Research Article

Influence of Different Production Systems on the Quality and Shelf Life of Poultry Meat: A Case Study in the German Sector

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Production-specific factors, such as breeding, diet, and stress, are known to influence meat quality, but the effect of different husbandry systems on the development of quality parameters and shelf life has hardly been investigated. Thus, the aim of the study was the investigation of an alternative production system based on a slow-growing, corn-fed, and antibiotics-free chicken line compared with conventional poultry production. Additionally, the effect on meat quality, microbiology, and spoilage was analyzed. In total, 221 breast filets from a German poultry meat producer were investigated. Nutritional, biochemical, and cooking loss analyses were conducted on a subset of samples 24 h after storage. The rest of the samples were stored aerobically at 4°C, and the spoilage process was characterized by investigating pH, color, lipid oxidation, microbiology, and sensory attributes subsequently every two days during storage. The alternative production line showed a significantly healthier nutritional profile with a higher protein and lower fat content. Additionally, the amount of L-lactic acid and D-glucose was significantly higher than in the conventional production line. The color values differed between both production lines, with the corn-fed line displaying more yellowish filets. The lipid oxidation and microbial spoilage were not affected by the production line. The shelf life did not differ between the investigation groups and was deemed 7 days in both cases. Despite the highest severity of white striping being observed most in the conventional production line, there was no overall difference in the incidence among groups. The purchase decision was affected by the occurrence of white striping and showed a tendency for a higher acceptance for the alternative production line.

1. Introduction

To meet the growing consumption and consumer demands, poultry production underwent a remarkable development of intensification. As a result of intense selection processes, poultry breeding lines were modified for shorter generation times, enhanced animal performance, and higher meat content [1]. The slaughter age was halved to five weeks, while the breast meat yield was significantly increased by 10% compared with poultry production 50 years ago [2, 3]. With the selection for growth velocity, an increase of muscle failures and health issues of the animals arose [4–6]. White striping (WS), for example, is a muscle myopathy correlated to heavy breast filets and fast muscle growth [7]. WS has a remarkable negative impact on consumer acceptance [7, 8]. Further undesirable characteristics caused by the selection for high production efficiency are immunological, behavioral, physiological, and stress-related problems [3].

Animal health issues were countered by increased application of antibiotics in industrial animal production,
which resulted in the proliferation of microorganisms with antibiotic resistance [9] with enormous impact on human health. In the context of these problems, the sustainability of poultry production is discussed increasingly, and consumer awareness is rising for animal health and welfare topics [10–13]. The increasing demand for extensive production systems which are vigilant for animal welfare resulted in a growing organic sector, local certified products, and the establishment of high-quality meat lines [10, 14]. One example for a high quality, local product is the French poultry line “Label Rouge,” which was successfully introduced in the market in the 1960s and is widely accepted [15]. In Germany, the production of specialized corn-fed poultry lines is a similar attempt to launch high-quality meat in the market and experience a positive resonance with the customer. As the meat market reached the saturation point in Germany, meat quality as well as animal welfare and sustainability have an increasing impact on the purchase decision of the consumer. Thus, a production system was developed focusing on enhanced animal welfare, antibiotics-free, corn-based fattening, and a slow-growing breed. The use of more sustainable systems, such as the proposed one, may increase consumer acceptance and the willingness-to-pay higher prices; however, any modification of the production system may also cause differences in the meat quality, nutritional parameters, and the shelf life of the final product. Several studies are conducted under controlled laboratory conditions and not in commercial production systems and thus do not fully reflect practical conditions of meat production.

Thus, the focus of this case study was the comparison of two commercial production lines regarding typical meat nutritional and quality parameters, typical defects (such as WS), and the shelf life of the products.

2. Materials and Methods

2.1. Study Design. The investigation focused on the characterization of two different industrial production lines: conventional and alternative, of a German poultry producer. For the alternative production line, the producer recently changed breeds for a new slow-growing race showing optimized muscle growth within the prolonged production time. Additionally, detailed information on feedstuff ingredients is not provided due to confidentiality clauses.

Characteristics of the alternative production line were as follows: the used race was the slow-growing Ranger Classic at a maximal stocking rate of 32 kg/m² and a toy-enriched environment, such as bales of straw and boxes. The diet of the birds contained more than 50% corn. The fattening focused on a slower growth of the animals and was conducted without antibiotic medication. The birds were slaughtered after 42–45 d.

