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Article

Evaluation of the Use of Vacuum-Dehydrated Minced Meat in Beef Patty Production

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Abstract: This study aimed to determine the usage potential of vacuum-dehydrated ground beef in beef patty production. First, the fresh ground beef was dehydrated in vacuum dryers at 25, 35, and 45 °C for dehydration kinetics and color change. Then, the vacuum-dehydrated ground beef was rehydrated, and three different beef patties were separately produced using fresh ground beef, the rehydrated ground beef, and a mixture of the two (1:1). According to the results, the dehydration significantly decreased the L^*, a^*, and b^* values of ground beef; however, after rehydration, the L^* and b^* values were not significantly different from the control values. The cooking loss for beef patties produced with rehydrated ground beef was higher than the control. However, there was no significant difference in the sensory of the beef patties among the treatments. In conclusion, there is potential for using vacuum-dehydrated ground beef in beef patty production.

Keywords: vacuum dehydration; minced meat; beef patty; dehydration kinetics; cooking quality

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1. Introduction

Meat is a significant part of a healthy diet due to its nutritional value. Because of its nature, meat is susceptible to microbiological spoilage and oxidative degradation. Various traditional processing techniques, such as dehydration, salting, and fermentation, have been applied for centuries to prevent microbiological spoilage and extend the meat's shelf life. Among these techniques, dehydration provides a microbiologically safe product by reducing its water activity below critical levels [1–3]. Sometimes, salting or smoking is also used to enhance the effectiveness of this technique. Additionally, the dehydration process can be part of producing certain meat products, such as dry-cured meats (pancetta, pastirma, Serano ham, bündnerfleisch, biltong) and dry-fermented meat products (sucuk, chorizo, pepperoni, kantwurst) [4,5].

Meat can be dehydrated using traditional methods or air-forced industrial dryers; however, these methods expose meat surfaces to atmospheric oxygen, leading to autoxidation in meat lipids. The lipid autoxidation results in the formation of primary and secondary oxidation products that reduce the shelf life of the dehydrated meat forming a rancid taste. Therefore, antioxidant additives or vacuum treatment can be used to increase the stability of dehydrated meat. Because of the negative impression of chemical additives on consumer perception, the removal of atmospheric oxygen with vacuum treatment during meat dehydration is a good way to limit the autoxidation process of meat lipids. In addition, vacuum dehydration is also appropriate for foods that are sensitive to the heat [6–9].

Dehydrated meat is used in the food industry to enhance the formulation of instant noodles, baby foods, instant soups, etc. [8,10]. Studies on the dehydration of fresh slaughterhouse products primarily focus on the dehydration of various types of meat like pork, beef, chicken, and goat meat cuts [8–14]. Despite the studies revealing the dehydration kinetics of the meat samples, it is essential to understand the changes occurring within the meat during the dehydration process. Thus, it is important to evaluate the potential effects of the dehydration technique on the sensory and physicochemical properties of the sample. There are a few studies [10] in the literature about the dehydration kinetics of minced meat; however, there is a lack of information about the dehydration kinetics of the flat-shaped minced meat dried in a vacuum dryer at different temperatures, and the physical, chemical and the sensory changes in the dehydrated minced meat after production.

Dehydrated minced meat has some advantages such as availability for international transportation, low volume/weight, easy storage, safety, inexpensiveness, and practical and fast use. These advantages may be useful in the production of certain cooked foods such as beef patties. Research on using vacuum-dehydrated minced meat in beef patty production presents an innovative concept by exploring dried meat technology from a different perspective.

The aim of the present study was to evaluate the potential use of dehydrated minced meat in beef patty production. For this purpose, the dehydration kinetics and some quality characteristics of the minced meat dehydrated under vacuum at 25, 35, and 45 °C were determined in the first stage. In the second stage, the dehydrated minced meat was rehydrated and used in beef patty production. The color, cooking, and sensory properties of the beef patty samples prepared with rehydrated minced meat were compared with those of beef patty samples produced using only fresh minced meat.

2. Materials and Methods

2.1. Material

Beef rounds were obtained from a local supermarket in Istanbul, Turkey. After the removal of excess fat and connective tissue from the surface, the lean meat was ground using a meat grinder with a 3 mm plate. The moisture, protein, and fat contents of minced meat used in the study were 72.6 ± 1.0%, 22.9 ± 0.3%, and 1.5 ± 0.2%, respectively. The minced meat was kept in a cooler at +2 °C during the process. Prior to the dehydration process, the minced meat (40 g) was shaped into a flat round with a thickness of 5 mm and a diameter of 90 mm. The shaped minced meat was then placed on a silicon dehydration plate (Figure 1).

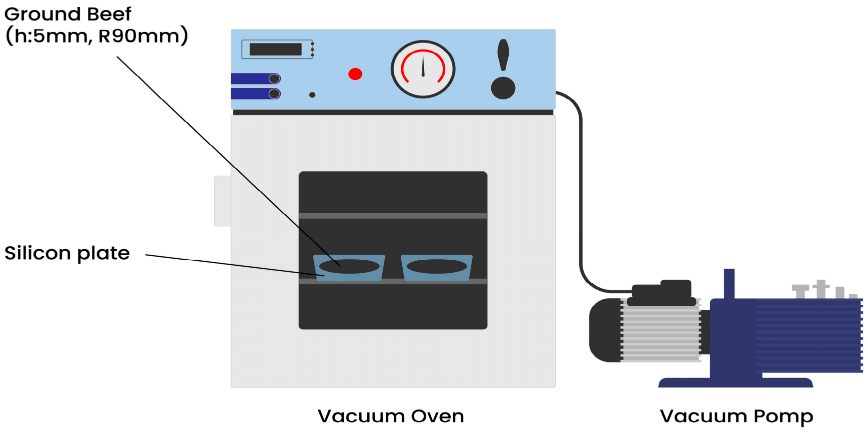

Figure 1. The vacuum drying equipment.

