INFLUENCE OF ANATOMICAL PART AND AGE ON SATURATED, MONOUNSATURATED, AND POLYUNSATURATED FATTY ACIDS IN LIMOUSINE BEEF: CASE STUDY IN FOOD TECHNOLOGY

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Received February 2025; Accepted March 2025; Published April 2025;

DOI: https://doi.org/10.31407/ijees15.213

ABSTRACT

Fatty acids in meat influence more than just flavor; they play a fundamental role in the nutritional quality, texture, cooking behavior, and shelf life of meat. This study examines the distribution of different types of fats saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) across various anatomical parts of beef, with particular emphasis on organ tissues such as the liver and lung, and muscle cuts including beef steak, rump steak, and round steak from the Limousin breed. The results indicate that organ meats are richer in health-promoting PUFAs, particularly as the animal ages, whereas muscle cuts exhibit higher concentrations of SFAs and MUFAs, contributing to better structure, flavor, and oxidative stability. Limousin beef is distinguished by a favorable lipid profile, characterized by low levels of saturated fatty acids and a higher proportion of beneficial monounsaturated fatty acids. Special attention is given to the role of omega-3 and omega-6 fatty acids, which enhance the nutritional value and health benefits of the meat. The study further explores how age and anatomical location influence the distribution of key fatty acids in Limousin beef, underlining the breed's lipidomic advantages. Through the application of visual tools such as heatmaps and dendrograms, clear distinctions in fatty acid profiles between organs and muscle cuts were identified, with age exerting a moderate but noticeable effect. These findings provide valuable insights for both consumers and producers, supporting more informed choices based on health objectives, taste preferences, and cooking methods.

Keywords: food technology, health, meat quality traits, fatty acid profile, beef anatomical parts, saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), eicosapentaenoic acid (EPA, omega-3), linoleic acid (omega-6), omega-6/omega-3 ratio.

INTRODUCTION

The types and amounts of fatty acids found in different parts of meat do more than just influence its flavor—they also shape its nutritional value and appeal to consumers. Fatty acids are generally categorized into three types: saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs). Each plays a distinct role in both human health and the physical qualities of meat. For instance, SFAs contribute to the structure and firmness of meat, MUFAs are associated with improved tenderness and flavor, and PUFAs—

especially essential ones like linoleic and arachidonic acids—offer well-documented health benefits, including anti-inflammatory properties and support for cardiovascular and neurological functions. As noted by (Simopoulos, 2002) the balance of omega-6 to omega-3 fatty acids is critical for health, while (Calder, 2015a) emphasizes the broader functional roles of PUFAs in disease prevention and immune regulation. Interestingly, the distribution of these fatty acids varies considerably across different anatomical parts of the animal. Organ tissues such as the lung and liver tend to be richer in PUFAs, reflecting their roles in metabolism, detoxification, and biochemical regulation. These tissues have a higher demand for dynamic lipid compositions that support enzymatic and signaling functions. In contrast, muscle cuts such as beef steak, rump steak, and round steak are typically dominated by SFAs and MUFAs, which not only contribute to a firm and structured texture but also enhance sensory qualities like juiciness and mouthfeel. As discussed by (Wood et al., 2008), oleic acid (a primary MUFA) is particularly associated with improved meat palatability due to its lower melting point and softer texture. Fatty acid profiles also change over time as the animal matures, driven by metabolic shifts and patterns of fat deposition. For example, lung and liver tissues show a notable increase in PUFA levels with age, which may enhance their nutritional value for health-conscious consumers. At the same time, muscle cuts accumulate more SFAs and MUFAs, supporting their oxidative stability and making them more suitable for high-temperature cooking methods such as grilling. (Wood et al., 2008) highlight that while increased SFA content improves the structural integrity and cooking stability of meat, it may also result in reduced tenderness if not properly prepared. These biochemical differences in fatty acid composition have broader implications beyond nutrition. They influence shelf life, marketability, and consumer preferences. High PUFA content, while beneficial for health, makes meat more prone to oxidation, which can lead to rancidity and reduced storage stability. On the other hand, cuts with higher MUFA and SFA content, such as rump steak and beef steak, are more resistant to oxidative degradation and therefore better suited for extended storage and culinary applications (Jacobsen et al., 2008). To better understand these dynamics, this study explores how fatty acid compositions differ between anatomical parts of beef and how these patterns evolve over time. Using heatmaps, dendrogram analysis, and fatty acid profiling, we identify significant differences in SFA, MUFA, and PUFA content across organ and muscle tissues. These insights may guide both consumers and producers in selecting meat products based on nutritional priorities, sensory expectations, and intended cooking methods.