Characteristics of the conventional production line were as follows: the race Ross 308 was used at a stocking rate of 39 kg/m². Antibiotic medication was administered when required. The birds were fed with a grain-based diet and slaughtered after 30–35 d.

All animals were slaughtered and processed the same day and in the same industrial slaughterhouse. The breast files were transported under temperature-controlled conditions to the laboratory of the University of Bonn.

To investigate the influence of the production system on the nutritional value (protein, intramuscular fat, collagen, and water content) and muscle characteristics (L-lactic acid and D-glucose), a subset of the samples \((n=32)\) was frozen directly after arrival at the laboratory.

A total of 221 filets were investigated in two repeated storage trials to assess the development of quality parameters and shelf life. After packaging aerobically in polypropylene trays with snap-on lids, the samples were stored in high-precision low-temperature incubators (Sanyo Mir 154-PE, Sanyo Electric Co., Ora-Gun, Gunma, Japan) at 4°C for 12 d. The investigations were conducted at six repeated investigation points during storage. For each investigation point, a total of 24 alternative and 13 conventional filets were investigated. The analyzed parameters comprised physicochemical parameters \((pH,\) drip and thawing loss, and color measurements), microbial investigations \((total\ viable\ count\ of\ Pseudomonas\ spp.,\ Brochothrix\ thermosphacta,\ and\ Enterobacteriaceae),\) and a sensory analysis including the assessment of WS and purchase decision (PD). The analyses were conducted on the complete filet with an excision only for microbial investigations. After all investigations were completed for an investigation point, samples were frozen at −18°C and stored for the measurement of thiobarbituric acid reactive substances. The first analyses started 24 h after slaughter (0 h of the experiment) to characterize the initial meat quality, WS, and microbial contamination of the poultry filets. Except for cooking and thawing loss, the development of quality and microbial parameters was investigated by six repeated measurements until the end of storage at 288 h \((12\ d)\).

2.2. Physicochemical Parameters

2.2.1. Analysis of Nutritional Value and Muscle Characteristics. To investigate the influence of the production system on the nutritional value of the meat and the susceptibility of the muscle for microbial spoilage, the main nutrients, D-glucose and L-lactic acid, were analyzed for a subset of the samples. The meat samples were frozen at a fresh condition 24 h after slaughter in a −18°C freezer. Before the analyses, the samples were thawed for 24 h at 4°C. The nutritional value of the poultry filets was analyzed with near-infrared spectroscopy on 32 filets. The whole filets were processed using a food processor (Moulinex DPA 141, Groupe SEB Deutschland GmbH, Offenbach, Germany). Afterwards, they were placed in the near-infrared spectrometer (NIRS DS2500, Foss, Rellingen, Germany) and analyzed automatically. The measurements comprised intramuscular fat, protein, water, and collagen content and are stated as percentages.

Two specific enzyme test kits were used to determine the content of L-lactic acid (Biopharm 1111281035, R-Biopharm AG) and D-glucose (Biopharm 10139106035, R-Biopharm AG) with a spectral photometer (Thermo Scientific™ GENESYS™, Fisher Scientific GmbH, Schwerte, Germany).
on 23 filets. Sample preparation was conducted following a modified protocol of [16]. A standardized sample size of \(4 \times 8 \text{ cm}^2\) was extracted with a scalpel and processed using a food processor. 5 g of the meat paste was transferred to a beaker glass, dissolved in 35 ml Aqua Bidest, and homogenized for 5 min on a magnetic stirrer without heating. After Carrez clarification and adjusting the pH value to 7.5–8 (testo 206-pH1, Testo, Lenzkirch, Germany) with 0.5 mol sodium hydroxide solution, the solution was transferred to a graduated flask, filled with Aqua Bidest up to 100 ml, and swiveled slightly. The solution was filtered (Whatman Filter 595 1/2, GE Healthcare Europe GmbH, Freiburg, Germany) and further processed following the instructions of the test kit. Samples were measured in repeat determination at 340 nm.

### 2.2.2. pH Value

The surface pH of the filets was measured with a portable surface pH meter (pH 8011, Peter Bock Umwelttechnik, Gersfeld, Germany). The pH meter works with a glass electrode, specifically developed for meat surface measurements. The pH meter is calibrated daily and checked regularly against penetration electrodes to justify correct measurements. Three measurements were performed for each meat sample by placing the electrode onto the meat surface. An average pH value was calculated for every sample \((n = 221)\).

