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Evaluation of partial dry-bleeding of Atlantic salmon (*Salmo salar*) and its effects on fillet quality and stability

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ABSTRACT

Salmonid blood is an abundant by-product of the relatively large and growing salmonid industry in Iceland and has recently gained increased interest as a source of diverse valuable compounds. Blood collection has posed a challenge due to the delicate nature of both the blood and the currently most valuable final product of the salmonid industry, the fillets. This study examined the efficiency of partial dry-bleeding Atlantic salmon (*Salmo salar*) related to blood recovery and its potential effects on fillet quality compared to traditional bleeding. The quality of fillets was assessed based on parameters, including sensory attributes, physiochemical, and microbial properties for both partially dry-bled and traditionally bled salmon. The results indicated that partial dry-bleeding for 4.5 min effectively recovered blood equal to 1–2 % of the live weight of Atlantic salmon, 75 % of which was obtainable in the first minute and 90 % during the first 2 min. Aside from possibly causing a slight increase in gaping in the fillet, partial dry-bleeding neither affected the flesh quality of fresh salmon compared to traditional bleeding nor following prolonged storage on ice post slaughter. These results provide valuable insight into salmon blood collection practices and preservation treatments for its utilization potential as a valuable resource.

1. Introduction

Globally, aquaculture production is a large and rapidly growing industry with the subsequent increase in by-product generation (FAO, 2024). Salmonid production is among aquaculture's continuously growing industries, with a global production of over 4 million tons in 2022, and Atlantic salmon (*Salmo salar*) the predominantly farmed salmonid species (FAO, 2024). By-products of the salmon industry, estimated at around 60 % of the total production, are increasingly being utilized to produce high-value products. An example of which is salmon blood (Ramakrishnan et al., 2024; Rudovica et al., 2021; Siddiqui et al., 2023). The blood volume in various salmonid species has been estimated at 3.0–7.0 % of the live body weight (Hayes & Gallagher, 2019; Rozas-Serri et al., 2022). It has been found to contain valuable components, such as proteins (e.g., haemoglobin, albumin, fibrin, and creatine), peptides, enzymes (e.g., thrombin and amylases), lipids, electrolytes, and minerals (Casanovas et al., 2021; Rozas-Serri et al., 2022; Stevens et al., 2018). However, salmon blood has been an underutilized raw material which is mostly discarded as a mere waste product diluted in wastewater from the processing, with subsequent environmental and disposal expenses (Hayes & Gallagher, 2019).

Traditional slaughtering procedures of farmed salmonids generally include stunning, gill cutting, and subsequent bleeding in cold water (Skare et al., 2021). Collecting the blood from the wastewater has posed a challenge and the currently available extraction technologies have been criticized as ineffective and costly (Hayes & Gallagher, 2019; Rudovica et al., 2021). Dry-bleeding, which involves bleeding the fish in air as opposed to ice water, has been proposed as a promising alternative technique for potential utilization of valuable blood components through the collection of undiluted blood during slaughtering, with the added benefits of reduced utilization of water and nutrient loss through processing water (Erikson et al., 2010). However, available literature on dry-bleeding is scarce, and optimization of methods of execution and collection of the blood is lacking, as well as optimization of handling and storing the blood once collected. Several challenges exist concerning the collection and utilization of fish blood, including rapid blood

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coagulation and vulnerability to microbial growth (Hayes & Gallagher, 2019; Olsen et al., 2006). Furthermore, it is crucial to investigate the potential effects that dry-bleeding may have on the quality and value of the final product. This includes assessing any changes in fillet quality, colour, texture, and overall consumer acceptability.

Seafoods are highly perishable, and it is therefore important to handle them correctly to maximize their shelf life and quality (Tavares et al., 2021). The shelf life of farmed salmon ranges between 11 and 21 days, depending on factors such as composition, processing methods, and temperature (He et al., 2013; Skare et al., 2021). Nutrient compositions of salmon fillets can vary between fish and be heterogeneous within the fillet itself (Colombo & Mazal, 2020; Gonçalves et al., 2021; Sprague et al., 2020). To ensure consistent sampling procedures on Atlantic salmon, a standardized cut called the Norwegian Quality Cut (NQC) is commonly implemented for flesh and quality assessment (Norwegian standard 9401.E, N. S., 1996; Nøstbakken et al., 2023). The quality of farmed Atlantic salmon is generally assessed based on freshness, lipid content, texture, flesh colour, and gaping (Laundry et al., 2023; Sveinsdottir et al., 2003). Due to their negative effect on both visual appearance and shelf life, blood residues, including bruises and blood stains in the flesh, are considered one of the main quality issues in the industry. Therefore, factors that may affect residual blood and blood spotting in salmon flesh have been a popular research topic (Olsen et al., 2006, 2008; Robb et al., 2003; Roth et al., 2005, 2009). Based on previous studies, the conclusions on causations are partly controversial, although insufficient bleeding has been considered the main one. However, there is no clear consensus on the optimal bleeding method and optimal process parameters for efficient blood drainage (Erikson et al., 2010).