2.2. Vacuum Dehydration Treatment

The minced meat was dehydrated using a vacuum oven (Daihan WOV-30, Republic of Korea; interior dimensions: 47.5 × 16.5 × 15.5 cm) equipped with an oil vacuum pump (EVP, 2XZ-2C, China) operating at an ultimate pressure of 60 mbar and a pump speed of 2 L/s. The samples were dehydrated at different temperatures (25, 35, and 45 °C) until a moisture content of 15% (dry basis) was reached.

2.3. Proximate Composition and pH Analysis

The dry matter, protein (Kjeldahl method), and fat (Soxhlet method) contents of the samples were determined according to AOAC methods. For pH measurement, the round beef samples (10 g) were homogenized with 100 mL of deionized and microfiltered water using an Ultra-Turrax (Daihan, HG-15D, Republic of Korea) operating at 10,000 rpm for 1 min. The pH value of the resultant suspension was measured with a glass electrode on a pH meter (Orion Star A111, Indonesia). The analysis of the samples was carried out with three replicates and three parallels for each group.

2.4. Color Analysis

The CIELAB-based color measurements of the samples were determined using a colorimeter (Chroma Meter CR-400, Japan) with illuminant D65, 2° observer. Following the calibration step, the color parameters (L^*: lightness, a^*: redness, and b^*: yellowness) of the sample were measured, and the total color difference (ΔE) was determined as in Equation (1). Here, the ΔE specifically refers to the CIELAB ΔE, calculated from the values of L, a, and b^*. The color analysis of the uncooked beef patty samples was conducted 15 min after the shaping. The color changes of the samples during the dehydration process were determined in 30 min intervals. The values of the cooked beef patty samples were measured on the outer surfaces of the beef patties 5 min after the cooking step. The color of the beef patties was also mesured three replicates with five samples in each group.

$$\Delta E = \sqrt{(\,\Delta L^*)^2 + (\,\Delta a^*)^2 + (\,\Delta b^*)^2} \tag{1}$$

ΔL^*: lightness difference ($L^*_{\text{sample}} - L^*_{\text{standard}}$)
Δa^*: red/green difference ($a^*_{\text{sample}} - a^*_{\text{standard}}$)
Δb^*: yellow/blue difference ($b^*_{\text{sample}} - b^*_{\text{standard}}$)

2.5. Mathematical Modeling of Dehydration Kinetics

During the vacuum dehydration, the weight of the samples was measured at 30 min intervals until they reached a moisture content of 15% (dry basis). Each measurement was completed within 15 s. In the study, the change in mass of moisture was described using the moisture ratio (MR) concept in Equation (2) [15]:

$$\text{MR} = \frac{w - w_e}{W_0 - W_e} \tag{2}$$

where w is the moisture content at any time, w_e is the equilibrium moisture content, and w_0 is the initial moisture content of the samples. In the present study, this equation was simplified to MR = w/w_0, as described by Rayaguru and Routray [15], since the w_e value was very small compared to w or w_0.

Dehydration curves were fitted using the nine models given in Table 1. In these models, MR represents the moisture ratio of the samples at any time, and t is the dehydration time. Also, the dehydration rate (DR) and effective moisture diffusivity (D_{eff}) values of the samples were calculated according to Equations (3) and (4), respectively [16]:

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \tag{3}$$

where M_t and $M_{t+\Delta t}$ are moisture content of the samples at time t and $t + \Delta t$, respectively, and t is time (min).

$$MR = \frac{8}{\pi^2} exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{4}$$

where D_{eff} is the effective moisture diffusivity (m^2/s) and L is the half-thickness of the samples.

The temperature dependence of D_{eff} was calculated using the Arrhenius equation expressed in Equation (5) [17].

$$D_{eff} = D^0_{eff} exp\left(-\frac{E_a}{RT}\right) \quad (5)$$

where $D_{eff}{}^0$ is the diffusivity at infinite temperature (m^2/s), T is the dehydration temperature (Kelvin), E_a is the activation energy (J/mol), and R is the gas constant (8.31451 J/mol K). The validation of the statistical models was assessed using R^2, χ^2, and RMSE values [16].

Table 1. Dehydration equations used to fit data obtained during dehydration of ground beef.

Model Name	Model Equation	Reference
Lewis	$MR = \exp(-k \cdot t)$	Bruce [18]
Page	$MR = \exp(-k \cdot t^n)$	Madamba et al. [19]
Modified Page	$MR = \exp(-(k \cdot t)^n)$	White et al. [20]
Henderson and Pabis	$MR = a \exp(-(k \cdot t))$	Henderson and Pabis [21]
Logarithmic	$MR = a \exp(-(k \cdot t)) + c$	Togrul and Pehlivan [22]
Two-term	$MR = a \exp(-k_0 \cdot t) + b \exp(-k_1 \cdot t) (-k_1 \cdot t)$	Henderson [23]
Two-term exponential	$MR = a \exp(-k \cdot t) + (1 - a) \exp(-k \cdot a \cdot t)$	Henderson [23]
Wang and Singh	$MR = 1 + a \cdot t + b \cdot t^2$	Wang and Singh [24]
Thompson	$t = a \ln MR + b (\ln MR)^2$	Thompson et al. [25]

MR: moisture ratio; a, b, c, and n are drying coefficients; k, k_0, and k_1 are drying constants.