### 2.2.3. Cooking and Thawing Loss

As a measure for the water binding capacity of the breast filets, the cooking loss and thawing loss were analyzed. The cooking loss analysis was performed on the inner filet of the meat sample at the beginning of storage \((n = 36)\). The inner filet was detached from the sample, weighed, transferred separately into an autoclave bag, and sealed. Samples were heated in an 80°C water bath (Memmert, Schwabach, Germany) until the core temperature reached 72°C. Temperature measurements were performed with a food core thermometer (Testo, Lenzkirch, Germany) in a reference sample. After cooking, the filets were dabbed and weighed again. The thawing loss was measured by weighing the whole filet before and after freezing in an \(-20°C\) freezing room. The thawing loss was determined at the beginning \((n = 22)\) and end of storage \((n = 21)\). Cooking loss and thawing loss, respectively, were calculated using the following equation:

\[
W_L = \frac{m_1 - m_2}{m_1} \cdot 100\%,
\]

where \(W_L\) is the water loss (%), \(m_1\) is the weight before treatment (g), and \(m_2\) is the weight after treatment (g).

### 2.2.4. Color Measurements

The color of the filets \((n = 196)\) was measured using a large view spectrophotometer (ColorFlex EZ 4500L, HunterLab, Murnau). The color measurement was conducted at a wavelength between 400 nm and 700 nm and with a 45°/0° geometry. The CIE 1976 \(L^*a^*b^*\) scale was used, measured with D65 illuminant (6500 K daylight). The filets were placed on the glass surface of the measurement device. The color was measured at three sample points for each filet to get a representative evaluation of the sample. Measurement values were averaged for each sample.

#### 2.2.5. Measurement of Thiobarbituric Acid Reactive Substances

For the investigation of fat oxidation in the tissue, thiobarbituric acid reactive substances (TBARS) were determined by a quantitative assessment of malondialdehyde (MDA) via extraction with trichloroacetic acid (TCA) and a fluorometric measurement in a microplate reader (ColorFlex EZ 4500L, HunterLab, Murnau). The measurement of TBARS was conducted during the second repetition of the trial on 131 breast filets \((n = 14\) alternative and \(n = 8\) conventional, per investigation point). For the preparation of samples, poultry filets were thawed at 4°C for 24 h. A standardized surface of the meat tissue with a size of \(4 \times 8 \text{ cm}^2\) and 0.5 cm thickness was punched and homogenized with a food processor. After transferring 7 g of the meat paste to a 50 ml tube, 15 ml TCA (7.5%) was added together with ethylenediaminetetraacetic acid (EDTA, 0.1%) and propyl gallate (0.1%). Each sample was homogenized with an Ultra Turrax (IKa Ultra-Turrax, Janke & Kunkel GmbH & Co KG, Staufen, Germany) for 60 s, and a further 10 ml TCA was added. The samples were stored on ice to prevent heating during the homogenization process. The homogenized samples were centrifuged for 15 min at 2000 rpm and 4°C. Then, the homogenate was filtered through a Whatman No. 4 filter, aliquoted, and stored at \(-80°C\) until further processing. For the TBA reaction, 100 μl of the thawed homogenates was transferred to reaction tubes. After adding 200 μl TCA (10%), samples were incubated on ice for 5 min and then centrifuged for 6.5 min at 13,200 rpm and 4°C. The supernatant was taken and diluted in Aqua Bidest \((1:2.5)\). TBA reagent was added to the samples and then incubated at 100.5°C for 60 min. The samples were then cooled in a 4°C centrifuge at 8000 rpm for 2 min. Samples were transferred to microplates and quantified in a microplate reader at excitation/emission 515/533 nm.