The current study aims to examine the efficiency of partial dry-bleeding of Atlantic salmon with respect to blood recovered during the first minutes following slaughtering and evaluate potential negative effects on the quality of the resulting fillets, compared to fillets derived from traditionally bled fish.

2. Materials and methods

2.1. Experimental design

The experiment was done at Samherji fiskeldi, a fish farm in Öxarfjörður in the northeast of Iceland. The experiment was composed of two parts: a trial evaluating a partial dry-bleeding with emphasis on the speed of potential blood collection during the first minutes following slaughtering and an evaluation of the effects of dry-bleeding on fillet quality. The dry-bleeding method was implemented into the traditional slaughtering process of a land-based salmon farm, described in section 2.2, and the blood was collected using a prototype of a blood-collecting chute (Fig. 1). Quality and storage stability of the fillets from the dry-bled salmon was compared to fillets from traditionally bled salmon. The fillet quality was evaluated using chemical, microbial, and sensory analysis, as well as physical properties (pH and colour). Furthermore, microbial analysis was conducted on the collected blood.

2.2. Slaughtering process and handling

Traditional slaughtering methods of Atlantic salmon at Samherji fiskeldi entails storage in 120 m^3 holding tanks for three days without feeding prior to slaughtering, with temperature in the storing tanks lowered from 10 to 11 °C to approximately 6 °C. The fish is then directed through a chute and manually fed into a *Baader 101 stunner* (Baader, Germany), which both mechanically stuns the fish and cuts the jugular veins. The equipment's performance capacity with manual infeed is up to 30 fish/min. The fish then goes through a chute into a 660 L tub/container containing fresh water and flake ice, at 0–4 °C, where the fish bleeds for approximately 25 min (20–40 min) prior to further processing. Then, the fish is transferred via a conveyor belt to a gutting machine

Fig. 1. Dry-bleeding experiment equipment, the blood collection chute.

followed by washing and consequent transferring to a cooling tank where the fish is kept for 30–90 min at −1 °C until packaging.

2.3. Sample preparation and experimental groups

Samples of fish ($n = 60$) were randomly divided into two groups at slaughtering and the fish either dry-bled ($n = 30$) or bled using traditional bleeding methods ($n = 30$). All 60 fish were used for evaluating the effects of dry-bleeding on the quality and stability of fillets during cold storage. Furthermore, a part of the dry-bled fish ($n = 10$) was used to evaluate the dry-bleeding protocol and blood collection potential through a complete dry bleeding of the fish. The length of all fish from both groups ($n = 60$) was measured, as well as weight before and after bleeding.

For evaluation of the dry-bleeding protocol, 10 fish were stunned and cut one at a time and then immediately dry-bled for 4.5 min in the bleeding chute (Fig. 1). The weight of the blood collected at every 10 s was measured for determination of the collection potential over time. The remaining 20 fish of the dry-bled group were then dry-bled for 4.5 min each (partial dry-bleeding). Directly following dry-bleeding, all fish of the dry-bled group ($n = 30$) were placed in 0–4 °C icewater for 20.5 min for further exsanguination followed by storage on ice until processing. The fish from the traditionally bled group ($n = 30$) were bled in 0–4 °C icewater for 25 min, according to the traditional processing method (Section 2.2). All fish were then packed on ice in polystyrene boxes, stacked on a pallet with a temperature data logger (Tidbid® v2 logger, OnSet Computer Corporation, Bourne, Maine, USA), and transported by a carrier truck to Matís (Reykjavík, Iceland) for further analysis where the fish arrived the following day.