MATERIAL AND METHOD

Methodology and instrumentation. The comparative lipidomic analysis of Limousine beef presented in Figure 1 reveals pronounced differences in the distribution of key fatty acids across organ and muscle tissues. These differences are biologically grounded in tissue-specific metabolic roles and have direct implications for both nutritional value and culinary performance.

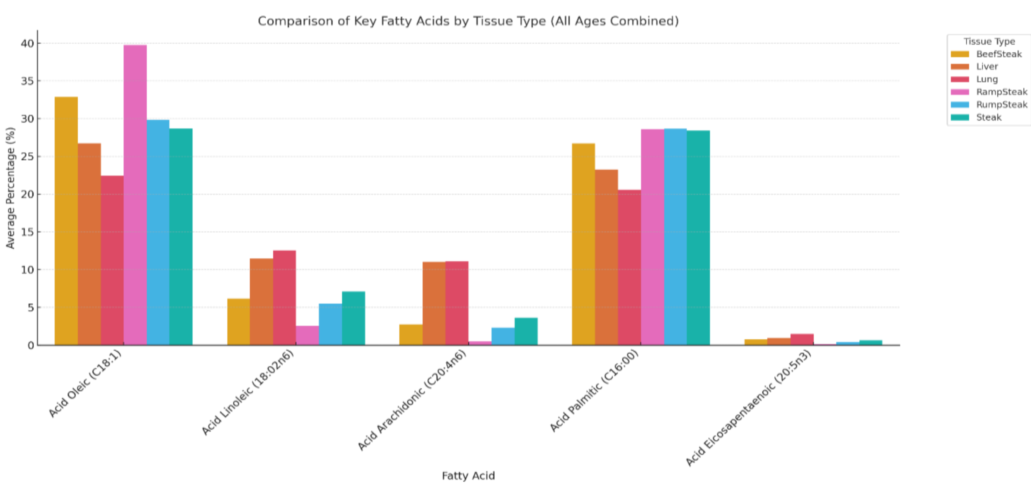

Figure 1. Average concentrations of selected fatty acids in different beef tissues (Lung, Liver, Beef steak, Rump steak, Round steak, Ramp steak), combining data from both 5-month and 12-month samples.

Fatty acids shown include oleic acid (C18:1), linoleic acid (C18:2n6), arachidonic acid (C20:4n6), palmitic acid (C16:0), stearic acid (C18:0), and eicosapentaenoic acid (EPA, 20:5n3).

Oleic Acid (C18:1) - oleic acid, a principal monounsaturated fatty acid (MUFA), exhibits its highest levels in muscle tissues, particularly Rump steak and Beef steak, with concentrations exceeding 30%. As previously described by Wood et al. (2008), oleic acid enhances meat palatability due to its lower melting point, contributing to improved tenderness, juiciness, and flavor. Its structural fluidity also plays a role in maintaining the integrity of cell membranes under thermal stress, further emphasizing its culinary importance in high-temperature cooking applications. Linoleic Acid (C18:2n6) and Arachidonic Acid (C20:4n6) - the polyunsaturated fatty acids (PUFAs) linoleic and arachidonic acid demonstrate a distinct enrichment in organ tissues, especially lung and liver.