### 2.3. Microbiological Analyses

Microbiological analyses were conducted to assess the initial contamination of the meat samples and to investigate the proliferation of typical spoilage organisms. The focus of the analyses was on total viable count (TVC) which was analyzed for every sample \((n = 219)\). *Pseudomonas* spp., *Brochothrix thermosphacta*, and Enterobacteriaceae were analyzed for a subset of samples \((n = 119)\). For microbial investigations, a standardized surface of meat tissue, with a size of \(5 \text{ cm}^2\), was extracted aseptically using a sterile punch and a scalpel. The samples were transferred to a sterile, filtered stomacher bag. The ninefold amount of saline peptone diluent \((0.85\% \text{ NaCl with } 0.1\% \text{ peptone Saline tablets, Oxoid BR0053G, Cambridge, United Kingdom})\) was added with an accuracy of 0.1 g for the first dilution step. The samples were mixed with a Stomacher 400 (Kleinfeld Labortechnik, Gehrden, Germany) and then incubated at 100.5°C for 60 min. The supernatant was taken and diluted in Aqua Bidest \((1:2.5)\). TBA reagent was added to the samples and then incubated at 100.5°C for 60 min. The samples were then cooled in a 4°C centrifuge at 8000 rpm for 2 min. Samples were transferred to microplates and quantified in a microplate reader at excitation/emission 515/533 nm.
Germany) for 60 s. Tenfold dilutions of the homogenate were prepared in saline peptone diluents.

The total viable count (TVC) was determined by the pour plate technique on Plate Count Agar (PCA, Merck, Darmstadt, Germany). The plates were incubated at 30°C for 48 h. \textit{Pseudomonas} spp. (PSE) were detected by the spread plate technique on Pseudomonas agar with Cetrimide-Fucidin-cephalosporine selective supplement (CFC, Oxoid, Cambridge, United Kingdom). Plates were incubated at 25°C for 48 hours. \textit{Brochothrix thermosphacta} was determined by the drop-plate technique on SIN agar (Streptomycin Inosit Toluylene Red Agar, Oxoid Limited, Basingstoke, United Kingdom) and counted after incubation at 25°C for 48 h. Enterobacteriaceae were identified using the pour plate technique with overlay treatment on Violet Red Bile Dextrose Agar (VRBD, Merck, Darmstadt, Germany). VRBD plates were incubated 24 h at 37°C.

2.4. Sensory Investigations. Sensory investigations were conducted by a trained sensory panel (four panelists) for a total of 221 filets. The analyses comprised the PD, assessment of WS, and the characterization of the freshness loss via the sensory index (SI). The PD was assessed via dichotomic response options. In detail, the panelist had to decide whether they would buy the product in a closed package or not. WS was graded via a three-point scoring system from 0 to 2 (0, no WS; 1, medium WS; 2, severe WS). For assessing freshness, poultry filets were evaluated based on a graded five-point scoring system with five meaning highest quality and one meaning spoiled. The evaluation was performed for the parameters color, odor, texture, meat juice color, and meat juice quantity for each sample. The sensory index (SI) was calculated as a weighted average with the following equation:

\[
SI = \frac{2 \cdot O + 2 \cdot C + T + JC + JA}{7}
\]

where O is the odor, C is the color, T is the texture, JC is the meat juice color, and JA is the meat juice.

According to the scheme, the product is spoiled when the SI reaches the level of 2.3. The SI was plotted as a function of time and fitted to a linear model. Thus, the shelf life of each sample was calculated following the procedure in [17].

2.5. Data Analysis and Statistics. Microbial data were \( \log_{10} \) transformed and plotted as function of time. The data were fitted to a nonlinear model (Levenberg–Marquardt algorithm) using the software package OriginPro 8G (OriginLab Corporation, Northampton, MA, USA). To describe the microbial growth curve, the modified Gompertz model was used [18]:

\[
N(t) = A + C \cdot e^{\left(-\frac{B}{K} \cdot \left(t - t_0\right)\right)},
\]

where \( N(t) \) is the microbial count \( \log_{10} \) (cfu/cm²) at time \( t \), \( A \) is the initial bacterial count (lower asymptotic line), \( C \) is the difference between upper asymptotic line of the growth curve (Nmax = maximum population level) and the lower asymptotic line, \( B \) is the relative growth rate at time \( M \) (1/h), \( M \) is the time at which the maximum growth rate is obtained (reversal point), and \( t \) is the time (h).

When TVC reached a level of \( \log_{10} 7.5 \text{ cfu/cm}^2 \), the product was considered spoiled. Microbial shelf life was calculated by transforming equation and including the calculated model parameters.

Since criteria for normal distribution and homoscedasticity were not met by most of the parameters, non-parametric testing was selected for all statistical analyses. Differences between both production lines were analyzed with the Mann–Whitney U test using SPSS Statistics 23 (IBM Corporation 1989, 2013, New York, USA). Spearman’s rank correlation and correlation plots were performed using the package corrplot and the software R (R Development Core Team, http://r-project.org). Multivariate testing was discarded due to the sample size at the single investigation points.