2.4. Fillet sampling protocol

Following storage at −0.7 ± 0.3 °C, 10 dry-bled and 10 traditionally bled fish were hand filleted on days 1, 13, and 22 post slaughter. It was also recorded on which side each fish was lying on arrival. The right and left fillets of each fish ($n = 10$ per group) were labelled for traceability. Five fish from each group were randomly selected, from which the left fillets ($n = 5$ per group) were subjected to microbial analysis and the remaining 15 fillets per group underwent sensory evaluation, conducted

using the Quality Index Method (QIM). This was repeated for fillets from all storage days, i.e., on days 2, 14, and 23 post slaughter. The corresponding right fillets ($n = 5$ per group) were subjected to analysis of chemical composition and physical properties, conducted using the Norwegian Quality Cut (NQC), demonstrated in Fig. 2.

2.5. Analyses of samples

2.5.1. Chemical composition

The water content of the fillets was determined by measuring the difference in weight of samples before and after drying for at least 4 h at 102–104 °C (ISO, 1999). Average values for five fillets per group were used for calculation of water content as a percentage of wet weight of the fish (%ww).

Total volatile basic nitrogen (TVB-N) was determined using the method of Malle and Poumeyrol (1989) and average values of five fillets per group are presented as mg N/100 g.

The lipid content was determined according to the method of Blight and Dyer (1959). An average of duplicate samples from five fillets per group ($n = 10$ per group) are presented as percentage of wet weight of the fish (%ww) using equation (1).

$$\textit{Lipid content}\ (\%) = \frac{g\ lipids\ in\ 50\ mL}{g\ sample} \times 100 \quad (1)$$

The average concentration of free fatty acids (FFAs) in duplicate samples from five fillets per group ($n = 10$ per group) was determined according to the method of Lowry and Tinsley (1976), with modification presented by Bernárdez et al. (2005). FFA concentration was calculated from a standard curve of 2–14 μmol oleic acid and the results presented as g FFA/100 g lipid.

2.5.2. Microbial analyses

Both muscle and blood samples were subjected to microbial analysis. Prior to sampling for the microbial analysis of muscle tissue, the skin of the salmon was sprayed with 75 % ethanol for a few seconds, the skin removed with sterile tongs, and the muscle tissue cut with a sterile knife. Muscles samples were collected from and around the NQC (Fig. 2), above the midline, using sterile instruments. Total viable counts (TVC) and presence of H_2S-forming bacteria were determined using the method of NMKL 184 (2006). The number of white colonies on iron agar indicates the number of aerobic bacteria (TVC), and the number of black colonies indicate the number of H_2S forming bacteria. The results are an average of five fillets per group ($n = 5$ per group) and presented on a logarithmic scale of colony-forming units (CFU)/g.

Microbial analysis of blood samples was conducted using chilled, untreated blood samples two days post collection. The TVC in 1 g at 22 °C was determined according to the method of NMKL 86 (2013). The numbers of faecal coliforms and *Escherichia coli* were measured according to a modified NMKL method, as described in NMKL 96 (2009). The presence of *Listeria monocytogenes* was determined according to the method of NMKL 136 (2010). Each analysis was carried out in triplicate, with results presented as CFU/g.

2.5.3. Physical properties

The pH of minced NQC sections of each fillet ($n = 5$ fish per group) was measured using a *Portavo 904* (Knick, Germany) and the fillet colour was determined according to the CIE Lab system method, using a *Minolta Chroma Meter CR-300* (Minolta, Japan). The device measures the L*-value, indicating the lightness from black to white (0–100), the a*-value indicating the red (+)/green (−) colour coordinate, and the b*-value indicating the yellow (+)/blue (−) colour coordinate. Colour was measured in three places on the NQC of each fillet, at the top of the fillet, just above the midline and on the belly flap (Fig. 2).

2.5.4. Sensory evaluation

The Quality Index Method (QIM) was performed on days 2, 14, and 23 post slaughter, by three trained sensory assessors. The salmon fillets were arranged randomly and coded with a three-digit number attached to each fillet to ensure that the judges did not know which fillet belonged to which group. The QIM scale used (Table 1), was constructed based on the QIM scale of Sveinsdottir et al. (2003), developed for a freshness assessment of farmed whole salmon. The scale was adapted to be applicable for evaluation of fillets rather than of whole fish, and in accordance with the training of judges, with the addition of identification of bloodspots. The attributes assessed were flesh odour, skin odour, gaping, and bloodspots. Lower scores indicate greater freshness.