2.6. Rehydration Treatment

The amount of water removed from the minced meat during the dehydration process was calculated and added back to the dehydrated minced meat in a bowl. The mixture was then allowed to rest in a cooler at +2 °C for 7 h to complete the rehydration step.

2.7. Beef Patty Production

Three different beef patty formulations were prepared in the study. These formulations were as follows:

I: 100% fresh minced meat (control group);
II: 50% fresh minced meat + 50% rehydrated minced meat;
III: 100% rehydrated minced meat.

In beef patty production, 98% minced meat and 2% NaCl were used. Nothing except for salt and minced meat was used in the production of meatballs in order to fully understand the overall effect of the dehydration process on the quality attributes (sensory and color) of the minced meat; neither seasoning nor animal fat was used in the formulation. A mold with 70 mm diameter was used for shaping the beef patties, each weighing 30 g. The rehydrated minced meat used in the production of the beef patty was obtained from the minced meat samples dehydrated at 25 °C. The production was carried out in three replicates. The cooking process of the beef patties was conducted at 175 °C for 6 min (3 min for each side) using a hot plate.

2.8. Cooking Properties

The shrinkage (%), cooking yield (%), cooking efficiency (%), moisture holding (%), and moisture retention (%) capacities of the beef patties were calculated using the equations suggested by Serdaroğlu et al. [26] and defined by Murphy et al. [27]. The cooking properties were carried out in three replicates with five samples in each group.

2.9. Sensory Analysis

The sensory properties of the cooked beef patty samples were determined using a hedonic scale, with evaluations in terms of appearance, texture, odor, bitterness, saltiness, juiciness, flavor, and overall assessment parameters by 12 experienced panelists. The hedonic scale for each sensory attribute was between 1 and 9. For appearance, texture, odor, juiciness, saltiness, flavor, and overall assessment parameters, a score of 1 indicates "very poor", and a score of 9 indicates "very good"; however, for the bitterness parameter, a score of 1 indicates "no bitterness", and a score of 9 indicates "very bitter". The study was carried out in two replicates.

2.10. Texture Profile Analysis

Texture profile analysis was carried out for cooked beef patty samples. After the cooked beef patties were cooled to room temperature, the samples were analyzed with five replicates for each group, and the hardness (g), adhesiveness (g·s), springiness, cohesiveness, gumminess, chewiness, and resilience values were measured using a texture analyzer (Stable Macro System—TA.XT2I) equipped with a cylindrical probe (25 mm—SMS P/25P) and a 5 kg load cell. The operating conditions of the system were pre-test speed: 1 mm/s, post-test speed: 5 mm/s, test speed: 5 mm/s, distance: 10 mm, time: 5 s, and trigger force: 5 g.

2.11. Statistical Analysis

The IBM SPSS 15.0 software package (IBM Corp., Armonk, NY, USA) was used for model fitting (Table 1), dehydration kinetics, and one-way ANOVA analysis ($p = 0.05$). The means of the data were compared using Duncan's multiple comparison test with a significance level of 0.05.

3. Results and Discussions

3.1. Dehydration Kinetics of the Minced Meat

The moisture, protein, and fat contents of the minced meat used in this study were 72.6 ± 1.0%, 22.9 ± 0.3%, and 1.5 ± 0.2%, respectively. To substantially restrict chemical degradation in minced meat or to avoid microbial activity, the moisture content was reduced to 15% (dry basis) from 72% using vacuum dehydration at temperatures of 25, 35, and 45 °C.

As found in many similar studies [28,29], it was seen that the dehydration rate in the first stage of the dehydration process was relatively faster and was found to be close to the linear trend in the later stage (Figure 2).

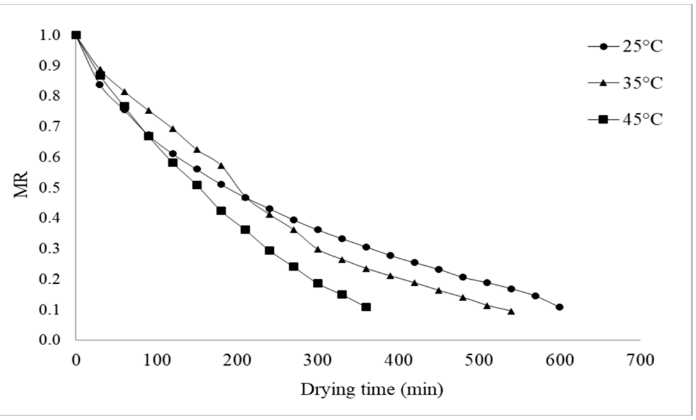

Figure 2. The drying curves of ground beef dried at different temperatures.

Nathakaranakule et al. [30] divide the dehydration period into three stages and report that the dehydration rate is slower in the second and third stages; in this study, such a dehydration and moisture ratio (MR) decreased exponentially (Figure 2). The time versus MR of minced meat was consistent with the nine models specified in Table 1.

