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Salt Diffusion in Rainbow Trout (*Oncorhynchus mykiss*)

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ABSTRACT

Salt diffusion kinetics was determined in filleted Rainbow Trout samples during dry curing at 20°C. Fish slabs with a thickness of *ca* 1 cm were cut from fillets and placed on a layer of coarse salt (*ca* 1 cm). Salt diffusion was monitored in samples taken hourly during a 10h-dry curing period. Dry matter and salt contents were determined in duplicate samples. The analytical solution of the second Fick's law considering one-dimensional diffusion through an infinite slab was used to calculate effective salt diffusion coefficients. Salt diffusion coefficients in fillets were in the range of 1.47×10^{-9} to 3.65×10^{-9} m^2/s.

Key Words: Salting, Diffusion, Fish

Gökkuşağı Alabalığında (*Oncorhynchus mykiss*) Tuz Difüzyonu

ÖZET

Çalışmada, 20°C'de kuru tuzlama işlemine tabi tutulmuş fileto halindeki gökkuşağı alabalıklarında tuz difüzyon kinetiklerinin belirlenmesi amaçlanmıştır. Bu amaçla balık filetolarından çıkarılan 1 cm kalınlığındaki dilimler yine 1 cm kalınlığındaki kaba tuz üzerine yerleştirilmiştir. Örnekleme işlemi 10 saat boyunca 1'er saatlik aralıklarla yapılmıştır. Her bir örnekleme anında iki örnek alınmış ve bu örneklerin her birinde kuru madde ve tuz içeriği analizleri gerçekleştirilmiştir. Sonsuz bir dilimde tek boyutlu difüzyon dikkate alınarak gerçekleştirilen Fick'in ikinci yasasının analitiksel çözümü, efektif tuz difüzyon katsayılarının hesaplanmasında kullanılmıştır. Sonuçta örneklerdeki tuz difüzyon katsayılarının 1.47×10^{-9} ile 3.65×10^{-9} m^2/s arasında olduğu tespit edilmiştir.

Anahtar Kelimeler: Tuzlama, Difüzyon, Balık.

INTRODUCTION

Salting (dry curing) is one of the oldest techniques known to man for the preservation and increasing of shelf life of fish [1]. Salting process is considered as an osmotic treatment that aims essentially to give specific organoleptic and sensory characteristics to the product, besides for preservation purposes [2-4]. Salting is also combined with other processes such as smoking, canning, marinating or drying in order to obtain stable final products [1, 5].

Salting process can be carried out by different procedures, the most usual being dry salting and brining, or a combination of both methods [5-7]. Dry salting is the traditional salt-curing technique used during processing of salted fish in many countries [8]. When salt solution or dry salt are used as salting agents, two main simultaneous flows, water loss and salt uptake, are usually generated [1, 9]. The latter depends on many factors including species, fillet thickness, composition, physiological state, salting method, brine concentration, ambient temperature, freezing and thawing [8,10,11].

During salting, salt and water transfer in fish muscle is complicated and depends on various mass transfer mechanisms [12,13]. Diffusion is said to be the most important mass transfer mechanism responsible for sodium and chloride transport. Solutes diffuse from the salting agent and water diffuses out of the fish, due to the differences in concentration and osmotic pressures between the inter-cells and the salting agent [13]. Knowledge of the diffusion rates is important since it allows the accurate determination of the necessary processing time, taking into account both the final salt concentration and distribution inside the product [14].

Mathematical models can help to a better understanding of the diffusion phenomena and to control the variables involved in the process [15]. Several researchers applied the Fick's second law of diffusion to study fish salting. They assumed constant salt diffusion coefficient and obtained various solutions to the Fick's second law for different boundary conditions and geometry of fish samples [9,11,15]. The solutions given by Crank [16] have been used to describe salt uptake and to determine diffusion coefficients.

In the literature, there are some reports about salt diffusivity in several fish species, but no data are available for the salt diffusivity in Rainbow Trout (*Oncorhynchus mykiss*). The objective of this work was to determine the salt diffusion kinetics in filleted Rainbow Trout samples during dry curing at 20°C.

MATERIALS and METHODS

Raw Material and Chemicals

Freshwater rainbow trout with an average of 250 g reared in a farm located in the Research and Extension Center of Fisheries Department in Agricultural Faculty at Atatürk University in Erzurum were used. Fillets were obtained by removing their heads and bones manually. Sodium chloride (table salt) was of food grade.