2.6. Statistical analyses

Statistical analysis was performed using Microsoft Corporation, 2023 to determine mean values and standard deviations, and JMP® (2021) to analyse statistical differences between the two groups. Statistical differences were determined using one-way ANOVA and further analysis carried out using the Student's t-test or Tukey's HSD (true significant difference) tests at significance level of 0.05.

3. Results and discussions

3.1. Dry bleeding protocol and blood collection potential

The average weight of the fish ($n = 10$) prior to dry-bleeding was 4.3 ± 0.9 kg and the average length was 70.9 ± 4.8 cm. The amount of blood collected through dry-bleeding of the salmon was registered every 10 s for a total of 270 s (4.5 min). The average blood volume obtained,

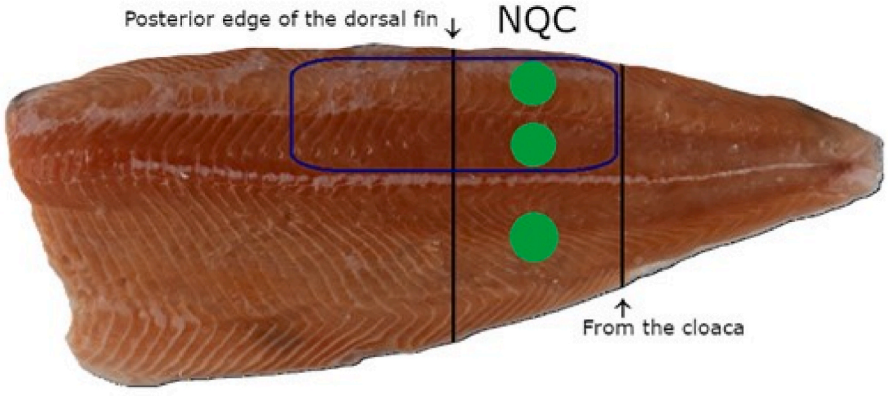

Fig. 2. Demonstration of the Norwegian Quality Cut (NQC) location (Norwegian standard 9401.E, N. S., 1996) and sampling sites for colour (marked in green) and microbiological measurements (marked in blue).

Table 1
The Quality Index Method (QIM) scale used for assessment of freshness of fillets from traditionally bled and dry-bled fish.

	Definition	Points
Flesh odour	Neutral	0
	Cucumber, melon	1
	Resembles fermentation, sour	2
	Rotten/rotten cabbage	3
Skin odour	Fresh seaweed, neutral	0
	Cucumber, hay, metal smell	1
	Sour, a rag smell	2
	Rotten	3
Gaping	No slits detected	0
	Few small slits	1
	Few small slits in >10 % of the fillet, or one larger slit	2
	Many small slits in 10–20 % of the fillet, or 2–3 larger slits	3
	Slight gaping in 20–30 % of the fillet, or 4–5 larger slits	4
	Quite a lot of gaping, many large slits, or gaping in 30–50 % of the fillet	5
	A lot of gaping, many large slits, and gaping in 50–100 % of the fillet	6
Bloodspots	No bloodspots visual	0
	Bloodspots are few and >5 mm in size	1
	Bloodspots clearly visible, many small spots, or 1–2 spots >5 mm	2
	Few large bloodspots, 2–4 large spots	3
	5 or more large bloodspots	4

measured as a ratio of the total body weight of the fish (n = 10), is presented for each timestep in Fig. 3. Previous studies reveal that the blood content of Atlantic salmon represents 3.0–7.0 % of the total body weight (Smith, 1966). However, a large portion of the blood is localized in muscular tissues and internal organs, and hence, only ~2 % of the blood is available for collecting through bleeding (Erikson et al., 2010). In the present study, approximately 50–70 mL of blood was collected from each of the ten dry-bled salmon, with the average blood collection of 1.4 ± 0.3 % of the total body weight of individual fish over the 4.5 min bleeding time (Fig. 3). As illustrated in Fig. 3, blood collection significantly decreased after the initial 2-min period. Assuming a maximum blood yield of 1.4 % of the live weight of the fish, approximately 75 % and 90 % of this maximum yield were attained after one and 2 min of bleeding, respectively, with negligible additional blood collected during the remaining 2.5 min of the experiment.

