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EVALUATION OF MATHEMATICAL MODELS WHICH DESCRIBE THE PROCESS OF DRYING GOAT MEAT

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Abstract

Drying is a step in the processing of goat meat. This paper presented the influence of salt and pH on moisture ratio over time, when the goat meat dries at 103℃, at thermobalance. From the obtained data it was observed that the water-holding capacity of goat meat was influenced only by lowering the pH by one unit. In the case of goat meat containing 3% salt, moisture ratio varied over time as in the case of the control sample. The mathematical models which describe the process of drying goat meat was investigated under each experiment conditions. An exponential variation of moisture ratio over time was obtained and this was best described by the exponential model named "Wang & Singh".

Key words: *goat meat, drying, moisture ratio, mathematical models*

INTRODUCTION

In Romania, goat breeding is done in the traditional system (domestic system), in the modernized traditional system (semi-intensive) or in the industrial system (intensive). Goat rearing is mainly done for milk production, while meat is appreciated mainly due to its lower fat content compared to meat from other animal species [5]. Goat meat is processed in the form of minced meat or specialties such as pastrami. In most cases the maturation-drying stage is encountered.

In goat meat, after slaughter, a significant decrease in pH values can be observed due to rigor mortis phenomena. Subsequently, the pH decreases under the action of bacteria, and can reach, depending on the time and storage conditions, to values lower than 6 [11]. In addition to the low pH value, the shelf life of goat meat products is also ensured by the salting and drying processes, which cause a decrease in water activity [16]. The way in which water is removed is important both economically and microbiologically [6]. The mass transfer takes place in two stages. Initially, water migrates from the inside of the meat to the surface, then from the surface to the environment. The diffusion of water inside the meat depends on the physicochemical characteristics and is of great importance to produce salted-and-dried goat meat [2]. Several researchers have investigated the drying kinetics of meat to evaluate different mathematical models for improving existing drying systems or even for process control [15].

The purpose of this article is to compare the mathematical models for drying of salted and acidified goat meat in relation to unpreserved meat.

MATERIALS AND METHODS

Goat was purchased from a domestic system and after slaughter and until the analysis was kept to a maximum of 4°C. Prior to the analysis, the connective tissue and superficial fat were removed from the leg and the muscle tissue was chopped to a size of 3 mm. After that, the meat was mixed, for the three samples, with equal volumes of distilled water (sample M), brine (sample SM) and lactic acid (sample AM), so that the sample SM contains 3% salt and the sample AM has a pH = 5.2 (The pH of samples M and SM was 6.2). Drying at 103°C, were preferred to obtain accurate results, in the shortest possible time, to reduce the influence of other factors or errors.

The first equation for mathematical modeling of the food drying process was proposed by Lewis [9].

$$\frac{dM}{dt} = -k(M - M_e) \quad (1)$$

where: M represents the bulk moisture content depends only on time t and M_e the equilibrium moisture content. After integrating equation 1, considering M_t is the moisture content of samples at time t and M_0 is the initial moisture content, results the moisture ratio (*MR*) [1].

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \exp(-k \cdot t) \quad (2)$$

Where M_e is the equilibrium moisture content and is relatively smaller than M_t or M_0 [19]. For this reason, equation 2 was simplified to:

$$MR = \frac{M_t}{M_0} \quad (3)$$

Over time, several mathematical models of drying have been proposed, nine of different moisture ratio equations which are given in Table 1.

Table 1. Mathematical meat drying models used for the approximation given by various authors

Eq. no.	Model name	Model equation	References
1	Lewis; O'Callaghan et al.	MR = exp (-k · t)	[9], [12]
2	Henderson & Pabis; Chhinan	MR = a · exp (-k · t)	[7], [4]
3	Yagcioglu	MR = a · exp (-k · t) + b	[20]
4	Midilli & Kucuk	MR = a · exp(-k · t^n)+b · t	[10]
5	Page; Zhang & Litchfield	MR = exp (-k · t^n)	[14], [21]
6	Modified Page	MR = a · exp [- (k · t^n)]	[14]
7	Overhults	MR = exp [- (k · t) ^{n}]	[13]
9	Wang & Singh	MR = b - a · exp [- (k · t^n)]	[18]
9	Karathanos	MR = a·exp(-kt) + a_1·exp(-k_1t) +a_2·exp(-k_2t)	[8]

Author's synthesis based on [4, 7, 8, 9, 10, 12, 13, 14, 18, 20, 21].

