Exploring the microbiological quality and safety of dry-aged beef: A cross-sectional study of loin surfaces during ripening and dry-aged beef steaks from commercial meat companies in Belgium

Tanuja K.G.M. Gowda a, Lieven De Zutter a, Geert Van Royen b, Inge Van Damme a, *

a Department of Veterinary Public Health and Food Safety, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, Merelbeke, B-9820, Belgium
b Research Institute for Agriculture, Fisheries and Food, Technology and Food Science Unit, Brusselsesteenweg 370, Melle, B-9090, Belgium

ARTICLE INFO

Keywords:
Dry-aging
Meat
Microbiology
Food safety

ABSTRACT

A cross-sectional survey was undertaken in Belgian beef producing companies to study the current practices and the microbiological load of dry-aged loins (during production) and trimmed steaks (final product). In each company, the temperature and relative humidity of the ripening chamber were measured, and two loins (each in a different stage of the ripening process) were sampled. From the surface of each loin, a lean meat and adipose tissue sample was analysed separately, and different groups of bacteria, yeasts and moulds were enumerated. The average relative humidity in the ripening chambers was 72 ± 13% and the temperature ranged between 0.0 °C and 5.9 °C. During the drying process, most of the lean meat and adipose tissue sample was analysed separately, and different groups of bacteria, yeasts and moulds were enumerated. The average relative humidity in the ripening chambers was 72 ± 13% and the temperature ranged between 0.0 °C and 5.9 °C. During the drying process, most of the lean meat and adipose tissue samples showed high numbers of total psychrotrophic aerobic bacteria, Pseudomonas spp., psychrotrophic lactic acid bacteria, and yeasts, but the variation between loins was high. The microbiological load on freshly cut dry-aged steaks was generally lower than on loin surfaces, but both psychrotrophic aerobic and anaerobic bacteria were present inside several steaks. The water activity inside dry-aged beef steaks was high (a w ≥ 0.98), which could allow growth of psychrotrophic pathogens, though more in-depth studies are necessary to determine potential growth during the storage of (trimmed) steaks or even inside loins during the dry-aging process.

1. Introduction

Dry-aging is a process whereby fresh meat is stored at low temperature and relative humidity for several weeks, resulting in improved tenderness and development of a unique flavour (Perry, 2012). Generally, primal or sub primal cuts of bovine carcasses are used for the dry-aging process, during which the cuts are hung or placed on a rack under refrigerated conditions without protective packaging. This exposes the product directly to the environment and elicits a risk of microbial contamination (Li et al., 2014; Parrish et al., 1991). The quality of meat prior to aging, hygienic practices during production, and storage conditions will determine the microbial quality of dry-aged beef (Ahnström et al., 2006; Dashdorj et al., 2016).

During meat storage, bacteria such as Pseudomonas spp., Brochothrix thermosphacta and lactic acid bacteria are able to grow, limiting the shelf life of meat (Ercolini et al., 2011; Labadie, 1999). Besides these spoilage bacteria, pathogenic bacteria such as Listeria monocytogenes, enterohaemorrhagic Escherichia coli (EHEC) and Salmonella spp. may be present and could multiply during meat storage under favourable conditions (Lee et al., 2017; Smadi et al., 2012; Wang et al., 2015). Nevertheless, the few challenge tests that have been performed for dry-aged meat indicate a reduction of pathogens over time (da Silva et al., 2019; Tittor et al., 2011). The process of dry-aging may provide opportunities for yeasts to become the dominating flora, causing meat spoilage (Ahnström et al., 2006). Furthermore, the process of dry-aging may promote the growth of moulds on the external surface of the crust, which have been suggested to contribute to the tenderness and flavour of dry-aged beef (Campbell et al., 2001; Ryu et al., 2018). Species that may potentially produce mycotoxins have been found on dry aged meat (Capouya et al., 2020), and low levels of aflatoxin (up to 8.3 ppb) have been detected (Tapp, 2006), though there are only few papers on mycotoxin production in dry aged meat to assess the potential risk for public health.

