chroma values and hue angle as noted in the current study are reported by Koziół et al. (2015). Despite rabbit meat being classified as a white meat, the changes of meat colour with ageing in the current study aligns with other studies on beef, such as Dikeman et al. (2013) and Kim et al. (2022), which demonstrated that wet ageing preserves the colour and retains the moisture of meat, whereas dry ageing leads to significant moisture loss, resulting in darker colours.

Warner-Bratzler shear force measurements serve as a reliable objective indicator of meat toughness or tenderness, providing valuable insights into its textural properties. The current study results on rabbit meat tenderness with ageing are consistent with previous studies on beef (Sitz et al., 2006; Laster et al., 2008; Kim et al., 2017, 2019; Moran et al., 2021), which collectively suggest a direct relationship between post-mortem ageing and enhancement of meat tenderness. The underlying mechanism for this improvement may be attributed to the proteolytic activity of

endogenous enzymes, leading to the weakening of intramuscular connective tissue and degradation of myofibrillar proteins (Lewis et al., 1991; Purslow, 2014; Kim et al., 2018). Specifically, the breakdown of proteins such as desmin, titin, troponin-T, and nebulin, as well as the weakening of Z-disks, contributes to increased myofibril fragility and subsequently enhances meat tenderness during postmortem ageing (Joo et al., 2023). Although there is a scarcity of research on the impact of postmortem ageing methods on rabbit meat's WB shear force, the present findings fall below the ranges reported for rabbit meat from Hyplus rabbits in pen vs cage systems (24.41 vs 24.23N vs; Krunt et al., 2022), and Hyplus rabbits fed soybean meal (24.3N) or dehulled white lupine seed 21.3N) and measured using the same methodology as the present study.

The reduced cooking loss in dry-aged meat may be attributed to the lower moisture content caused by evaporation during the ageing process (Obuz et al., 2014). Since meat's free water is released during cooking, variations in cooking loss are likely due to differences in moisture content before cooking, which is affected by the dry-ageing process. Despite using similar methodology and Hyplus rabbit lines, the cooking losses in the present study were lower than reported in Krunt et al. (2022) but similar to those of Volek et al. (2018). Other rabbit studies have reported variable cooking losses of 28.3% by Gonçalves et al. (2024), 36.98% by Abdel-Naem et al. (2021), and 30.8% by Combes et al. (2004), as expected due to experimental differences. The lowest moisture content of dry-aged meat after 14 days of ageing in the present study is expected since dry-aged meat usually has a higher moisture loss due to its greater exposure to air and thus higher evaporation losses during storage, as similarly noted in beef (Dikeman et al., 2013; Li et al., 2014).

On the other hand, the higher protein content in dry-aged meat after 14 days suggests that the dry-ageing process may help concentrate protein due to moisture loss, which may be a beneficial method for producing high-quality meat products with improved protein content and thus nutritional value. The underlying mechanisms contributing to this increase in protein content include the breakdown of connective tissue, reduction of fat, and enzymatic activity during the dry-ageing process (Nishimura et al., 1988; Baird, 2008; Perry, 2012; Dashdorj et al., 2015). While some research (Kim et al., 2016; Iida et al., 2016) suggests that the increase in protein concentration due to moisture loss may be insignificant, they also proposed that protein degradation during dry-ageing plays a crucial role in developing the characteristic taste and flavour of dry-aged meat. The protein content of dry-aged rabbit meat in this study were also higher than reported in other Hyplus rabbit meat (fresh) by Krunt et al. (2022) and Volek et al. (2018), as well as other rabbit studies (21.3-21.5 g/100 g; Metzger et al., 2003; Baiomy & Hassanien, 2011; Nistor et al., 2013).

Moreover, the elevated MDA levels in dry-aged rabbit meat on D7 suggest a higher degree of lipid oxidation. MDA is produced as a secondary product peroxidation of polyunsaturated fatty acids and its quantity reflects the intensity of non-enzymatic lipid peroxidation by radical reaction initiated by reactive oxygen species (Czauderna et al., 2011). A previous study by Cho et al. (2010) showed that as beef ages, its nutrients concentrate, including lipids. However, during the dry ageing process, lipids are oxidised due to exposure to air and thus higher levels of MDA can be expected in the dry ageing sample. Lipid oxidation can have negative effects on meat and meat products, as this process produces many secondary compounds such as aldehydes and alcohols, which cause unpleasant odours and flavours, but in some cases can also contribute (at low concentrations) to the formation of pleasant aromas. Of these compounds, aldehydes are the most abundant lipid oxidation product and play the most important role in meat due to their low threshold for olfactory perception (Dominguez et al., 2019). Although the MDA values in the present study were higher for dry-aged samples, they did not reach even half the values that are referred to as thresholds for the sensory perception of rancidity in meat (Campo et al., 2006). Nonetheless, it is crucial to control this process during dry ageing to prevent undesirable aftertastes and bitterness resulting from lipid oxidation (Gorraiz et al., 2002; Dashdorj et al., 2015). Future studies should consider the lipid oxidation process during rabbit meat ageing on the same meat samples over time to understand this process, as unfortunately this was not possible in the current study due to the sample size needed for the other analyses and the small muscle size.

The main attribute of palatability influencing consumer acceptance of meat is toughness (Jeremiah et al., 2003; Mennecke et al., 2007). As expected, the WB shear force in the present study decreased after ageing, regardless of the method used. This indicated that both wet-aged and dry-aged rabbit meats maintained their typical tenderness. Higher WB shear force values are associated with tougher meat (Lyon & Lyon, 1997; Cavitt et al., 2005; Xiong et al., 2006). Previous studies (Laville et al., 2009; Aaslyng & Meinert, 2017) have linked improved meat tenderness during ageing (both wet and dry) to the proteolysis of myofibrillar protein and degradation of structural proteins.

The sensory analysis from the present study on D7 revealed greater flavour intensity in wet-aged meat (a result of the higher rabbit flavour intensity scores) while off-odour intensity was higher after dry ageing. This likely reflects the higher MDA levels also found in the dry-aged meat after 7 days. Furthermore, the tenderness of rabbit meat was also higher after 7 days of dry ageing (despite no differences in the WBSF) but no differences were seen in the overall acceptance at day 7. On the other hand, sensory parameters assessed on D14 showed that dry-aged meat had higher scores for overall acceptance (despite lower juiciness scores), likely due to the more positive flavour development at this stage, with lower off-flavour intensity and

greater roasted flavour intensity than wet-aged meat. These findings align with the conclusion that, also in rabbits, dry ageing enhances meat flavour attributes compared with wet ageing, as seen in beef (Warren & Kastner, 1992). The degradation of proteins by aminopeptidases and peptidases during ageing leads to an increase in free amino acids, resulting in flavour changes and tenderization (Nishimura, 1998). Dry ageing is known to impart a unique flavour profile to meat, featuring descriptive attributes such as brown-roasted, beefy/brothy, buttery, nutty, roasted nut, and sweet notes, which contribute to its enhanced palatability (Warren & Kastner, 1992; Campbell et al., 2001; Kim et al., 2016). Additionally, microbiological activity during dry ageing can lead to the breakdown of myofibrils in meat, attributed to the proteolytic activities of moulds and yeast, this could improve the eating quality and acceptability of dry-aged meats (Mikami et al., 2021) but may have detrimental effects on microbial shelf life.

6.6. Conclusion

The current study demonstrates the impact of post-mortem ageing on the physicochemical and sensory properties of rabbit meat. Wet and dry ageing methods show distinct effects on physical and sensory characteristics, with ageing duration (7 and 14 days) influencing the extent of these changes. Whilst no benefit in rabbit meat tenderness is likely to motivate ageing, in both methods, dry ageing for 14 days allowed for the development of roasted flavour, increasing the overall acceptance of this product compared to wet ageing. This technique presents an opportunity to create new rabbit meat products with enhanced flavour profiles, while increasing their attractiveness to consumers. Future work should consider the effects of ageing duration on rabbit meat sensory quality, as well as the effects of ageing on the microbiological quality of rabbit meat, and the economics surrounding these processing techniques.

CHAPTER 7

General discussion

Chapter 4 evaluated yellow mealworm meal (YMM) as a protein alternative to soybean meal (SBM) in lactating rabbit diets and found it to be nutritionally viable without compromising performance. This is the first investigation of feeding YMM to lactating rabbit does. The YMM and SBM diets had comparable chemical compositions, protein content, amino acid profiles, and nearly identical energy, starch, and fiber fractions, indicating that protein quality and quantity were not limiting factors. However, the YMM diet contained higher ether extract, resulting in greater total saturated fatty acids and lower polyunsaturated and total unsaturated fatty acids, along with reduced vitamin E levels compared to SBM. Despite these differences, doe weight, milk yield, and feed intake were statistically similar between treatments, and feed efficiency from days 1–21 was actually higher for YMM-fed does. Milk chemical composition, mineral, vitamin, and ash contents were also comparable across diets and fell within established ranges for rabbit milk, with discrepancies versus older studies likely attributable to genotype rather than diet. The absence of morbidities or mortalities further indicated that all diets were well-tolerated.

The most notable effect of YMM inclusion was on milk fatty acid composition and kit performance. Although the YMM diet itself was higher in SFAs and lower in UFAs, milk from YMM-fed does had significantly lower SFAs and higher MUFAs and UFAs, while SBM-fed does produced milk with more SFA, C8:0, C10:0, and C12:0. This suggests that hindgut fermentation, metabolic processes, and selective absorption modify dietary fatty acids before they appear in milk. YMM-fed does also produced milk with a higher n-6/n-3 ratio, which may influence kit development. Kit body weight and average daily gain from days 1–32 were unaffected by diet, and although feed intake was lower in YMM-fed does, FCR remained unchanged, indicating efficient nutrient utilization. These findings are consistent with earlier work on fattening rabbits, where YMM supported comparable ADG, FCR, digestibility, and final weight, though short-term growth reductions occurred when crude protein was lower. Overall, YMM effectively replaced SBM in lactating rabbit doe diets, maintaining doe and kit performance while shifting milk fatty acid profiles toward a more unsaturated composition.

Camelina sativa is emerging as a promising sustainable plant protein source for food-producing animals. This trial (**Chapter 5**) found no changes in meat proximate composition, but the inclusion of camelina meal in the diet did increase

PUFA and reduce SFA in the *longissimus lumborum* muscle, improving the meat's nutritional quality. The present study is the first to replace rapeseed cake (RSC) with *Camelina sativa* cake (CSC) in growing rabbit diets. CSC and RSC have similar crude protein, amino acid profile, and crude fiber, but CSC contains more crude fat with a better fatty acid profile—higher total PUFA and lower SFA and MUFA—and more antioxidants with fewer anti-nutritional factors. Unpublished data from the first part of the study showed that CSC-fed rabbits had production efficiency similar to controls, suggesting economic feasibility.

Replacing RSC with CSC mainly altered the fatty acid profile and content of hindleg meat, with only minor effects on physicochemical properties and proximate composition. CSC did not affect muscle pH in the *biceps femoris* or *longissimus lumborum* muscles, consistent with studies on RSC and camelina in poultry. Yellowness (b^* values) in LL muscles was lower in CSC-fed rabbits, likely due to antioxidant compounds rather than pH differences. Proximate composition was largely unchanged except for a slight, biologically negligible decrease in water content. Most importantly, CSC progressively increased meat unsaturation by raising linoleic and α -linolenic acid, boosting total n-3 FA and cutting the n-6/n-3 ratio by half at 10% inclusion. At 10% CSC, meat met the EU “source of omega-3 fatty acids” claim and showed improved health indices like h/H and lower atherogenic index. However, the higher unsaturation also increased fatty, rancid, and abnormal flavours in the CS10 group, likely from lipid oxidation, which could affect shelf life. Overall acceptance scores were unaffected at 5% and 10% inclusion. Overall, CSC is a viable protein source for growing rabbits that enhances meat's nutritional quality without harming physicochemical traits or sensory acceptance of fresh meat at moderate inclusion levels.

Chapter 6 examined how wet and dry post-mortem ageing affects the quality of rabbit *longissimus thoracis et lumborum* meat, with the goal of maximizing sensory properties, shelf life, and marketability. Ageing had no effect on pH, which remained in the normal range of 5.6–5.7 at 24 h post-mortem and stayed below 6 throughout 7 and 14 days, indicating suitability for storage and reduced risk of spoilage from proteolytic bacteria. This aligns with previous rabbit and beef studies showing pH stability during ageing. Colour differed by method: wet-aged meat retained higher lightness and redness due to better moisture retention, while dry-aged meat became darker from moisture loss, a trend consistent with beef ageing studies. Tenderness improved with ageing in both methods, likely due to proteolytic breakdown of myofibrillar proteins like desmin, titin, and troponin-T. Dry-aged meat had lower cooking loss and higher protein content after 14 days, attributed to moisture evaporation concentrating nutrients, though it also showed elevated MDA levels on day 7, indicating greater lipid oxidation. However, MDA values remained well below the threshold for sensory perception of rancidity.

Sensory analysis revealed distinct effects of ageing method over time. At day 7, wet-aged meat had greater rabbit flavour intensity, while dry-aged meat showed higher off-odour intensity. Dry-aged meat was perceived as more tender at day 7, though Warner-Bratzler shear force values showed no difference, and overall acceptance was similar. By day 14, dry-aged meat scored higher for overall acceptance and roasted flavour, with lower off-flavour intensity despite lower juiciness scores. This suggests that longer dry ageing promotes desirable flavour development through protein degradation and free amino acid accumulation, relative to wet ageing. The results indicate that both ageing methods maintain rabbit meat tenderness, but dry ageing enhances flavour complexity and acceptance over time, while wet ageing better preserves colour and juiciness. These findings provide practical guidance for producers aiming to improve rabbit meat quality and shelf life, though future work should directly assess lipid oxidation over time given the small muscle size and sample constraints.

CHAPTER 8

General conclusion and recommendations

The findings of this research demonstrate that yellow mealworm (*Tenebrio molitor*) meal (YMM) can effectively replace soybean meal in the diets of lactating rabbit does without compromising growth performance, body weight maintenance, milk yield, or kit development. Minor alterations in milk fatty acid composition were observed, but these did not affect the growth of the kits before weaning. The results indicate that YMM likely closely meets the nutritional requirements of lactating does. Similarly, partial and total replacement of rapeseed meal with *Camelina sativa* cake (CSC) in the diets of fattening rabbits effectively modified the fatty acid profile of rabbit meat, increasing polyunsaturated and n-3 fatty acids while maintaining acceptable physicochemical meat characteristics. A 5% inclusion level was sufficient to qualify the meat as a “source of omega-3 fatty acids” under EU regulations, with a 10% level further enhancing the n-3 content and health indices. However, inclusion at 10% altered the flavour profile, increasing roasted and rancid notes. Thus, rather lower inclusion rates are recommended for the diets of fattening rabbits due to the potential negative impacts on meat sensory attributes. Furthermore, it is recommended to use CSC only during the finishing period to achieve the benefits of increased omega-3 fatty acids, potentially allowing for the classification as a functional food, while minimizing effects on flavour and feed costs. Restricting CSC to the rabbit finishing period avoids negative impacts on early growth, prevents digestive stress from anti-nutritional compounds in young kits. Further studies should evaluate the economic feasibility of large-scale YMM and CSC inclusion and consider their use in other production stages throughout the rabbit meat production chain. Furthermore, their effects on the shelf-life of rabbit meat should be considered when feeding to fattening rabbits. Regarding post-mortem processing, both wet and dry ageing maintained the physicochemical stability of rabbit meat, without detrimental effects on sensory attributes. Dry ageing for 14 days enhanced flavour development, particularly roasted notes, and improved overall sensory acceptance, relative to wet-aged meat, despite lower juiciness, while wet ageing better preserved colour and juiciness. Tenderness improved with ageing in both methods, consistent with proteolytic breakdown of myofibrillar proteins. Future experiments should, however, include the assessment of unaged meat. Further studies should investigate the utilisation of aged rabbit meat in the development of novel rabbit meat products which meet modern consumer demands and improve the attractiveness of rabbit meat products; consumer studies would be of value in this regard. Future studies should also incorporate sensory analysis across all ageing periods, including Day 1, to directly compare consumer preference for aged rabbit meat versus fresh rabbit meat.