The results align with those of Erikson et al. (2010), which suggested that the blood flow during dry-bleeding of Atlantic salmon more or less ceased after 1–2 min, with an obtained blood volume in the range of 1.9–2.0 % of the body weight of the fish. Notably, various challenges exist related to the collection and appropriate handling of salmon blood during slaughtering of the fish, particularly when considering the technical design implications for scalability. To mention an example, with manual infeed the Baader 101 stunner used in this study has the capacity to stun and cut up to 30 fish/min (T. Helmig, personal communication, August 9th, 2023) and in order to obtain 90 % of the obtainable blood, each fish would need to be dry-bled for 2 min. For industrial exploitation, an apparatus for dry-bleeding of up to 60 fish simultaneously would therefore be required. Moreover, appropriate collection containers would need to be implemented for scalability and the arrangements aimed at preserving the quality of the recovered blood. Furthermore, storing the blood in large volumes could pose an additional challenge due to the need for adequately sized storage containers and conditions, with energy requirements and other costs involved.

3.2. Analyses of samples

3.2.1. Chemical composition

The water content of the salmon fillets was measured at in the range of 65–67 %ww (Table 2), corresponding to around 69.2 ± 4.9 %ww

Table 2
The water and fat content (% of wet weight; %ww) of fillets from traditionally bled (TBF) and dry-bled (DBF) fish on days 2, 14, and 23 post slaughter. Also shown is the content of total volatile basic nitrogen (TVB-N; mg N/100 g). Results are presented as an average ± SD of triplicate of five fillets per group, with different subscript letters indicating significant differences ($p < 0.05$) between the two groups at individual days.

		Water (%ww)	*Fat (%ww)*	*TVB-N (mg N/100 g)*
Day 2	TBF	65.4 ± 0.5^{b}	7.1 ± 0.4^{a}	17.5 ± 0.4
	DBF	67.4 ± 1.7^{a}	6.4 ± 0.2^{b}	16.7 ± 1.7
Day 14	TBF	67.2 ± 0.5	6.8 ± 0.6	20.3 ± 0.5
	DBF	66.7 ± 1.1	7.1 ± 0.4	19.7 ± 1.1
Day 23	TBF	65.9 ± 1.9	7.0 ± 0.8	20.2 ± 1.0^{a}
	DBF	65.9 ± 1.4	7.3 ± 0.6	17.6 ± 1.3^{b}

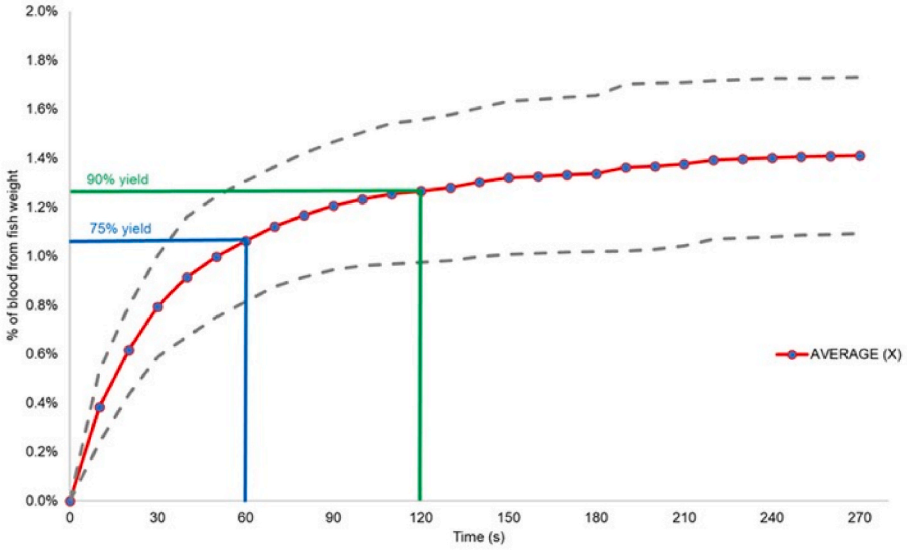

Fig. 3. The amount of blood collected from Atlantic salmon during dry-bleeding, calculated as the average ratio (%) of the total body weight of ten fish (whole line), ±standard deviation (broken lines). The amount of blood collected was measured in 10 s intervals for 270 s (4.5 min). Blue and green lines represent 75 % and 90 % of calculated maximum blood yield (1.4 % of body weight), respectively.

commonly measured in salmon (He et al., 2013). The fat content of the salmon fillets was 6–7 %ww (Table 2), which is lower than reported in the studies of Veliyulin et al. (2005) and Nøstbakken et al. (2023), where the fat content of the NQC of farmed salmon measured 9–18 % ($n = 39$) and 15.5 ± 2.7 % ($n = 34$), respectively. Similar water and fat content was measured in the two groups and at the different observation points. Minor differences in measured values may be due to natural variation in the raw material or farming practices (Gillies et al., 2023; Gonçalves et al., 2021).