Recently, there has been a worldwide increased interest in dry-aging meat (Dashdorj et al., 2016). The methods that are used during production and the microbiological quality of dry-aged meat vary according
to the geographical location (Dashorj et al., 2016; DeGeer et al., 2009). Although several studies have evaluated the microbiological status of aged meat under controlled laboratory conditions (Ahnstrom et al., 2006; Campbell et al., 2001; Cho et al., 2018; da Silva Bernardino et al., 2020, Bernardino et al., 2020; DeGeer et al., 2009; Hulankova et al., 2018; Kim et al., 2019; Lee et al., 2018; Li et al., 2013; Smaldone et al., 2019), little is known in scientific literature about the ageing conditions and microbial quality and safety of dry-aged beef produced for human consumption under field conditions. Although microbiological criteria are imposed by the European Commission (Regulation (EC) No 2073/2005) for different types of foodstuffs, no such criteria exist for dry-aged meat. In food safety and quality management, quantitative microbiological risk assessment is an essential tool, though requires a lot of data (Fegan and Jenson, 2018). The lack of real world data on current practices and microbiological loads currently hampers the development of reliable models for dry-aged meat. Therefore, a cross-sectional survey was undertaken to assess the practices and to explore the microbiological load on dry-aged beef loins produced in Belgium. Physicochemical parameters (pH and $a_w$) as well as production parameters (temperature and relative humidity) were also measured. Moreover, the microbiological quality of dry-aged beef steaks was assessed by determining the superficial as well as internal load of the final product.

2. Material and methods

2.1. Dry-aging practices and microbiological load of dry-aged beef loins

2.1.1. Study design

To evaluate current practices and the microbiological load on the surface of dry-aged loins during the dry-aging process, 15 dry-aged meat producing companies were visited in Belgium. The companies were selected from a list of dry-aged beef producers, provided by the Belgian Federal Agency for the Safety of the Food Chain. In each company, a questionnaire was administered to assess the practices that were used for dry-aging meat. The temperature and relative humidity of the ripening chamber or cabinet was recorded, and two loins were sampled per company for microbiological analysis. Whenever possible (based on the availability of loins that were present during the sampling visit), one loin was selected that was at the beginning and another one near the end of the ripening process (according to the company’s own criteria to define which loins were still at the beginning and which were at the end of the process, ready to be sold).

2.1.2. Environmental conditions and physicochemical parameters

The temperature and relative humidity at the time of sampling were recorded at four different locations of the ripening chamber/cabinet using a Klima Guard electronic thermo-hygrometer (TFA, Germany) according to ISO 9001 and the average of these four measurements was recorded.

2.1.3. Sample collection and microbiological analysis

From each loin, 25 cm$^2$ of the surface of both lean meat and adipose tissue was delineated using a sterile stainless-steel template and a layer of the surface (ca. 3 mm) was excised using a sterile surgical knife and forcep. Each individual sample was immediately placed in a stomacher bag. In one company, no loins were available at the beginning of the ripening process, resulting in a total of 58 tissue samples that were collected for microbiological analysis. All samples were immediately transported to the laboratory in an insulated container with ice packs. Transport times were no longer than 2 h. Upon arrival at the laboratory, samples were stored at 4 C and processed within 1 h. Each surface sample (25 cm$^2$) was homogenized in 25 ml of 0.1% peptone water, using a stomacher blender (Masticator, IUL Instruments, Led Techno, Belgium) for 2 min. One hundred microliter of the homogenate and 100-fold dilutions were used to quantify different microorganisms using a spiral plater (Eddy Jet, IUL Instruments, Led Techno, Belgium), resulting in a detection limit of 10 CFU/cm$^2$.