3. Results

The analysis of the nutritional value and muscle characteristics revealed significant differences between both production lines (Table 1). The content of intramuscular fat and water is significantly lower for the alternative filets. Besides, the content of protein is significantly higher compared to the conventional poultry meat. There was no significant difference for collagen. The level of L-lactic acid and D-glucose was significantly increased for the alternative filets. Both parameters significantly affected the pH value (Figure 1). Higher amounts of L-lactic acid lowered the pH value \((k: \sim 0.806, p < 0.001, n = 23)\) and high amounts of D-glucose \((k: \sim -0.541, p < 0.001, n = 23)\).

The mean pH value of the filets was 6.25 for the alternative and 6.30 for the conventional production line at the beginning of storage (Table 2). The pH value remained stable during storage and showed an increase at 240 h. At the end of storage, the pH increased to 7.28 for alternative and 7.34 for conventional filets. The pH values for the alternative group were lower at every investigation point, but the difference is only significant for the investigation after 72 h and 168 h.

The measurements for cooking loss and thawing loss showed a high variation between the groups. The mean cooking loss was slightly lower for alternative (14.13%) than for conventional filets (16.54%), but the difference was not significant (Table 2). At the beginning of storage, the thawing loss was 5.05% for alternative and 4.89% for conventional filets. For both production lines, thawing loss declined until the end of storage. Altogether, no significant difference in the water binding capacity was detected between either production line. Both parameters showed a significant negative correlation to the pH value (cooking loss \( k: -0.616, p < 0.001, n = 22 \); thawing loss \( k: -0.599, p < 0.001, n = 22 \)).

The color measurements of the filets revealed remarkable differences between both groups. The \( L^* \) value was lower for the alternative filets at most investigation points with significant differences after 120 h and 168 h of storage. For both
storage time, TBARS was significantly correlated to TVC ($k: 0.442, p < 0.001, n = 131$). Additionally, TBARS was correlated significantly to all sensory parameters, especially odor ($k: 0.499, p < 0.001, n = 131$), color ($k: 0.490$), and the color of the meat juice ($k: 0.487, p < 0.001, n = 131$).

Regarding the microbial investigations, the initial TVC differed significantly and was higher for the alternative files ($2.44 \log_{10} \text{cfu/cm}^2$) than for the conventional files ($2.10 \log_{10} \text{cfu/cm}^2$). During storage, this difference in the initial contamination vanished with the proliferation of the microorganisms. The initial counts of *Pseudomonas* spp. were below the detection limit 24 h after slaughter. Pseudomonads grew progressively dominant during storage and remained at the same order of magnitude as TVC. Thus, *Pseudomonas* spp. can be confirmed as a specific spoilage organism (SSO) (Figure 2) for both groups. TVC reached a maximum of $9.43 \log_{10} \text{cfu/cm}^2$ and $9.34 \log_{10} \text{cfu/cm}^2$, respectively. The maximum of *Pseudomonas* spp. was at 9.35 $\log_{10} \text{cfu/cm}^2$ for alternative and 9.30 $\log_{10} \text{cfu/cm}^2$ for conventionally produced meat. No differences were observed in the progression of the growth curve of TVC and *Pseudomonas* spp. for both meat types.

For both investigation groups, no significant differences of the initial bacterial counts for *B. thermosphacta* and Enterobacteriaceae were detected since bacteria were under the detection limit 24 h after slaughter. The growth of *B. thermosphacta* reached a mean maximum of $6.72 \log_{10} \text{cfu/cm}^2$ (alternative) and $6.61 \log_{10} \text{cfu/cm}^2$ (conventional) after 288 h of storage. Enterobacteriaceae displayed mean maximum values of $5.86 \log_{10} \text{cfu/cm}^2$ (alternative) and $6.04 \log_{10} \text{cfu/cm}^2$ (conventional) after 288 h. Thus, the development of microbial growth was very similar for both investigation groups.

The shelf life also showed no differences between both investigation groups. The microbial spoilage level of 7.5 $\log_{10} \text{cfu/cm}^2$ for TVC was reached by the alternative files after 178 h and by the conventional produced files after 175 h (Figure 3). The sensory shelf life was reached after 201 h (alternative) and 192 h (conventional), respectively. The alternative group achieved better scores at a few investigation points, mainly due to better evaluations for color or odor. However, these discrepancies did not lead to a significant difference in shelf life.