Total volatile basic nitrogen (TVB-N) is often used as a criterion for the freshness of fish as it indicates the quantity of volatile compounds formed during decomposition by enzymes and microorganisms (Moosavi-Nasab et al., 2021). The TVB-N content of the fillets measured similar in both groups and the different observation points, aside from measuring slightly lower in the dry-bled than in the traditionally bled fish on day 23 ($P = 0.0018$). Additionally, TVB-values in the fillets from both groups and at all observation points measured below the set TVB-N limit values of 35 mg N/100 g of flesh, as established for fresh Atlantic salmon in the Commission Implementing Regulation (EU) 2019/627.

FFAs form when the ester bonds of lipids are hydrolysed by for instance enzymes and microorganisms, and the accumulation of FFAs may negatively affect both the quality and shelf-life of seafood. FFA levels can therefor be used as an indicator for lipid bread down in a sample (Bernárdez et al., 2005). The concentration of FFAs in the fillets from both the dry-bled and the traditionally bled fish measured in the range of 0.01–0.04 g FFAs/100 g lipid, with negligible differences in FFA concentration observed between the two groups on the individual sampling days.

The results indicate that dry-bleeding did not affect the water and fat content of the salmon fillets compared to the traditional bleeding method. Furthermore, that dry-bleeding may cause a slightly lowered formation of TVB-N when compared to traditional bleeding. However, with only a slight difference observed between the two groups. Additionally, only negligible differences in lipid break down were observed between the two groups, indicating that dry-bleeding did not affect the concentration of FFAs in fillets compared to the traditional bleeding method.

3.2.2. Microbial analyses

No significant difference in total viable counts of bacteria (log CFU/g) was observed in fillets from traditionally bled fish at different days post slaughter (Table 3). In contrast, the TVC measured significantly higher in fillets from the dry-bled fish on day 23 as compared with days 2 and 14, but no difference in the number of H_2S-forming microbes was observed in the dry-bled group at the different preservation days investigated. However, the number of H_2S-forming microbes measured significantly higher in fillets from the traditionally bled fish on day 23 as compared with days 2 and 14. When comparing the two groups, no significant differences in neither the number of TVC nor H_2S-forming microbes were observed on days 2, 14, and 23, aside from day 23, where significantly fewer H_2S-forming microbes were observed in fillets from the dry-bled group as compared to the traditionally bled fish ($P = 0.0018$).

The results indicate that dry-bleeding did not affect TVC in the salmon fillets compared to the traditional bleeding method. Furthermore, that lower numbers of H_2S-forming microbes were observed in fillets from dry-bled as compared to traditionally bled fish as the storage time progressed.

The TVC at 22 °C measured on average 2.8 ± 2.9 log CFU/g (260–1600/g) in chilled untreated blood. *L. monocytogenes* was not detected and the number of Coliforms and *E. coli* measured <0.5 log CFU/g. Microbial contamination of raw materials such as blood can negatively affect the utilization potential, for example due to threats to consumer safety (Jamilah et al., 2021). Hence, it is important to prevent contamination by spoilage and pathogenic bacteria during and following slaughtering of the fish as well as during blood collection and further processing steps (Jacobsen et al., 2019). There are currently no specific regulations set by the European Union that directly address the use of fish blood for human consumption and subsequently, there are no specific microbiological reference values to consider. However, the absence of *L. monocytogenes, E. coli* and coliform bacteria in the chilled untreated blood provide a positive indicator regarding the safety of the material for human consumption.

3.2.3. Physical properties

The results of pH measurements show that the acidity was rather constant, measuring at approximately pH 6.3 in both groups with no significant difference between the two groups on the individual days post slaughter (Table 4). Acidity has been used as an indicator of freshness and decomposition of fish and generally measures between pH 6.1–6.3 in fresh salmon (Moon et al., 2020). Furthermore, no significant difference was observed in fillet colour between the two groups on the individual days post slaughter (Table 4).

The results indicate that dry-bleeding affected neither the acidity nor colour of the salmon fillets compared to fillets from traditionally bled fish.