Sample Preparation

Fish slabs with a thickness of ca 1cm and a diameter of 3cm were cut from fillets and placed on top of a 1cm bed of coarse salt at 20°C. Samples were taken hourly during 10 hours. Duplicat samples were used to determine dry matter and salt contents of samples. Equilibration studies were extended up to 30 days.

pH and Proximate Analyses

pH and proximate analyses of samples were conducted according to the methods of Association of Official Analytical Chemists [17].

Salt Content

The salt content of each sample was determined by using ion selective electrode (CRISON Code: 9652, Cl-I.S. Electrode).

Salt Diffusion Coefficient

The analytical solution of second Fick's law considering one-dimensional diffusion through an infinite slab was used to calculate effective salt diffusion coefficients. It is expressed as shown in Equation 1:

$$\frac{M_t}{M_\infty} = \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} \exp\left(-D\,(2n+1)^2 \pi^2 t / 4l^2\right) \qquad (1)$$

where t = time, M_t = mass of salt entered the product at time t, M_∞ = mass of salt in the product in equilibrium with the dry salt, l = slab thickness.

RESULTS and DISCUSSION

pH and Proximate Analysis

The initial pH values of samples were in the range of 6.40-6.50. These values were close to values reported for fresh fish meat [18].

The composition of the Rainbow Trout flesh is presented in Table 1. These results are in agreement with those obtained by several authors [21-25] for fresh Rainbow Trout fillets. The chemical composition of fish varies greatly from one species and one individual to another depending on age, sex, environment and season. The lipid fraction is the component showing the greatest variation. Often the variation within a certain species will display a characteristic seasonal curve with a minimum around the time of the spawning [19, 20]. The variation in the percentage of fat is reflected in the percentage of water since fat and water normally constitute around 80 % of the fillet.

Table 1. Composition of fresh Rainbow Trout fillets

Component	Content (%)
Moisture	73.94
Protein	18.71
Fat	5.98
Ash	1.27

Dry Matter and Salt Contents

Changes in dry matter and salt contents of the samples during the salting time are shown in Figures 1 and 2, respectively. Because of the water loss and salt uptake, dry matter and salt contents of the samples increased. Dry matter content of the samples reached 38.26% and salt contents 23.12 g /100g dry matter at the end of 10 hours. Dry matter and salt contents increased with salting time. A sharp increase in the fillets' salt content was observed in the first 2 hours of the process, followed by a slower increase until 10 hours. Faster salt gain at the first few hours of the salting process can be due to a larger concentration gradient between the dry salt and samples. This gradient is probably reduced with time elapsing as a consequence of a high salt content layer that is formed on the sample surface exposed to salt and acts as a barrier against further salt uptake [9,26].

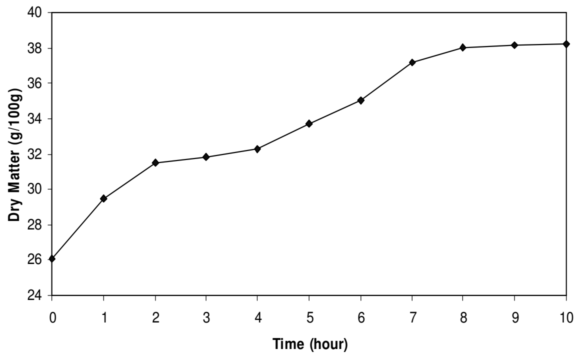

Figure 1. Changes in dry matter content of the samples during the salting time

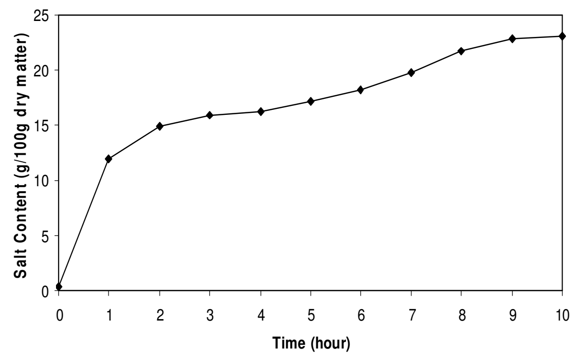

Figure 2. Changes in salt content of the samples during salting time

Salt Diffusion Coefficient

Diffusion coefficients of samples obtained at 1 hour intervals were given in Table 2. Salt diffusion coefficients in the fillets were in the range of 1.47 x 10^{-9} to 3.65 x 10^{-9} m^2/s.