Estimated model parameters obtained from fitting the drying models for ground beef are presented in Table 2.

Table 2. Estimated model parameters obtained from fitting the drying models for ground beef.

Model	**Parameters**	**Dehydration Temperature**		
		25 °C	**35 °C**	**45 °C**
Lewis (Newton)	k	0.003519	0.003745	0.004725
	R^2	0.986	0.987	0.991
	χ^2	0.00096	0.00093	0.00081
	RMSE	0.03023	0.02974	0.02739
Page	k	0.007915	0.001404	0.002197
	N	0.8585	1.1825	1.1400
	R^2	0.995	0.996	0.996
	χ^2	0.00030	0.00029	0.00037
	RMSE	0.01651	0.01606	0.01773
Modified Page	k	0.213467	0.224727	0.285328
	n	0.858566	1.175135	1.152527
	R^2	0.995	1.000	1.000
	χ^2	0.00030	0.00029	0.00037
	RMSE	0.01651	0.01606	0.01773
Henderson and Pabis	k	0.196799	0.234340	0.292690
	a	0.9401	1.0367	1.0249
	R^2	0.993	0.991	0.991
	χ^2	0.00044	0.00081	0.00073
	RMSE	0.01989	0.02695	0.02507
Logarithmic	k	0.205892	0.173129	0.187742
	a	0.927153	1.170104	1.261
	c	0.018023	−0.162439	−0.270141
	R^2	0.993	0.996	1.000
	χ^2	0.00106	0.00037	0.00095
	RMSE	0.03023	0.01732	0.02739
Two-term	k_1	3.025370	0.234340	0.292691
	k_2	0.292690	0.234340	0.292690
	a	0.104522	0.939658	0.463285
	b	0.186206	0.097136	0.561630
	R^2	0.998	0.995	0.991
	χ^2	0.00020	0.00092	0.00088
	RMSE	0.01279	0.02695	0.02507
Two-term exponential	k	0.196609	0.234264	0.292646
	a	0.970094	1.018	1.012
	R^2	0.993	0.991	0.991
	χ^2	0.00046	0.00086	0.00080
	RMSE	0.01989	0.02695	0.02507
Wang and Singh	a	−0.177713	−0.180646	−0.225420
	b	0.009289	0.009016	0.013699
	R^2	0.965	0.998	0.998
	χ^2	0.00219	0.00020	0.00013
	RMSE	0.04457	0.01338	0.01035
Thompson	a	−5.184	−4.973758	−4.226896
	b	−0.225222	−0.488357	−0.603903
	R^2	0.986	0.997	0.999
	χ^2	0.15338	0.02547	0.00240
	RMSE	0.37341	0.15096	0.04536

R^2 values must be close to 1 to indicate that the dependent variable is successfully modeled as a function of the parameter in question. In other words, the dehydration curve obtained experimentally must be close to the curve estimated by the model. In order to determine the accuracy of the model, the RMSE value representing variations between experimental and predicted data, as well as χ^2 values, should be close to 0. These values have been calculated and are presented in Table 2. The modified Page model, which has the lowest RMSE (0.01606–0.01773) and χ^2 (0.00029–0.00037) and also the highest R^2 (0.995–1.000) among the nine models applied, was observed to be the best-fit model. Therefore, it is essential that the moisture content can be predicted at any time of dehydration using these models.

The dehydration time for the dehydrated minced meat at temperatures of 25, 35, and 45 °C was 630, 540, and 390 min, respectively (Table 3). As expected, an increase in dehydration temperature substantially decreased the dehydration time (approx. 38%). The reduction in dehydration time may be explained by an increase in the D_{eff} (m^2/s) value (Table 3). As the vapor pressure of water increases with increasing temperature, water moves faster within the minced meat. Therefore, the dehydration speed and D_{eff} values are linearly correlated with temperature rise [31].

Table 3. Dehydration time effective moisture diffusivity and Arrhenius equation parameters calculated for the D_{eff} value of ground beef.

Temperature (°C)	Drying Time (min)	D_{eff} (m^2/s)	R^2	Arrhenius Parameters D_0 (m^2/s)	Arrhenius Parameters Ea (J/mol)
25	630	1.675×10^{-6}	0.957	0.186487	11768.84
35	540	1.774×10^{-6}	0.903		
45	390	2.224×10^{-6}	0.902		

D_{eff}: effective moisture diffusivity; Ea: activation energy.

The D_{eff} values (55–75 °C) determined in some previous studies [28,29] for beef, chicken, and fish were lower than the D_{eff} values determined in this study (25–45 °C). The main reason for this is the breakdown of micro-channels holding water in the minced beef, which could cause water to move away during the processing of minced meat, and therefore, the water is considered to move more easily. The second reason is that the high temperatures during dehydration may result in the denaturation of proteins and create a gel matrix that can cause the evaporation of the water in the interior of the minced meat to be slightly more difficult [30]. However, since low temperatures were used in our study, protein denaturation or gelation is not expected to occur.

