Textural properties of raw Atlantic salmon (*Salmo salar*) fillets measured by different methods in comparison to expressible moisture

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Abstract

Textural properties of fresh Atlantic salmon (*Salmo salar*) fillets were measured on seven locations along the fillet by four different instrumental methods, and were correlated to expressible moisture. Two methods were based on puncturing, either by using a flat ended cylinder, measuring hardness at different distances into the fillet and the first fracture (yield point) of the muscle fibres, or by a non-destructive method using a spherical probe to measure the hardness of the fillet. The other two methods were based on Kramer shear-compression cell or Warner-Bratzler shear cell, by shearing the fillet with blades, measuring the shear force (toughness). The ability to separate textural properties in different muscle segments by using these four methods were compared. The expressible moisture, was determined by using the filter paper method by compression. Hardness and shear force of the fillets generally increased from the anterior to the posterior part of the fillet while the necessary force applied to map the yield point decreased towards the tail section. The results from the present study indicated that the puncture method with the spherical probe and the shearing device by Warner-Bratzler were better suited for measuring differences in the textural properties between different parts of raw salmon fillet, than the flat ended cylinder and Kramer shear compression cell. The expressible moisture, varying between 1.8 and 2.7%, showed a significant ($P < 0.05$) linear correlation with the spherical probe texture measurements ($r = 0.83$) and the Kramer shear compression cell ($r = 0.77$).

KEY WORDS: Atlantic salmon, expressible moisture, hardness, shear force, texture, yield point

Introduction

The main textural parameters applied instrumentally on fish may be divided into puncturing, compressing, shearing, cutting and pulling. Double compression or puncturing allows a texture profile analysis (TPA), giving plots of force vs. distance vs. time (Bourne 1978).

The chemical composition and physical structure vary along the fillet and will effect the textural properties, so the location where the sample is taken is thus of importance and should be considered when measuring the textural properties in the fillet (Børresen 1986; Love 1988; Botta 1991; Reid & Durance 1992; Sigurgisladottir *et al.* 1999). Texture is also related to the diameter of the muscle fibres. The cooked muscle is firmer with higher number of fibres of smaller diameter, than raw muscle with lower number of fibres of larger diameter (Hatae *et al.* 1990). Hatae *et al.* (1986) studied the influence of connective tissue content on meat texture of fish species. The results showed that species with firmer raw meat texture contained higher collagen content than the species with softer texture ($r = 0.70$). Montero & Borderias (1989) observed that the shear strength values of trout (*Salmo irideus* Gibb) were higher near the tail owing to a higher proportion of insoluble collagen.

Bouton & Harris (1972) compared some instrumental methods to assess meat tenderness and demonstrated a strong relationship between Instron compression and the adhesion measurements ($r = 0.90$), and also between Warner-Bratzler shear force and fibre tensile strength measurements ($r = 0.86$). High correlations between compression and penetration force values were seen in surimi gels

prepared from Alaskan pollock (*Theragra chalcogramma*) and red hake (*Urophycis chuss*) (Lee & Chung 1989). Izquierdo-Pulido *et al.* (1992) observed low correlation between penetration and compression on struggled and anaesthetised sturgeon (*Acipenser transmontanus*). Zapata & Price (1982) evaluated the texture in a cooked minced sucker fish (*Catostomus commersoni* and *Moxostoma anisurum*), by using Instron compression, Kramer shear cell and Penetrometer. The results indicated that Instron compression and Kramer instruments seemed to be more sensitive than the penetrometer in estimating the texture of the sucker matrix, based on the fact that more significant differences among binder treatments were detected by these methods.

The water holding properties of the muscle tissue are of major importance for commercial value and consumer acceptance. Lipid and water together make up about 80% of the fish muscle (Suzuki 1981). The 'free' water, amounts to about 90% of the tissue water, is held by capillary and surface tension forces mainly in intracellular locations. Water holding capacity of muscle is greatly influenced by structural changes in the muscle proteins, fibril swelling-contraction and the distribution of fluid between intra- and extracellular locations (Offer & Trinick 1983; Schnepf 1989).