3.2.4. Sensory evaluation

The Quality Index Method (QIM) assesses the quality and freshness of fish using a quality rating scale based on the relevant sensory factors at any given time. The combined score of the sensory evaluation factors, the so-called quality index (QI), indicates how far the fish has progressed from initial freshness, with the lowest possible QI being maximum freshness. With this method, a linear relationship between QI and the storage time of the fish should be obtained, which indicates the remaining shelf life (Esteves & Aníbal, 2021). The QIM has been adapted to many fish species, including salmon (Sveinsdottir et al., 2003).

The flesh odour, skin odour, gaping, and bloodspot scores of fillets from traditionally and dry-bled fish, assessed on days 2, 14, and 23 post slaughter are presented in Table 5. Overall, the average scores of each of

Table 3
The total viable count (TVC) of microbes and H2S forming microbes measured in fillets from traditionally bled (TBF) and dry-bled (DBF) fish at days 2, 14, and 23 post slaughter. Values (log colony-forming units, CFU)/g) are presented as an average ± SD of five fillets (n = 5 per group), with different subscript letters indicating significant differences ($p < 0.05$) between the two groups at individual days.

		TVC (log CFU/g)	*H_2S-forming (log CFU/g)*
Day 2	TBF	1.4 ± 1.0	1.3 ± 0.0
	DBF	1.3 ± 0.0	1.3 ± 0.0
Day 14	TBF	4.9 ± 4.7	3.9 ± 3.6
	DBF	4.6 ± 4.5	3.2 ± 3.2
Day 23	TBF	6.1 ± 6.1	5.1 ± 4.9 [a]
	DBF	5.9 ± 5.7	4.0 ± 3.8 [b]

Table 4
The pH and colour measured in fillets from traditionally (TBF) and dry-bled (DBF) fish on days 2, 14, and 23 post slaughter. The L, a, and b* values describe the colours lightness (0–100), red/green, and yellow/blue tones, respectively. Results are presented as an average ± SD of triplicate samples of five fillets per group, with different subscript letters indicating significant differences ($p < 0.05$) between days within each group.

		L value*	*a* value*	*b* value*	*pH*
TBF	Day 2	51.6 ± 7.6	11.3 ± 4.0	14.2 ± 3.6	6.3 ± 0.0
	Day 14	49.1 ± 5.8	11.3 ± 2.0	16.6 ± 3.9	6.3 ± 0.1
	Day 23	49.3 ± 5.8	10.1 ± 1.0	15.1 ± 2.1	6.4 ± 0.0
DBF	Day 2	53.0 ± 5.7	12.1 ± 3.3	15.1 ± 2.1[b]	6.3 ± 0.1
	Day 14	48.5 ± 5.8	11.4 ± 1.6	16.9 ± 3.6	6.2 ± 0.0[b]
	Day 23	52.1 ± 7.0	12.3 ± 2.1	18.3 ± 3.2 [a]	6.4 ± 0.1[a]

Table 5
Scores of assessed factors for fillets from traditionally bled (TBF) and dry-bled (DBF) fish, assessed on days 2, 14, and 23 post slaughter. Results (n = 45) are presented as an average ± SD, with different subscript letters indicating significant differences ($p < 0.05$) between the two groups at individual days.

		Flesh odour	*Skin odour*	*Gaping*	*Bloodspots*
Day 2	TBF	0.2 ± 0.4	0.2 ± 0.4	0.5 ± 0.7 ^{b}	0.9 ± 1.2 ^{b}
	DBF	0.2 ± 0.4	0.2 ± 0.3	1.7 ± 1.2 ^{a}	1.6 ± 1.0 ^{a}
Day 14	TBF	0.3 ± 0.5	0.5 ± 0.5	1.4 ± 1.0 ^{b}	1.0 ± 1.1 ^{a}
	DBF	0.4 ± 0.5	0.6 ± 0.5	1.9 ± 0.9 ^{a}	0.5 ± 1.0 ^{b}
Day 23	TBF	1.5 ± 0.5 ^{a}	2.1 ± 0.4	2.0 ± 0.8	1.2 ± 1.0
	DBF	1.2 ± 0.4 ^{b}	2.0 ± 0.4	2.3 ± 0.7	1.2 ± 1.1

the assessed attributes were similar between the two groups. A minor difference in gaping was observed between the groups on both day 2 and 14, where scores were slightly higher ($P < 0.0001$ and $P = 0.0123$, respectively) in fillets from the dry-bled as compared with the traditionally bled group. However, no significant difference in gaping was observed between the two groups on day 23. Furthermore, more bloodspots were identified in fillets from the dry-bled as compared with the traditionally bled fish on day 2 ($P = 0.002$). However, on day 14, the number of bloodspots was less in the dry-bled compared with the traditionally bled group ($P = 0.0043$). No difference was observed in the number of bloodspots between the two groups on day 23.