3.2. Color Changes during Dehydration of the Minced Meat

The *L**, *a**, and *b** values of the fresh minced meat were 44.28 ± 1.28, 20.21 ± 1.03, and 3.06 ± 0.14, respectively (Table 4). These values changed to ranges of 31.05/34.57, 11.69/13.39, and −1.75/−3.47 after the dehydration. The changes in color values during the dehydration process of the minced meat are presented in Figure 3. The highest decrease in *L** and *a** values compared to the control (fresh minced meat) was observed at 45 °C. In addition, the values of *b** and ΔE dramatically decreased, and the most significant change was observed at 25 °C. The removal of the water from the minced meat by dehydration caused significant changes in the color parameters. These changes could be due to the variations in the scattering of light on the minced meat surface [32]. In addition, the molecular change of oxymyoglobin to metmyoglobin can also play a significant role in the formation of lower *a** values of the samples [33]. Similar results were also found by Rahman et al. [13] on vacuum-dehydrated meat samples whose *L**, *a**, and *b** values decreased after vacuum dehydration. However, a different trend was observed in the color values (*L**, *a**, and *b**) of minced meat dried under vacuum in the study conducted by Aksoy et al. [34]. After the rehydration of dehydrated samples, the *L**, *a**, and *b** values of the samples were measured to be at the intervals of 44.12/46.15, 9.37/10.57, and 3.80/4.45, respectively (Table 4). As seen in Table 4, a positive increase in *L** and *b** values with rehydration was observed compared to dehydrated samples, but a small decrease in *a** value was determined. Since the presence of oxygen alone is not sufficient for the formation of oxymyoglobin from metmyoglobin, metmyoglobin must first be reduced to myoglobin with the help of some reducing enzymes. These enzymes needed for the reduction of metmyoglobin to myoglobin lose their activities with a prolonged period of storage [4]. Therefore, the decrease in *a** values observed in rehydrated minced meat can be explained by this phenomenon.

Table 4. Color parameters and total color difference of the ground beef after dehydration and rehydration.

Color Parameter	Raw Material	Dehydration Temperature (°C) of Ground Beef			Rehydrated Temperature (°C) of Ground Beef		
		25	35	45	25	35	45
*L**	44.28 ± 1.28 ^{a}	34.57 ± 1.12 ^{b}	33.08 ± 1.07 ^{bc}	31.01 ± 1.11 ^{c}	44.12 ± 1.46 ^{a}	45.42 ± 1.74 ^{a}	46.15 ± 1.22 ^{a}
*a**	20.21 ± 1.03 ^{a}	12.18 ± 0.95 ^{bc}	11.69 ± 0.87 ^{c}	13.32 ± 0.98 ^{b}	9.37 ± 0.75 ^{e}	9.46 ± 0.40 ^{e}	10.57 ± 0.58 ^{d}
*b**	3.06 ± 0.14 ^{b}	−1.75 ± 0.04 ^{d}	−2.80 ± 0.02 ^{cd}	−3.47 ± 0.06 ^{c}	3.80 ± 0.23 ^{a}	4.29 ± 1.74 ^{ab}	4.45 ± 0.72 ^{a}
Δ*E*	-	13.43 ± 0.95 ^{b}	15.60 ± 1.05 ^{a}	15.35 ± 0.96 ^{a}	11.29 ± 0.83 ^{c}	11.86 ± 0.85 ^{c}	10.81 ± 1.18 ^{c}

Note: Values in the same line with different lowercase letters ($^{a, b, c, d, e}$) are significantly different as per Duncan's test ($p < 0.05$).