General references

- Aaslyng, M. D., & Meinert, L. (2017). Meat flavour in pork and beef-From animal to meal. *Meat Science*, 132, 112–117.
- Abdel-Naeem, H. H. S., Sallam, K. I., & Zaki, H. M. B. A. (2021). Effect of different cooking methods of rabbit meat on topographical changes, physicochemical characteristics, fatty acids profile, microbial quality and sensory attributes. *Meat Science*, 181, 108612.
- Abiola-Olagunju, O., & Olusoji, A. (2015). Agro-industrial by-products: Potentials and applications in animal feeding. *Journal of Agriculture and Rural Development*, 6(2), 44–52.
- Abraham, E. M., Ganopoulos, I., Madesis, P., Mavromatis, A., Mylona, P., Nianiou-Obeidat, I., Parissi, Z., Polidoros, A., Tani, E., & Vlachostergios, D. (2019). The use of lupin as a source of protein in animal feeding: Genomic tools and breeding approaches. *International Journal of Molecular Sciences*, 20(4), 851.
- Adanguidi, J. (2020). Analysis of consumer demand and preference for rabbit meat in Benin. *International Journal of Marketing Studies*, 12(1), 14.
- Adarme-Vega, T. C., Lim, D. K., Timmins, M., Vernen, F., Li, Y., & Schenk, P. M. (2012). Microalgal biofactories: A promising approach towards sustainable omega-3 fatty acid production. *Microbial Cell Factories*, 11, 96.
- Adegbola, T. A. (1991). Effects of protein levels on growth and feed utilization of rabbits in a humid tropical environment. *Journal of Agriculture, Science and Technology*, 1(2), 158–160.
- Adhikari, P., Aryal, N., Ghimire, A., & Khanal, P. (2021). Sustainable biowaste recycling using insects. In *Clean energy and resources recovery* (pp. 399–420). Elsevier.
- Adu, E., Paterson, R., Rojas, F., Laswai, G., Fielding, D., & Osafo, E. (2005). Grasscutters, guinea pigs and rabbits. In *Small livestock and their feed in integrated smallholder farming systems* (pp. 325–341).
- Aduku, A. O., & Olukosi, J. O. (1990). *Rabbit management in the tropics: Production, processing, utilization, marketing, economics, practical training, research and future prospects*. G. U. Publications.
- Ahmad, I., Yuzir, A., Mohamad, S. E., Iwamoto, K., & Abdullah, N. (2021). Role of microalgae in sustainable energy and environment. *IOP Conference Series: Materials Science and Engineering*, 1051(1), 012059.
- Ahmad, M., Waraich, E. A., Hafeez, M. B., Zulfikar, U., Ahmad, Z., Iqbal, M. A., Raza, A., Slam, M. S., Rehman, A., Younis, U., & Kamran, M. (2023). Changing climate scenario: Perspectives of *Camelina sativa* as low-input

- biofuel and oilseed crop. *Global agricultural production: Resilience to climate change*, 197–236.
- Ahnström, M.L., Hunt, M.C. & Lundström, K. (2012). Effects of pelvic suspension of beef carcasses on quality and physical traits of five muscles from four gender–age groups. *Meat Science*, 90, 528–535.
- Ajala, M. K., & Balogun, J. K. (2004). Economics of rabbit production in Zaria, Kaduna State, Nigeria. *Tropical Journal of Animal Science*, 7(1), 1–10.
- Akande, K. E. (2015). The requirements of protein and amino acids in rabbit nutrition and production. *Case Studies Journal*, 4(4), 13–16.
- Akande, O. A., Falade, O. O., Badejo, A. A., & Adekoya, I. (2020). Assessment of mulberry silkworm pupae and African palm weevil larvae as alternative protein sources in snack fillings. *Heliyon*, 6(5), e03754.
- Akhigbe, O. & Akaeze, N.C. (2023). Consumer's preference and perception of different types of meat among respondents in Wukari, Taraba, Nigeria. *Journal of Applied Sciences & Environmental Management*, 27(8).
- Akinnusi, F. A. O., Bamgbose, M., Sogunle, O. M., Oso, A. O., & Afolabi, F. O. (2007). Comparative effect of different animal protein concentrate on the carcass quality of rabbits. In E. A. Agiang, L. N. Agwunobi, & O. O. Olawoyin (Eds.), *Proceedings of the 32nd Annual Conference of the Nigerian Society for Animal Production*. University of Calabar, Cross River State, Nigeria.
- Alam, A. M. M. N., Mia, N., Monti, J. A., Hashem, M. A., & Ali, M. S. (2024). Enhancing the qualitative attributes of meat through processing and preservation techniques-A review. *Meat Research*, 4(3).
- Alboghady, M. A., & Alashry, M. K. (2010). The demand for meat in Egypt: An almost ideal estimation. *African Journal of Agricultural and Resource Economics*, 4(1), 70–81.
- Amara, A. A., & El-Baky, N. A. (2023). Fungi as a source of edible proteins and animal feed. *Journal of Fungi*, 9(1), 73.
- American Rabbit Breeders Association. (2023). Nutritional profile of rabbit meat. <https://www.arba.net>
- Andersen, H.A., Oksbjerg, N., Young, J.F. & Therkildsen, M. (2005). Feeding and meat quality—a future approach. *Meat Science* 70: 543–554.
- AOAC. (2003). *Official Methods of Analysis of AOAC International* (17th ed., rev. 2). W. Horwitz (Ed.). Gaithersburg, MD, USA.
- AOAC. (2012). *Official methods of analysis* (19th ed.). Arlington, VA, USA: Association of Official Analytical Chemists.
- AOAC International (2000). *Official methods of analysis*, 17th ed. Official Methods of Analysis of AOAC, Washington, DC, USA.

- AOAC International (2005). Official methods of analysis, 18th ed. Official Methods of Analysis of AOAC, Gaithersburg, MD, USA.
- Ayensu, J., Lutterodt, H., Annan, R. A., Edusei, A., & Loh, S. P. (2019). Nutritional composition and acceptability of biscuits fortified with palm weevil larvae (*Rhynchophorus phoenicis Fabricius*) and orange-fleshed sweet potato among pregnant women. *Food Science & Nutrition*, 7(5), 1807–1815.
- Baiomy, A. A., & Hassanien, H. H. M. (2011). Effect of breed and sex on carcass characteristics and meat chemical composition of New Zealand white and Californian rabbits under upper Egyptian environment. *Egyptian Poultry Science Journal*, 31, 275–284.
- Baird, B. (2008). Dry aging enhances palatability of beef. Beef Safety and Quality. Available from: (<http://www.beefusa.org/uDocs/dryagingenhancespalatabilityofbeef>) [Accessed April 2008].
- Baviera-Puig, A., Buitrago-Vera, J., Escriba-Perez, C., & Montero-Vicente, L. (2017). Rabbit meat sector value chain. *World Rabbit Science*, 25(2), 95–108.
- Becker, E. W. (2007). Micro-algae as a source of protein. *Biotechnology Advances*, 25(2), 207–210.
- Berger, J., Kim, Y.H.B., Legako, J.F., Martini, S., Lee, J., Ebner, P., & Zuelly, S.M.S. (2018). Dry aging improves meat quality attributes of grass-fed beef loins. *Meat Science* 145, 285–91.
- Bhutta, Z. A., Das, J. K., Rizvi, A., Gaffey, M. F., Walker, N., Horton, S., Webb, P., Lartey, A., & Black, R. E. (2013). Evidence-based interventions for improvement of maternal and child nutrition: What can be done and at what cost? *The Lancet*, 382(9890), 452–477.
- Biasato, I., Gasco, L., De Marco, M., Renna, M., Rotolo, L., & Dabbou, S. (2018). Yellow mealworm larvae (*Tenebrio molitor*) inclusion in diets for male broiler chickens: effects on growth performance, gut morphology, and histological findings. *Poultry Science*, 97, 540–8.
- Bízková, Z., & Tůmová, E. (2010). Physical characteristics of rabbit meat: a review. *Scientia Agriculturae Bohemica*, 41, 236–241.
- Blasco, A. & Piles, M., (1990). Muscular pH of the rabbit. In *Annales de Zootechnie*. 39(2): 133-136).
- Blasco, A., & Ouhayoun, J. (1996). Harmonization of criteria and terminology in rabbit meat research: Revised proposal. *World Rabbit Science*, 4, 93–99.
- Boles, J. A., & Pegg, R. (2001). Meat colour. Montana State University and Saskatchewan Food Product Innovation Program.
- Bordiean, A., Krzyżaniak, M., Stolarski, M. J., Czachorowski, S., & Peni, D. (2020). Will yellow mealworm become a source of safe proteins for Europe? *Agriculture*, 10(6), 233.

- Bravo-Lamas, L., Barron, L. J. R., Farmer, L. & Aldai, N. (2018). Fatty acid composition of intramuscular fat and odour-active compounds of lamb commercialized in northern Spain. *Meat Science*, 139, 231-238.
- Brunner, T. A., van der Horst, K., & Siegrist, M. (2010). Convenience food products. Drivers for consumption. *Appetite*, 55(3), 498–506.
- Cadinu, L. A., Barra, P., Torre, F., Delogu, F., & Madau, F. A. (2020). Insect rearing: Potential, challenges, and circularity. *Sustainability*, 12(11), 4567.
- Calvete, C., Estrada, R., Villafuerte, R., Osácar, J. J., & Lucientes, J. (2002). Epidemiology of viral haemorrhagic disease and myxomatosis in a free-living population of wild rabbits. *Veterinary Record*, 150(25), 776-782.
- Campbell, R., Hunt, M., Levis, P., & Chambers, E. (2001). Dry-aging effects on palatability of beef longissimus muscle. *Journal of Food Science*, 66 (2), 196-199.
- Campo M. M., Nute, G. R., Hughes, S. I., Enser, M., Wood, J.D., & Richardson, R. I. (2006). Flavour perception of oxidation in beef. *Meat Science*, 72, 303-311.
- Cavani, C., Petracci, M., Trocino, A., & Xiccato, G. (2009). Advances in research on poultry and rabbit meat quality. *Italian Journal of Animal Science*, 8,741-750.
- Cavitt, L. C., Meullenet, J. F., Xiong, R., & Owens, C. M., (2005). The relationship of razor blade shear, Allo-Kramer shear, Warner-Bratzler shear and sensory tests to changes in tenderness of broiler breast fillets. *Journal of Muscle Foods*, 16 (3), 223-242.
- Cerisuelo, A., Ferrer, P., Gómez, E. Á., Woyengo, T. A., Stein, H. H., Martínez, M., Cano, J. L., & Piquer, O. (2023). Nutritional value of Spanish *Camelina sativa* co-products for pigs. *Animal Feed Science and Technology*, 301, 115665.
- Chaves, H., Singh, R. B., Khan, S., Wilczynska, A., & Takahashi, T. (2019). High omega-6/omega-3 fatty acid ratio diets and risk of noncommunicable diseases: Is the tissue, the main issue? In R. B. Singh, R. R. Watson, & T. Takahashi (Eds.), *The role of functional food security in global health* (pp. 217–259). Academic Press.
- Chen, C. Y., Yeh, K. L., Aisyah, R., Lee, D. J., & Chang, J. S. (2011). Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review. *Bioresource Technology*, 102(1), 71–81.
- Chen, X., Feng, Y., Zhang, H., & Chen, Z. (2010). Review of the nutritive value of edible insects (pp. 85–92). Food and Agriculture Organization of the United Nations.
- Cherfaoui, D. J., Theau-Clement, M., Zerrouki, N., & Berchiche, M. (2013). Reproductive performance of male rabbits of Algerian local population. *World Rabbit Science*, 21(2), 91–99.
- Cherwon, A. K., Wanyoike, M. M., & Gachuri, C. K. (2020). Rabbit production practices in Kiambu County, Kenya. *International Journal of Livestock Production*, 11(4), 114–121.

- Chisti, Y. (2007). Biodiesel from microalgae. *Biotechnology Advances*, 25(3), 294–306.
- Cho, S. H., Kim, J., Park, B. Y., Seong, P. N., Kang, G. H., Kim, J. H., Jung, S. G., Im, S. K., & Kim, D. H. (2010). Assessment of meat quality properties and development of a palatability prediction model for Korean Hanwoo steer beef. *Meat Science*, 86, 236–242.
- Chrenek, P., Chrastinova, L., Kirchnerova, K., Makarevich, A. V., & Foltys, V. (2007). The yield and composition of milk from transgenic rabbits. *Asian-Australasian Journal of Animal Sciences*, 20, 482–486.
- Christensen, D. L., Orech, F. O., Mungai, M. N., Larsen, T., Friis, H., & Aagaard-Hansen, J. (2006). Entomophagy among the Luo of Kenya: A potential mineral source? *International Journal of Food Sciences and Nutrition*, 57(3–4), 198–203.
- Church, D. C. (1991). *Livestock feeds and feeding* (3rd ed.). Prentice Hall Incorporation, New Jersey, USA, pp 546
- Cieslak, A., Stanisz, M., Wojtowski, J., Pers-Kamczyc, E., Szczechowiak, J., El-Sherbiny, M., & Szumacher-Strabel, M. (2013). *Camelina sativa* affects the fatty acid contents in M. longissimus muscle of lambs. *European Journal of Lipid Science and Technology*, 115(11), 1258–1265.
- Clavel, C., Hernández, E., Herrera, J., Hernández, V., & Hernández, D. (2004). Small cuniculture family farm on the south coast of Guerrero State, México. In *Proceedings of the 8th World Rabbit Congress* (pp. 1465–1470). Puebla, México.
- Coates, M. E., Gregory, M. E., & Thompson, S. Y. (1964). The composition of rabbit's milk. *British Journal of Nutrition*, 18, 583–586.
- Colin, M., & Lebas, F. (1994). La production du lapin dans le monde [Rabbit production in the world]. Paper presented at the 6èmes Journées de la Recherche Cunicole en France, Paris, France.
- Colombini, S., Broderick, G. A., Galasso, I., Martinelli, T., Rapetti, L., Russo, R., & Reggiani, R. (2014). Evaluation of *Camelina sativa* (L.) Crantz meal as an alternative protein source in ruminant rations. *Journal of the Science of Food and Agriculture*, 94(4), 736–743.
- Combes, S., Lepetit, J., Darche, B., & Lebas, F. (2004). Effect of cooking temperature and cooking time on Warner-Bratzler tenderness measurement and collagen content in rabbit meat. *Meat Science*, 66(1), 91–96.
- Contini, C., Boncinelli, F., Gerini, F., Scozzafava, G., & Casini, L. (2018). Investigating the role of personal and context-related factors in convenience foods consumption. *Appetite*, 126, 26–35.
- Corbin, C.H., Quinn, O., Garmyn, T.G., Legako, A.J., Hunt, J.F., Dinh, M.R., Rathmann, T.T.N., Brooks, R.J. & Miller, J.C. (2015). Sensory evaluation of