The reduced chi-square (χ^2) and root mean square error (*RMSE*) can be calculated as follows [3]:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{pre\,i} - MR_{\exp i}\right)^2}{N} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre\,i} - MR_{\exp i}\right)^2}{N}} \quad (5)$$

where $MR_{pre\ i}$ and $MR_{exp\ i}$ represent predictive moisture ratio and experimental moisture ratio; N is the number of observations

RESULTS AND DISCUSSIONS

In Figure 1 it can be observed that, for all samples, *MR* values decrease in two stages. The decrease is accentuated up to a value of about 0.1, after which it tends slowly towards the value zero. However, in the case of dried meat products, these do not dry completely. Depending on sensory preferences, local traditions or shelf life, meat products dry until the *MR* reaches values around 0.45. As seen in Figure 1, especially in the final drying period of meat products, there are significant differences between the control and meat with higher acidity (lower pH)

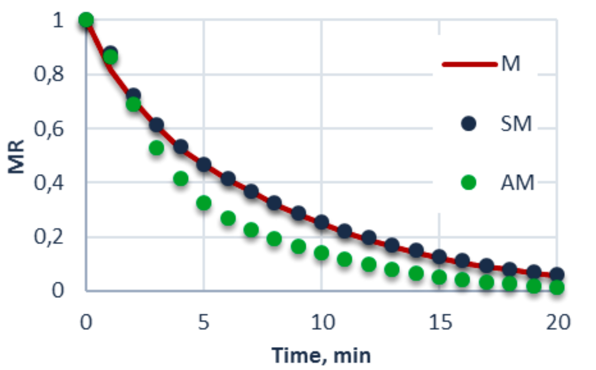

Fig. 1. The effect of salting and acidification on the moisture ratio (MR) values of IR-dried minced goat meat
Source: own processing.

By changing the parameters of the environment, such as varying the speed of air circulation, the amount of evaporated water changes. So, the limiting factor is the water transfer to the surface of the meat, and this depends on water-holding capacity of meat. In the case of salted meat, there is no difference from the control (unsalted meat), while the decrease in pH, as expected, favors the elimination of water. While in salted meat, the water retention capacity of the meat increases due to the presence of dissociating salt, the salt also favors the extraction of myosin which has a hydrophobic and a hydrophilic part. Thus, it is reduced the repulsion between water and fat. This may explain why the results obtained for the control and for the salted meat are very close. Previously, other authors have observed that the presence of salt insignificantly influences cooking losses, while large differences were obtained depending on the post-slaughter stage in which the meat was because pre-rigor muscle had a higher pH value than post-rigor muscle [17].

Fitting of experimental drying data to model

The experimental drying data observed were fitted to the nine models listed in Table 1.

The coefficients: *k*, k_1, k_2, *a*, a_1, a_2, *b*, *n*, the regression coefficients (R^2), the reduced chi-square (χ^2) and root mean square error (*RMSE*) values results of the different models are listed in Table 2.

Table 2. The coefficients (*k*, *k1*, k_2, *a*, a_1, a_2, *b*, *n*), the regression coefficients (R^2), the reduced chi-square (χ^2) and root mean square error (*RMSE*) values obtained by application of nine equations to the experimental drying data for dried goat meat.