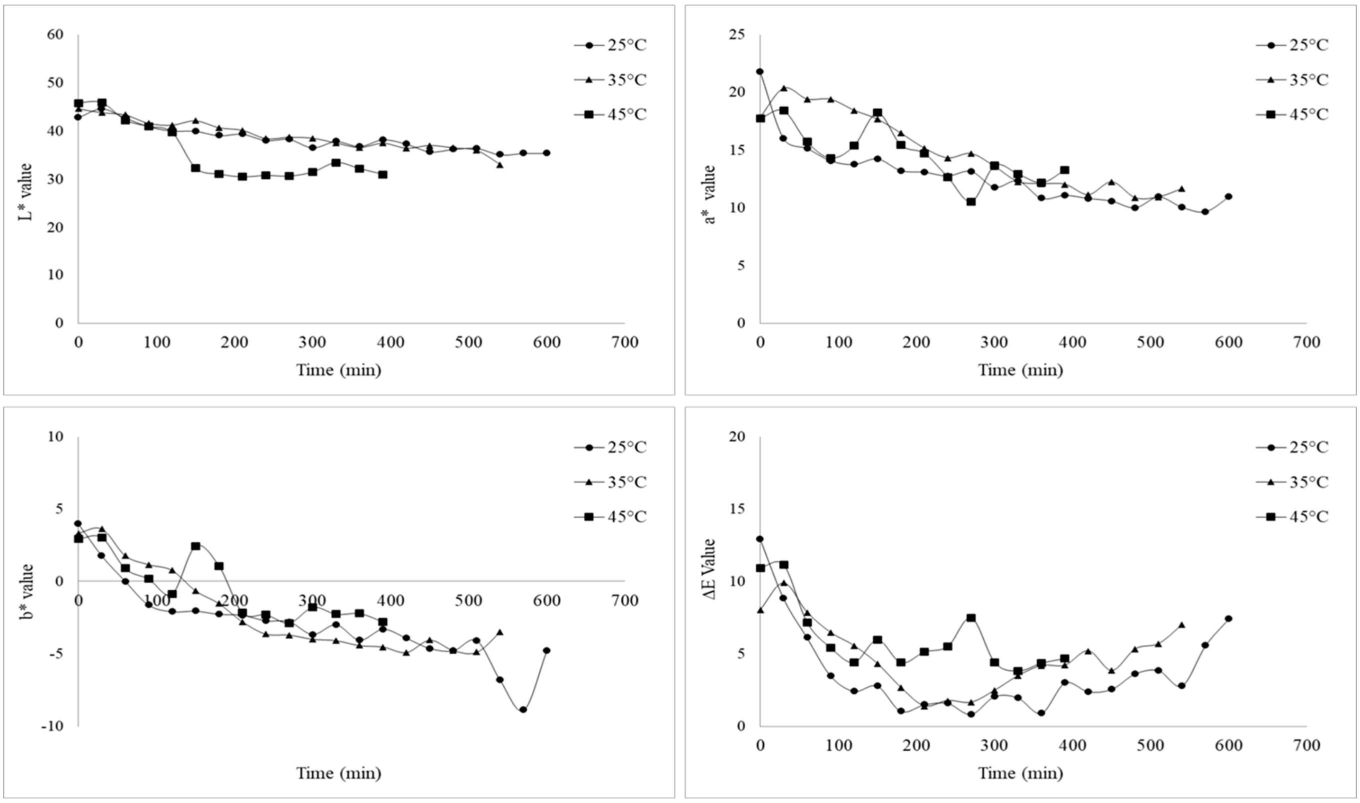

Figure 3. *L**, *a**, *b**, and Δ*E* color parameters of the ground beef during the dehydration process.

3.3. Quality Parameters of Beef Patties Produced with the Rehydrated Minced Meat

The minced meat samples dehydrated at 25 °C under vacuum were mixed with water to provide 100% rehydration. Porous structure formation and deformation rates during the processing of minced meat are effective in the rehydration of the sample [34]. It was found that the rehydrated minced meat had a similar appearance to the normal minced meat appearance (sensory appearance). The changes in quality parameters (color, cooking, sensory, and texture) of rehydrated beef patty samples were investigated in detail.

3.3.1. Color and pH

The color values of uncooked and cooked beef patties are presented in Table 5. As seen from this table, it was observed that as the rate of rehydrated minced meat in uncooked beef patties increased, the *L** value increased ($p < 0.05$), and the *a** and *b** values decreased

($p < 0.05$). This increase in L value (ΔL_{max}) reached 5.51, and the maximum decreases in Δa^*_{max} and Δb^*_{max} were 9.26 and 0.82, respectively (Table 5). The L^* values of the cooked beef patties increased significantly ($p < 0.05$) with the use of the rehydrated minced meat. The differences in pH cause alteration in the myofibrillar volume that affects the light scattering power [35]. The differences observed in L^* values of uncooked and cooked beef patties can be attributed to the pH and/or moisture values (Tables 5 and 6). Similar results were also observed by Joo et al. [36] on L^* values of longissimus thoracis and lumborum porcine muscles with different pH and moisture values. In addition, statistically significant differences ($p < 0.05$) for the a^* value were also found among the uncooked beef patty groups with respect to the use of rehydrated minced meat. An increase in rehydrated minced meat in the formulation resulted in lower a^* values. This case can be explained by the lack of metmyoglobin-reducing enzymes' activity during the storage period [4] as stated above. The differences between the mean b^* values of the cooked beef patties were found to be statistically insignificant ($p > 0.05$). As a result, it is seen that the addition of rehydrated minced meat to the beef patty formulation can significantly affect the color parameters of the uncooked product. On the other hand, after the cooking process, the differences in color parameters of the samples considerably decreased. The b^* values of the samples were not statistically significant ($p > 0.05$). A slight difference in a^* values was detected in beef patty samples. Compared to the control sample, the difference in a^* values for beef patties produced with 50% rehydrated minced meat was not statistically significant ($p > 0.05$); the difference in a^* values for beef patties produced with 100% rehydrated minced meat was significant compared to other groups ($p < 0.05$). There was a statistically significant difference among the samples in terms of the L^* values ($p < 0.05$).

Table 5. Color and pH values of uncooked and cooked beef patties.

Material	Parameters	Fresh Ground Beef (Control) [1]	Mix (1:1) Ground Beef [2]	Rehydrated Ground Beef [3]
Uncooked Beef Patty	L^*	29.84 ± 0.27^{c}	32.48 ± 1.02^{b}	35.35 ± 0.53^{a}
	ΔL^*	-	2.64	5.51
	a^*	17.24 ± 0.69^{c}	11.41 ± 1.02^{b}	7.98 ± 0.32^{a}
	Δa^*	-	5.83	9.26
	b^*	6.34 ± 0.19^{a}	5.52 ± 0.12^{b}	5.93 ± 0.21^{ab}
	Δb^*	-	0.82	0.34
	pH	5.54 ± 0.02^{c}	5.73 ± 0.01^{b}	5.88 ± 0.00^{a}
Cooked Beef Patty	L^*	35.10 ± 0.47^{b}	37.05 ± 0.78^{a}	38.06 ± 0.75^{a}
	ΔL^*	-	1.95	2.96
	a^*	5.71 ± 0.22^{a}	5.71 ± 0.21^{a}	5.39 ± 0.23^{b}
	Δa^*	-	0.00	0.32
	b^*	7.56 ± 0.30^{a}	7.55 ± 0.26^{a}	7.34 ± 0.20^{a}
	Δb^*	-	0.01	0.22
	pH	5.81 ± 0.03^{c}	5.89 ± 0.01^{b}	6.01 ± 0.01^{a}

* Values in the same line with different lowercase letters ($^{a, b, c}$) are significantly different according to Duncan's test ($p < 0.05$). [1]: Control sample: ground beef obtained from fresh meat. [2]: Mix (1:1) of the control ground beef and the rehydrated ground beef dehydrated at 25 °C. [3]: One hundred percent rehydrated ground beef after vacuum dehydration at 25 °C.