- tender beef strip loin steaks of varying marbling levels and quality treatments. *Meat Science*, 100, 24–31.
- Covinsky, K., & Katz, M. J. (2020). Supplemental Nutrition Assistance Program: Do not take the food out of patients' mouths. *JAMA Internal Medicine*, 180(4), 605–606.
- Crews, T. E., & Peoples, M. B. (2004). Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. *Agriculture, Ecosystems & Environment*, 102(3), 279–297.
- Cullere, M., & Dalle Zotte, A. (2018). Rabbit meat production and consumption: State of knowledge and future perspectives. *Meat Science*, 143, 137–146.
- Cullere, M., Dalle Zotte, A., Tasoniero, G., Giaccone, V., Szendrő, Z., Szín, M., Odermatt, M., Gerencsér, Z., Dal Bosco, A., & Matics, Z. (2018). Effect of diet and packaging system on the microbial status, pH, colour and sensory traits of rabbit meat evaluated during chilled storage. *Meat Science*, 141, 36–43.
- Cullere, M., Singh, Y., Pellattiero, E., Berzuini, S., Galasso, I., Clemente, C., & Dalle Zotte, A. (2023). Effect of the dietary inclusion of *Camelina sativa* cake into quail diet on live performance, carcass traits, and meat quality. *Poultry Science*, 102(6), 102650.
- Czauderna, M., Kowalczyk, J., & Marounek, M. (2011). The simple and sensitive measurement of malondialdehyde in selected specimens of biological origin and some feed by reversed phase high performance liquid chromatography. *Journal of Chromatography. B, Analytical Technologies in the Biomedical and Life Sciences*, 879(23), 2251–2258.
- da Silva, K. G., Borges, T. D., Costa, L. B., & Sotomaior, C. S. (2021). Characteristics of meat, pet, and research rabbit farms in Brazil: An overview based on twelve farms. *World Rabbit Science*, 29(2), 115–123.
- Dabbou, S., Gai, F., Biasato, I., Capucchio, M. T., Biasibetti, E., & Dezzutto, D. (2018). Black soldier-fly defatted meal as a dietary protein source for broiler chickens: Effects on growth performance, blood traits, gut morphology and histological features. *Journal of Animal Science and Biotechnology*, 9, 49.
- Dalle Zotte, A. (2002). Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. *Livestock Production Science*, 75(1), 11–32.
- Dalle Zotte, A. (2004). Avantages diététiques: le lapin doit apprivoiser le consommateur [Dietary advantages: rabbit must tame consumers]. *Viandes et Produits Carnés*, 23, 161–167. Retrieved from https://www.researchgate.net/publication/285199973_Dietary_advantages_rabbit_must_tame_consumers (Accessed June, 2024).
- Dalle Zotte, A. (2007). Meat quality of rabbits reared under organic production system. In G. Zhou & W. Zhang (Eds.), *Proceedings of the 53rd International Congress of Meat Science and Technology* (pp. 87–88). Beijing, China.

- Dalle Zotte, A., & Paci, G. (2014). Rabbit growth performance, carcass traits and hind leg bone characteristics as affected by sire genetic origin, slaughter season, parity order and gender in an organic production system. *Animal Science Papers and Reports*, 32(2), 143–159.
- Dalle Zotte, A., & Ragno, E. (2005). Influence of the paternal genetic origin and season on the live performances and the carcass yield of rabbits reared in the organic production system. *Italian Journal of Animal Science*, 4(2), 544–546.
- Dalle Zotte, A., & Szendrő, Z. (2011). The role of rabbit meat as functional food. *Meat Science*, 88(3), 319–331.
- Dalle Zotte, A., Cullere, M., Martins, C., Alves, S. P., Freire, J. P., Falcão-e-Cunha, L., & Bessa, R. J. (2018). Incorporation of black soldier fly (*Hermetia illucens* L.) larvae fat or extruded linseed in diets of growing rabbits and their effects on meat quality traits including detailed fatty acid composition. *Meat Science*, 146, 50–58.
- Danowska-Oziewicz, M., & Kurp, L. (2017). Physicochemical properties, lipid oxidation and sensory attributes of pork patties with lupin protein concentrate stored in vacuum, modified atmosphere and frozen state. *Meat Science*, 131, 158–165.
- Dashdorj D, Tripathi VK, Cho S, Kim Y, Hwang I. 2016. Dry aging of beef; Review. *Journal of Animal Science and Technology*, 58, 20–31.
- Dashdorj, D., Amna, T., & Hwang, I. (2015). Influence of specific taste-active components on meat flavour as affected by intrinsic and extrinsic factors: An overview. *European Food Research and Technology*, 241, 157–171.
- de Blas, C., & Mateos, G. G. (2020). Feed formulation. In C. de Blas & J. Wiseman (Eds.), *Nutrition of the rabbit* (3rd ed., pp. 243–253). CAB International.
- de Blas, C., & Wiseman, J. (2003). *The nutrition of the rabbit*. CABI Publishing. Oxon, UK
- De Blas, J. C., Pérez, E., Fraga, M. J., Rodriguez, J. M., & Gálvez, J. F. (1981). Effect of diet on feed intake and growth of rabbits from weaning to slaughter at different ages and weights. *Journal of Animal Science*, 52(6), 1225–1232.
- de Blas, C. & Mateos, G. G. (2010). Feed formulation. In *Nutrition of the rabbit* (pp. 222–232). Wallingford UK: CABI.
- de Castro, R. J. S., Ohara, A., Aguilar, J. G. d. S., & Domingues, M. A. F. (2018). Nutritional, functional and biological properties of insect proteins: Processes for obtaining, consumption and future challenges. *Trends in Food Science & Technology*, 76, 82–89.
- Deeb, B. J. (2009). Respiratory disease and pasteurellosis. *Ferrets, Rabbits, and Rodents*, 172.
- Delver, J. J., & Smith, Z. K. (2024). Opportunities for Camelina meal as a livestock feed ingredient. *Agriculture*, 14(1), 116.

- Demann, J., Petersen, F., Dusel, G., Bog, M., Devlamynck, R., Ulbrich, A., Olf, H. W., & Westendarp, H. (2022). Nutritional value of duckweed as protein feed for broiler chickens—Digestibility of crude protein, amino acids and phosphorus. *Animals*, 13(1), 130.
- Deng, Y., Nie, Q., Zhou, Y., Wang, W., Wu, Z., Ji, L., Zhang, J. & Zhou, D. (2024). Research progress in processing technology of rabbit meat. *Food Bioengineering*, 3(3), 314-322.
- Dewi, Y. L., Sofyan, A., Herdian, H., Sakti, A. A., Irawan, A., Jasmadi, J., Anggraeni, A. S., Mardawati, E., Adriyanto, A., Mahata, M. E., & Handayani, U. F. (2024). Processing technology to improve seaweed nutritional quality as a feed for poultry: A review and its implementation. *World's Poultry Science Journal*, 80(1), 207–235.
- de Domingues, C. H. F., Borges, J. A. R., Ruviano, C. F., Guidolin, D. C. F., & Carrijo-Mauad, J. (2020). Understanding the factors influencing consumer willingness to accept the use of insects to feed poultry, cattle, pigs and fish in Brazil. *PLoS ONE*, 15(11), e0224059.
- de Visser, C. L. M., Schreuder, R., & Stoddard, F. (2014). The EU's dependency on soya bean import for the animal feed industry and potential for EU produced alternatives. *Ocl*, 21(4), D407.
- Dhiman, S., Kumari, A., Kumari, S., & Sharma, R. (2025). Advanced biodegradable starch-based nanocomposite films incorporating zinc oxide nanoparticles: Synthesis, characterization, and efficacy in antibacterial food packaging applications. *Journal of Environmental Chemical Engineering*, 13, 116296.
- Dikeman, M. E., Obuz, E., Gok, V., Akkaya, L., & Stroda, S. (2013). Effects of dry, vacuum, and special bag aging; USDA quality grade; and end-point temperature on yields and eating quality of beef *Longissimus lumborum* steaks. *Meat Science*, 94, 228-233.
- Dinh, T. T. N., Legako, J. F., Miller, M. F., & Brooks, J. C. (2018). Effects of USDA quality grade and cooking on water-soluble precursors of beef flavour. *Meat Science*, 146, 122–130.
- Dobermann, D., Swift, J. A., & Field, L. M. (2017). Opportunities and hurdles of edible insects for food and feed. *Nutrition Bulletin*, 42(4), 293–308.
- Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W., & Lorenzo, J. M. (2019) Comprehensive review on lipid oxidation in meat and meat products. *Antioxidants*, 8, 429.
- Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can seaweed farming play a role in climate change mitigation and adaptation? *Frontiers in Marine Science*, 4, 100.
- Dutra, D. R., Villegas-Cayllahua, E. A., Baptista, G. G., Ferreira, L. E., Castilha, L. D., & Borba, H. (2024). Characterization of Post-Mortem pH Evolution and Rigor Mortis Process in Botucatu Rabbit Carcasses of Different Categories. *Animals*, 14(17).

- EEC, (1986). Council Directive 86/609/EEC of 24 November 1986 on the approximation of laws, regulations and administrative provisions of the Member States regarding the protection of animals used for experimental and other scientific purposes. Official Journal of the European Communities, L358, 1–29. <https://op.europa.eu/en/publication-detail/-/publication/cc3a8ccb-5a30-4b6e-8da8-b13348caeb0c/language-en>
Retrieved July 4, 2024.
- EFSA Panel on Animal Health and Welfare (AHAW), Nielsen, S. S., Alvarez, J., Bicot, D. J., Calistri, P., Depner, K., Drewe, J. A., Garin-Bastuji, B., Rojas, J. L. G., Schmidt, C. G., Michel, V., Chueca, M. A. M., Roberts, H. C., Sihvonon, L. H., Spooler, H., Stahl, K., Calvo, A. V., Viltrop, A., Buijs, S., Edwards, S., Candiani, D., Mosbach-Schulz, O., Van der Stede, Y., and Winckler, C. (2020). Health and welfare of rabbits farmed in different production systems. *EFSA Journal*, 18(1), 5944
- El-Ashram, S., Aboelhadid, S. M., Abdel-Kafy, E. S. M., Hashem, S. A., Mahrous, L. N., Farghly, E. M., & Kamel, A. A. (2020). Investigation of pre- and post-weaning mortalities in rabbits bred in Egypt, with reference to parasitic and bacterial causes. *Animals*, 10(3), 537.
- Elemo, B. O., Elemo, G. N., Makinde, M. A., & Erukainure, O. L. (2011). Chemical evaluation of African palm weevil, *Rhynchophorus phoenicis*, larvae as a food source. *Journal of Insect Science*, 11, 146.
- El-Raffa, A. M. (2004). Rabbit production in hot climates. In Proceedings of the 8th Congress of the World Veterinary Rabbit Association (WRSA) (pp. 7–11).
- Escriba-Perez, C., Baviera-Puig, A., Buitrago-Vera, J., & Montero-Vicente, L. (2017). Consumer profile analysis for different types of meat in Spain. *Meat Science*, 129, 120–126.
- Escribá-Pérez, C., Baviera-Puig, A., Montero-Vicente, L., & Buitrago-Vera, J. (2019). Children's consumption of rabbit meat. *World Rabbit Science*, 27(3), 113–122.
- Etukudo, O. M., Ekerette, E. E., Johnson, E. I., & Okon, B. A. (2024). Mini review on the nutritional benefits of rabbit meat. *Nutrition and Food Science International Journal*, 13(4), 555866.
- European Commission. (1998). Commission directive 98/64/EC of 3 September 1998 establishing community methods of analysis for the determination of amino acids, crude oils and fats, and olaquinox in feeding stuffs and amending Q2 directive 71/ 393/EEC. Official Journal of the European Union, 257(14). Retrieved from <https://op.europa.eu/en/publication-detail/-/publication/856db9b7-6f1d-4d6e-a778-c766c9fa1776> (Accessed June, 2024).
- European Commission. (2010). Commission regulation (EU) no 116/2010 of 9 February 2010 amending regulation (EC) no 1924/2006 of the European Parliament and of the council with regard to the list of nutrition claims. Official Journal of the European Union, 37, 16–18. L37/16-18, 10.2.2010.

- Retrieved from <https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX%3A32010R0116&qid=1649772621224> (Accessed June, 2024).
- European Commission, 2017. Overview report: commercial rabbit farming in the European Union.
- Falola, A., Mukaila, R., & Emmanuel, J. O. (2022). Economic analysis of small-scale fish farms and food security in North-Central Nigeria. *Aquaculture International*, 30(6), 2937–2952.
- Fanatico, A., & Green, C. (2012). Small-scale sustainable rabbit production (IP445). National Center for Appropriate Technology. <https://attra.ncat.org>
- FAOSTAT. The Statistics Division of the FAO, (2020). Available online: <http://www.fao.org/faostat/en/#data>
- FAOSTAT. (2023). Crops and livestock products. <https://www.fao.org/faostat/en/#data/QCL>
- Fearnside, P. M. (2001). Soybean cultivation as a threat to the environment in Brazil. *Environmental Conservation*, 28(1), 23–38.
- Fernández-Carmona, J., Blas, E., Pascual, J. J., Maertens, L., Gidenne, T., Xiccato, G., & García, J. (2005). Recommendations and guidelines for applied nutrition experiments in rabbits. *World Rabbit Science*, 13(4), 209–228.
- Finke, M. D. (2002). Complete nutrient composition of commercially raised invertebrates used as food for insectivores. *Zoo Biology*, 21(3), 269–285.
- Finke, M. D. (2013). Complete nutrient content of four species of feeder insects. *Zoo Biology*, 32(1), 27–36.
- Finke, M.D. & Oonincx, D.G.A.B., (2017). Nutrient content of insects. In: Van Huis, A. and Tomberlin, J.K. (eds) *Insects as food and feed: from production to consumption*. Wageningen Academic Publishers, Wageningen, the Netherlands, pp. 290-317.
- Finzi, A. (2000). Raising rabbits for food security. In *Proceedings of the 7th World Rabbit Congress* (Vol. 8, pp. 13–38).
- Finzi, A., Morera, P., & Kuzminsky, G. (1992). Effect of shearing on rabbit bucks performances in hot ambient conditions. *Journal of Applied Rabbit Research*, 15, 489–494.
- Fischer, J., Haas, T., Leppert, J., Lammers, P. S., Horner, G., Wüst, M., & Boeker, P. (2014). Fast and solvent-free quantitation of boar taint odorants in pig fat by stable isotope dilution analysis-dynamic headspace thermal desorption-gas chromatography/time-of-flight mass spectrometry. *Food Chemistry*, 158, 345–350.
- Fogang Mba, A. R., Kansci, G., Viau, M., Ribourg, L., Fogoh Muafor, J., Hafnaoui, N., Le Gall, P., & Genot, C. (2018). Growing conditions and morphotypes of African palm weevil (*Rhynchophorus phoenicis*) larvae influence their