Severe WS was observed most in the conventional production line at every investigation point, but the difference is not significant. There was no clear tendency or pattern, indicating that the categories “no WS” or “medium WS” developed differently in either of the investigation group (Figure 4). Additionally, no effect of storage on the display of WS could be observed. Due to the strong

### Table 1: Analysis of nutrients in the alternative and conventional production line, mean values, and standard deviations.

<table>
<thead>
<tr>
<th></th>
<th>Collagen (%)</th>
<th>Intramuscular fat (%)</th>
<th>Protein (%)</th>
<th>Water (%)</th>
<th>L-Lactic acid (g/100 g)</th>
<th>D-Glucose (g/100 g)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>0.90±0.155</td>
<td>23.68±0.208</td>
<td>74.25±0.534</td>
<td>0.952±0.454</td>
<td>0.056±0.0598</td>
<td>0.0173±0.144</td>
<td>15</td>
</tr>
<tr>
<td>Conventional</td>
<td>0.85±0.179</td>
<td>1.48±0.473</td>
<td>22.37±0.778</td>
<td>0.786±0.562</td>
<td>0.038±0.0173</td>
<td>0.0161±0.014</td>
<td>8</td>
</tr>
</tbody>
</table>

Bold parameters indicate differences between the production systems are significant at the 0.05 level.

**FIGURE 1:** Correlation between physicochemical parameters. Only correlations significant at the 0.05 level are displayed.
discoloration of the filets caused by spoilage, the incidence of WS is only displayed until 168 h of storage. WS showed a significant negative correlation to the $b^*$ value ($k: -0.426, p = 0.048, n = 22$) at the first investigation point, meaning that more yellowish filets showed a less pronounced WS. Regarding the overall storage time, WS was significantly correlated to the pH ($k: 0.377, p < 0.001$) and significantly affected the PD negatively ($k: -0.271, p < 0.001, n = 221$). Moreover, WS was not correlated to filet weight or any other physicochemical parameters.

The PD was higher for alternative filets at every investigation point (Figure 5). This difference is significant for the first investigation point. The PD declined during storage, as the meat showed a loss of freshness. A high rejection rate of the samples was obvious after 120 h and less than 10% were accepted after 168 h of storage. All filets were rejected by the panel after 240 h, when the filets were spoiled. The PD was influenced significantly by the other parameters assessed by the sensory panel, especially color ($k: 0.910, p < 0.001, n = 221$) and WS. All other sensory parameters were also

### Table 2: Mean values and standard deviations of investigated meat quality parameters during storage (alternative: $n = 24$ per investigation point; conventional: $n = 13$ per investigation point).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0 h</th>
<th>72 h</th>
<th>120 h</th>
<th>168 h</th>
<th>240 h</th>
<th>288 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Alternative</td>
<td>277.44 ± 36.16</td>
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</tr>
<tr>
<td>Conventional</td>
<td>300.74 ± 28.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>pH</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative</td>
<td>6.25 ± 0.11</td>
<td>6.15 ± 0.13</td>
<td>6.24 ± 0.10</td>
<td>6.24 ± 0.13</td>
<td>6.95 ± 0.49</td>
<td>7.28 ± 0.35</td>
</tr>
<tr>
<td>Conventional</td>
<td>6.30 ± 0.23</td>
<td>6.30 ± 0.18</td>
<td>6.29 ± 0.16</td>
<td>6.35 ± 0.13</td>
<td>7.24 ± 0.29</td>
<td>7.34 ± 0.46</td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alternative</td>
<td>14.13 ± 1.63</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Conventional</td>
<td>16.54 ± 4.52</td>
<td></td>
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<tr>
<td>Thawing loss (%)</td>
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<tr>
<td>Alternative</td>
<td>5.05 ± 1.83</td>
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<tr>
<td>Conventional</td>
<td>4.89 ± 1.24</td>
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<tr>
<td>$L^*$ value</td>
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</tr>
<tr>
<td>Alternative</td>
<td>57.82 ± 1.95</td>
<td>56.41 ± 1.97</td>
<td>55.79 ± 2.45</td>
<td>55.60 ± 1.71</td>
<td>55.59 ± 1.44</td>
<td>51.21 ± 2.49</td>
</tr>
<tr>
<td>Conventional</td>
<td>58.35 ± 0.96</td>
<td>57.43 ± 2.67</td>
<td>57.80 ± 2.36</td>
<td>57.55 ± 2.35</td>
<td>54.12 ± 2.29</td>
<td>52.85 ± 3.28</td>
</tr>
<tr>
<td>$a^*$ value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative</td>
<td>5.25 ± 0.64</td>
<td>5.89 ± 1.18</td>
<td>5.77 ± 1.46</td>
<td>5.75 ± 0.90</td>
<td>5.73 ± 0.80</td>
<td>6.70 ± 1.49</td>
</tr>
<tr>
<td>Conventional</td>
<td>4.07 ± 0.54</td>
<td>3.87 ± 0.53</td>
<td>4.15 ± 0.98</td>
<td>3.87 ± 0.79</td>
<td>4.15 ± 1.21</td>
<td>4.41 ± 1.21</td>
</tr>
<tr>
<td>$b^*$ value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>16.45 ± 1.55</td>
<td>13.29 ± 0.81</td>
<td>14.93 ± 4.64</td>
<td>14.16 ± 1.16</td>
<td>18.07 ± 2.22</td>
<td>17.57 ± 2.37</td>
</tr>
<tr>
<td>TBARS (mg MDA/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative</td>
<td>0.120 ± 0.018</td>
<td>0.115 ± 0.013</td>
<td>0.121 ± 0.011</td>
<td>0.132 ± 0.017</td>
<td>0.152 ± 0.019</td>
<td>0.133 ± 0.028</td>
</tr>
<tr>
<td>Conventional</td>
<td>0.115 ± 0.014</td>
<td>0.111 ± 0.011</td>
<td>0.118 ± 0.013</td>
<td>0.119 ± 0.014</td>
<td>0.150 ± 0.017</td>
<td>0.144 ± 0.021</td>
</tr>
</tbody>
</table>