To quantify different groups of bacteria, the following media and conditions were used: Plate Count Agar (Oxoid, Belgium) at 22 °C for 5 days for the total psychrotrophic aerobic bacteria (Potheakos et al., 2012); Violet Red Bile Glucose (Oxoid, Belgium) at 37 °C for 24 h for Enterobacteriaceae (ISO 21528–2); Tryptone Bile Glucuronic (Oxoid, Belgium) agar at 44 °C for 24 h for E. coli (ISO 16649–2); Baird-Parker agar (Oxoid, Belgium) at 37 °C for 48 h for coagulase-positive staphylococci (ISO 6888–2); Streptomycin Sulphate Thallous-Acetate Acetidione (Oxoid, Belgium) at 22 °C for 48 h for B. thermoplastic (ISO 13722); Man-Rogosa-Sharpe (Oxoid, Belgium) agar at 25 °C for 48 h for Pseudomonas spp. (ISO 13720); Dichloran-Rose Bengal Chloramphenicol (Oxoid, Belgium) agar at 25 °C for 5 days for yeasts and moulds (ISO 21527–1); Agar Listeria according to Ottaviani and Agosti (Oxoid, Belgium) at 37 °C for 24–48 h for Listeria spp. and L. monocytogenes (ISO 11290–2/A1). To evaluate the internal microbiological load, 10 g of tissue was aseptically excised using a sterile scalpel and forceps, after which 10g of deep tissue from the exposed area was cut and steaks were trimmed by a meat handler of the company (similar as they would do under routine practices), after which 25 cm$^2$ of the surface of each of two steaks was aseptically excised by a researcher. In addition, one of the two steaks were collected to evaluate the internal microbiological load.

2.2. Microbiological quality of retail dry-aged beef steaks

2.2.1. Sampling

To explore the microbiological load on dry-aged beef steaks after trimming, five companies were selected among the 15 companies that were sampled in the cross-sectional survey (section 2.1.1). In each of the five companies, three loins at the end of the dry-aging process were selected. From each loin, the crust was sampled in a sterile manner by excising 25 cm$^2$ of the meat surface, similarly as above. Then, the loin was cut and steaks were trimmed by a meat handler of the company (similar as they would do under routine practices), after which 25 cm$^2$ of the surface of each of two steaks was aseptically excised by a researcher.

2.2.2. Microbiological analysis and physicochemical parameters

Surface samples were analysed as described before (section 2.1.3). To evaluate the internal microbiological load, 10 g of tissue was aseptically sampled in duplicate after aerationization of the surface (ISO 6887–2) using a rounded iron bar that was heated by placing it over a Bunsen burner for 10 min. The surface was exposed until charring occurred. A layer of the charred area was removed using a sterile scalpel and forceps, after which 10g of deep tissue from the exposed area was collected. After homogenisation in 90 ml of 0.1% peptone water, one-ml aliquots were poured plated using PCA and Reinforced Clostridial Agar (RCA) for the enumeration of total psychrotrophic aerobic and anaerobic bacteria, respectively. After incubation at 22 °C for 5 days, plates containing up to 300 colonies were counted. The pH of the steaks was measured as described before (section 2.1.2). The $a_w$ of the freshly cut meat was measured using a$a_w$-Kryometer Type AWK-20 (Nagy, Germany).

2.3. Statistical analysis

Microbiological count data were log$_{10}$-transformed prior to analysis. Descriptive statistics were done using R version 4.0.2 (R Core Team, 2020). The datasets are available on Mendeley Data (dataset Van Damme et al., 2020). Microbiological numbers were visualized using the package ggplot2 using violin plots (Wickham, 2016). For total psychrotrophic aerobic bacteria, Enterobacteriaceae, Pseudomonas, B. thermoplastic, lactic acid bacteria and yeasts, linear mixed models were fit to evaluate the difference between lean meat and adipose tissue, using the package lim4 (Bates et al., 2015). To account for the dependence between samples from the same loin, a random intercept for loin was included in each of the models. Similarly, the effect of ripening time
(binary variable; beginning or end of the dry-aging period) was evaluated, including a random intercept for company to allow for the dependence of loins from the same company. To estimate the difference in counts between the surface of loins and steaks, linear mixed models were used, including a random intercept per loin. For samples that were negative (i.e. below the limit of detection, $< 1 \log_{10}$ CFU/cm$^2$), a value of 0.5 log$_{10}$ CFU/cm$^2$ was assumed for the analyses. A significance level of 5% was used for all tests.