- lipophilic nutrient but not their amino acid compositions. *Journal of Food Composition and Analysis*, 69, 87–97.
- Folch, J. M., Lees, M., & Sloane-Stanley, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry*, 226, 497–509.
- Font-i-Furnols, M., & Guerrero, L. (2014). Consumer preference, behaviour and perception about meat and meat products: An overview. *Meat Science*, 98(3), 361–371.
- Food and Agriculture Organization of the United Nations. (2016). The state of world fisheries and aquaculture: Opportunities and challenges. <http://www.fao.org/3/i5555e/i5555e.pdf>
- Food and Agriculture Organization of the United Nations. (2018). World livestock: Transforming the livestock sector through the Sustainable Development Goals. FAO. <https://www.fao.org/3/CA1969EN/ca1969en.pdf>
- Food and Agriculture Organization of the United Nations. (2021). Land statistics: Global, regional and country trends, 1990–2018 (FAOSTAT Analytical Brief Series No. 15). FAO.
- Food and Agriculture Organization. (1992). Act No. 246/1992 on the protection of animals against cruelty. <https://www.fao.org/faolex/results/details/en/c/LEX-FAOC094515/>
- Food and Agriculture Organization. (1997). “In: The Rabbit: Husbandry, Health and Production”. David Lubin Memorial Library cataloguing in publication data, pp 205
- Fraanje, W., & Garnett, T. (2020). Soy: Food, feed, and land use change. In H. Breewood (Ed.), *Foodsource: Building blocks*. Food Climate Research Network, University of Oxford. <https://www.foodsource.org.uk/building-blocks/soy-food-feed-and-land-use-change>
- Frank, D., Zhang, Y., Li, Y., Luo, X., Chen, X., Kaur, M., Mellor, G., Stark, J., & Hughes, J. (2019). Shelf life extension of vacuum packaged chilled beef in the Chinese supply chain: A feasibility study. *Meat Science*, 153, 135–143.
- Fritz, J., Walia, C., Elkadri, A., Pipkorn, R., Dunn, R. K., Sieracki, R., Goday, P. S., & Cabrera, J. M. (2019). A systematic review of micronutrient deficiencies in pediatric inflammatory bowel disease. *Inflammatory Bowel Diseases*, 25(3), 445–459.
- Froescheis, O., Moalli, S., Liechti, H., & Bausch, J. (2000). Determination of lycopene in tissues and plasma of rats by normal-phase high-performance liquid chromatography with photometric detection. *Journal of Chromatography B: Biomedical Sciences and Applications*, 739, 291–299.
- Gasco, L., Dabbou, S., Gai, F., Bruguapaglia, A., Schiavone, A., Birolo, M., Xiccato, G., & Trocino, A. (2019). Quality and consumer acceptance of meat from

- rabbits fed diets in which soybean oil is replaced with black soldier fly and yellow mealworm fats. *Animals*, 9(9), 629.
- Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/i3437e/i3437e.pdf>
- Gerencsér, Z., Szendrő, Z. S., Matics, Z., Radnai, I., Kovács, M., Nagy, I., Cullere, M., Dal Bosco, A., & Dalle Zotte, A. (2014). Effect of dietary supplementation of spirulina (*Arthrospira platensis*) and thyme (*Thymus vulgaris*) on apparent digestibility and productive performance of growing rabbits. *World Rabbit Science*, 22(1), 1–9.
- Gibbs, H. K., Rausch, L., Munger, J., Schelly, I., Morton, D. C., Noojipady, P., Soares-Filho, B., Barreto, P., Micol, L., & Walker, N. F. (2015). Brazil's soy moratorium. *Science*, 347(6220), 377–378.
- Gidenne, T., Garreau, H., Drouilhet, L., Aubert, C., & Maertens, L. (2017). Improving feed efficiency in rabbit production, a review on nutritional, technico-economical, genetic and environmental aspects. *Animal Feed Science and Technology*, 225, 109–122.
- Gleeson, M., Calder, P. C., & Yaqoob, P. (2013). Exercise nutrition and immunity. In P. Calder & P. Yaqoob (Eds.), *Diet, immunity and inflammation* (pp. 652–685). Woodhead Publishing.
- Goli, Z., Akinmoladun, O. F., Mpetile, Z., Mazhangara, I. R., & Jaja, I. F. (2025). Consumer perceptions of rabbit meat as an alternative animal protein source: a university-based study. *Food Res [Internet]*, 9(1), 55-64.
- Gonçalves, C., Silva-Santos, T., Ferreira, L., Santos, I., Silva, M., Nunes, P., Teixeira, J., Monteiro, D., & Pinheiro, V. (2024). Effect of three cooking methods on cooking loss and edible weight of rabbit meat. *Acta Portuguesa de Nutrição*, 39, 38–43.
- Gondret, F., Larzul, C., Combes, S., & De Rochambeau, H. (2005). Carcass composition, bone mechanical properties, and meat quality traits in relation to growth rate in rabbits. *Journal of Animal Science*, 83, 1526–1535.
- Gorraiz, C., Beriain, M., Chasco, J., & Insausti, K. (2002). Effect of aging time on volatile compounds, odor, and flavour of cooked beef from Pirenaica and Friesian bulls and heifers. *Journal of Food Science*, 67, 916–922.
- González-Redondo, P., Mena, Y., & Fernández-Cabanas, V. M. (2010). Factors affecting rabbit meat consumption among Spanish university students. *Ecology of Food and Nutrition*, 49(4), 298–315.
- Grădinaru, A. C. (2017). The Transylvanian Giant Rabbit: An efficient selection for qualitative and quantitative genetic traits. *Rabbit Genetics*, 7(1), 1–6.

- Grau, T., Vilcinskas, A., & Joop, G. (2017). Sustainable farming of the mealworm *Tenebrio molitor* for the production of food and feed. *Zeitschrift für Naturforschung C*, 72(9-10), 337–349.
- Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector: A review. *Meat Science*, 66, 259–272.
- Guendouz, A., Hannachi, A., Benidir, M., Fellahi, Z. E. A., & Frih, B. (2022). Agro-biochemical Characterisation of *Camelina sativa*: A Review. *Agricultural Reviews*, 43(3).
- Haddad, L., Hawkes, C., Webb, P., Thomas, S., Beddington, J., Waage, J., & Flynn, D. (2016). A new global research agenda for food. *Nature*, 540(7631), 30–32.
- Haider, M. W., Abbas, S. M., Saeed, M. A., Farooq, U., Waseem, M., Adil, M., Javed, M. R., Haq, I. U., & Osei Tutu, C. (2025). Environmental and nutritional value of fruit and vegetable peels as animal feed: A comprehensive review. *Animal Research and One Health*, 3(2), 149–164.
- Halls, A. E. (2010). Nutritional requirements for rabbits [PDF]. Shur-Gain, Nutreco Canada Inc. <http://nutrecocanada.nutreco-t.com/docs/shur-gain---specialty/nutritional-requirements-of-rabbits.pdf>
- Hancz, C., Sultana, S., Nagy, Z., & Biró, J. (2024). The role of insects in sustainable animal feed production for environmentally friendly agriculture: A review. *Animals*, 14(7), 1009.
- Hao, Y., Li, C., Li, F., Liu, C., Wang, H., & Xie, X. (2023). Effect of tissue composition and microstructure on rabbit meat optical properties. *Applied Spectroscopy*, 77(6), 623–635. <https://doi.org/10.1177/00037028231166004>
- Hartmann, C., & Siegrist, M. (2017). Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. *Trends in Food Science & Technology*, 61, 11–25.
- Hasnah Hassan, S., 2011. Managing conflicting values in functional food consumption: the Malaysian experience. *British Food Journal*, 113(8):1045-1059.
- Heckmann, L.-H., Andersen, J. L., Gianotten, N., Calis, M., Fischer, C. H., & Calis, H. (2018). Sustainable mealworm production for feed and food. In *Edible insects in sustainable food systems* (pp. 321–328). Springer International Publishing.
- Hedrick, H. B., Stringer, W. C., & Clarke, A. D. (1993). Recommendations for aging beef. University of Missouri Extension. <https://mospace.umsystem.edu/items/0ec4bef5-e953-42cf-acb9-73dda09fd87a> (Accessed March 2024)
- Hernández, P., & Gondret, F. (2006). Rabbit meat quality. In L. Maertens & P. Coudert (Eds.), *Recent advances in rabbit sciences* (pp. 283–302). ILVO, Merelbeke,

- Belgium. Retrieved from <http://world-rabbit-science.com/Documents/Cost848.pdf> (Accessed June, 2024).
- Hernandez, P., Ariño, B., Grimal, A., & Blasco, A. (2006). Comparison of carcass and meat characteristics of three rabbit lines selected for litter size or growth rate. *Meat Science*, 73, 645–650.
- Herrera-Mendez, C. H., Becila, S., Boudjellal, A., & Ouali, A. (2006). Meat ageing: Reconsideration of the current concept. *Trends in Food Science & Technology*, 17(8), 394–405.
- Hicks, C. C., Cohen, P. J., Graham, N. A. J., Nash, K. L., Allison, E. H., D’Lima, C., Mills, D. J., Roscher, M., Thilsted, S. H., Thorne-Lyman, A. L., & MacNeil, M. A. (2019). Harnessing global fisheries to tackle micronutrient deficiencies. *Nature*, 574(7776), 95–98.
- Hixson, S. M., Parrish, C. C., & Anderson, D. M. (2014). Full substitution of fish oil with camelina (*Camelina sativa*) oil, with partial substitution of fishmeal with camelina meal, in diets for farmed Atlantic salmon (*Salmo salar*) and its effect on tissue lipids and sensory quality. *Food Chemistry*, 157, 51–61.
- Hoffman, L. C., Nkhabutlane, P., Schutte, D. W., & Vosloo, C. (2004). Factors affecting the purchasing of rabbit meat: A study of ethnic groups in the Western Cape. *Journal of Family Ecology and Consumer Sciences*, 32(1), 26–35.
- Hong, J., & Kim, Y. Y. (2022). Insect as feed ingredients for pigs. *Animal Bioscience*, 35(2), 347.
- Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*, 49, 447–457.
- Hopkins, D., & Thompson, J. (2002). Factors contributing to proteolysis and disruption of myofibrillar proteins and the impact on tenderisation in beef and sheep meat. *Crop and Pasture Science*, 53(2), 149–166.
- Huff-Lonergan, E., & Lonergan, S. M. (2005). Mechanisms of water-holding capacity of meat: The role of post-mortem biochemical and structural changes. *Meat Science*, 71(2), 194–204.
- Huffman, K. L., Miller, M. F., Hoover, L. C., Wu, C. K., Brittin, H. C., & Ramsey, C. B. (1996). Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *Journal of Animal Science*, 74(1), 91–97.
- Iida, F., Miyazaki, Y., Tsuyuki, R., Kato, K., Egusa, A., Ogoshi, H., & Nishimura, T. (2016). Changes in taste compounds, breaking properties, and sensory attributes during dry aging of beef from Japanese black cattle. *Meat Science*, 112, 46–51.
- International Organization for Standardisation. (2012). ISO 8586:2012. Sensory analysis – general guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors. Retrieved from

<https://www.iso.org/obp/ui/#iso:std: iso:8586:ed-1:v2:en> (Accessed June, 2024).

- International Organization for Standardization, (2015). Standard terms and definitions that apply to all quality management and quality management system standards.
- Jagtap, S., Garcia-Garcia, G., Duong, L., Swainson, M., & Martindale, W. (2021). Codesign of food system and circular economy approaches for the development of livestock feeds from insect larvae. *Foods*, 10(8), 1701.
- Jantzen da Silva Lucas, A., Quadro Oreste, E., Leão Gouveia Costa, H., Martín López, H., Dias Medeiros Saad, C., & Prentice, C. (2021). Extraction, physicochemical characterization, and morphological properties of chitin and chitosan from cuticles of edible insects. *Food Chemistry*, 343, 128550.
- Jayasena, D. D., Ahn, D. U., Nam, K. C., & Jo, C. (2013). Flavour chemistry of chicken meat: A review. *Asian-Australasian Journal of Animal Sciences*, 26(5), 732–742.
- Jeremiah, L. E., Dungan, M. E. R., Aalhus, J. L., & Gibson, L. L. (2003). Assessment of the relationship between chemical components and palatability of major beef muscles and muscle groups. *Meat Science*, 65, 1013–1019.
- Jiang, T., Busboom, J. R., Nelson, M. L., O’Fallon, J., Ringkob, T. P., Rogers-Klette, K. R., Joos, D., & Piper, K. (2010). The influence of forage diets and aging on beef palatability. *Meat Science*, 86(3), 642–650.
- Jiya, E. Z., Ijaiya, A. T., Olorunsanya, A. O., & Ayanwale, B. A. (2013). Performance of rabbits fed diets containing graded levels of processed tallow (*Detarium microcarpum*) seed meal. *Nigerian Journal of Animal Production*, 40(2), 59–70.
- Joo, S. T., Lee, E. Y., Son, Y. M., Hossain, M. J., Kim, C. J., Kim, S. H., & Hwang, Y. H. (2023). Aging mechanism for improving the tenderness and taste characteristics of meat. *Journal of Animal Science and Technology*, 65(6), 1151–1168.
- Jumare, A. I., Mohammed, S., & Ibrahim, L. (2024). Agro-industrial by-products in livestock feeding: Nutritional evaluation and future perspectives. *Tropical Animal Health and Production*, 56(4), 212–225.
- Juodka, R., Nainienė, R., Juškieienė, V., Juška, R., Leikus, R., Kadžienė, G., & Stankevičienė, D. (2022). Camelina (*Camelina sativa* (L.) Crantz) as feedstuffs in meat type poultry diet: A source of protein and n-3 fatty acids. *Animals*, 12(3), 295.
- Kallas, Z., & Gil, J. M. (2012). A dual response choice experiments (DRCE) design to assess rabbit meat preference in Catalonia: A heteroscedastic extreme-value model. *British Food Journal*, 114(10), 1394–1413.

- Kamel, L., & Lukefahr, S. D. (1990). A note on the social impact of village scale rabbit project development in rural Egypt. *Journal of Applied Rabbit Research*, 12, 259–262.
- Kaplan-Pasternak, M. (2011). Promoting entrepreneurial opportunities through rabbit production in Haiti. Rabbit Production in Developing Countries. World Rabbit Science Association. <http://world-rabbit-science.com/>
- Kaplan-Pasternak, M., & Lukefahr, S. D. (2011). WRSA project: Rabbit production development in response to the earthquake disaster in Haiti [Interim report to the WRSA]. World Rabbit Science Association. <http://world-rabbit-science.com/>
- Karim, D. A., & Grace, K. (2023). A review of non-conventional animal protein sources as poultry feeds. *International Journal of Veterinary Science and Animal Husbandry*, 8, 243–252.
- Kemp, C. M., Sensky, P. L., Bardsley, R. G., Buttery, P. J., & Parr, T. (2010). Tenderness—an enzymatic view. *Meat Science*, 84(2), 248–256.
- Kerstetter, J. E., O'Brien, K. O., Caseria, D. M., Wall, D. E., & Insogna, K. L. (2005). The impact of dietary protein on calcium absorption and kinetic measures of bone turnover in women. *Journal of Clinical Endocrinology and Metabolism*, 90(1), 26–31.
- Khan, M. I., Jung, S., Nam, K. C., & Jo, C. (2016). Post-mortem aging of beef with a special reference to the dry aging. *Korean Journal for Food Science of Animal Resources*, 36(2), 159–169.
- Khusro, M., Andrew, N. R., & Nicholas, A. (2012). Insects as poultry feed: A scoping study for poultry production systems in Australia. *World's Poultry Science Journal*, 68(3), 435–446.
- Kim, J. H., Kim, D. H., Ji, D. S., Lee, H. J., Yoon, D. K., & Lee, C. H. (2017). Effect of aging process and time on physicochemical and sensory evaluation of raw beef top round and shank muscles using an electronic tongue. *Korean Journal for Food Science of Animal Resources*, 37, 823–832.
- Kim, J., & Fagan, J.M. (2014). Eat Rabbit; a global source of protein.
- Kim, M., Choe, J., Lee, H. J., Yoon, Y., Yoon, S., & Jo, C. (2019). Effects of aging and aging method on physicochemical and sensory traits of different beef cuts. *Food Science of Animal Resources*, 39(1), 54–64.
- Kim, S., Kim, G., Moon, C., Ko, K., Choi, Y., Choe, J., & Ryu, Y. (2022). Effects of Aging Methods and Periods on Quality Characteristics of Beef. *Food science of animal resources*, 42(6), 953–967.
- Kim, Y. H. B., Kemp, R., & Samuelsson, L. M. (2016). Effects of dry-aging on meat quality attributes and metabolite profiles of beef loins. *Meat Science*, 111, 168–176.
- Kim, Y. H. B., Ma, D., Setyabrata, D., Farouk, M. M., Lonergan, S. M., Huff-Lonergan, E., & Hunt, M. C. (2018). Understanding post-mortem