Measurement of expressible moisture in fish have been used to estimate the water holding capacity. Lower water holding capacity gives a higher expressible moisture content and higher shear strength in muscle. Expressible moisture has been analysed in surimi gel, in minced fish samples (Lee & Toledo 1976; Cheng *et al.* 1979; Zapata & Price 1982; Hsieh & Regenstein 1989; Chang & Regenstein 1997) and in whole fillets (LeBlanc & LeBlanc 1992, Orban *et al.* 1997), but a clear correlation between textural properties and expressible moisture in the fillets is missing.

Our objectives were to find which instrumental method was best suited to measure differences in textural properties between different parts of raw salmon fillets using a multi-location sampling technique and to correlate the expressible moisture in the fillets with textural properties.

Materials and methods

Samples

Samples of 25 salmon were used for textural evaluation and estimation of expressible moisture. A land-based salmon farm in Iceland supplied fresh Atlantic salmon, with an average weight ($\pm$ SEM) of 3.7 $\pm$ 0.1 kg in June 1997. The fish were bled immediately after slaughtering and then gutted and iced. The salmon were classified as superior. The fish samples were stored on ice in sealed boxes in a refrigerator at 4 °C for 3 days after slaughtering. Preparation and measurements of the samples took place at the Technological Institute of Iceland on the 4th day from slaughtering. The fish were filleted and skinned. Multilocation sampling technique was employed in which each fillet was cut into seven parts (location 1–7), above the lateral line (Fig. 1). These locations were selected as the muscle cell dimensions and arrangement vary throughout the fillet and the textural properties differ in the different parts of the fillet. Each sample was 4 cm in diameter and 2 cm in thickness. To preclude the influence from the various thickness along the fillet on the measurements, all the samples were prepared in equal thickness and were taken from the inner part of the fillet (adjacent to the spinal cord). The measurements in the tail section were performed near the gut opening because the thickness of the sample did not exceed 2 cm further down the tail section. The measurements of expressible moisture were performed at parallel locations to the locations 1–7, 1 cm ventrally from the lateral line. These samples were of equal size, 2.0 cm in diameter and 1.5 cm in thickness.

Textural measurements

The results in our study were based on the application of the TA.XT2® Texture analyser (Stable Micro Systems, Haslemere, Surrey, UK). All instrumental measurements were carried out at a deformation rate of 2 mm s^{-1}. Four different attachments (flat ended cylinder with diameter 20 mm (typeP/20), spherical probe with diameter 25.4 mm (type P/1S), Kramer cell (type HDP/KS5) and Warner-Bratzler shear
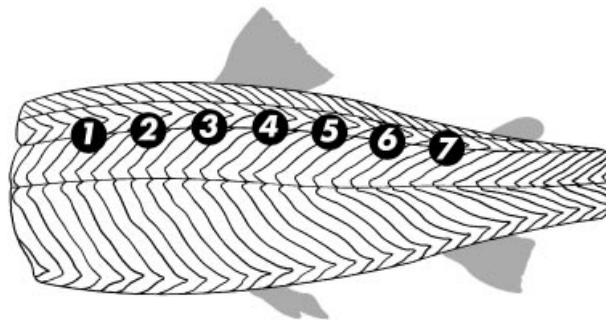

Figure 1 Textural measurements were performed on locations (1–7) marked on the Atlantic salmon fillet. Each sample is 4 cm in diameter and 2 cm in thickness.

blade (type HDP/BS) were applied on both fillets in each fish. Our pre-studies showed no significant differences in textural properties between the right and the left fillets in salmon, because of a high variability between individuals. Thus, different methods were applied on each fillet, and the spherical probe and Kramer cell were applied repeatedly on the same sample, the former first as it is non-destructive. Total number of replicates were 25 in each location for each instrumental attachment.

Flat ended cylinder

A flat ended cylinder of 20 mm in diameter was selected to simulate the human finger using a method described by Børresen (1986) with minor modification. The penetration depth and the speed were expressed as the force (N) necessary for the probe to penetrate each sample and a force–distance curve was plotted from the results. The forces necessary to penetrate each sample were read from the curve at a penetration depth of 5.00, 6.25, 7.50 mm and at the yield point. The yield point was described as the first abrupt change in the slope in the force–distance curve or the first breaking point in the sample, occurs when the probe causes irreversible crushing in the muscle. The yield point is regarded as the toughness of the fillet (Ando *et al.* 1991), while the resistance of the muscle fibres against compression (maximum force) expresses hardness (Børresen 1986).