3. Results

3.1. Dry-aging practices

The most frequently mentioned cattle breeds that were used for dry-aging by the 15 companies were Belgian Blue (n = 11 companies), Simmental (n = 10), Limousin (n = 10), Holstein Friesian (n = 9), Rubia Gallega (n = 8) and Aberdeen Angus (n = 8). The age of the animals (mostly females) that were used for dry-aging varied between 2 and 18 years. The time between slaughter and the start of the dry-aging process was reported to vary between one day up to 21 days. All companies used closed drying chambers (no circulation of fresh air). The temperatures of the dry-aging chambers were set between $1^\circ$C and $3^\circ$C, and the relative humidity was set between 40% and 75%. The minimal duration of dry aging that was used in the companies was three or four weeks (mentioned by 3 and 12 of the companies, respectively). The maximum ripening period in the companies varied between 4 and 10 weeks (median of 5 weeks). All companies performed dry-aging bone-in, and mainly used loins (from the sixth rib onwards), either hanging up (n = 2), laying down (n = 4) or both (n = 9). None of the companies used UV lighting nor special dry-aging bags. None of the companies used an all-in/all-out system in the drying cabinets/chambers, but continuously included new loins. The shelf life of the end product (trimmed steaks) varied between 2 and 10 days for steaks that were unpacked (median 4 days; reported by 11 companies), and between 5 and 30 days for vacuum packed steaks (median 18 days, reported by 11 companies). One company packed steaks in modified atmosphere, with a shelf life of five days.

3.2. Dry-aged beef loins during ripening

3.2.1. Production parameters and loin characteristics

The average relative humidity of the ripening chambers at the time of the visit was $72 \pm 13\%$ (range between 50 and 90%). The temperature in these chambers ranged between $0.0^\circ$C and $5.9^\circ$C.

In each company, one loin was sampled that was at the start and another one near the end of the ripening period. In one company, no loins were available at the beginning of the ripening period. The mean ripening period of the loins was $24 \pm 22$ days (n = 29). The ripening period of the 15 loins that were sampled at the end of the ripening period ranged between 19 and 78 days. The collected loins originated from the Belgian White Blue breed (n = 11), local dual purpose breeds (n = 5), Blonde d'Aquitaine (n = 3), Charolais (n = 2), and Simmental (n = 2). Other breeds were Angus, Aubrac, Highland, Italian Mediterranean buffalo, Limousin, and Maine-Anjou (one loin of each breed).

![Fig. 1. Violin plot of microbiological counts on the surface of dry-aged beef loins during ripening. Mirrored density plots including the median, the first and third quartile are shown for adipose tissue (white; n = 29) and lean meat (grey; n = 29) samples separately. Individual observations are plotted using points and triangles (for loins that were sampled at the beginning and the end of the dry-aging period, respectively). The limit of detection (1 log$_{10}$ CFU/cm$^2$) is shown using a horizontal dashed line. A: total psychrotrophic aerobic bacteria; B: Enterobacteriaceae; C: Pseudomonas spp.; D: B. thermosphacta; E: psychrotrophic lactic acid bacteria; F: yeasts.](image-url)
3.2.2. Microbiological loads of loins during ripening

Detailed summary data of microbiological counts are provided in Appendix (Table S1) for each of the microbiological groups that were tested. High numbers of total psychrotrophic aerobic bacteria, Enterobacteriaceae, Pseudomonas spp., B. thermosphacta, psychrotrophic lactic acid bacteria and yeasts were detected on the surface of beef loins during ripening (Fig. 1). The numbers on lean meat were similar to the numbers on adipose tissue (p > 0.05 for all microbiological groups tested). Nevertheless, the numbers that were found on both lean meat and adipose tissue varied greatly between loins (Fig. 1). Total psychrotrophic aerobic bacteria varied from 1.6 to 8.8 log10 CFU/cm2. Pseudomonas spp. from <1.0 to 8.8 log10 CFU/cm2, B. thermosphacta from <1.0 to 7.4 log10 CFU/cm2, psychrotrophic lactic acid bacteria from <1.0 to 7.3 log10 CFU/cm2, and yeasts from <1.0 to 6.4 log10 CFU/cm2. Enterobacteriaceae were usually present in low numbers (median value below the limit of detection), though values up to 6.4 log10 CFU/cm2 were also observed. Moulds were detected (≥1.0 log10 CFU/cm2) in 16 out of 29 lean meat and 13 out of 29 adipose tissue samples, in numbers up to 4.0 log10 CFU/cm2. Coagulase-positive staphylococci were only detected on the lean meat and adipose tissue of one and three loins, respectively. Only one sample showed detectable levels of E. coli, which was a loin that was at the very beginning of the ripening period. L. monocytogenes was not detected in any of the samples, but Listeria spp. were recovered from three samples (two samples at the beginning and one at the end of the dry-aging process).