- biochemical processes and post-harvest aging factors to develop novel smart-aging strategies. *Meat Science*, 144, 74-90.
- Kinyuru, J. N., Mogendi, J. B., Riwa, C. A., & Ndung'u, N. W. (2015). Edible insects—A novel source of essential nutrients for human diet: Learning from traditional knowledge. *Animal Frontiers*, 5(2), 14–19.
- Kırkpınar, F., Açıkgoz, Z., & Niyonshuti, E. (2025). Current situation, future goals, and strategies of the global feed and feed additives industries. In *Animal feeds and additives*. IntechOpen.
- Kohles, M. (2022). Gastrointestinal function and proper nutrition of the rabbit. *Oxbow Animal Health*. <https://www.oxbowaustralia.com/wp->
- Korsa, G., Alemu, D., & Ayele, A. (2024). Azolla plant production and their potential applications. *International Journal of Agronomy*, 2024, 1716440
- Koutsos, L., McComb, A., & Finke, M. (2019). Insect composition and uses in animal feeding applications: A brief review. *Annals of the Entomological Society of America*, 112(6), 544–551.
- Kowalska, D., Gugolek, A., & Strychalski, J. (2020). Evaluation of slaughter parameters and meat quality of rabbits fed diets with silkworm pupae and mealworm larvae meals. *Annals of Animal Science*, 20(2), 551–564.
- Kowalska, D., Strychalski, J., & Gugolek, A. (2021). The effect of silkworm pupae and mealworm larvae meals as dietary protein components on performance indicators in rabbits. *Revista Mexicana de Ciencias Pecuarias*, 12, 151–162.
- Kozioł, K., Maj, D., & Bieniek, J. (2015). Changes in the colour and pH of rabbit meat in the aging process. *Medycyna Weterynaryjna*, 71(2), 104-108.
- Kristensen, L., & Purslow, P. P. (2001). The effect of ageing on the water-holding capacity of pork: Role of cytoskeletal proteins. *Meat Science*, 58(1), 17–23.
- Kromhout, D., Spaaij, C. J. K., de Goede, J. & Weggemans, R. M. (2016). The 2015 Dutch food-based dietary guidelines. *European Journal of Clinical Nutrition*, 70(8), 869–878.
- Kröncke, N., Grebenteuch, S., Keil, C., Demtröder, S., Kroh, L., Thünemann, A. F., Benning, R., & Haase, H. (2019). Effect of different drying methods on nutrient quality of the yellow mealworm (*Tenebrio molitor* L.). *Insects*, 10(4), 84.
- Krunt, O., Zita, L., Kraus, A., Bureš, D., Needham, T., & Volek, Z. (2022). The effect of housing system on rabbit growth performance, carcass traits, and meat quality characteristics of different muscles. *Meat Science*, 193, Article 108953.
- Kumar, D., Risam, K. S., Bhatt, R. S., & Singh, U. (2013). Reproductive performance of different breeds of broiler rabbits under sub-temperate climatic conditions. *World Rabbit Science*, 21(3), 169–173.

- Kumar, P., Sharma, N., Narnoliya, L. K., Verma, A. K., Umaraw, P., Mehta, N., Ismail-Fitry, M. R., Kaka, U., Yong-Meng, G., Lee, S. J., & Sazili, A. Q. (2025). Improving quality and consumer acceptance of rabbit meat: Prospects and challenges. *Meat Science*, 219, 109660.
- Kurasiak-Popowska, D., & Stuper-Szablewska, K. (2020). The phytochemical quality of *Camelina sativa* seed and oil. *Acta Agriculturae Scandinavica Section B Soil and Plant Science*, 70(1), 39–47.
- Lähteenmäki-Uutela, A., Grmelová, N., Hénault-Ethier, L., Deschamps, M.-H., Vandenberg, G. W., Zhao, A., Zhang, Y., Yang, B., & Nemane, V. (2017). Insects as food and feed: Laws of the European union, United States, Canada, Mexico, Australia, and China. *European Food and Feed Law Review*, 22–36.
- Lambert, A. D., Smith, J. P., & Dodds, K. L. (1991). Shelf-life extension and microbiological safety of fresh meat: A review. *Food Microbiology*, 8(4), 267–297.
- Laster, M. A., Smith, R. D., Nicholson, K. L., Nicholson, J. D. W., Miller, R. K., Griffin, D. B., Harris, K. B., & Savell, J. W. (2008). Dry versus wet aging of beef: Retail cutting yields and consumer sensory attribute evaluations of steaks from ribeyes, strip loins, and top sirloins from two quality grade groups. *Meat Science*, 80, 795–804.
- Laureati, M., Proserpio, C., Jucker, C., & Savoldelli, S. (2016). New sustainable protein sources: Consumers' willingness to adopt insects as feed and food. *Italian Journal of Food Science*, 28(4), 652–668.
- Laville, E., Sayd, T., Morzel, M., Blinet, S., Chambon, C., Lepetit, J., Renand, G., & Hocquette, J. F. (2009). Proteome changes during meat aging in tough and tender beef suggest the importance of apoptosis and protein solubility for beef aging and tenderization. *Journal of Agricultural and Food Chemistry*, 57, 10755–10764.
- Lawrie, R.A. (1985) *Meat Science*. Pergamon Press, Oxford, page 451.
- Lee, H. J., Choe, J. H., Kim, K. T., Oh, J., Lee, D. G., Kwon, K. M., Choi, Y. I., & Jo, C. (2017). Analysis of low-marbled Hanwoo cow meat aged with different dry-aging methods. *Asian-Australasian Journal of Animal Sciences*, 30(7), 7–8.
- Lee, H. J., Yoon, Y. W., Kim, M., Oh, H., Yoon, Y., & Jo, C. (2019). Changes in microbial composition on the crust by different air flow velocities and their effect on sensory properties of dry-aged beef. *Meat Science*, 153, 152–158.
- Lee, C. M., Trevino, B., & Chaiyawat, M. (1996). A simple and rapid solvent extraction method for determining total lipids in fish tissue. *Journal of AOAC International*, 79(2), 487–492.
- Leiber, F., Meier, J. S., Burger, B., Wettstein, H. R., Kreuzer, M., Hatt, J. M., & Clauss, M. (2008). Significance of coprophagy for the fatty acid profile in body tissues of rabbits fed different diets. *Lipids*, 43(9), 853–865.

- Leroy, F., & Petracci, M. (2021). Rabbit meat: Valuable nutrition or too-cute-to-eat? *World Rabbit Science*, 29(4), 239–246.
- Lewis, G. J., Purslow, P. P., & Rice, A. E. (1991). The effect of conditioning on the strength of perimysial connective tissue dissected from cooked meat. *Meat Science*, 30(1), 1–12.
- Li, X., Babol, J., Bredie, W. L. P., Nielsen, B., Tománková, J., & Lundström, K. (2014). A comparative study of beef quality after ageing longissimus muscle using a dry ageing bag, traditional dry ageing or vacuum package ageing. *Meat Science*, 97(4), 433–442.
- Li, K., Pang, S., Li, Z., Ding, X., Gan, Y., Gan, Q., & Fang, S. (2023). House ammonia exposure causes alterations in microbiota, transcriptome, and metabolome of rabbits. *Frontiers in Microbiology*, 14, 1125195.
- Li, Y. Q., Li, C. B., Li, H., Lin, X. S., Deng, S. L., & Zhou, G. H. (2016). Physicochemical and fatty acid characteristics of stewed pork as affected by cooking method and time. *International Journal of Food Science and Technology*, 51(2), 359–369.
- Li, K., Qiao, K., Xiong, J., Guo, H., & Zhang, Y. (2023). Nutritional values and bio-functional properties of fungal proteins: Applications in foods as a sustainable source. *Foods*, 12(24), 4388.
- Li, S., Zeng, W., Li, R., Hoffman, L. C., He, Z., Sun, Q., & Li, H. (2018). Rabbit meat production and processing in China. *Meat Science*, 145, 320–328.
- Li, X., & Mupondwa, E. (2016). Production and value-chain integration of *Camelina sativa* as a dedicated bioenergy feedstock in the Canadian prairies. Paper presented at the 24th European Biomass Conference & Exhibition, Amsterdam, Netherlands.
- Liceaga, A. M. (2022). Chapter four: Edible insects, a valuable protein source from ancient to modern times. In J. Wu (Ed.), *Advances in food and nutrition research* (Vol. 101, pp. 129–152). Academic Press.
- Lisboa, H. M., Nascimento, A., Arruda, A., Sarinho, A., Lima, J., Batista, L., Dantas, M. F., & Andrade, R. (2024). Unlocking the potential of insect-based proteins: Sustainable solutions for global food security and nutrition. *Foods*, 13(12), 1846.
- Liu, Z., Liao, W., & Liu, Y. (2016). A sustainable biorefinery to convert agricultural residues into value-added chemicals. *Biotechnology for Biofuels*, 9, 197.
- Lu, S., Taethaisong, N., Meethip, W., Surakhunthod, J., Sinpru, B., Sroichak, T., Archa, P., Thongpea, S., Paengkoum, S., Purba, R. A. P., & Paengkoum, P. (2022). Nutritional composition of black soldier fly larvae (*Hermetia illucens* L.) and its potential uses as alternative protein sources in animal diets: A review. *Insects*, 13(9), 831.
- Lu, Q., Kenfack Woumeza, C. D., Sarker, N. T., Yang, L., & Li, H. (2026). Yellow mealworm as a next-generation nutrient source for aquafeeds: Critical

- thoughts on current problems and future development. *Frontiers in Sustainable Food Systems*, 10, 1778511.
- Lucas, M. M., Stoddard, F. L., Annicchiarico, P., Frías, J., Martínez-Villaluenga, C., Sussmann, D., Duranti, M., Seger, A., Zander, P. M., & Pueyo, J. J. (2015). The future of lupin as a protein crop in Europe. *Frontiers in Plant Science*, 6, 705.
- Ludwiczak, A., Składanowska-Baryza, J., Kuczyńska, B., & Stanisław, M. (2020). Hycole doe milk properties and kit growth. *Animals*, 10, 214.
- Lukefahr, S. D. (1998). Review of global rabbit genetic resources: special emphasis on breeding programs and practices in the lesser developed countries. *Animal Genetic Resources/Resources génétiques animales/Recursos genéticos animales*, 23, 49-67.
- Lukefahr, S. (2008). Role of organic rabbit farming for poverty alleviation. In Proceedings of the MEKARN Rabbit Conference: Organic rabbit production from forages. Cantho University, Vietnam.
- Lukefahr, S. D., & Cheeke, P. R. (1991a). Rabbit project development strategies in subsistence farming systems. 1. Practical considerations. *World Animal Review*, 69, 26–35.
- Lukefahr, S. D., & Cheeke, P. R. (1991b). Rabbit project development strategies in subsistence farming systems. 2. Research applications. *World Animal Review*, 69, 60–70.
- Lukefahr, S. D., Cheeke, P. R., McNitt, J. I., & Patton, N. M. (2004). Limitations of intensive meat rabbit production in North America: A review. *Canadian Journal of Animal Science*, 84(3), 349–360.
- Lukefahr, S. D., Schuster, G., McCuiston, K. G., Verma, T., & Flores, R. (2010). Self-sustaining rabbit projects: A pilot study involving feed of sweet potato forage. In Proceedings of the 4th Rabbit Congress of the Americas. Córdoba, Argentina.
- Lyon, B.G., & Lyon, C.E. (1997). Sensory descriptive profile relationships to shear values of deboned poultry. *Journal of Food Science*, 62 (5), 885-897
- Mačanga, J., Koréneková, B., Nagy, J., Marcinčák, S., Popelka, P., & Kožárová, I. (2011). Post-mortem changes in the concentration of lactic acid, phosphates and pH in the muscle of wild rabbits (*Oryctolagus cuniculus*) according to the peri-mortal situation. *Meat Science*, 88(4), 701–704.
- Magalhães, S. C. Q., Fernandes, F., Cabrita, A. R. J., Fonseca, A. J. M., Valentão, P., & Andrade, P. B. (2017). Alkaloids in the valorization of European *Lupinus* spp. seeds crop. *Industrial Crops and Products*, 95, 286–295.
- Maertens, L., Lebas, F., & Szendrő, Zs. (2006). Rabbit milk: A review of quantity, quality and non-dietary affecting factors. *World Rabbit Science*, 14, 205–230.

- Mailu, S. K., Wanyoike, M. M., Muhammad, L., & Mwanza, R. N. (2017). The frequency and some correlates of rabbit meat consumption in Kenya. *Tanzania Journal of Agricultural Sciences*, 16, 62–71.
- Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197, 1–33.
- Malik, A. A., Kudu, Y. S., Abdullahi, M. and Ibrahim, M. J. 2020. Growth performance and digestibility of nutrients by weaner rabbits (*Oryctolagus cuniculus*) fed diets containing varying levels of cowpea (*Vigna unguiculata*) milling waste. *Nigerian Journal of Animal Production* 47(3), 149 – 154
- Maringa, P. (2007). Abstracts of the 3rd Rabbit Congress of the Americas. *World Rabbit Science*, 15(1), 43–60.
- Masako, M. (2024). Alternative protein sources in animal diets: A sustainable solution for the future of animal agriculture. *Journal of Nutrition Science Research*, 9, 285.
- Mayer, J. (2024). Nutrition of rabbits. MSD Veterinary Manual. <https://www.msddvetmanual.com/exotic-and-laboratory-animals/rabbits/nutrition-of-rabbits>
- Medenou, E. H., Koura, B. I., & Dossa, L. H. (2020). Typology and sustainability assessment of rabbit farms in the urban and peri-urban areas of southern Benin (West Africa). *World Rabbit Science*, 28, 207–219.
- Mène-Saffrané, L. (2018). Vitamin E biosynthesis and its regulation in plants. *Antioxidants*, 7(2).
- Mennecke, B. E., Townsend, A. M., Hayes, D. J., & Lonergan, S. M. (2007). A study of factors that influence consumer attitudes toward beef products using the conjoint market analysis tool. *Journal of Animal Science*, 85, 2639-2659.
- Meredith, A. (2011). Rabbit nutrition-an overview. *Irish Veterinary Journal*, 64 (3), 160-164.
- Mertens, D. R. (2002). Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: Collaborative study. *Journal of AOAC International*, 85, 1217–1240.
- Metzger, S. Z., Kustos, K., Szendrő, Z. S., Szabó, A., Eiben, C. S., & Nagy, I. (2003). The effect of housing system on carcass traits and meat quality of rabbit. *World Rabbit Science*, 11, 1–11.
- Mikami, N., Toyotome, T., Yamashiro, Y., Sugo, K., Yoshitomi, K., Takaya, M., & Shimada, K. (2021). Dry-aged beef manufactured in Japan: Microbiota identification and their effects on product characteristics. *Food Research International*, 140.
- Mlcek, J., Rop, O., Borkovcova, M., & Bednarova, M. (2014). A comprehensive look at the possibilities of edible insects as food in Europe—A review. *Polish Journal of Food and Nutrition Sciences*, 64(3), 147–157.