Arachidonic acid, in particular, reaches values upwards of 8–9% in these organs, reflecting their involvement in eicosanoid synthesis, inflammatory signaling, and membrane phospholipid remodeling (Calder, 2015). Linoleic acid, an essential omega-6 fatty acid, contributes to immune modulation and cellular communication, and its presence in these metabolically active organs reinforces their nutritional density (Simopoulos, 2002). These findings are in line with Jacobsen et al. (2008), who noted that high PUFA levels enhance the health value of food products but increase their susceptibility to oxidative degradation. Palmitic Acid (C16:0) and Stearic Acid (C18:0) - saturated fatty acids (SFAs) such as palmitic and stearic acid are more prominent in muscle cuts. These fatty acids contribute to the structural firmness and oxidative stability of meat. According to De Smet et al. (2004), stearic acid, in particular, is metabolically neutral in terms of blood cholesterol impact but plays a crucial role in meat texture and shelf life. Elevated SFA levels make these cuts more suitable for cooking methods like grilling, which demand lipid thermal resistance and retention of structure. Eicosapentaenoic Acid (EPA, 20:5n3) - although present in lower absolute quantities, EPA is more prevalent in lung and liver, consistent with their roles in lipid metabolism and detoxification. EPA is a well-known omega-3 fatty acid with cardioprotective and anti-inflammatory benefits (Calder, 2015b). Its presence in organ meats enhances their value for health-conscious consumers, despite potential trade-offs in taste and texture.

RESULTS

Differences Based on Anatomical Parts

Lung tissue typically possesses a greater concentration of polyunsaturated fatty acids (PUFAs) relative to other anatomical regions, exhibiting a significant rise over time. After one year, the PUFA level in the lung attains 32.7%, highlighting its abundant composition of important fatty acids. Polyunsaturated fatty acids (PUFAs), such as essential fatty acids like linoleic and arachidonic acids, are vital for human health, providing anti-inflammatory advantages and facilitating cardiovascular and neurological activities (Simopoulos, 2002; (Calder, 2015b). Saturated fatty acids (SFAs) in lung tissue exhibit considerable stability throughout time, with levels recorded at 46.75% at 5 months and 47.78% at 1 year. This stability indicates that lung tissue may possess a lipid composition that is less susceptible to fluctuation, perhaps attributable to its metabolic role and physiological activities. The liver has a notably elevated quantity of polyunsaturated fatty acids, especially after one year, when PUFA level attains 32.07%. In contrast to the lung, the liver exhibits a marginal rise in saturated fatty acids with life, escalating from 45.5% at 5 months to 45.8% at 1 year. Oleic acid (C18:1), a principal monounsaturated fatty acid (MUFA), is found in the liver at lower concentrations compared to muscle cuts such as rump and beef steak, indicating a unique fatty acid distribution associated with the liver's metabolic functions, likely due to its involvement in lipid and cholesterol metabolism (Gurr Michael et al., 2016). The elevated PUFA content in both lung and liver indicates that these tissues may be particularly beneficial nutritionally, attracting health-conscious customers who emphasize essential fatty acid consumption (Simopoulos, 2002). The decreased concentrations of monounsaturated fatty acids (MUFAs) in lung and liver tissues, in contrast to meat cuts, may influence the softness and juiciness commonly attributed to meat cuts, which have higher amounts of oleic acid (C18:1). Monounsaturated fatty acids (MUFAs), such as oleic acid, are associated with enhanced sensory attributes, including softness and a pleasing mouthfeel, due to their softer nature and lower melting points (Wood et al., 2008). The reduced MUFA concentration in lung and liver may render these tissues less appealing to customers who emphasize the sensory attributes of conventional beef cuts. Meat cuts including round steak, rump steak, and beef steak have a significant prevalence of saturated fats. The saturated fat concentration in rump steak attains 57.36% at one year, markedly above that found in lung and liver tissues. Saturated fats enhance the meat's hardness and structure, rendering it more appropriate for cooking techniques such as grilling, as they preserve stability and texture at elevated temperatures (Wood et al., 2008). Monounsaturated fatty acids, especially oleic acid (C18:1), significantly influence the lipid composition of these slices. At one year, beef steak and rump steak have elevated amounts of monounsaturated fatty acids (MUFAs), at 40.14% and 33.41%