Spherical probe

A sphere (25.4 mm in diameter) was selected as the second probe to simulate the human finger. The probe was pressed 5-mm deep into the fillet without breaking the muscle fibres. Double compression was applied by the following procedure. The sphere approached the sample and penetrated 5 mm into the fillet. Then the applied force was released and the fillet was allowed to rebound for 15 s with the sphere just touching the surface of the fillet. The sphere was then repressed into the fillet a second time and TPA parameters were obtained by analysing the force vs. time curve (Bourne 1978). Hardness is defined as the maximum force (N) that occurs at any time during the first compression cycle.

Kramer shear cell

The Kramer shear cell consists of five 3.0-mm thick and 70-mm wide shear bars or blades that pass through a box having a corresponding number of slots. The maximum peak force (N) was recorded as shear force required to shear through the sample. This is not pure shear force but involves a combination of shearing and compression forces (Szczesniak 1963).

Warner-Bratzler shear blade

A v-shaped blade with a thickness of 3.20 mm, height of 125 mm and width of 70 mm was assembled to the TA.XT2® Texture Analyser. The maximum peak force (N) required to shear through the sample was recorded as shear force. This method incorporates compression of fibres beneath the blade, tension in the adjoining fibres and shearing of the fibres (Bouton *et al.* 1975).

Expressible moisture

The expressible moisture (EM) was estimated, as the quantity of liquid squeezed from fillets upon compression (Borderias *et al.* 1983). Measurements of expressible moisture were performed on the Texture Analyser by a flat ended probe, 50 mm in diameter, at 60% deformation according to Lee & Chung (1989) and LeBlanc & LeBlanc (1992) with minor modifications. The samples were compressed between layers of weighed Whatman filter papers no. 4. The speed of the probe was 0.8 mm s^{-1}. After compression, the sample was removed and the filter papers were reweighed. The filter papers were dried in an oven at 105 °C over night, and reweighed again. This was carried out to minimize the weighing error because of filter paper absorption of fat from the sample. The expressible moisture was calculated on the basis of the fluid absorbed by the filter paper divided by the sample weight. The following equation 1 was used for estimation of expressible moisture:

$$\%EM \ (g \ fluid/g \ sample) = \left[\frac{(\text{weight of 'wet' filter paper (g)})}{\text{initial weight of sample (g)}} - \frac{(\text{weight of filter paper after drying (g)})}{\text{initial weight of sample (g)}} \right] \times 100 \quad (1)$$

Statistics

The data sets were compared by multiple comparison ANOVA using all pair wise comparison by Sigmastat 2.0 (Jandel Scientific Software, Ontario, Canada). Significance of difference was defined at $P < 0.05$. Pearson's correlation coefficients (r) were determined between each textural method (cylinder, sphere, Kramer shear cell and Warner-Bratzler

shear blade) and expressible moisture. The coefficient of variation (CV), was calculated for each method and each location (1–7). The CV was used to compare the precision of the texture measurements which have different mean values or magnitudes. The CV represents the sum of natural variation between fish and the variation related to the different methods and fillet locations (Nortvedt *et al.* 1996).

Results and discussion

General trends

Hardness and shear force values from the four different instrumental methods gave slightly concave curves, when plotted against the different locations on the fillet (from the anterior to the posterior part) (Figs 2 and 3). Hardness and shear force values from the spherical probe, Kramer shear cell and Warner-Bratzler shear blade, were significantly higher ($P < 0.05$) in the tail section than in other locations of the fish, indicating a firmer structure of the muscle in the tail section (Fig. 2). Sigurgisladottir *et al.* (1999) observed similar results, when measuring hardness and shear force in different locations on salmon fillets.