The pH values of uncooked and cooked beef patties are presented in Table 5. The addition of dehydrated minced meat increased the pH of the beef patties ($p < 0.05$). The dehydration technique, storage temperature, and packaging method have an important effect on the pH of the dehydrated meat [14,37]. On the other hand, the cooking process also increased the pH values of the beef patty samples in all batches. The loss of cellular buffer ability as a result of the cooking process is probably the reason for this increase [38,39]. In addition, it is also known that the loss of free acidic groups within the meat during the heat treatment increases the pH [40].

Table 6. Cooking values of cooked beef patties.

Cooking Value	Fresh Ground Beef (Control) [1]	Mix (1:1) Ground Beef [2]	Rehydrated Ground Beef [3]
Shrinkage (%)	7.09 ± 1.70 ^{b}	13.92 ± 1.27 ^{a}	14.94 ± 1.39 ^{a}
Increase in beef patty thickness (%)	53.33 ± 4.97 ^{a}	35.56 ± 4.97 ^{b}	35.56 ± 4.97 ^{b}
Decrease in beef patty diameter (%)	14.86 ± 1.63 ^{b}	20.29 ± 1.20 ^{a}	21.43 ± 1.01 ^{a}
Cooking efficiency (%)	67.30 ± 0.55 ^{c}	72.86 ± 1.89 ^{b}	75.59 ± 0.45 ^{a}
Moisture holding (%)	43.59 ± 0.84 ^{b}	48.00 ± 1.39 ^{a}	47.98 ± 0.57 ^{a}

Note: Values in the same line with different lowercase letters ($^{a, b, c}$) are significantly different according to Duncan's test ($p < 0.05$). [1]: Control sample obtained from fresh meat. [2]: Mix of the control meat and the rehydrated meat dehydrated at 25 °C (1:1). [3]: One hundred percent rehydrated meat after vacuum dehydration at 25 °C.

3.3.2. Cooking Values

In order to observe the changes in the cooking properties of the beef patty samples, the shrinkage (%), increase in thickness (%), decrease in diameter (%), cooking yield (%), and moisture retention (%) values were measured, and the results are presented in Table 6.

The use of rehydrated minced meat in the beef patty mixture was found to have a statistically significant effect ($p < 0.05$) on the cooking properties of the samples compared to the samples prepared with the use of fresh minced meat. Except for cooking yield ($p < 0.05$), no statistically significant difference was observed among the cooking properties of batches that were produced with the rehydrated minced meat. The cooking yield and moisture retention properties of the samples produced with the rehydrated minced meat were higher than those of the samples produced with the fresh minced meat, probably due to the differences in pH values. The minced meat samples with higher pH values have higher water-holding capacities because of the distance from the isoelectric point [7,41]. In addition, changes in protein structure that occur during drying can also increase the water-holding capacity [41]. There was no statistically significant difference ($p > 0.05$) among the mixtures that contained 50% and 100% rehydrated minced meat in terms of the shrinkage, increase in beef patty thickness, and decrease in beef patty diameter values. In contrast, the beef patty samples prepared with fresh minced meat were statistically significantly different ($p < 0.05$) from the other groups with respect to those cooking properties. These differences between the groups containing rehydrated minced meat and fresh minced meat could be attributed to the results of the changes that occurred during the dehydration of the minced meat in the vacuum dryer [8]. The shrinkage of the cooked beef patties determined in the present study was probably due to the transversal and longitudinal shrinkage of the meat fibers in the beef patty mixture during cooking [42].

3.3.3. Sensory Properties

The ANOVA results revealed that there was no statistically significant difference ($p > 0.05$) among the sensory properties (except for bitterness) of the beef patties produced using both fresh minced meat and rehydrated minced meat (Table 7). On the other hand, despite the higher sensory scores obtained for the appearance, texture, juiciness, and overall acceptability of the beef patty samples that were produced with the rehydrated minced meat, these values were not statistically significant. In parallel with our research findings, in a study on the use of dehydrated minced meat, no statistically significant difference was found between the acceptability levels of the meat products produced with reconstituted dried minced meat and the meat products produced with fresh meat [43]. On the other hand, despite a statistically significant difference ($p < 0.05$) between the moisture retention values of the cooked beef patties (Table 6), there was no statistically significant difference ($p > 0.05$) between the sensory juiciness values. However, according to Hamm [43], as the water-holding capacity of the meat product increases, the sensory juiciness value of the product also increases. In contrast to Hamm [43], no statistically significant correlation was found in the present study between water retention and sensory juiciness values. On the other hand, a slight decrease that was not statistically significant was observed in the flavor, saltiness, and odor values ($p > 0.05$), which could probably be due to the temperature and vacuum conditions used in dehydration. It could be stated that minimizing the autoxidation under vacuum conditions and keeping the temperature at 25 °C seemed to prevent the occurrence of significant changes in the minced meat that could result in sensory differences in the beef patties.