Bold parameters indicate differences between productions systems are significant at the 0.05 level.

**Figure 2:** Evolution of microbiological contamination on filets of the alternative (a) and conventional (b) production line.
significantly correlated to the PD with correlation coefficients between 0.8 and 0.9. Additionally, PD was correlated to the $L^*$ value ($k: 0.461, p < 0.001, n = 196$) with a higher rejection rate for darker filets.

4. Discussion

The results of this study showed that different production systems can have a significant influence on biochemical composition, nutritional value, and physicochemical characteristics of poultry meat. Generally, the nutritional values and muscle characteristics of the investigated poultry fillets were comparable to former studies [19–21]. Filets of the alternative line had significantly higher protein and lower water and intramuscular fat content in comparison to the conventional production line. Different dietary strategies are known for their ability to modify the nutritional profile of poultry meat [22]. Maize-based diets provide an easily accessible source of energy leading to a higher protein conversion in comparison to wheat-based
feed [23]. Additionally, the race and the opportunity for a regular exercise can lower the fat and increase the protein content of poultry meat [24]. However, detailed analyses focusing on both investigated breeds are lacking. A higher motor activity favors myogenesis over lipogenesis as stated by Castellini et al [21]. Thus, a higher meat quality of the filets was observed in the alternative production line with a maize-based diet, lower stocking density, and enhanced motivation for physical activity by offering toys. The amount of L-lactic acid and D-glucose in the muscle was comparable to the results of Bruckner et al. [16]. The higher values of L-lactic acid and D-glucose can be explained by a higher glycolytic potential in the muscle of the alternative production line [25]. The glycolytic potential of the muscle antemortem has been related to the breeding and fattening of the animals, stress, exercise levels, or age [26–30]. Additionally, the selection for growth rate and age influences the glycolytic potential and the pH decline postmortem [31, 32]. The lower pH values observed for the alternative production line can be explained by the close relationship between L-lactic acid and pH value [16]. Thus, the production system and choice of a specific slower growing race showed implicit consequences for technological traits of the product. For fresh poultry meat, the pH value ranges between 5.8 and 6.2 [16, 26, 32, 33]. According to these studies, pH values observed in this investigation were comparatively high. However, higher pH values have been reported before for the Ross line and other modern poultry lines selected for fast growth and early slaughter age [31, 32, 34]. This is in agreement with the findings of this study in which the fast-growing Ross 308 had higher pH values than the slower growing line Ranger Classic. At the end of storage, the pH value shows a significant decrease which is typical for high bacterial cell counts. This is caused by the accumulation of ammonia as a result of amino acid degradation when glucose decreased to insufficient levels [29]. The pH value was closely related to the cooking loss, thawing loss, and color values of the poultry filets, which is in accordance with former studies [21, 35, 36]. Even though the dietary composition and breed were reported to have an impact on water holding capacity of the meat [27, 37–39], no differences in cooking and thawing loss could be detected between the production lines in this study.