The values for hardness obtained from the flat ended cylinder at penetration depth 5.00, 6.25 and 7.50 mm into the fillet indicated generally that locations 1 and 7 were significantly harder than the other locations ($P < 0.05$) (Fig. 3). However, the values for yield point decreased significantly ($P < 0.05$) from the anterior to the posterior part of the fillet. Separations between locations decreased relatively as the probe penetrated deeper into the muscle ($P < 0.05$). A yield point or breaking point was observed in the compression curves for penetrations deeper than 5 mm. No yield point was observed when pressing the probe 5 mm into the sample. Sigurgisladottir *et al.* (1999) also found no breaking points in compression curves for a flat ended cylinder when pressing 5 mm into the intact muscle tissue of salmon of similar size. A sudden change in the slope of the compression curve in present study was observed for penetration of 6.25 mm or deeper. From this we conclude that textural measurements at the yield point and at the linear part of the force–distance curve, were expressing different textural properties. This is in agreement with Børresen (1986), as he pointed out that the resistance against compression measured in the linear part of the curve may express the hardness of the fillet. On the other hand the yield point may reflect the toughness of the fillet as it depends on how easy the probe penetrates the fillet and rupture the structure (Ando *et al.* 1991).

Present results indicated also that the muscle fibres near the tail section of the fillet (locations 5 and 6) were more sensitive to rupture than the anterior part of the fillet. The reason may be because of the smaller diameter of the muscle fibres near the tail region, and higher in numbers, than in the anterior part of the fillet, according to Love (1970). Comparing the force from the compression curves with the force applied in the yield point by the flat ended cylinder, the correlation coefficient obtained for 5 mm distance was low ($r = 0.43$, Table 1), indicating that the flat ended cylinder at the yield point is not measuring the same property as in the compression mode. When pressing deeper into the fillet,
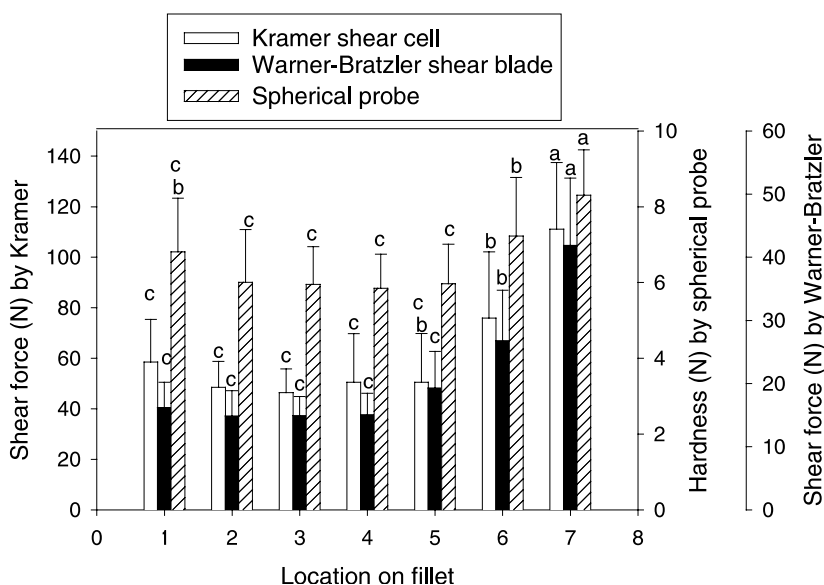

Figure 2 Hardness and shear force of salmon fillets measured by spherical probe Kramer shear cell and Warner-Bratzler shear blade, at seven locations from the anterior to the posterior part of the fillet. The bars express mean and standard deviation of 25 fish. Different letters indicate significant differences for each method ($P < 0.05$).
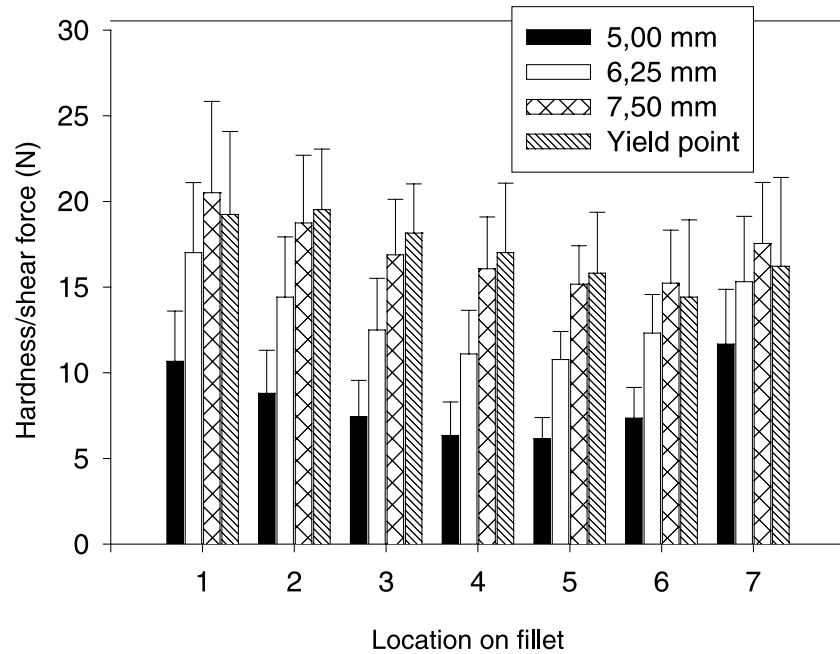
Figure 3 Hardness at three penetration depths and yield point of salmon fillet, measured by puncturing with a flat ended cylinder at seven locations from the anterior to the posterior part of the fillet. The bars express mean and standard deviation of 25 fish.