respectively, which increases texture and flavor, hence leading to a superior culinary experience. The increased MUFA concentration correlates with softness, juiciness, and an appealing mouthfeel (Wood et al., 2004). Nevertheless, polyunsaturated fatty acids are significantly lower in meat cuts than in lung and liver, signifying a diminished essential fatty acid composition. For instance, rump steak at 5 months includes just 3.89% PUFAs, indicating that these cuts may possess a restricted nutritional value for important fatty acids. Although reduced PUFA content may be nutritionally suboptimal, it offers a considerable benefit for oxidative stability. Polyunsaturated fatty acids (PUFAs) are more susceptible to oxidation, resulting in rancidity and decreased shelf life (Jacobsen, Let, Nielsen & Meyer, 2008). Consequently, the reduced PUFA level in meat cuts can enhance taste stability and prolong shelf life, which is advantageous for both customers and merchants. The fatty acid composition of various anatomical regions of meat influences both its nutritional value and sensory quality. Lung and liver tissues, characterized by elevated PUFA levels, provide health advantages that may attract customers in search of a nutrient-rich choice. Meat cuts such as rump steak and beef steak, characterized by elevated levels of saturated and monounsaturated fats, offer superior oxidative stability, taste, and texture, rendering them more appropriate for conventional culinary uses.

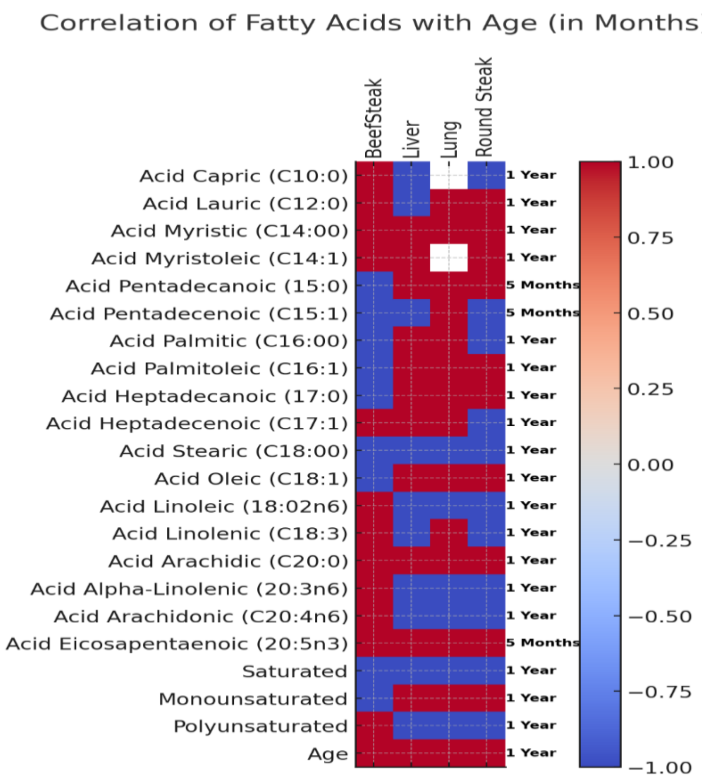

Figure 2. Heat map correlation of Fatty Acids with Age (in Months) by Anatomical Part.

Short-Chain Saturated Fatty Acids (Capric Acid (C10:0) and Lauric Acid (C12:0)):

From the Figure 2, it is evident that in cuts like Beef steak and Round Steak, short-chain saturated fatty acids, such as capric and lauric acids, demonstrate positive correlations with age, indicating that their content generally rises as the calf matures. This trend suggests an age-related accumulation of these lipids, possibly tied to shifts in fat metabolism or deposition patterns in muscle tissue over time (Wood et al., 2008). However, due to their relatively low abundance in muscle cuts, the practical impact of these short-chain SFAs on overall meat quality is minimal. Short-chain SFAs typically have lower melting points and remain liquid at room temperature, contributing less to the firmness and structure of the meat. Consequently, they have a limited effect on sensory qualities such as flavor and texture, as their contributions to overall mouthfeel and juiciness are minor (Chizzolini et al., 1999);(Wood et al., 2004). Longer-Chain Saturated Fatty Acids (Myristic Acid (C14:0) and Stearic Acid (C18:0)): In contrast, longer-chain SFAs like myristic and stearic acids are more prominent in cuts such as Beef steak and Round Steak, showing strong positive correlations with age, which signifies a consistent rise in their concentrations as the animal matures.