The total QI score from the fillet assessment on days 2, 14, and 23, are presented in Fig. 4. On day 2, the QI score was significantly higher ($P < 0.0001$) in the dry-bled group (3.7 ± 2.0) compared to the traditionally bled (1.8 ± 1.8). However, no significant differences in total QI scores were observed between the groups on days 14 and 23.

The results indicate that dry-bleeding does not cause increased skin and flesh odour of the salmon fillets or increases the likelihood of blood stain formation. Additionally, previous studies have suggested that gravity is an influencing factor when it comes to the number of blood stains, i.e., that more blood stains are measured in the fillet that the fish lies on during storage, and therefore, is a factor that needs to be considered (Olsen et al., 2006; Roth et al., 2005). In the following study, however, there was no significant difference in the number of bloodspots in the left or right fillet of fish lying on the right side ($P = 0.08$) nor on the left side ($P = 0.35$) upon arrival, indicating that gravity was not an influencing factor in the formation of blood stains in the fillets. However, there is a possibility that the drainage of blood from both groups was adequate and subsequently, an insufficient amount of loose residual blood would be available to flow between the sides under gravity.

4. Conclusions

The present study investigated the impact of dry-bleeding salmon, evaluated by blood collection efficiency and potential effects on fillet quality. The study's findings indicate that dry-bleeding salmon can yield blood volumes of 1.4 ± 0.3 % of the body weight, mostly obtainable within the first 2 min of the dry-bleeding procedure. Furthermore, that dry-bleeding does not impact the overall freshness, colour, acidity, water content, lipid content, or the number of free fatty acids in salmon fillets compared to fillets from traditionally bled fish. However, there are indications that dry-bleeding may cause slightly more gaping in the fillet. In addition, the findings indicate that dry-bleeding does not affect the formation of TVB-N nor TVC and may prevent growth of H_2S-producing microorganism during storage compared to fillets from traditionally bled fish.

For dry-bleeding to become a viable industrial option it is essential that the process does not degrade flesh quality and that the value and quality of the fillets are maintained. The results of the study indicate that dry-bleeding does not negatively affect the flesh quality of salmon compared to traditional bleeding. Therefore, further research should focus on evaluating the potential of implementing such a bleeding method on an industrial scale for collecting and utilizing blood from farmed salmon, providing both access to new raw material and potentially limiting the environmental impact of the process with changes in water use and valuable materials lost with waste or processing water.

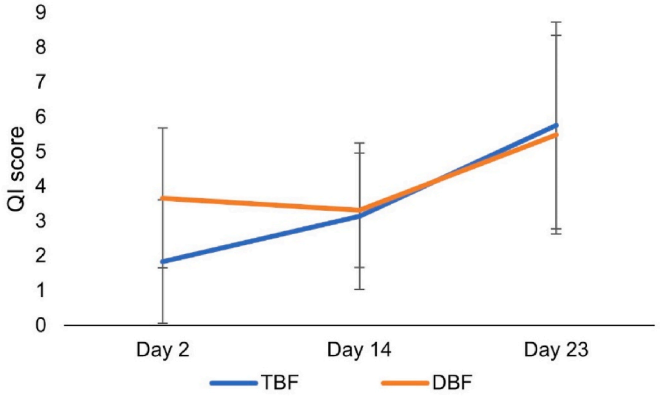

Fig. 4. The Quality Index (QI) score of fillets from traditionally bled (TBF) and dry-bled (DBF) fish following freshness assessment at days 2, 14, and 23 post slaughter. Values are an average (n = 45), and error bars represent standard deviation.

CRediT authorship contribution statement

Helena Thordis Svavarsdottir: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sæmundur Elíasson:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hildur Inga Sveinsdóttir:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Friðbjörg María Björnsdóttir:** Visualization, Investigation, Data curation. **Rannveig Bjornsdottir:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

We hereby declare that there are no conflicts of interest regarding the study.

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Data availability

Data will be made available on request.

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