the muscle fibres started to break at 6–8 mm depending on the location in the fillet applied. Andersen (1995) observed lower hardness in salmon at a distance 7.50 mm into the fillet in location 4 than was observed in present study, when a flat ended cylinder was used, although she observed similar values for yield point as in our study. The difference in hardness values may be because of the size of the fish, or other biological factors. The average weight of the fish in Andersen's study was 2.6 kg, while it was 3.7 kg in our study. This is in agreement with Love (1970), who concluded that the meat of large fish is slightly tougher than that of small specimen.

Hardness force from the spherical probe was significantly higher ($P < 0.001$) in the tail section at location 7 than in other parts of the fillet, indicating a firmer structure in the tail section. No significant differences were observed between locations 1 to 5 on the fillet ($P > 0.05$). This is in agreement with results from a prior study (Sigurgisladottir *et al.* 1999).

Comparison of the methods

The force required by the Kramer cell to shear through the samples was approximately triple compared to the Warner-Bratzler device as would be expected from a multiblade system compared to a single blade system (Fig. 2). However, the shape of the force spectrum lengthwise in the fillet was very similar. The coefficient of correlation between the Kramer and the Warner-Bratzler methods was high ($r = 0.98$), which may indicate that both devices were measuring the same property, as they sheared through the

Table 1 Correlation coefficient (r) between different instrumental methods and expressible moisture

	Kramer	Warner-Bratzler	Sphere	Cylinder (mm)			Yield point	Expressible moisture
				5.00	6.25	7.50		
Kramer	1.00							
Warner-Bratzler	0.98*	1.00						
Sphere	0.97*	0.93*	1.00					
Cylinder (mm)								
5	0.65	0.55	0.74	1.00				
6.25	0.38	0.24	0.53	0.93*	1.00			
7.5	−0.01	−0.15	0.14	0.74	0.91*	1.00		
Yield point	−0.40	−0.51	−0.26	0.43	0.67	0.92*	1.00	
Expressible moisture	0.77*	0.7	0.83*	0.74	0.64*	0.35	−0.02	1.00

*$P < 0.05$

connective tissue in the fillet (Table 1). A high coefficient of correlation was also found between results from the Kramer shear device and the spherical probe ($r = 0.97$). These two methods are based upon different principles, where the Kramer cell measures the textural properties through the muscle fibres and the connective tissue, while the spherical probe compresses the muscle fibres and thereby estimates the hardness of the sample. This could indicate a close relationship between the hardness of the outer layer and the strength of the fibres and the connective tissue. Bouton & Harris (1972) suggested that compression values were more strongly influenced by the strength of the materials holding the fibres together than by the strength of the fibres themselves, when studying the tenderness of meat.

In the present study a significant correlation ($r = 0.93$) was obtained between the results from Warner-Bratzler shear device and the spherical probe ($P < 0.05$). A non-significant negative correlation was found between the yield point with the flat ended cylinder and the spherical probe ($r = -0.26$), Kramer shear test ($r = -0.4$) and Warner-Bratzler shear test ($r = -0.51$). The negative correlation underlines that the values of yield point is decreasing towards the tail section, while the values for the other methods (hardness by flat end cylinder, spherical probe, and shear force by Kramer and Warner-Bratzler) is increasing. These results demonstrate that there is a strong relationship between puncturing with a spherical probe, Kramer shear cell and Warner-Bratzler shear blade. Hinnergardt & Tuomy (1970) stated that puncture showed good correlation as a measure of hardness and that this method could afford certain advantage over the shear test because it is less destructive.

