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Effect of Tumbling Conditions on the Tendinous and Tenderness Index of Chicken Leg Meat

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Abstract: This article presents the results of the effect of chicken leg meat tumbling parameters on its texture, as assessed by the tendinous-tenderness index $K_{Z\text{-}S}$, where the value of $K_{Z\text{-}S} = 1$ index means maximum tendinous—no tenderness and the value of $K_{Z\text{-}S} = 0$ means no tendinous—maximum tenderness. The tumbling of the meat was performed in an agitator-tilt tumbler. The variable factors of the tumbling process were temperature (T), time (τ), rotational speed (ω) and angle of the tumbler drum inclination (α). The meat texture was tested using the universal testing machine TMS-Pro with a Warner–Bratzler knife. The results of the study were described using second-degree polynomial correlation functions with couplings and presented in the form of diagrams. The effect of the favorable reduction of the tendinous in favor of the tenderness of meat is most significantly influenced by the angle of the inclination of the drum of the tumbler and the time of massage. The optimal results for the tendinous-tenderness index $K_{Z\text{-}S}$ were obtained for the angle of the inclination of the drum of the tumbler $\alpha = 45°$ and tumbling duration $\tau = 50$ min. For such tumbling parameters, the index $K_{Z\text{-}S} = 0.25$ (reduced meat tendons). It is unfavorable, whereas massage tumbling at T = 0 °C, compared to higher and lower temperatures of massaging. The effect of the agitator speed ω depends on the time and temperature. The research results showed that the most favorable effects of the tendinous loss in favor of the tenderness, determined by the tendinous-tenderness index $K_{Z\text{-}S}$, are obtained by the tumbling condition with high a high angle of inclination of the tank ($\alpha > 45°$), a low value of the rotational speed ($\omega < 12$ [1/min]), a longer time ($\tau > 50$ min) and a temperature different from 0 °C.

Keywords: meat tumbling; meat texture; tendinous-tenderness index

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1. Introduction

Meat and meat products are an important source of protein in human diets, and their consumption depends on socio-economic factors, ethics or religious beliefs, and tradition. Many studies show that consumers prefer more tender and sometimes juicier meat, with moderate firmness and not exhibiting tendinous characteristics [1,2]. These are meat characteristics strongly correlated with the overall perceived quality and intention and readiness for purchase. In this context, the important components of meat are the water in its structure and the form of its tendinous components [3].

It is beneficial to keep water in the structure of the meat tissue. The water in the meat should be bound, it should not be perceptible as free water causing leakage. It is unfavorable to lose water during the thermal processing, that influences on the hardness of the texture and consequently lowers the sensory acceptability of the final product [4,5]. In order to bind water in the meat structure and maintain its juiciness, curing and marinating is carried out, and an important part of the meat processing is tumbling. The tumbling is a frequently used technology that improves the texture of meat products and helps achieve the tenderization under mechanical forces (e.g., friction, extrusion and impact forces). The tumbling actions enlarge the intercellular space within the tissues, that reduces the mechanical strength of the myofibers, accelerates the permeation and diffusion of saline ions and breaks the myofilaments (cellular damage). These mechanical forces also help rearrange the distribution of the moisture within the muscular tissues [3,6].

Chicken meat is one of the most desirable meats, due to its low price and its good nutritive value, because of the presence of high-quality protein, a low amount of fat, a high amount of unsaturated fatty acids and relatively less saturated fatty acids. Chicken leg meat, compared to that from the breast, has a richer protein composition [5]. The collagen components, which are contained in the tendinous elements of the connective tissue are particularly valuable. However, the tendinous elements are not acceptable to consumers. They are malleable, hard and cause difficulty in chewing. In order to achieve a proper sensory acceptability, meat with connective tissue elements requires appropriate processing for the formation of its texture. The tumbling process makes it possible to obtain the more favorable characteristics of the product, from chicken leg meat that contains connective tissue tendinous elements. Through tumbling, the original tendinous, malleable texture can be transformed into a tender texture that is sensorily acceptable [7–9].