The counts on loins at the end of the dry-aging period were estimated to be higher than the ones at the beginning of the dry-aging period, though the differences were not statistically significant (for total psychrotrophic aerobic bacteria (0.9, 95% CI [0.0; 1.8]), Enterobacteriaceae (0.8, 95% CI [0.6; 1.6]), Pseudomonas spp. (0.6, 95% CI [−0.5; 1.7]), B. thermosphacta (0.0, 95% CI [−0.9; 0.9]), and lactic acid bacteria (0.7, 95% CI [−0.1; 1.5]). Only for yeasts, the average numbers on loins at the end of the ripening period were estimated to be significantly higher (1.0 [0.2–1.7] log10 CFU/cm2) compared to loins that were sampled at the beginning of the ripening period (p = 0.017).

3.3. Microbiological quality of retail dry-aged beef steaks

The microbiological quality of dry-aged beef after cutting was evaluated by analysing the surface (crust) and two meat cuts (steaks) from each of 15 loins originating from five dry-aged beef producing companies. From two loins, the surface sample of the crust could not be sampled because the steaks were already cut at the time of sampling. The average ripening period of the beef loins for which the ripening time was known (n = 13) was 41 ± 15 days (minimum 21, maximum 76 days). The mean pH of the steaks (n = 14) was 5.73 ± 0.12. The aw of the steaks varied between 0.98 and 0.99 (n = 14).

Detailed summary data of microbiological counts on steaks and the corresponding loins are provided in Appendix (Table S2). The distribution of total psychrotrophic aerobic bacteria, Enterobacteriaceae, Pseudomonas spp., B. thermosphacta, psychrotrophic lactic acid bacteria and yeasts on the loin surface and steaks are visualized in Fig. 2. Similar to the loin surface, the numbers on steaks varied largely between different steaks. Numbers varied from <1.0 log10 CFU/cm2 up to 7.4 log10 CFU/cm2 for total psychrotrophic aerobic bacteria, 7.4 log10 CFU/cm2 for Enterobacteriaceae, 5.0 log10 CFU/cm2 for Pseudomonas spp., 3.3

Fig. 2. Violin plot of microbiological counts on the surface of dry-aged beef loins (white, n = 13) and dry-aged beef steaks after trimming (grey, n = 30). Mirrored density plots including the median, the first and third quartile are shown. The limit of detection (1 log10 CFU/cm2) is shown using a horizontal dashed line. A: total psychrotrophic aerobic bacteria; B: Enterobacteriaceae; C: Pseudomonas spp.; D: R. thermosphacta; E: psychrotrophic lactic acid bacteria; F: yeasts.
log$_{10}$ CFU/cm$^2$ for *B. thermosphacta*, 5.0 log$_{10}$ CFU/cm$^2$ for psychrotrophic lactic acid bacteria, and 3.7 log$_{10}$ CFU/cm$^2$ for yeasts. The numbers on steaks were significantly lower than on loins for total psychrotrophic aerobic bacteria (−1.0, 95% CI [−0.3; −1.7]), *Pseudomonas* (−0.9, 95% CI [−0.3; −1.5]), and *B. thermosphacta* (−0.8, 95% CI [−0.3; −1.4]). *Enterobacteriaceae* were detected on four out of 13 loins before cutting (31%; maximum of 4.3 log$_{10}$ CFU/cm$^2$) and on 12 out of 30 steaks (40%; in numbers up to 7.4 log$_{10}$ CFU/cm$^2$). Coagulase positive staphylococci were found on two loins and three steaks, in low numbers (1.0 log$_{10}$ CFU/cm$^2$ and ≤ 2.0 log$_{10}$ CFU/cm$^2$, respectively). *E. coli* and *L. monocytogenes* were not detected on any of the steaks. *Listeria* spp. were detected on three steaks, but not on any of the loin surfaces. Moulds were detected on four out of 13 loins (31%) and three out of 30 steaks (10%), on the latter with a maximum of 1.5 log$_{10}$ CFU/cm$^2$.