- Moloney, A. P., Woods, V. B., & Crowley, J. G. (1998). A note on the nutritive value of camelina meal for beef cattle. *Irish Journal of Agriculture and Food Research*, 37(2), 243–247.
- Moningkey, S. A. E., Tuturoong, R. A. V., & Lumenta, I. D. R. (2021). Evaluation of corn forages nutrition value in a complete feed on rabbit production performance. Scientific Papers. Series D. *Animal Science*, 64, 117–121.
- Montowska, M., Kowalczewski, P. Ł., Rybicka, I., & Fornal, E. (2019). Nutritional value, protein and peptide composition of edible cricket powders. *Food Chemistry*, 289, 130–138.
- Morais, T., Inácio, A., Coutinho, T., Ministro, M., Cotas, J., Pereira, L., & Bahcevandziev, K. (2020). Seaweed potential in the animal feed: A review. *Journal of Marine Science and Engineering*, 8(8), 559.
- Moran, L., Barron, L. J. R., Wilson, S. S., O'Sullivan, M. G., Kerry, J. P., Prendiville, R., & Moloney, A. P. (2021). Effect of pelvic suspension and post-mortem ageing on the quality of three muscles from Holstein Friesian bulls and steers. *Journal of the Science of Food and Agriculture*, 101, 1892–1900.
- Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., & Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14, 1–8.
- Mu, T., Xu, Z., Tian, J., Yao, Y., & Hu, H. (2026). Potential, challenges, and research progress of *Tenebrio molitor* as a protein supplement for ruminants: A review. *Frontiers in Animal Science*, 7, 1873125.
- Mukaila, R. (2022). Agricultural entrepreneurship among the youth: The case of youth involvement in rabbit production in Nigeria. *International Entrepreneurship Review*, 8, 35–46.
- Mukaila, R. (2023). Measuring the economic performance of small-scale rabbit production agribusiness enterprises. *World Rabbit Science*, 31, 35–46.
- Muscat, A., de Olde, E. M., de Boer, I. J. M., & Ripoll-Bosch, R. (2020). The battle for biomass: A systematic review of food-feed-fuel competition. *Global Food Security*, 25, 100330.
- Mwangi, M. N., Oonincx, D. G. A. B., Stouten, T., Veenenbos, M., Melse-Boonstra, A., Dicke, M., & van Loon, J. J. A. (2018). Insects as sources of iron and zinc in human nutrition. *Nutrition Research Reviews*, 31(2), 248–255.
- Narita, R. L. (2026). Adoption of rabbit farming as a sustainable livelihood strategy in the southern Philippines. *World Rabbit Science*, 34(1), 75-85.
- Nasir, S. Q., Palupi, E., Nasution, Z., Ploeger, A., Susanto, I., Setiawan, B., Rimbawan, R., & Jayanegara, A. (2024). Edible insects as a sustainable protein source: A meta-analysis. *Journal of Insects as Food and Feed*, 10(4588), 1–13.
- National Academies of Sciences, Engineering, and Medicine. (2016). Nutrient requirements of beef cattle (8th ed.). National Academies Press.

- National Research Council. (1977). Nutrient requirements of rabbits. National Academy of Sciences. Washington, D.C.
- Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C., Clay, J., Folke, C., Lubchenco, J., Mooney, H., & Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature*, 405(6790), 1017–1024.
- Ncobela, C. N., & Chimonyo, M. (2015). The potential of using non-conventional animal protein sources for sustainable intensification of scavenging village chickens: A review. *Animal Feed Science and Technology*, 208, 1–11.
- Neethling, N. E., Suman, S. P., Sigge, G. O., & Hoffman, L. C. (2016). Muscle-specific colour stability of blesbok (*Damaliscus pygargus phillipsi*) meat. *Meat Science*, 119, 69–79.
- Ng, Z. Y., Kee, P. E., Abdullah, R., Lan, J. C. W., Ling, T. C., Jiang, J. J., Lim, J. W., & Khoo, K. S. (2025). Conversion of lignocellulosic biomass waste into mycoprotein: Current status and future directions for sustainable protein production. *Biomass Conversion and Biorefinery*, 15(24), 31337–31363.
- Nishimura, T. (1998). Mechanism involved in the improvement of meat taste during postmortem aging. *Food Science and Technology International, Tokyo*, 4(4), 241–249.
- Nishimura, T., Rhue, M. R., Okitani, A., & Kato, H. (1988). Components contributing to the improvement of meat taste during storage. *Agricultural and Biological Chemistry*, 52(9), 2323–2330.
- Nistor, E., Bampidis, V. A., Păcală, N., Pentea, M., Tozer, J., & Prundeanu, H. (2013). Nutrient content of rabbit meat as compared to chicken, beef and pork meat. *Journal of Animal Production Advances*, 3(4), 172–176.
- Nistor, E., Bampidis, V. A., Păcală, N., Pentea, M., Tozer, J., & Prundeanu, H. (2013). Nutrient content of rabbit meat as compared to chicken, beef and pork meat. *Journal of Animal Production Advances*, 3(4), 172–176.
- Nowak, V., Persijn, D., Rittenschober, D., & Charrondiere, U. R. (2016). Review of food composition data for edible insects. *Food Chemistry*, 193, 39–46.
- Nowakowicz-Dębek, B., Wlazło, Ł., Czech, A., Kowalska, D., Bielański, P., Ryszkowska-Siwko, M., & Florek, M. (2021). Effects of fermented rapeseed meal on gastrointestinal morphometry and meat quality of rabbits (*Oryctolagus cuniculus*). *Livestock Science*, 251, 104663.
- Obour, A. K., Sintim, H. Y., Obeng, E., & Jeliaskov, D. V. (2015). Oilseed camelina (*Camelina sativa* L. Crantz): Production systems, prospects and challenges in the USA Great Plains. *Advances in Plants & Agriculture Research*, 2(2), 00043.
- Obuz, E., Akkaya, L., Gök, V., & Dikeman, M. E. (2014). Effects of blade tenderization, aging method and aging time on meat quality characteristics of *Longissimus lumborum* steaks from cull Holstein cows. *Meat Science*, 96(3), 1227–1232.

- Odeyinka, S. M., Oyedele, O. J., Adeleke, T. O., & Odedire, J. A. (2008). Reproductive performance of rabbits fed *Moringa oleifera* as a replacement for *Centrosema pubescens*. In Proceedings of the 9th World Rabbit Congress (pp. [page range if available]). June 10–13, 2008, Verona, Italy.
- Okamoto, N., Nagao, F., Umebayashi, Y., Bito, T., Prangthip, P., & Watanabe, F. (2021). Pseudovitamin B12 and factor S are the predominant corrinoid compounds in edible cricket products. *Food Chemistry*, 347, 129048.
- Olawale, C., Odesanmi, V., Chidi, A., Olusola, A., & Emmanuel, J. (2025). Emerging use of non-conventional feed resources in rabbit nutrition: Functional properties, sustainability and the implications on meat quality: A review. *International Journal of Advanced Multidisciplinary Research and Studies*, 5(5), 1170–1176.
- Omole, T. A. (1982). The effect of levels of dietary protein on growth and reproductive performance in rabbits. *Journal of Applied Rabbit Research*, 5(3), 83–88.
- Onte, S., Bhattacharjee, S., Arif, M., & Dey, D. (2019). Non-conventional feed resources. *Ağrı*, 1, 29–35.
- Onuoha, C.H., Harry, B.J., Fayenuwo, J.O., Durotoye, E.S. 2020. Reproductive and Growth Performance of Rabbit Fed Different Inclusion Levels of African Yam Bean (*Sphenostylis stenocarpa*). *Open Journal of Animal Sciences*, 10, 301-312.
- Onwudike, O. C. (1995). Use of the legume tree crops *Gliricidia sepium* and *Leucaena leucocephala* as green feeds for growing rabbits. *Animal Feed Science and Technology*, 51(1-2), 153–163.
- Oonincx, D. G. A. B., & De Boer, I. J. M. (2012). Environmental impact of the production of mealworms as a protein source for humans: A life cycle assessment. *PLoS ONE*, 7(12), e51145.
- Oonincx, D. G. A. B., van Itterbeeck, J., Heetkamp, M. J. W., van den Brand, H., van Loon, J. J. A., & van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PLoS ONE*, 5(12), e14445.
- Orkusz, A. (2021). Edible insects versus meat—Nutritional comparison: Knowledge of their composition is the key to good health. *Nutrients*, 13(4), 1207.
- Oseni, S. O., & Ajayi, B. A. (2010). Descriptive characterization of a Nigerian heterogeneous rabbit population: Factors affecting litter traits. *World Rabbit Science*, 18(2), 111–116.
- Oseni, S. O., & Lukefahr, S. D. (2014). Rabbit production in low-input systems in Africa: Situation, knowledge and perspectives—A review. *World Rabbit Science*, 22(2), 147–160.
- Ouali, A., Gagaoua, M., Boudida, Y., Becila, S., Boudjellal, A., Herrera-Mendez, C. H., & Sentandreu, M. A. (2013). Biomarkers of meat tenderness: Present

- knowledge and perspectives in regards to our current understanding of the mechanisms involved. *Meat Science*, 95(4), 854–870.
- Owen, O. J., & Amakiri, A. O. (2010). The potentialities and challenges of rabbitry in Nigeria: A review. *Journal of Environmental Issues in Agriculture and Developing Countries*, 2, 22–27.
- Pałka, S. E., Otwinowska-Mindur, A., Migdał, Ł., Kmiecik, M., & Wojtysiak, D. (2021). Effect of a diet supplemented with nettle (*Urtica dioica* L.) or fenugreek (*Trigonella foenum graecum* L.) on the post-slaughter traits and meat quality parameters of Termond White rabbits. *Animals*, 11(6), 1566.
- Palupi, E., Nasir, S. Q., Jayanegara, A., Susanto, I., Ismail, A., Iwansyah, A. C., Setiawan, B., Sulaeman, A., Damanik, M. R. M., & Filianty, F. (2025). Meta-analysis on the fatty acid composition of edible insects as a sustainable food and feed. *Future Foods*, 11, 100529.
- Pascual, J. J., Cervera, C., Blas, E., & Fernández-Carmona, J. (2003). High energy diets for reproductive rabbit does: Effect of energy source. *Nutrition Abstracts and Reviews Series B: Livestock Feeds and Feeding*, 73(5), 27R–39R.
- Pascual, J. J., Savietto, D., Cervera, C., & Baselga, M. (2013). Resources allocation in reproductive rabbit does: A review of feeding and genetic strategies for suitable performance. *World Rabbit Science*, 21, 123–144.
- Paul, A., Frederich, M., Megido, R. C., Alabi, T., Malik, P., Uyttenbroeck, R., Francis, F., Blecker, C., Haubruge, E., Lognay, G., & Danthine, S. (2017). Insect fatty acids: A comparison of lipids from three *orthopterans* and *Tenebrio molitor* L. larvae. *Journal of Asia-Pacific Entomology*, 20(2), 337–340.
- Paula, E. M., da Silva, L. G., Brandão, V. L. N., Dai, X., & Faciola, A. P. (2019). Feeding canola, camelina, and carinata meals to ruminants. *Animals*, 9(9), 704.
- Payne, C. L. R., Scarborough, P., Rayner, M., & Nonaka, K. (2016). Are edible insects more or less ‘healthy’ than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition. *European Journal of Clinical Nutrition*, 70(3), 285–291.
- Peiretti, P. G., Gai, F., Rotolo, L., & Gasco, L. (2012). Effects of diets with increasing levels of dried tomato pomace on the performances and apparent digestibility of growing rabbits. *Asian Journal of Animal and Veterinary Advances*, 7(6), 521–527.
- Peiretti, P. G., Mussa, P. P., Prola, L., & Meineri, G. (2007). Use of different levels of false flax (*Camelina sativa* L.) seed in diets for fattening rabbits. *Livestock Science*, 107 (2–3), 192–198.
- Perry, D., Shorthose, W. R., Ferguson, D. M., & Thompson, J. M. (2001). Methods used in the CRC program for the determination of carcass yield and beef quality. *Australian Journal of Experimental Agriculture*, 41(7), 953–957.

- Perry, N. (2012). Dry aging beef. *International Journal of Gastronomy and Food Science*, 1, 78–80.
- Petracci, M., Soglia, F., Baldi, G., Balzani, L., Mudal, S., & Cavani, C. (2018). Estimation of real rabbit meat consumption in Italy. *World Rabbit Science*, 26(1), 91–96.
- Petrescu, D. C., & Petrescu-Mag, R. M. (2018). Consumer behaviour related to rabbit meat as functional food. *World Rabbit Science*, 26(4), 321–333.
- Petterson, D. S. (2000). The use of lupins in feeding systems – Review. *Asian-Australasian Journal of Animal Sciences*, 13(6), 861–882.
- Pla, M., Pascual, M., & Ariño, B. (2004). Protein, fat and moisture content of retail cuts of rabbit meat evaluated with the NIRS methodology. *World Rabbit Science*, 12(3), 149–158.
- Pond, W. G., Church, D. C., & Pond, K. R. (1995). Basic animal nutrition and feeding (4th ed.). John Wiley & Sons.
- Popescu, D. V., Voinea, L., & Negrea, M. T. (2015). Nutritional imbalance—dominant consumption behaviour of Romanian youth. *Amfiteatru Economic*, 17(40), 1228–1243.
- Pradhan, P., Lüdeke, M. K. B., Reusser, D. E., & Kropp, J. P. (2013). Embodied crop calories in animal products. *Environmental Research Letters*, 8, 044.
- Prola, L., Mussa, P. P., Strazzullo, G., Mimosi, A., Radice, E., & Meineri, G. (2011). Oxidative status in rabbit supplemented with dietary false flax seed (*Camelina sativa*). *Journal of Animal and Veterinary Advances*, 10(10), 1309–1312.
- Purslow, P. P. (2014). New developments on the role of intramuscular connective tissue in meat toughness. *Annual Review of Food Science and Technology*, 5, 133–153. doi: 10.1146/annurev-food-030212-182628.
- Rabe, S., Krings, U., & Berger, R. G. (2003). Influence of oil-in-water emulsion properties on the initial dynamic flavour release. *Journal of the Science of Food and Agriculture*, 83(11), 1124–1133.
- Racewicz, P., Biesiada, H., Majewski, M., Ludwiczak, A., Stanis, M., & Składanowska-Baryza, J. (2023). Impact of packaging system on the microbial quality of chilled rabbit meat over 21 days of storage. *Animal Science Journal*, 94(1), e13852.
- Ralinala, K. M., Netshirovha, T. R., Nesengani, T. L., Mapholi, N. O., & Chimonyo, M. (2026). A review on the potential of water hyacinth to enhance ruminant performance. Preprints, 2026020289.
- Ramos-Elorduy, J. (2008). Energy supplied by edible insects from Mexico and their nutritional and ecological importance. *Ecology of Food and Nutrition*, 47(3), 280–297.