Elevated levels of these longer-chain SFAs significantly contribute to the structural integrity and oxidative stability of the meat. This is largely due to the formation of a solid, stable fat matrix, which reduces susceptibility to oxidative rancidity and enhances the shelf life of the meat (De Smet et al., 2004). Nonetheless, the increased firmness brought on by higher SFA content can also negatively impact tenderness. When the SFA content is high, the meat may feel less juicy and tender, particularly when cooked with dry methods such as grilling, as SFAs are less likely to melt during cooking (Wood et al., 2008). Therefore, while longer-chain SFAs enhance storage stability and firmness, adjustments in cooking techniques are often recommended to maintain the meat's tenderness and sensory appeal.

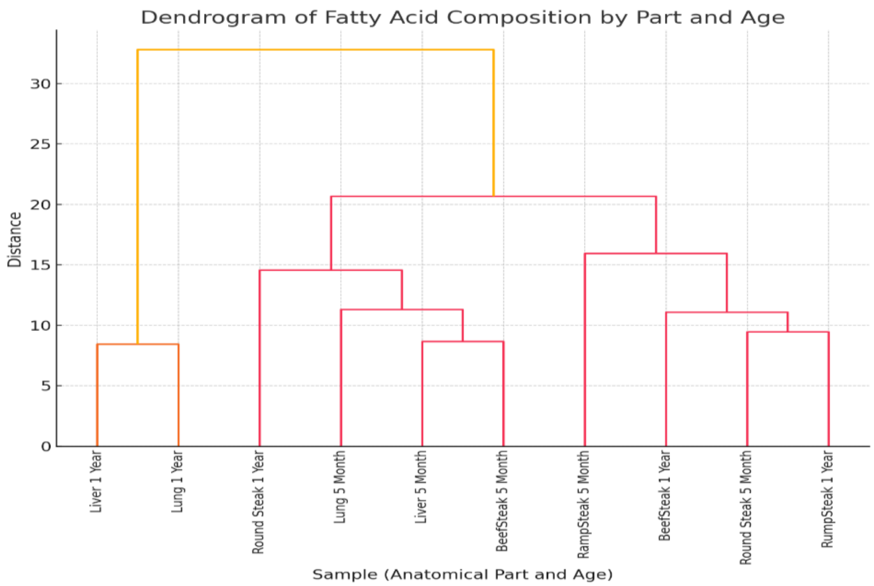

Figure . Dendrogram of Fatty Acid Composition by Anatomical Part and Age.

The dendrogram analysis (in Figure 3) reveals distinct clustering patterns based on anatomical part and age, indicating that fatty acid composition is primarily influenced by tissue type. Muscle cuts, including Beef steak, Round Steak, and Rump steak, cluster closely together across ages, reflecting similar profiles dominated by saturated and monounsaturated fatty acids, which are associated with structural firmness and oxidative stability. In contrast, organ tissues like liver and lung form a separate cluster, distinguished by higher concentrations of polyunsaturated fatty acids (PUFAs), essential for metabolic functions. Sub-clustering within each primary group suggests that age impacts fatty acid composition in a secondary capacity, with slight increases in SFAs in older samples. This clustering underscores the unique lipid profiles of muscle versus organ tissues and highlights the stability of fatty acid composition by part, with minor age-related modifications.

CONCLUSION

This study highlights how the type and distribution of fatty acids in beef vary significantly depending on the anatomical part and the age of the animal. Organ tissues like the lung and liver are particularly rich in polyunsaturated fatty acids (PUFAs), which are known for their health benefits, including anti-inflammatory effects and support for heart and brain function. These tissues also show increasing PUFA levels as the animal matures, enhancing their nutritional value over time. In contrast, muscle cuts such as beef steak, rump steak, and round steak are dominated by saturated (SFAs) and monounsaturated fatty acids (MUFAs). These fats contribute to the meat's structure, oxidative stability, and desirable sensory qualities such as tenderness, juiciness, and flavor. As animals age, these cuts show increasing levels of SFAs and MUFAs, making them more suitable for high-temperature cooking and extended storage. While organ meats may appeal more to health-conscious consumers due to their PUFA content, muscle cuts are better suited for those prioritizing taste, texture, and culinary performance. Heatmap and dendrogram analyses reinforce these patterns, showing clear groupings based on tissue type and subtle changes with age. Understanding these fatty acid profiles helps guide more informed decisions in meat production, marketing, and consumption—balancing nutrition, flavor, and functionality.

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