There are a few studies related chicken meat tumbling. Studies taking into account the time of tumbling, were conducted by Gurikar et al. [10]. They assessed the effect of tumbling on the technological performance of meat block products. Bharti et al. [7] and Lee et al. [8] evaluated the effect of chicken meat tumbling on the improvement of the sensory quality, but Yadav et al. [11] and Singh et al. [4] assessed the effect of tumbling on the texture of goat meat, determined by the force measurement in the Warner–Bratzler test. The effect of the varying temperatures in the tumbling treatment, on the fat and protein structures of chicken meat, was evaluated in [8,9,12–14]. Kim studied the effects of time and temperature in the tumbling operation on the firmness and technological yield of chicken meat [12], while Li studied the effects of these parameters on the degree of leakage [9]. Xargayó conducted research on the effects of the agitator speed and tumbling time on the hardness and sensory properties [15]. Zhaoming, in his article, presented the results of evaluations of the effects of time and speed of rabbit meat tumbling on the technological performance [16]. The research by Dolata concerned tumbling using different agitator designs [17,18]. In the above mentioned publications, the results of the influence of the single parameters of the tumbling process on the selected meat properties were present. On this basis, it is not possible to comprehensively evaluate the effectiveness of the tumbler.

This article presents the results of a study on the efficiency of tumbling in an agitator tumbler. This design variation of the tumbler, in comparison with typical drum tumblers, has great possibilities for selecting the parameters of the tumbling process. The program includes a study of the simultaneous influence of the four factors of the tumbling process (the angle of inclination of the tumbler tank, the agitator speed, the tumbling time, the temperature in the tumbler tank). This made it possible to analyze the influence of the tumbling process factors on the effect of the tumbling. The obtained results allow for the identification of favorable operating parameters.

The presented article is a further elaboration of the results of the research, which were presented in [19–22], where the use of multiple discriminators to evaluate the tumbling effect was analyzed and where the statistical significance of the impact of the tumbler setting parameters on the tumbling effect was analyzed.

Meat obtained from a chicken leg was subjected to a tumbling treatment. The aim of the study was to determine, to what extent the setting parameters of the stirrer tumbler in the tumbling treatment, influenced the change in the meat texture. The texture was evaluated by the tendinous and tenderness index, which determines the favorable direction of change from a tendinous and ductile form to an acceptable tender form. The tendinous-tenderness evaluation method, developed by the authors and presented in [20,21], was used. In a previous study [22] it was shown that the tendinous-tenderness index, compared to other texture indicators, is the most distinctive and effective in assessing the effectiveness of tumbling.

2. Materials and Methods

The material for the test was deboned chicken leg meat. The material was obtained from a certified supplier (according to the declaration—the poultry breed wasDominant White Cornish, aged 6–8 weeks, and before the purchase, the meat was stored at the temperature T = 2 °C for one day). An agitator-tilt vacuum tumbler with a capacity of 150 L was used for the tumbling (Figure 1a). Portions of the tumbled meat had a weight of 30 kg. The tumbling process was carried out under vacuum conditions of 90–95%. The meat in the barbecue grill fix functional marinade was thermally stabilized to the specified temperature, according to the test program, for 8 h. Then it was tumbled. Following the tumbling process, the stabilization was carried out for 6 h at 4 °C and then the samples were taken for the meat evaluation.