- Rashwan, A. A., Yamani, K. A., & Abd El-Ghani, A. I. (1997). Performance of 3 rabbit strains and their reciprocal crosses in Egypt during summer. *World Rabbit Science*, 5(2), 55–60.
- Ravindran, V., & Blair, R. (1993). Feed resources for poultry production in Asia and the Pacific. III. Animal protein sources. *World's Poultry Science Journal*, 49(3), 219–235.
- Rempel, J., Grover, K., & El-Matary, W. (2021). Micronutrient deficiencies and anemia in children with inflammatory bowel disease. *Nutrients*, 13(1), 236.
- Renna, M., Schiavone, A., Gai, F., Dabbou, S., Lussiana, C., & Malfatto, V. (2017). Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae meal as ingredient for rainbow trout (*Oncorhynchus mykiss* Walbaum) diets. *Journal of Animal Science and Biotechnology*, 8, 57.
- Riaz, R., Ahmed, I., Sizmaz, O., & Ahsan, U. (2022). Use of *Camelina sativa* and by-products in diets for dairy cows: A review. *Animals*, 12(9), 1082.
- Ribeiro, A. J., Silva, F., Teixeira, P., & Saraiva, C. M. (2025). Dry-Aged Beef: A Global Review of Meat Quality Traits, Microbiome Dynamics, Safety, and Sustainable Strategies. *Journal of food science*, 90(10), e70589.
- Righini, D., Zanetti, F., & Monti, A. (2016). The bio-based economy can serve as the springboard for camelina and crambe to quit the limbo. *OCL – Oilseeds fats Crops Lipids*, 23(5), 504–513.
- Robertson, J. B., & Van Soest, P. J. (1981). The detergent system of analysis. In W. P. T. James & O. Theander (Eds.), *The analysis of dietary fibre in food* (pp. 123–158). Marcel Dekker, NY, USA.
- Rødbotten, M., Kubberød, E., Lea, P., & Ueland, Ø. (2004). A sensory map of the meat universe: Sensory profile of meat from 15 species. *Meat Science*, 68(1), 137–144.
- Roos, N. (2018). Insects and human nutrition. In A. Halloran, R. Flore, P. Vantomme, & N. Roos (Eds.), *Edible insects in sustainable food systems* (pp. 83–91). Springer International Publishing.
- Rosell, J., & de la Fuente, L. (2016). Infertility of female rabbits on commercial units. In *Proceedings of the 11th World Rabbit Congress* (pp. 15–18). Qingdao, China.
- Rosell, J. M., & de la Fuente, L. F. (2018). Mastitis on rabbit farms: Prevalence and risk factors. *Animals*, 8.
- Rumpold, B. A., & Schlüter, O. K. (2013). Nutritional composition and safety aspects of edible insects. *Molecular Nutrition & Food Research*, 57(5), 802–823.
- Ruschioni, S., Loreto, N., Foligni, R., Mannozi, C., Raffaelli, N., Zamporlini, F., Pasquini, M., Roncolini, A., Cardinali, F., Osimani, A., & Aquilanti, L. (2020). Addition of olive pomace to feeding substrate affects growth performance and nutritional value of mealworm (*Tenebrio molitor* L.) larvae. *Foods*, 9(3), 317.

- Russo, R., & Reggiani, R. (2017). Glucosinolates and sinapine in camelina meal. *Food and Nutrition Sciences*, 8(12), 1063–1073.
- Saidin, N., Abd Rahman, F., & Yaakob, M. A. Z. (2022). Developing the halal animal feed standard: analysis of feed supply chain issues. *al-Qanatr: International Journal of Islamic Studies*, 28(2), 83-91.
- Samkol, P., & Lukefahr, S. D. (2008). A challenging role for organic rabbit production towards poverty alleviation in South East Asia. In *Proceedings of the 9th World Rabbit Congress*. Verona, Italy.
- Sanah, I., Becila, S., Djeghim, F., & Boudjellal, A. (2020). Rabbit meat in the East of Algeria: Motivation and obstacles to consumption. *World Rabbit Science*, 28(4), 221–237.
- Sanad, S. E., Reda, F. M., Ashour, E. A., & El Nagar, A. G. (2023). Genetic analysis of post-weaning growth traits in a simple crossbreeding experiment between Gabali and Hyplus line rabbits. *Animal Biotechnology*, 34(9), 4448-4456.
- Sanah, I., Kahina, H., Fairouz, D., Romeila, B., Ghania, Z., Zakaria, K., Abdelghani, B., Angel, S. M. and Samira, B. (2024). Physicochemical properties and sensory profile of some breeds of rabbits in Algeria. *Food Science and Technology International*, 0(0), 10820132241238790.
- Sanchez, J. P., de la Fuente, L. F., & Rosell, J. M. (2012). Health and body condition of lactating females on rabbit farms. *Journal of Animal Science*, 90, 2353–2361.
- Sanchez-Sabate, R., & Sabaté, J. (2019). Consumer attitudes towards environmental concerns of meat consumption: A systematic review. *International Journal of Environmental Research and Public Health*, 16(7), 1220.
- Sándor, Z. J., Banjac, V., Vidosavljević, S., Káldy, J., Egessa, R., Lengyel-Kónya, É., Tömösközi-Farkas, R., Zalán, Z., Adányi, N., Libisch, B., & Biró, J. (2022). Apparent digestibility coefficients of black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio molitor*), and blue bottle fly (*Calliphora vicina*) insects for juvenile African catfish hybrids (*Clarias gariepinus* × *Heterobranchus longifilis*). *Aquaculture Nutrition*, 2022, 4717014.
- Sankian, Z., Khosravi, S., Kim, Y.-O., & Lee, S.-M. (2018). Effects of dietary inclusion of yellow mealworm (*Tenebrio molitor*) meal on growth performance, feed utilization, body composition, plasma biochemical indices, selected immune parameters and antioxidant enzyme activities of mandarin fish (*Siniperca scherzeri*) juveniles. *Aquaculture*, 496, 79–87.
- Savietto, D., Blas, E. E., Cervera, C. C., Baselga, M. M., Friggens, N. N., Larsen, T. T., & Pascual, J. J. J. (2012). Digestive efficiency in rabbit does according to environment and genetic type. *World Rabbit Science*, 20, 131–140.
- Schardong, I. S., Freiberg, J. A., Santana, N. A., & dos Santos Richard, N. S. P. (2019). Brazilian consumers' perception of edible insects. *Ciência Rural*, 49(10), e20190142.

- Schlüter, O., Rumpold, B., Holzhauser, T., Roth, A., Vogel, R. F., Quasigroch, W., Vogel, S., Heinz, V., Jäger, H., Bandick, N., & Kulling, S. (2017). Safety aspects of the production of foods and food ingredients from insects. *Molecular Nutrition & Food Research*, 61(6), 1600520.
- Schmidt, A., Call, L.-M., Macheiner, L., & Mayer, H. K. (2019). Determination of vitamin B12 in four edible insect species by immunoaffinity and ultra-high performance liquid chromatography. *Food Chemistry*, 281, 124–129.
- Shaahu, D.T., Dzungwe, E.N., Akpe, M.E. 2014. Digestibility and Growth Performance of Rabbits Fed Raw or Processed *Lablab Purpureus* Seed in Diets. *International Journal of Advances in Agricultural Science and Technology*, 2(6), 01-07
- Shah, A. A. (2021). State of the art on production, processing and uses of meal worm *Tenebrio molitor* (Tenebrionidae: Coleoptera). Zenodo (CERN European Organization for Nuclear Research).
- Shah, A. A., Totakul, P., Maharach, M., Cherdthong, A., Harnboonsong, Y., & Wanapat, M. (2022). Nutritional composition of various insects and potential uses as alternative protein sources in animal diets. *Animal Bioscience*, 35(2), 317–331.
- Shah, S., Oh, J., Bang, Y., Jung, S., Kim, H.-C., Jeong, K. S., Park, M. H., Lee, K. A., Ryoo, J.-H., Kim, Y.-J., et al. (2025). Pregnant women's lifestyles and exposure to endocrine-disrupting chemicals: A machine learning approach. *Environmental Pollution*, 366, 125309.
- Shahidi, F., & Zhong, Y. (2010). Novel antioxidants in food quality preservation and health promotion. *European Journal of Lipid Science and Technology*, 112(9), 930–940.
- Siddiqui, S. A., Adli, D. N., Nugraha, W. S., Yudhistira, B., Lavrentev, F. V., Shityakov, S., Feng, X., Nagdalian, A., & Ibrahim, S. A. (2024). Social, ethical, environmental, economic and technological aspects of rabbit meat production—A critical review. *Heliyon*, 10(8), e29012.
- Siddiqui, S. A., Elsheikh, W., Ucak, I., Hasan, M., Perlita, Z. C., & Yudhistira, B. (2025). Replacement of soy by mealworms for livestock feed: A comparative review between soy and mealworms considering environmental aspects. *Environment, Development and Sustainability*, 27(12), 29105–29148.
- Simopoulos, A. P. (2016). An increase in the omega-6/omega-3 fatty acid ratio increases the risk for obesity. *Nutrients*, 8, 1–17.
- Singh, Y., Cullere, M., & Dalle Zotte, A. (2023a). *Camelina sativa* as a sustainable and feasible feedstuff for laying poultry: A review. *Biotechnology in Animal Husbandry*, 39(2), 117–130.
- Singh, Y., Cullere, M., Tůmová, E., & Dalle Zotte, A. (2023b). *Camelina sativa* as a sustainable and feasible feedstuff for broiler poultry species: A review. *Czech Journal of Animal Science*, 68, 277–295.

- Sitz, B. M., Calkins, C. R., Feuz, D. M., Umberger, W. J., & Eskridge, K. M. (2006). Consumer sensory acceptance and value of wet-aged and dry-aged beef steaks. *Journal of Animal Science*, 84, 1221–1226.
- Siulapwa, N., Mwambungu, A., Lungu, E., & Sichilima, W. (2014). Nutritional value of four common edible insects in Zambia. *International Journal of Scientific Research*, 3(4), 876–884.
- Sivakumar, K., Thiruvankadan, A. K., Kumar, V. R. S., Muralidharan, J., Singh, D. A. P., Saravanan, R., & Jeyakumar, M. (2013). Analysis of production and reproduction performances of Soviet Chinchilla and White Giant rabbits in tropical climatic conditions of India. *World Rabbit Science*, 21(2), 101–106.
- Smit, M. N., & Beltranena, E. (2017). Effects of feeding camelina cake to weaned pigs on safety, growth performance, and fatty acid composition of pork. *Journal of Animal Science*, 95(6), 2496–2508.
- Sonandi, A., Masika, P. J., & Van Averberke, W. (1996). Rabbit production systems in selected areas of five provinces in South Africa. In Proceedings of the 6th World Rabbit Congress Toulouse, France.
- Spanier, A. M., McMillin, K. W., & Miller, J. A. (1990). Enzyme activity levels in beef: Effect of post-mortem aging and end point cooking temperature. *Journal of Food Science*, 55(2), 318–322.
- Spencer, R. (2013). Rabbit Cuisine: A Healthy Alternative and Culinary Delight. Alabama Cooperative Extension System, 1-6.
- Spolaore, P., Joannis-Cassan, C., Duran, E., & Isambert, A. (2006). Commercial applications of microalgae. *Journal of Bioscience and Bioengineering*, 101(2), 87–96.
- Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., & De Haan, C. (2006). Livestock's long shadow: Environmental issues and options. Food and Agriculture Organization of the United Nations. <https://doi.org/10.1787/9789264015379-en>
- Strychalski, J., Juśkiewicz, J., Kowalska, D., & Gugolek, A. (2021). Performance indicators and gastrointestinal response of rabbits to dietary soybean meal replacement with silkworm pupae and mealworm larvae meals. *Archives of Animal Nutrition*, 75(4), 294–310.
- Sultana, K., Jayathilakan, K., & Sajeevkumar, V. A. (2022). Chemistry of animal tissues. In *Advances in Food Chemistry: Food Components, Processing and Preservation* (pp. 385–437). Springer Nature Singapore.
- Sydor, M., Kurasiak-Popowska, D., Stuper-Szablewska, K., & Rogoziński, T. (2022). Camelina sativa: Status quo and future perspectives. *Industrial Crops and Products*, 187, 115531.
- Szendrő, K. (2016). Consumer perceptions, concerns, and purchasing practices of rabbit meat in Hungary. *Journal of Food Products Marketing*, 22(6), 683–693.

- Szendrő, K., Nagy, M. Z., & Tóth, K. (2020). Consumer Acceptance of Meat from Animals Reared on Insect Meal as Feed. *Animals*, 10(8), 1312.
- Szendro, K., Szabó-Szentgróti, E., & Szigeti, O. (2020). Consumers' attitude to consumption of rabbit meat in eight countries depending on the production method and its purchase form. *Foods*, 9(5), 654
- Tacon, A. G., & Metian, M. (2015). Feed matters: Satisfying the feed demand of aquaculture. *Reviews in Fisheries Science & Aquaculture*, 23(1), 1–10.
- Taiwo, B. B. I., & Ogunsiji, O. (1999). Reproductive and growth performance of rabbits raised by forage crops. In A. D. Ologhobo, G. N. Egbunike, M. K. Adewumi, A. M. Bamgbose, E. A. Iyayi, & A. O. K. Adesehinwa (Eds.), *Proceedings of the 4th Annual Conference of Animal Science Association of Nigeria (ASAN)* (pp. 108–109).
- Terjung, N., Witte, F., & Heinz, V. (2021). The dry aged beef paradox: Why dry aging is sometimes not better than wet aging. *Meat Science*, 172, 108355.
- Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D., & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science*, 292(5515), 281–284.
- Toviho, O. A., & Bársony, P. (2022). Nutrient composition and growth of yellow mealworm (*Tenebrio molitor*) at different ages and stages of the life cycle. *Agriculture*, 12, 1924.
- Trocino, A., Filiou, E., Tazzoli, M., Bertotto, D., Negrato, E., & Xiccato, G. (2014). Behaviour and welfare of growing rabbits housed in cages and pens. *Livestock Science*, 167, 305–314.
- Trukhanova, K. A., Mechtaeva, E. V., Novikova, M. V., Sorokoumov, P. N., Ryabukhin, D. S., & Mechtaeva, E. V. (2022). Influence of drying and pretreatment methods on certain parameters of yellow mealworm larvae (*Tenebrio molitor*). *Theory and Practice of Meat Processing*, 7(3), 247–257.
- Tudisco, R., Lombardi, P., Bovera, F., d'Angelo, D., Cutrignelli, M. I., Mastellone, V., Terzi, V., Avallone, L., & Infascelli, F. (2006). Genetically modified soybean in rabbit feeding: Detection of DNA fragments and evaluation of metabolic effects by enzymatic analysis. *Animal Science*, 82(2), 193–199.
- Tůmová, E., Bízková, Z., Skřivanová, V., Chodová, D., Martinec, M., & Volek, Z. (2014). Comparisons of carcass and meat quality among rabbit breeds of different sizes, and hybrid rabbits. *Livestock Science*, 165, 8–14.
- U.S. Department of Agriculture, National Agricultural Statistics Service. (2019). 2017 Census of Agriculture. <https://www.nass.usda.gov/Publications/AgCensus/2017/>
- Ugosor, S. A., Ochu, A. O., & Agbulu, O. N. (2016). Identification of breeding skills required by farmers in rabbit production for income generation in Benue State, Nigeria. *Scholarly Journal of Agricultural Science*, 6, 204–210.

- Ulbricht, T. L. V., & Southgate, D. A. T. (1991). Coronary heart disease: Seven dietary factors. *The Lancet*, 338(8773), 985–992.
- Van Broekhoven, S., Oonincx, D. G. A. B., Van Huis, A., & Van Loon, J. J. A. (2015). Growth performance and feed conversion efficiency of three edible mealworm species (*Coleoptera: Tenebrionidae*) on diets composed of organic by-products. *Journal of Insect Physiology*, 73, 1–10.
- van Huis, A. (2022). Edible insects: Challenges and prospects. *Entomological Research*, 52(3), 161–177.
- van Huis, A., & Gasco, L. (2023). Insects as feed for livestock production. *Science*, 379(6628), 138–139.
- van Huis, A., & Oonincx, D. G. A. B. (2017). The environmental sustainability of insects as food and feed: A review. *Agronomy for Sustainable Development*, 37, 43.
- van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible insects: Future prospects for food and feed security (FAO Forestry Paper No. 171). Food and Agriculture Organization of the United Nations.
- Veldkamp, T., & Bosch, G. (2015). Insects: A protein-rich feed ingredient in pig and poultry diets. *Animal Frontiers*, 5(2), 45–50.
- Veldkamp, T., & Vernooij, A. G. (2021). Use of insect products in pig diets. *Journal of Insects as Food and Feed*, 7, 781–793.
- Veljković, V. B., Kostić, M. D., & Stamenković, O. S. (2022). Camelina seed harvesting, storing, pretreating, and processing to recover oil: A review. *Industrial Crops and Products*, 178, 114539.
- Verbeke, W. (2005). Consumer acceptance of functional foods: Socio-demographic, cognitive and attitudinal determinants. *Food Quality and Preference*, 16(1), 45–55.
- Vergara, H., Berruga, M. I., & Linares, M. B. (2005). Effect of gas composition on rabbit meat quality in modified atmosphere packaging. *Journal of the Science of Food and Agriculture*, 85(12), 1981–1986.
- Ververs, M. T., & Gabra, M. (2020). Nutritional care for patients with Ebola virus disease. *Emerging Infectious Diseases*, 26(1), 20–25.
- Villafuerte, R., Calvete, C., Blanco, J. C. & Lucientes, J. (1995). Incidence of viral haemorrhagic disease in wild rabbit populations in Spain. *Mammalia* 59, 651–659
- Vissio, A., Grygier, A., Składanowska-Baryza, J., Kmiecik, D., Stanisiz, M., Majewski, A., & Rudzińska, M. (2024). Storage of rabbit meat in vacuum extends the oxidative stability of fat. *European Journal of Lipid Science and Technology*, 126(12), e202400146.