Table 2. Diffusion coefficients of samples during curing

Time (hour)	Diffusion coefficient [x 10^{-9} (m^2/s)]
1	3.65
2	2.91
3	2.21
4	1.73
5	1.56
6	1.47
7	1.53
8	1.68
9	1.72
10	1.61

A comparison of salt diffusivities of different species of fish reported in the literature is shown in Table 3. It appears that the values obtained in this work are in agreement with those obtained by Mujaffar and Sankat [9] for shark, Boudhrioua *et al.* [4] for sardine and Zhang *et al.* [15] for *Grass carp*. However, there are some differences with the values reported by other authors. These differences could be due to fish compositions or salting conditions, since in some studies different temperatures and brines were used and in other some experiments the fish were completely covered with salt.

Figure 3 indicates that the values of diffusion coefficient were strongly time dependent. The diffusion coefficients of sodium chloride in fish muscle decreased with an increase in salting time. The changes in diffusion coefficient with respect to processing time are essentially attributed to the increasing in salt concentration in muscle.

Table 3. Comparison of salt diffusivities (De) in different fish samples

Fish	Salting Method	Concentration (%)	Temperature (°C)	De x 10^{-10} (m^2/s)	Reference
Swordfish	Brine	4.10 – 18.14	5 – 25	6.4 – 14.5	Del Valle and Nickerson (1967) [a]
Cod	Brine	26.33	23 – 33	9.3 – 14.1	Peters (1971) Murray and Burt (1972) [a]
Pike	Brine	21	6 – 20	7.78 – 10.1	Stefanovskaya *et al.* (1976) [a]
Tuna	Brine	5.85	30	10.4	Sakai and Miki (1982) [a]
Baltic Herring	Brine	14	2 – 20	1.14 – 2.44	Rodger *et al.* (1984) [a]
River chum salmon	Brine	11.7	15	7.9	Sakai and Suzuki (1985) [a]
Ocean chum salmon	Brine	11.7	15	8.38	
Atlantic salmon	Brine	19.9	10	1.09 – 1.52	[11]
Cod	Dry	-	5	1.64	[12]
Cod	Brine	25	5	1.64	[12]
Shark	Brine	36	20 – 50	15 – 25	[9]
Atlantic Cod	Brine	15 - 25	4	1.51 – 1.76	[8]
Atlantic Salmon	Brine	15 - 25	4	5.19 – 5.81	[8]
European sea bass	Dry	-	4	0.75	[1]
Sardine	Dry	-	5	25 – 39	[4]
Sardine	Dry	-	20	45	[4]
Cod	Brine	6 - 24	2	4.00 – 5.45	[5]
Grass carp	Brine	3	5 – 15	3.15 – 58.6	[15]
Rainbow trout	Dry	-	20	14.7 – 36.5	This Research

[a] data from Wang [27].

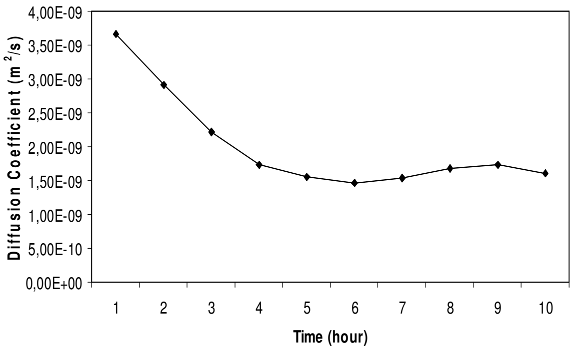

Figure 3. Diffusion coefficients of samples as a function of salting time

Faster salt gain at the beginning of the salting process can be due to a larger concentration gradient between the dry salt and samples. This gradient is reduced with time elapsing as a consequence of a high salt content layer that is formed on the sample surface exposed to salt and acts as a barrier against further salt uptake [9, 26]. As a result, the mass transfer resistance for sodium chloride progressively rises and the diffusion coefficients decrease.

CONCLUSIONS

At the end of 10 hours of salting process, dry matter and salt contents of the samples reached 38.26% and 23.120 g NaCl /100g dry matter, respectively. Salt diffusion coefficients in fillets were in the range of 1.47 x 10^{-9} to 3.65 x 10^{-9} m^2/s. The diffusion coefficients of sodium chloride in fish muscle decreased with salting time. Determination of salt diffusion coefficient is important for predicting the salt uptake of fish samples, at a particular time during the salting process. Moreover, it can be useful for determining the optimum salting conditions for a salting process. Further studies should focus on the effect of temperature on salt diffusion kinetics in Rainbow trout.

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