The $L^*$ values showed no significant difference between groups but were higher than the optimal range for poultry reported in former studies [36, 40–42]. Since cooking and thawing loss were in a normal range, a pale soft and exudative- (PSE-) like condition was not observed according to the criteria defined in former studies [40, 41]. Besides, a high variation in the $L^*$ value of fresh poultry meat has been reported before and was explained by different preslaughter and processing conditions, resulting in varying $L^*$ values [36]. The decrease of $L^*$ values during storage for both investigation groups can be explained by the biochemical degradation of myoglobin and is typical for the spoilage of meat [43]. Differences in the $a^*$ and $b^*$ values between groups reflected the intense and more yellowish color of the filets of the alternative production. This effect was caused by the maize-based diet and higher amount of carotenoids [44]. During storage, $a^*$ values and $b^*$ values of the alternative line increased, while only $b^*$ values of the conventional line showed a slight increase. Thus, the alternatively produced filets show no typical discoloration process during spoilage, characterized by a fading of the pink color typical for fresh meat. The filets rather displayed a change to a darker and more orange color.

The investigation of TBARS showed no significant difference between both production lines, even though an influence of animal diet on lipid oxidation has been reported before [45]. During storage, TBARS values showed a significant increase which is in accordance with former studies [46–48]. Thus, the differences in physicochemical properties measured between both groups did not result in a varying spoilage process. Significantly higher levels of glucose, which is a key substrate for microorganisms [49], could indicate an accelerated microbial growth on filets of the alternative group, but this was not observed. Since animals of both production lines were slaughtered and processed in the same production facility on the same day, the amount and diversity of contaminating and proliferating microorganisms showed no relevant difference. For both groups, the initial TVC contamination was low in comparison to other studies conducted under industrial slaughter conditions [16, 50–52]. The abandonment of antibiotics showed no impact on microbial contamination or growth in this study. For both groups, the microbial shelf life was in accordance with the sensory shelf life and is in the normal range for fresh, aerobically packaged poultry [37]. Shorter shelf lives for similar products were reported as well but could be related to higher initial microbial contamination [16, 52, 53]. Both production systems resulted in high quality poultry products with no implications for the spoilage process and shelf life. Since the usage of antibiotics in meat production has a high impact on environment, the increase of antibiotic resistances, and human health [9, 54], antibiotics-free systems reveal important opportunities towards a more sustainable poultry production. According to the results of this study, the realization of an alternative production system without antibiotics is possible without impacts on meat quality and shelf life. The decelerated growth of the animals and gentle fattening had no impact on the incidence of WS. Even though the conventional group displayed the highest occurrence of severe WS, no significant difference could be detected between the investigation groups. WS was significantly correlated to growth rate, genotype, slaughter age, and filet weight in former studies [2, 8, 55], but no significant correlation between the filet weight and WS was observed in this study. In contrast to former studies reporting an effect of WS on the water binding capacity [56–58], no effect of WS on drip or thawing loss was observed here, also stated by [59]. As a result of WS incidence, the PD was affected. A low consumer acceptance for filets displaying WS was also observed before [55]. The PD was mainly dominated by the color of the filets. A tendency for a preference for the alternative filets was observed, but the difference was only significant at the first investigation point.
5. Conclusion

The alternative line encompasses the opportunity towards a more sustainable poultry production due to an extensive husbandry system without antibiotics, a slower growth, and enhanced animal welfare. This investigation revealed a significant benefit for the biochemical composition and nutritional value of alternatively produced poultry meat. The poultry filets of both production lines showed an overall high quality, and no effect of the production system on the development of quality parameters and shelf life could be detected. The abandonment of antibiotics in the alternative line had no impact on the microbial quality, safety, or shelf life of the product. The decelerated growth of the animals did not lead to a significant improvement for the incidence of WS in comparison to conventional production systems. A trial repetition to confirm the findings with a higher sample size is desired.

Data Availability

The authors declare that all results can be found in the Institute of Animal Science, University of Bonn, Germany.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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