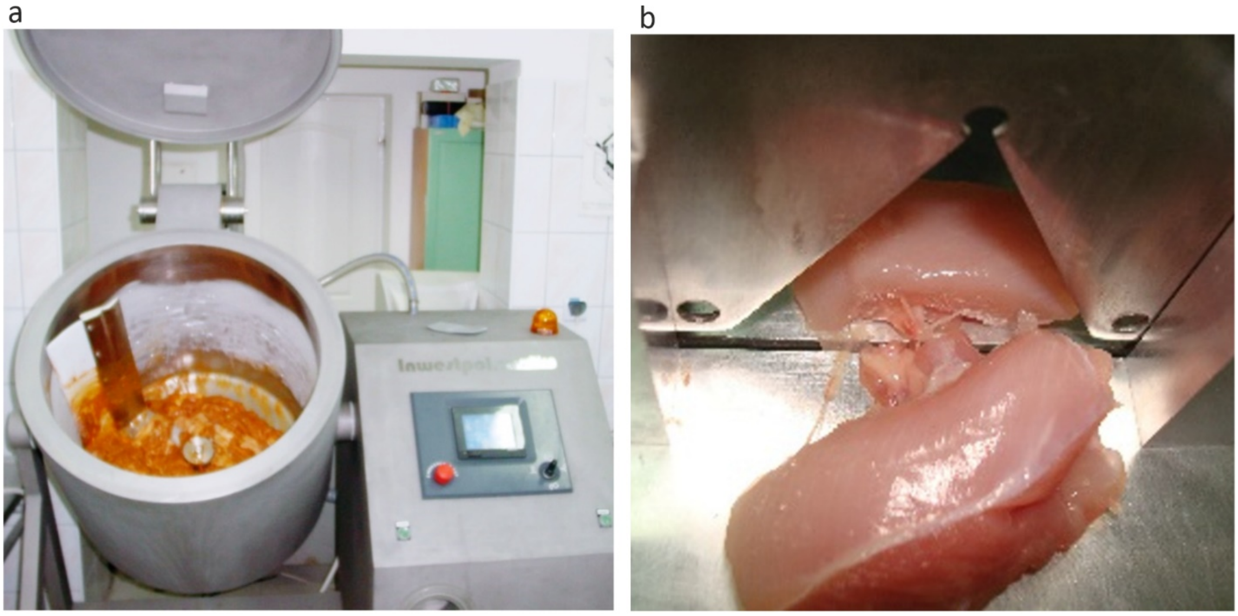

Figure 1. Elements of the research and measurement methods: (**a**) agitator-tilt tumbler with the tumbling meat portion (Inwestpol-Consulting MA150 company, Gdańsk, Poland), (**b**) meat sample subjected to cutting with a Warner–Bratzler knife.

The determination of the tendinous-tenderness index ($K_{Z\text{-}S}$) was carried out, according to the methodology developed by [21] using specimens (1 cm × 4 cm × 3 cm) cut with a Warner–Bratzler knife (Figure 1b). The tendinous-tenderness index was determined over a range of values from $K_{Z\text{-}S} = 1$ (maximum tendinous, zero tenderness), to a value of $K_{Z\text{-}S} = 0$ (zero tendinous, maximum tenderness). A texture analyzer (TMS-Pro, Food Technology Corporation—FTC company, West Sussex, VA, USA, type 432–240) was used to sample the cut meat.

The range of the tumbling variable factors (test program) included the following values of the tumbler operating parameters:

- angle of the tank α [°] changed in the range: 15, 30, 45, 50, 75; (for the vertical axis setting $\alpha = 0°$, there is a mild, low intensity impact, for horizontal axis setting $\alpha = 90°$, there is an intense impact on the tumbled meat);
- stirrer rotation speed ω [1/min] changed in the range: 2, 7, 12, 17, 22;
- meat temperature T [°C] changed in the range: −6, −3, 0, +3, +6;
- massaging time τ [min] changed in the range: 10, 30, 50, 70, 90.

In the full name of the parameter, the word notation is in bold, which will be abbreviated in the following text. In the list of parameter values of the test program, the central values are in bold.

Taking into account all of the configurations of the parameter values of the tumbler, this test program (full, static) included 256 runs of the tumbling operations. The test program was carried out for a combination of the parameter value layout, which was generated in the DOE (design of experiment) module in Statistica 10 QC (quality control) software for a stellar, orthogonal, two-level plan. Nineteen sets of the tumbler parameter layouts were generated. In the test plan, there are three runs of tumbling for the values of the central parameters (three repetitions), which were distinguished in the summary with bold recorded values. From each run of the tumbling operation, three to five samples of meat, subjected to testing, were cut for the determination of tendinous-tenderness index.

Approximation Function and the Statistical Methods

The analysis of the influence of the tumbling factors is described by a mathematical model of approximation (correlation) with the form of a second-degree polynomial function (quadratic function) with couplings.

The general notation of a quadratic function with couplings is of the form:

$$K_{Z\text{-}S} = a_{01} + b_{11}\,\alpha + b_{21}\,\omega + b_{31}\,T + b_{41}\,\tau + c_1\,\alpha^2 + c_2\,\omega^2 + c_3\,T^2 + c_4\,\tau^2 + d_1\,\alpha\,\omega + \\ + d_2\,\alpha\,T + d_3\,\alpha\,\tau + d_4\,\omega\,T + d_5\,\omega\,\tau + d_6\,T\,\tau \quad (1)$$

The components of the first-degree function take into account the proportional interactions. The components of the second degree (second power) inform about the amplification of the impact of a parameter, in relation to the proportional impact, and indicate the possible presence of an extreme (optimum). The coupled parameter interactions provide evidence of the significance of the impact of a specific parameter in combination with another.

