Comparison of fat content measured by MRI water-fat separation, MR spectroscopy and chemical analysis on salmon

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Targeted audience

This work, in particular the experimental results (chemical analysis comparison), could benefit to researchers in the field of fat quantification by water/fat separation .

Purpose

Our purpose is to measure by MRI the quantity and the anatomic distribution of lipid in fish which are of major importance for the quality of the product. This study aimed at validating results from MRI water/fat separation approach by comparing them with MR spectroscopy (MRS) and with chemical analysis.

Methods

MRI and MRS comparison was performed on a whole wild Scottish salmon on 36 localized spectroscopic voxels. MRI and chemical analysis comparison was performed on 15 cutlets of Scottish farmed salmon whose skin and fish bones had been previously removed. The weight proportions of lipid (g/100g) were measured by chemical analysis. The MRI and MRS acquisitions were performed on a 1.5T Avanto Siemens at 4°C in order to ensure a minimal loss of water while keeping the fat non-crystallized. All data were collected using standard head array coil.

Spectroscopic analysis: All spectra were acquired with a PRESS sequence on a 15x15x5mm^3 voxel, 1500 Hz bandwidth, 1024 points, 128 averages, TE=30ms and TR=3000ms. Spectra were acquired without water suppression. Fat fraction was quantified as the ratio of the area under the three largest peaks (0.9, 1.3 and 5.3ppm) to the area under the fat peaks plus water. These areas were measured using the Siemens spectroscopic tool available on the MR system.

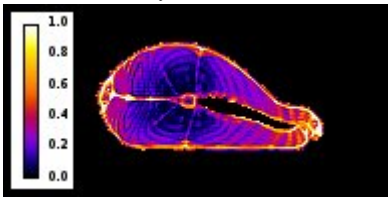


Fig. 1: *Fat fraction image of salmon*

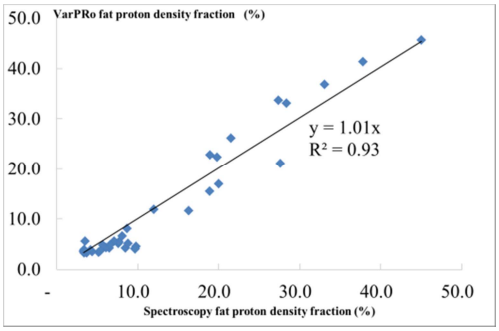
Chemical analysis The 15 cutlets were grounded, homogenized, and hydrolyzed with hydrochloric acid. The residue obtained was filtered and dried. The fat was then extracted with petroleum ether. The residue fat extracted was weighed after cooling. The results were given with an uncertainty equal to 1.1 g/100g.

Water-fat separation

The MRI sequence was a gradient multi-echo with TR=3000ms, 6 echoes at TE= [2.35; 4.85; 7.35; 9.85; 12.35; 14.85] ms and flip angle $\pi/2$. TR was chosen with a value high enough to avoid any T_1-weighted confounding effect (the T_1 of fat and water had been previously estimated respectively to 380 and 600 ms). The bandwidth was 1500Hz/pixel, 2 repetitions and the slice thickness was 5mm. We used the following model for the signal $s(t_n)$ in a voxel:

$$s(t_n) = \left(\rho_w e^{i2\pi f_B t_n} + \rho_f \sum_{m=1}^{M} \alpha_m \, e^{i2\pi(f_B + f_{F,m})t_n}\right) e^{-R_2^* t_n}$$

where f_B is the local frequency offset due to field inhomogeneity, ρ_w and ρ_f are the water and fat amplitudes, α_m and $f_{F,m}$ are the relative amplitudes and frequencies of the fat spectral peaks, t_n is the echo time shift. R_2^* was assumed common for water and fat. The frequencies of the fat spectral peaks $f_{F,m}$ were fixed as described by Hamilton et al[1]. The relative amplitudes α_m were calculated from the average fatty acid carbon chain length (CL), the unsaturation degree (UD), and the polyunsaturation degree (PUD). CL, UD and PUD values for salmons were set as found in the literature[2]. We used the VarPro[3] method which we implemented in Scilab to estimate f_B, ρ_w, ρ_f and R_2^*. The fat fraction was computed as the ratio $|\rho_f|/(|\rho_w| + |\rho_f|)$. In the case of the comparison with the chemical analysis, this ratio was converted in weight fraction using the average molar mass and number of hydrogen atoms of the triglyceride molecule used in our model.



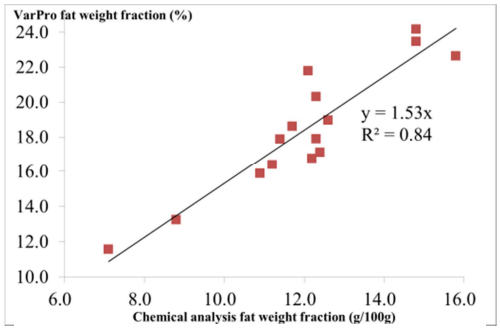


Fig. 2 *Fat fraction measured by MRI vs. MRS (top) and vs chemical analysis (bottom).*

Results and discussion

Figure 1 represents the fat proton density fraction on a slice used for the MRI/MRS comparison. The result presents quite good localized information of fat fraction; it is coherent with the expected repartition of fat inside a salmon with a high fat content in the subcutaneous area and a decreasing gradient towards the area around the central fin.

Figure 2 (top) represents the fat proton density fraction measured by VarPro vs. MRS. The correlation between the two approaches was very high (R^2=0.93) in the range of 0 to 50% of fat. The slope of the linear regression was close to 1 which indicated that the techniques were in very good agreement. However we observed some differences in particular for low level of fat fraction. This could be due to poor spectral resolution at 1.5T which did not allow to clearly separate the water peak from the 5.3 ppm peak of the fat.

Figure 2 (bottom) represents the fat weight fraction measured by VarPro vs. the chemical analysis. The correlation was a bit lower than in the previous case however still high (R^2=0.84). The percentage found by VarPro was larger leading to a slope of the linear regression of 1.53. One cause of this discrepancy was due to the fact that, contrary to the chemical analysis, VarPro measurements did not take in account the proteins, giving no signal with our MRI sequence. If we assume 20% of protein in each cutlet this reduces the ratio measured by VarPro and consequently the slope to 1.2 whereas a similar study in mice livers led on the contrary to the underestimation of fat fraction by MRI explained by the non-detection of bound or aggregate lipids by MRI[4]. The fat weight fraction measured by VarPro depends on the choice of the spectral model (α_m and $f_{F,m}$). A potential limitation of this method is the use of a precalibrated approach in modeling the spectral complexity of fat whereby the relative fat peaks are assumed constant between and within fishes. Further tests should be led in order to explain this overestimation.

Conclusion

MRI measurements of fat content using water/fat separation with VarPro were compared to spectroscopy and chemical analysis on salmon. High correlations were found in both cases which confirmed that MRI water/fat separation could be a good alternative for the fat content measurement in fish. Further work will be needed to understand the onbserved overestimation of MRI compared to chemical analysis. New investigations on a larger set and with more accurate chemical analysis and spectroscopy at higher field should be led in order to better qualify the performance of this technique.

References

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