Table 7. Sensory properties of cooked beef patties.

Sensory Property	Fresh Ground Beef (Control) [1]	Mix (1:1) Ground Beef [2]	Rehydrated Ground Beef [3]
Appearance	5.54 ± 2.37 ^{a}	6.92 ± 1.71 ^{a}	7.08 ± 1.38 ^{a}
Texture	6.31 ± 1.65 ^{a}	6.54 ± 1.61 ^{a}	6.62 ± 1.19 ^{a}
Smell	5.85 ± 2.12 ^{a}	5.54 ± 1.76 ^{a}	5.62 ± 2.29 ^{a}
Salinity	4.38 ± 1.26 ^{a}	3.92 ± 1.50 ^{a}	4.38 ± 1.85 ^{a}
Juiciness	4.85 ± 2.64 ^{a}	4.50 ± 2.50 ^{a}	5.62 ± 2.10 ^{a}
Bitterness	1.18 ± 0.4 ^{b}	1.18 ± 0.4 ^{b}	1.90 ± 1.4 ^{a}
Flavor	6.08 ± 1.85 ^{a}	6.18 ± 2.18 ^{a}	5.88 ± 2.62 ^{a}
Overall Acceptability	5.92 ± 1.44 ^{a}	5.98 ± 1.70 ^{a}	6.62 ± 0.87 ^{a}

Note: Values in the same line with different lowercase letters ($^{a, b, c}$) are significantly different according to Duncan's test ($p < 0.05$). [1]: Control sample obtained from fresh meat. [2]: Mix of the control meat and the rehydrated meat dehydrated at 25 °C (1:1). [3]: One hundred percent rehydrated meat after vacuum dehydration at 25 °C.

3.3.4. Textural Properties

The textural properties in terms of hardness (g), adhesiveness (g·s), springiness (mm), cohesiveness, gumminess (g), chewiness (g·mm), and resilience values of the cooked beef patty samples were determined, and the results are given in Table 8. Except for the cohesiveness, gumminess, and resilience, no statistically significant difference was observed among the beef patty samples for textural parameters ($p > 0.05$). On the other hand, the cohesiveness, gumminess, and resilience values of the cooked beef patty samples produced using rehydrated minced meat were lower than those of the control group ($p < 0.05$). The dehydration process causes structural changes like porosity formation and shrinkage in vacuum-dehydrated minced meat [34]. The variations detected in some textural parameters could be the result of these structural changes that occurred during vacuum dehydration. In addition, moisture content and pH values are also important factors that affect the texture of the meat [44]. Therefore, when evaluating the textural properties of meat products, average pH (Table 5) and moisture retention values (Table 6) should be taken into account.

Table 8. Textural properties of cooked beef patties.

Textural Property	Fresh Ground Beef (Control) [1]	Mix (1:1) Ground Beef [2]	Rehydrated Ground Beef [3]
Hardness (g)	55,799 ± 4090 ^{a}	52,246 ± 5722 ^{a}	56,373 ± 4070 ^{a}
Adhesiveness (g·s)	−6.911 ± 3.02 ^{a}	−8.266 ± 3.474 ^{a}	−8.488 ± 2.860 ^{a}
Springiness (mm)	0.881 ± 0.05 ^{a}	0.912 ± 0.03 ^{a}	0.915 ± 0.03 ^{a}
Cohesiveness	0.750 ± 0.01 ^{b}	0.706 ± 0.01 ^{a}	0.692 ± 0.03 ^{a}
Gumminess (g)	41,806 ± 2623 ^{b}	36,821 ± 3479 ^{a}	38,980 ± 2479 ^{ab}
Chewiness (g·mm)	36,797 ± 2890 ^{a}	33,609 ± 3895 ^{a}	35,711 ± 3288 ^{a}
Resilience	0.371 ± 0.006 ^{b}	0.342 ± 0.004 ^{a}	0.342 ± 0.018 ^{a}

Note: Values in the same line with different lowercase letters ($^{a, b, c}$) are significantly different according to Duncan's test ($p < 0.05$). [1]: Control sample obtained from fresh meat. [2]: Mix of the control meat and the rehydrated meat dehydrated at 25 °C (1:1). [3]: One hundred percent rehydrated meat after under the vacuum dehydration at 25 °C.

4. Conclusions

The first conclusion of the study is that dehydrated minced meat can be commercially used in addition to the international livestock or frozen meat trade by eliminating the characteristic of meat being easily perishable. This means that the advantages of dehydrated foods such as reduced storage space, improved shelf life, and reduced shipping costs can also apply to dried minced meat. The second conclusion of this study is that minced meat dehydrated under vacuum at low temperature can be rehydrated and successfully used in the production of beef patties. It could be also stated that rehydrated minced meat has the potential to be used in the production of various cooked foods. In the study, the effect of different temperatures on the drying kinetics of vacuum-dried minced meat was investigated, however, no hypothesis has been established to evaluate the possible changes in microbiological, physicochemical, and sensory parameters of beef patties produced using minced meat, dehydrated at different temperatures. Therefore, further studies are needed to determine the process conditions for the dehydration of minced meat to be used in beef patty production.

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