The coefficient of variation (CV) (Table 2), had the lowest average value in compression with spherical probe (18.5%), which is in agreement with Sigurgisladottir *et al.* (1999) that obtained a CV value for the same method of 17.5%. The highest CV was obtained with the Kramer shear cell (29.3%), which indicates less need for replication of measurements using the spherical probe. The CV for the spherical probe was significantly lower compared to Warner-Bratzler ($P = 0.002$) and Kramer shear cell ($P = 0.004$). Borderias *et al.* (1983) obtained lower values for CV in rainbow trout (*Salmo irideus* Gibb) fillets than in our study, using shearing, compression and puncturing. However, that results were based on only five replicates for each method. The discrepancy suggests that the muscle structure of trout appears to be more uniform than that of salmon. Orban *et al.* (1997) studied the texture of frozen sea bream (*Sparus aurata*) from different farming systems. The coefficient of variation obtained for firmness and puncture strength appeared rather high (24–35%) but are in keeping with data found in the literature, both on other types of fish and on other foods (Borderias *et al.* 1983). From this we conclude that by applying spherical probe the lowest variability in repeated measurements of similar fillet parts is observed, and less number of replicates should be needed, according to these results.

Sigurgisladottir *et al.* (1999) found that the shear force method based on cutting with a knife edge blade was more sensitive than the puncture methods and more discriminatory when determining textural properties between different locations, as well as between samples of different origin ($n = 15$), although the precision was lower for the sphere which is in agreement with this current study. However, Sigurgisladottir *et al.* (1999) concluded that the puncture method with spherical probe was less destructive, the samples do not have to be cut into equally thick parts and the fillets samples can be of natural thickness using samples from location 2–4 (Fig. 1). From present study, the relative differences in measured force values between the different parts of the fillet were similar for the penetration with a spherical probe, Kramer shear cell and Warner-Bratzler shear blade. The similarity between these two studies as well as our pre-studies, were based on clearer separations between locations 5–7, using the shearing methods than the puncture

Location	Flat ended cylinder (mm)			Yield point	Kramer	Warner-Bratzler	Sphere
	5	6.25	7.5				
1	27.4	24.0	26.0	22.8	28.7	24.6	20.7
2	28.6	24.4	21.1	18.0	21.1	27.0	23.2
3	28.6	24.1	19.1	15.8	20.2	20.3	16.8
4	30.7	23.0	18.8	23.8	38.2	22.5	15.5
5	20.0	15.2	14.7	22.5	28.7	29.7	17.4
6	24.3	18.3	20.3	31.3	39.4	29.7	21.4
7	27.5	24.9	20.3	31.9	28.5	25.4	14.4
Average	26.7	22.0	20.0	23.7	29.3	25.6	18.5

Table 2 Coefficient of variation CV (%) from different texture measurements and locations from the anterior (1) to the posterior (7) part of the fillet

methods despite of the same significant differences in these locations between the methods (Fig. 2). According to this, the shearing method would be better suited for measuring the differences in textural properties between the different locations on the fillet.

In the present study the textural properties measured by the spherical probe showed lower variability, based on repeated measurements in each part of the fillet than the Warner-Bratzler shearing blade and Kramer shear cell. The reason is probably that the Warner-Bratzler and the Kramer shear blades measures the texture through the whole fillet, by shearing the connective tissue, while the spherical probe measures the texture on the surface of the fillet. In conclusion penetration with a spherical probe could afford certain advantage over the shearing devices because it is less destructive and shows the lowest variability. Borderias *et al.* (1983) and Barroso *et al.* (1998) suggested that the Kramer cell compression method would be the most suitable method for whole fish because it overcomes the problem of sample heterogenity and correlates well with sensory analysis. According to our experience with Kramer cell in this study, the disadvantages of using Kramer cell is that it uses large samples, it is time consuming to rinse the slot and the cell after each measurement, and an error in measurements can occur as the blades sometimes strike the slots. It is also difficult to use the 10 blade device, if measuring the tail section of the salmon fillet, because higher load cell than 25 kg of the instrument is needed. We conclude inspite of the high correlation between the Kramer cell and the spherical probe, the latter would be a more suitable device to evaluate the textural properties in salmon fillets.