### 3.4. Internal microbiological load

Aerobic psychrotrophic bacteria above the limit of enumeration (>1 log$_{10}$ CFU/g) were observed inside 21 out of 28 steak samples (75%; Fig. 3). The plates from two samples (both were from the same loin) were discarded due to overgrowth by moulds. In five steak samples, the number of bacteria were above the upper limit of enumeration (>300 colonies per plate or > 3.5 log$_{10}$ CFU/g). The median total aerobic psychrotrophic bacteria in samples with countable numbers (n = 16) was 1.5 log$_{10}$ CFU/g. Anaerobic psychrotrophic bacteria above the limit of enumeration were observed in 20 out of 30 samples (67%), of which four were above 3.5 log$_{10}$ CFU/g. In samples with countable numbers (n = 16), the median number of anaerobic psychrotrophic bacteria was 1.2 log$_{10}$ CFU/g. Most of the replicates had similar results, with either both steaks being positive (n = 9 and n = 8 steaks for aerobic and anaerobic bacteria) or negative (n = 2 and n = 3, respectively). In three (aerobic bacteria) and four (anaerobic bacteria) steaks, one positive and one negative sample was found.

### 4. Discussion

Our study demonstrates that the microbiological loads on loins under field conditions in commercial dry aged beef producing companies in Belgium vary greatly, which may be caused by a variety of factors, including the differences in production parameters (temperature, relative humidity) and meat-related factors (such as pH and the storage before the start of the process) that are used in practice. Particularly the dry-aging time varied greatly between and within the different companies, with reported aging times up to 10 weeks. To the best of our knowledge, a definition for dry-aging currently doesn’t exist, though all companies in our study dry-aged for a minimum of three to four weeks.

*Pseudomonas* spp., *B. thermosphacta* and lactic acid bacteria have been shown to predominate in dry-aged meat (Parrish et al., 1991). In the present study, high numbers of total psychrotrophic aerobic bacteria, *Pseudomonas* spp., lactic acid bacteria and *B. thermosphacta* were detected on the dried crust of beef loins at the end of the ripening process, though the numbers varied greatly between different loins. Several studies have reported different degrees of bacterial loads on dry-aged beef under controlled conditions. Li et al. (2014) observed higher numbers of total aerobic bacteria (8.8 and 6.9 log$_{10}$ CFU/cm$^2$ for lean meat and adipose tissue), and *Enterobacteriaceae* (5.4 and 2.1 log$_{10}$ CFU/cm$^2$), but lower numbers of lactic acid bacteria (3.2 and 2.2 log$_{10}$ CFU/cm$^2$) on dry-aged beef and meat after 19 days at an average temperature of 2.9 °C (relative humidity not reported). In contrast, Campbell et al. (2001) observed low numbers of total aerobic bacteria (3.3 log$_{10}$ CFU/cm$^2$), lactic acid bacteria (2.0 log$_{10}$ CFU/cm$^2$) and *Pseudomonas* (3.3 log$_{10}$ CFU/cm$^2$) on lean meat and adipose tissue of meat aged for 21 days at 2 °C and 75% relative humidity. Similarly, DeGeer et al. (2009) observed low numbers of total aerobic bacteria (3.5 log$_{10}$ CFU/cm$^2$) and lactic acid bacteria (1.3 log$_{10}$ CFU/cm$^2$) in dry-aged beef loins after 21 or 28 days at 2.2 °C, a relative humidity of less than 50%, air filtering and continuous UV radiation to control the surface microbiological load. The results that are generated under (a limited number of) controlled laboratory conditions should thus be interpreted with caution, as they may only represent a small fraction of dry aging practices, and are not generalizable to the total population. Future studies are thus encouraged to include a wide range of plausible process conditions when possible, to capture the true variability of processes that are used.

During this cross-sectional study, the initial bacterial concentration of the loins at the start of the dry-aging process was not known. Nevertheless, since the bacterial numbers also varied greatly between the loins that were sampled at the beginning of the dry-aging process, the preservation of the meat between slaughter and the start of the ripening process may play an important role. In the present study, the period between the time of slaughter of the animals and the start of the dry-aging process varied between 0 and 18 days (average of 4 days; n = 36) ([dataset](Van Damme et al., 2020)). Therefore, the contamination level of the carcasses and storage conditions of the loins prior to aging may also determine the levels of microorganisms during the production process (Cherrourd et al., 2014).