Eq. no.	Model name	Sample	Coefficients								Model precision		
			k	k_1	k_2	a	a_1	a_2	b	n	R^2	χ^2	*RMSE*
1	Lewis;	M	0.1620								0.9969	0.7418	0.8613
	O'Callaghan	SM	0.1433								0.9979	0.7386	0.8594
	et al.	AM	0.2062								0.9973	0.8154	0.9030
2	Henderson	M	0.1401			0.9586					0.9984	0.6791	0.8241
	& Pabis	SM	0.1405			0.9807					0.9983	0.71054	0.8429
	Chhinan	AM	0.1669			1.0013					0.9976	0.81702	0.9039
3	Yagcioglu	M	0.1396			0.9588			-0.000881		0.9984	0.8921*10^-4^	0.0094
		SM	0.1404			0.9807			-0.000219		0.9983	1.0191*10^-4^	0.0101
		AM	0.2112			1.0172			0.001777		0.9969	1.2430*10^-4^	0.0111
4	Midilli &	M	0.1719			0.9873			-2.1057*10^-4^	0.9150	**0.9993**	**0.0351*10^-4^**	**0.0019**
	Kucuk	SM	0.1686			1.0064			-1.8469*10^-4^	0.9242	**0.9990**	**0.0089*10^-4^**	**0.0009**
		AM	0.2159			1.0219			0.1185*10^-4^	0.9865	**0.9976**	**0.1048*10^-4^**	**0.0032**
5	Page	M	0.1745							0.9191	0.9988	0.6557*10^-4^	0.0081
	Zhang &	SM	0.1612							0.9463	0.9988	0.7230*10^-4^	0.0085
	Litchfield	AM	0.2029							1.009	0.9973	1.3717*10^-4^	0.0117
6	Modified	M	0.1644			0.9824				0.9385	0.999	0.8091*10^-4^	0.0090
	Page	SM	0.1626			1.0026				0.9435	0.9988	0.7335*10^-4^	0.0086
		AM	0.2161			1.0221				0.9856	0.9976	1.6211*10^-4^	0.0127
7	Overhults	M	0.1471							0.5240	0.8602	79.3769*10^-4^	0.0891
		SM	0.1464							0.5465	0.8792	71.4773*10^-4^	0.0845
		AM	0.1734							0.5698	0.8380	83.9961*10^-4^	0.0916
8	Wang &	M	0.1734			-0.9992			-0.0102	0.9037	**0.9994**	**0.0262*10^-4^**	**0.0016**
	Singh	SM	0.1693			-1.0158			-0.0084	0.9162	**0.9990**	**0.0121*10^-4^**	**0.0011**
		AM	0.2150			-1.0202			-0.0013	0.9904	**0.9976**	**0.0778*10^-4^**	**0.0028**
9	Karathanos	M	1.0770	0.1000	0.1008	0.1160	-26.746	27.6301			0.9999	0.0688*10^-4^	0.0026
		SM	2.1908	2.1908	0.1324	52182	-52181	0.9170			0.9995	7.9663*10^-4^	0.0282
		AM	0.9531	0.1785	0.9532	31640	0.78216	-31640			0.9996	0.2776*10^-4^	0.0053

Source: Own calculation on the basis Desmos Graphing Calculator and Scientific Calculator.

Models analysis were based on the values that the regression coefficient of determination (R^2) should be close to 1. At the same time, *RMSE* and χ^2 should be very low [1].

These requirements have been met by the models ”Midilli & Kucuk” and ”Wang & Singh”.

0.9994 was the highest value of R^2 and was obtained for the control sample (M), using the model proposed by ”Wang & Singh”. The lowest values of *RMSE* and χ^2 were obtained for sample SM, using ”Midilli & Kucuk” equation. However, the model that best describes the drying process for all three samples is the model ”Wang & Singh”. For all samples, the decrease of *MR* is exponential and the values of R^2 have values very close to 1. Also χ^2 and *RMSE* have values less than $0.0778 \cdot 10^{-4}$ and 0.0028, respectively.

CONCLUSIONS

The drying time of meat products and the choice of drying conditions depends on water-holding capacity of samples. As expected, *MR* had the largest variation in the unit of time for the AM sample. The mathematical model noted "Wang & Singh" best describes the exponential variation of *MR* over time for all samples.

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