- Volek, Z., & Marounek, M. (2011). Effect of feeding growing-fattening rabbits a diet supplemented with whole white lupin (*Lupinus albus* cv. Amiga) seeds on fatty acid composition and indexes related to human health in hind leg meat and perirenal fat. *Meat Science*, 87, 40–45.
- Volek, Z., Adamková, A., Zita, L., Adamek, M., Plachý, V., Mlcek, J., Marounek, M. 2021. The effects of the dietary replacement of soybean meal with yellow mealworm larvae (*Tenebrio molitor*) on the growth, nutrient digestibility and nitrogen output of fattening rabbits. *Animal Feed Science and Technology* 280 (2021), 115048
- Volek, Z., Adamková, A., Zita, L., Adamek, M., Plachý, V., Mlcek, J., & Marounek, M. (2021). The effects of the dietary replacement of soybean meal with yellow mealworm larvae (*Tenebrio molitor*) on the growth, nutrient digestibility and nitrogen output of fattening rabbits. *Animal Feed Science and Technology*, 280, 115048.
- Volek, Z., Bureš, D., & Uhlířová, L. (2018). Effect of dietary dehulled white lupine seed supplementation on the growth, carcass traits and chemical, physical and sensory meat quality parameters of growing-fattening rabbits. *Meat Science*, 141, 50–56.
- Volek, Z., Šufliarský, P., Taubner, T., Plachý, V., Kokošková, T., Aremu, T., Cullere, M., Galasso, I., Chodová, D., Tůmová, E., & Dalle Zotte, A. (2025). Effect of replacing rapeseed cake with camelina (*Camelina sativa* (L.) Crantz) cake on nutrient digestibility, pancreatic enzyme activity, growth performance and carcass traits in fattening rabbits. *Animal Feed Science and Technology*, 320(1), 116218.
- Volek, Z., Uhlířová, L., & Zita, L. (2020). Narrow-leaved lupine seeds as a dietary protein source for fattening rabbits: A comparison with white lupine seeds. *Animal*, 144, 881–888.
- Volek, Z., Zita, L., Adámková, A., Adámek, M., Mlček, J., & Plachý, V. (2023). Dietary inclusion of crickets (*Acheta domesticus*) and yellow mealworm meal (*Tenebrio molitor*) in comparison with soybean meal: Effect on the growth, total tract apparent digestibility, and nitrogen balance of fattening rabbit. *Animals*, 13(10), 1637.
- Waraich, E. A., Ahmed, Z., Ahmad, R., Ashraf, M. Y., Naeem, M. S., & Rengel, Z. (2013). *Camelina sativa*, a climate proof crop, has high nutritive value and multiple-uses: A review. *Australian Journal of Crop Science*, 7(10), 1551–1559.
- Warren, K. E., & Kastner, C. L. (1992). A comparison of dry-aged and vacuum-aged beef strip. *Journal of Muscle Foods*, 3, 151–157.
- Wiebe, M. (2002). Myco-protein from *Fusarium venenatum*: A well-established product for human consumption. *Applied Microbiology and Biotechnology*, 58(4), 421–427.

- Wijffels, R. H., Kruse, O., & Hellingwerf, K. J. (2013). Potential of industrial biotechnology with cyanobacteria and eukaryotic microalgae. *Current Opinion in Biotechnology*, 24(3), 405–413.
- Williams, J. P., Williams, J. R., Kirabo, A., Chester, D., & Peterson, M. (2016). Chapter 3: Nutrient content and health benefits of insects. In A. T. Dossey, J. A. Morales-Ramos, & M. G. Rojas (Eds.), *Insects as sustainable food ingredients* (pp. 61–84). Academic Press.
- Woods, V. B., & Fearon, A. M. (2009). Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk and eggs: A review. *Livestock Science*, 126 (1–3), 1–20.
- Wu, L. (2024). Worldwide rabbit meat trade. In *Veterinary care of farm rabbits: A complete practice guide to rabbit medicine and production* (pp. 67–92). Springer International Publishing.
- Wyrwisz, J., Moczowska-Wyrwisz, M., & Kurek, M. A. (2025). Development of modified gas composition for atmosphere packaging of sliced apple chips. *Applied Sciences*, 15, 2832.
- Xiccato, G., & Trocino, A. (2010). Energy and protein metabolism and requirements. In C. de Blas & J. Wiseman (Eds.), *Nutrition of the rabbit* (2nd ed., pp. 83–118). CAB International.
- Xiccato, G., Trocino, A., Carraro, L., Fragkiadakis, M., & Majolini, D. (2008). Digestible fibre to starch ratio and antibiotic treatment time in growing rabbits affected by epizootic rabbit enteropathy. In *Proceedings of the 9th World Rabbit Congress* (pp. 10–13). Verona, Italy.
- Xiccato, G., & Trocino, A. (2020). Energy and protein metabolism and requirements. In C. de Blas & J. Wiseman (Eds.), *Nutrition of the rabbit* (3rd ed., pp. 89–125). CAB International.
- Xiong, R., Cavitt, L. C., Meullenet, J. F., & Owens, C.M. (2006). Comparison of Allo-Kramer, Warner-Bratzler and razor blade shears for predicting sensory tenderness of broiler breast meat. *Journal of Texture Studies*, 37 (2), 179–199.
- Yitbarek, M. (2019). Livestock and livestock product trends by 2050. *International Journal of Animal Research*, 4, 30.
- Zanetti, F., Alberghini, B., Marjanović Jeromela, A., Grahovac, N., Rajković, D., Kiproviski, B., & Monti, A. (2021). Camelina, an ancient oilseed crop actively contributing to the rural renaissance in Europe: A review. *Agronomy for Sustainable Development*, 41, 1–18.
- Zanetti, F., Alberghini, B., Marjanovic Jeromela, A., Grahovac, N., Rajkovic, D., Kiproviski, B., & Monti, A. (2021). Camelina, an ancient oilseed crop actively contributing to the rural renaissance in Europe. A review. *Agronomy for Sustainable Development*, 41, 8.
- Zanetti, F., Eynck, C., Christou, M., Krzyżaniak, M., Righini, D., Alexopoulou, E., Stolarski, M. J., Van Loo, E. N., Puttick, D., & Monti, A. (2017). Agronomic

- performance and seed quality attributes of Camelina (*Camelina sativa* L. Crantz) in multi-environment trials across Europe and Canada. *Industrial Crops and Products*, 107, 602–608.
- Zanetti, F., Gesch, R. W., Walia, M. K., Johnson, J. M. F., & Monti, A. (2020). Winter camelina root characteristics and yield performance under contrasting environmental conditions. *Field Crops Research*, 252, 107794
- Zeising, C. (2000). Rabbit production in Ciskei—Do more than ten years of existence prove sustainable development. In *Proceedings of the 7th World Rabbit Congress* (pp. 4–7). Valencia, Spain.
- Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature*, 528(7580), 51–59.
- Zhang, Z.-J., Zhang, S.-S., Niu, B.-L., Ji, D.-F., Liu, X.-J., Li, M.-W., Bai, H., Palli, S. R., Wang, C.-Z., & Tan, A.-J. (2019). A determining factor for insect feeding preference in the silkworm, *Bombyx mori*. *PLoS Biology*, 17(2), e3000162.
- Zhou, Y., Wang, D., Zhou, S., Duan, H., Guo, J., & Yan, W. (2022). Nutritional composition, health benefits, and application value of edible insects: A review. *Foods*, 11(24), 3961.
- Zielinska, E., Baraniak, B., Karaś, M., Rybczynska, K., & Jakubczyk, A. (2015). Selected species of edible insects as a source of nutrient composition. *Food Research International*, 77, 460–466.
- Zwoliński, C., Gugolek, A., Strychalski, J., Kowalska, D., Chwastowska-Siwiecka, I., & Konstantynowicz, M. (2017). The effect of substitution of soybean meal with a mixture of rapeseed meal, white lupin grain, and pea grain on performance indicators, nutrient digestibility, and nitrogen retention in Popielno White rabbits. *Journal of Applied Animal Research*, 45(1), 570–576.

CHAPTER 10

Annexes

Annex 1.

Supplementary Table 5.1. Chemical composition (g/kg, as fed) and energy content (MJ/kg) of camelina (*Camelina sativa*) cake and experimental diets.

	Camelina cake	Experimental diets		
		Control	CS5	CS10
Dry matter	903	910	915	909
Crude protein	308	154	157	154
Ether extract	203	33.1	37.4	45.5
Ash	46.1	75.8	75.9	74.4
Starch	20.9	159	158	153
NDF	210	346	336	345
ADF	115	197	192	193
ADL (without AIA)	28.6	45.8	46.1	46.5
Gross energy	21.4	16.9	17.1	17.1

Control: 10% rapeseed meal; CS5: 5% rapeseed meal and 5% camelina cake, CS10: 10% camelina cake.

Annex2: Curriculum vitae Tolulope Sabainah Aremu



MSc. TOLULOPE SABAINAH AREMU

Kamycka 1281, Prague 6, Czech Republic

[aremu@ftz.czu.cz/](mailto:aremu@ftz.czu.cz)

aremutolulope@gmail.com

ORCID 0000-0003-1718-6473

December 07, 1987

Prague, Czech Republic

WORK EXPERIENCES

2015 - 2017: **Graduate Research Associate**

Department of Animal Production and Health, Federal University of Agriculture, Abeokuta

EDUCATION

2022 - Present

PhD (Tropical Agrobiolology and Bioresources Management)

Czech University of Life Science, Prague, Czech Republic

June 2015-2017

Master of Agriculture (Non-Ruminant Production)

Federal University of Agriculture, Abeokuta, Nigeria.

June 2008-2013

Bachelor of Agriculture (Animal Production and Health)

Federal University of Agriculture, Abeokuta, Nigeria

INTERNATIONAL INTERNSHIPS

02/2024 - 06/2024

University of Padova, Italy

DEPARTMENT OF ANIMAL MEDICINE, PRODUCTION AND HEALTH

SCIENTIFIC PUBLICATIONS

Safiyu, K. K., Onabanjo, R. S., Adedokun, O. O., Akinsola, K. L., Ewetola, I. A., **Aremu, T. S.**, & Sogunle, O. M. (2026). Effect of oral supplementation of Jackfruit leaf extract on growth performance, faecal bacteria count, carcass characteristics and meat quality in broiler chickens. *Animal-Open Space*, 5, 100132. <https://doi.org/10.1016/j.anopes.2026.100132>

Kokošková, T., Pontalti, E., **Aremu, T. S.**, Tůmová, E., Chodová, D., Bureš, D., Lebedová, N., Volek, Z., Singh, Y., Cullere, M., & Palumbo, B. (2025). Assessing the impact of dietary *Camelina sativa* (L.) Crantz inclusion on meat quality and sensory traits of growing rabbits. *Meat Science*, 219: 109679. <https://doi.org/10.1016/j.meatsci.2024.109679>

Aremu, T. S., Bureš, D., James, T. E., Lebedová, N., Urbanová, K., Dalle Zotte, A., Volek, Z., & Kokošková, T. (2025). Effect of wet and dry post-mortem rabbit loin meat ageing on its physicochemical and sensory properties. *Meat Science*, 229, 109901. <https://doi.org/10.1016/j.meatsci.2025.109901>

Volek, Z., Šufliarský, P., Taubner, T., Plachý, V., Kokošková, T., **Aremu, T.**, & Cullere, M. (2025). Effect of substitution of Camelina (*Camelina sativa* (L.) Crantz) cake for rapeseed cake on the nutrient digestibility, pancreatic enzyme activity, growth performance and carcass traits in fattening rabbits. *Animal Feed Science and Technology*, 116218. <https://doi.org/10.1016/j.anifeedsci.2025.116218>

Safiyu, K.K., Akinsola, K.L., Onabanjo, R.S., Adedokun, O.O., Ewetola, I.A., Oluebube, P.C., Nwabueze, N.C., Chidorom, J.N. & **Aremu, T.S.** (2025). Physiological responses of finisher broiler chickens to supplementation of *Artocarpus heterophyllus* leaf extract in drinking water. *Journal of Sustainable Veterinary and Allied Sciences*, 7(1): 24-32.

Safiyu, K. K., Akinsola, K. L., Onabanjo, R. S., Adedokun, O. O., Ewetola, I. A., Ngonadi, G. E., Awoms, E. G., **Aremu T. S.** and Oyewole Y. O. 2025. Evaluation of the Phytogenic potential of *Chromolaena odorata* Leaf Extract on Haematology, Serum Biochemistry, and Intestinal Bacterial Count of Broiler Chickens. *Nigerian Journal of Animal Science and Technology*, 8(2):14–26.

Sogunle, O. M., **Aremu, T. S.**, Olatubosun, O. O., Njoku, C. P., & JA, A. (2019). Growth performance and blood profile of rabbit bucks in two housing types on

aqueous extract of oyster mushroom (*Pleurotus ostreatus*). Nigerian Journal of Animal Production, 46(1), 51-60.

Olatubosun, O. O., Sogunle, O. M., Adeyemi, O. A., Bamgbose, A. M., & **Aremu, T. S.** (2019). White Blood Cell and Serum Biochemistry of Rabbits on Varying Levels of Oyster Mushroom (*Pleurotus ostreatus*) Extract under Two Housing Types. Bulletin UASVM Animal Science and Biotechnologies, 76, 2.

Olatubosun, O. O., Sogunle, O. M., Adeyemi, O. A., Bamgbose, A. M., & **Aremu, T. S.** (2019). Growth and carcass yield of rabbits in two housing types administered aqueous extract of oyster mushroom (*Pleurotus ostreatus*). Animal Health and Production, 67, 151-160.

Sogunle, O. M., Odutayo, O. J., **Aremu, T. S.**, Safiyu, K. K. & Iyanda, A.I. (2017). Effects of two feed forms on the growth performance, carcass yield and duodenal villus morphology of locally-adapted turkeys. Bulletin of Animal Health and Production in Africa 65(1): 113-120.

CONFERENCES, WORKSHOPS, AND SUMMER SCHOOL

Poster Presentation, Agrinatura conference, Czech University of Life Science Prague, Czech Republic, 11 May 2023

Oral Presentation, Tropentag conference paper presented at Berlin, Germany, September 20 - 22, 2023.

Oral Presentation, 3rd EAAP Regional Meeting, University of Agriculture Krakow, Poland, April 09 - 11, 2025

Oral Presentation, 25th International Workshop for Young Scientists “BioPhys Spring 2026”, Czech University of Life Science Prague, Czech Republic May 28 - 29, 2026

Summer school. ELLS Summer School 2022. University of Natural Resources and Life Sciences, Vienna (BOKU) Austria August 8 - 19, 2022