Ahnström et al. (2006) observed a decrease in the number of lactic acid bacteria and an increase in the number of yeasts with a longer ripening period. However, Li et al. (2014) found higher numbers of total bacterial count, *Enterobacteriaceae*, lactic acid bacteria and yeasts with a longer aging period. In contrast, Campbell et al. (2001) reported that the ripening period does not influence the number of total aerobic bacteria. In the present study, the average number of total aerobic bacteria, *Pseudomonas*, *B. thermosphacta*, lactic acid bacteria and yeasts were higher on loins at the end of the ripening period, though the difference was only significant for yeasts. Nevertheless, the results from this cross-sectional study should be interpreted with caution as each of the companies used different production parameters, which were not accounted for in the analyses due to the relatively small sample size.

When comparing the microbiological loads of lean meat and adipose tissue, Ahnström et al. (2006) observed similar numbers in total aerobic bacteria and lactic acid bacteria on both tissue types. However, these authors reported lower yeast counts on adipose tissue (3.9 log$_{10}$ CFU/cm$^2$) than on lean meat (5.2 log$_{10}$ CFU/cm$^2$). Similarly, Li et al.
T.K.G.M. Gowda et al.

Food Microbiology 102 (2022) 103919

In the present study, microbiological numbers on the surface of dry aged beef loins exhibited large variations. Our results may not be generalizable to other countries/regions around the world, but the dry-aging conditions and especially aging times were already highly variable between and even within companies in Belgium. The temperatures that were used in the present study don’t allow growth of most pathogens. Moreover, Enterobacteriaceae and E. coli numbers were mostly low/absent, which is in line with the general belief that dry aging reduces these bacteria. Nevertheless, the vast range of parameters that is used in practice and the higher loads that were occasionally found, suggests that future studies should also assess the growth/survival of (psychrotrophic) pathogens under experimental conditions at the outer ranges. Immediately after cutting, the microbiological load of dry-aged steaks is relatively low, but the water activity of freshly cut dry-aged beef steaks is very similar to fresh meat. Therefore, we cannot completely rule out the potential growth of psychrotrophic pathogens during storage, which may be similar to fresh meat, though this still needs to be assessed. Hygiene during cutting/trimming and proper storage of the end product remains of critical importance. In some cases, high numbers of bacteria are found inside the meat, addressing the need for further identification of these bacteria to assess their importance for the quality and safety of the end product.

5. Conclusions

Despite the increasing popularity of dry-aged meat, the current knowledge on the microbiological quality and safety of commercially produced dry-aged meat is still rather limited. In this cross-sectional study, microbiological numbers on the surface of dry aged beef loins exhibited large variations. Our results may not be generalizable to other countries/regions around the world, but the dry-aging conditions and especially aging times were already highly variable between and even within companies in Belgium. The temperatures that were used in the present study don’t allow growth of most pathogens. Moreover, Enterobacteriaceae and E. coli numbers were mostly low/absent, which is in line with the general belief that dry aging reduces these bacteria. Nevertheless, the vast range of parameters that is used in practice and the higher loads that were occasionally found, suggests that future studies should also assess the growth/survival of (psychrotrophic) pathogens under experimental conditions at the outer ranges. Immediately after cutting, the microbiological load of dry-aged steaks is relatively low, but the water activity of freshly cut dry-aged beef steaks is very similar to fresh meat. Therefore, we cannot completely rule out the potential growth of psychrotrophic pathogens during storage, which may be similar to fresh meat, though this still needs to be assessed. Hygiene during cutting/trimming and proper storage of the end product remains of critical importance. In some cases, high numbers of bacteria are found inside the meat, addressing the need for further identification of these bacteria to assess their importance for the quality and safety of the end product.

Author contributions

Tanuja Gowda: Investigation, Writing – Original Draft; Lieven De Zutter: Conceptualization, Methodology, Resources, Writing – Review & Editing, Funding acquisition; Geert Van Royen: Conceptualization, Methodology, Investigation, Writing – Review & Editing, Funding acquisition; Inge Van Damme: Conceptualization, Methodology, Formal analysis, Data Curation, Writing – Original Draft, Visualization, Funding acquisition.

Funding

This work was supported by the Belgian Federal Agency for the Safety of the Food Chain (FAV/2015–02). The funders have no role in the study design, data collection, analysis, interpretation of data, nor in writing of the report.