Expressible moisture content

The estimate of expressible moisture, varying between 1.8 and 2.7%, displayed the same overall trend as the data from the texture measurements, giving a concave curve with the lowest values in the dorsal fin area of the fillet (Fig. 4). The tail part of the fillet was significantly higher in expressible moisture than the dorsal fin area, given the sample size $n = 25$ and $P = 0.001$. The expressible moisture showed significant linear correlation with textural properties, when measuring hardness with a spherical probe ($r = 0.83$) and with Kramer shearing method ($r = 0.77$) (Table 1). Lower coefficient of correlation was obtained between the expressible moisture and Warner-Bratzler shear blade ($r = 0.70$). Zapata & Price (1982) obtained much lower coefficient of correlation between water-holding capacity and Kramer shear cell ($r = -0.13$) when evaluating the texture and water
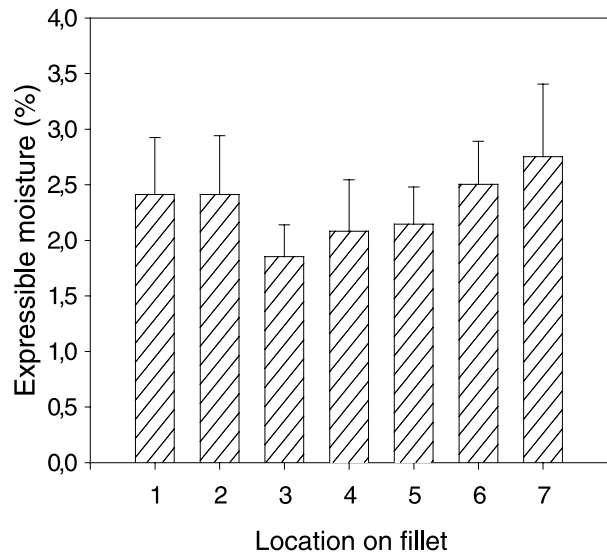

Figure 4 Expressible moisture of salmon fillets by 60% strain compression of the muscle by a flat ended cylinder at seven locations from the anterior to the posterior part of the fillet, below the lateral line, and subsequent collection and weighing of the liquid squeezed from the fillets upon compression. The bars express mean and standard deviation of 25 fish.

holding capacity in cooked minced fish, using the filter method. Hsieh & Regenstein (1989) studied the texture changes of frozen stored cod and concluded that expressible moisture was consistent with the increase of hardness of the cod mince. Ofstad *et al.* (1993) observed liquid loss of 2% in chopped salmon (*Salmo salar*), which is similar to the amount observed in present study. Ofstad suggested that the low liquid loss of salmon was probably related to intrinsic structural features such as: the denser impression of the myofibrils, intra and extracellular lipids and the amorphous material filling intracellular spaces, probably consisting of sarcoplasmic proteins. It can also be explained by the pH values of the sample as it is not so close to the isoelectric point of the muscle proteins, according to Hermannson (1986) and Honikel (1989). Dunajski (1979) concluded in his review that fluctuations in the water content have a significant impact on the texture of fish muscle. Lee & Toledo (1976) evaluated free or mobilizable water as a textural parameter as it provides a measure not only of water holding capacity (WHC) but also could affect sensory perception of juiciness of the fillet. In conclusion the expressible moisture in different parts of salmon fillet from the anterior to the posterior part is related to textural properties even though the expressible moisture content showed low variation between locations.

The main conclusion from this work was that the most suitable methods to measure the textural properties in different parts of raw salmon fillet is a puncture method by penetration with a spherical probe and shearing method by Warner-Bratzler device. The reason is that the spherical probe is more suitable for non-destructive measurement of salmon fillets and showed the lowest variability in repeated measurements of similar fillet parts (CV = 18.5). The Warner-Bratzler shearing device showed a clearer separation among locations 5–7, than the spherical probe. Both the sphere and the Warner-Bratzler devices have certain advantages over the Kramer cell method and the puncture methods by flat ended cylinder.

Expressible moisture gradually increased from the dorsal fin towards the tail section of the fillet, although the differences between locations were low, but showed significant differences, and was consistent with the trends of textural measurements in salmon fillet.

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