The coefficients a, b, c, and d, are the calculated coefficients of the regression equations. The Statistica 10 QC program was used for the calculation and the statistical analysis. Assuming a significance level of $\alpha = 0.05$ and eliminating the non-significant components, the approximation function is of the form (the significance analysis procedure is presented in [20–22]:

$$K_{Z\text{-}S} = 0.889 - 0.825\cdot(\alpha - 45)/15 - 0.679\cdot(\tau - 50)/20 - 0.343(T/3)^2 + \\ + 0.996\cdot((\alpha - 45)/15\cdot(\omega - 12)/5) + 1.653\cdot((T/3)\cdot(\tau - 50)/20) \quad (2)$$

The approximation function takes into account the influence of all of the factors studied. There is a linear (proportional) influence of the angle of inclination of the tumbler tank (α), the tumbling time (τ) and the quadratic (second power) character of the influence of the temperature (T). There are two expressions to account for the coupled effects of the angle (α) with the speed (ω) and the temperature (T) with the time (τ). The level of approximation of the measurement results is characterized by the coefficient of determination $R^2 = 0.30$ and the correlation coefficient $r = 0.55$. Their values indicate a sufficient level of correlation of the approximation function to the measurement results. Only a sufficient level of correlation is due to the fact that the material subjected to the tumbling process (chicken leg meat) is characterized by a high heterogeneity of the histological structure. It contains elements of pure meat tissue, fragments of tendons, and skin. The individual samples were characterized by a large variation in the texture. This is a natural feature of this meat (research material).

The approximation function (Equation (2) of the tendinous-tenderness index $K_{Z\text{-}S}$, within the range of variation of the test factors, takes on the values that exceed the permissible range of values (0–1), implied by the definition of the coefficient. This is due to the mathematical form of the function (second-degree polynomial), which can take a wide range of values. In order to obtain the analyzed tendinous-tenderness index ($K_{Z\text{-}S}$) within the acceptable range of values (0–1), its normalization was carried out with a function from the Statistica program catalog of the form:

$$Z = \exp(Y - 0.5)/(1 + \exp(Y - 0.5)) \quad (3)$$

The original magnitude of $K_{Z\text{-}S}$ in Equation (2) is denoted by Y, while the corrected magnitude (normalized to a range of 0–1) is denoted by Z. The magnitude of Y can take values in the range from (−) infinity to (+) infinity, and after the correction (normalization), the values of Z are limited to the range (0–1). The nature of the transformation is shown graphically in Figure 2. There is an overlap of the original and normalized values in the center (for Y = 0.5 there is Z = 0.5) and the proportionality of the transformation in the range of the original value of the range from Y = 0 to Y = 1 and the corrected value of the range from Z = 0.25 to Z = 0.75. When this range of Y values is exceeded (unacceptable due to the physical, interpreted sense), the value of the normalized function Z is pulled down to an acceptable range (0–1).

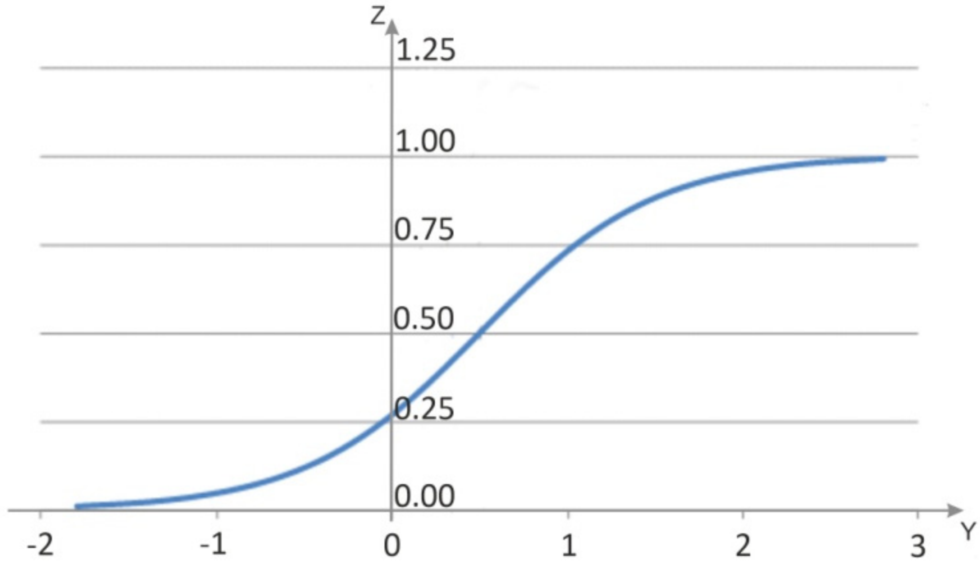

Figure 2. Graphic illustration of the normalization of a function to a range of values (0–1).

3. Results

The nature of the influence of the tumbling parameters on the value of the tendinous-tenderness index, described by the approximation function Equation (2) and normalized to the range of values 0–1, according to (3), is illustrated graphically in Figures 3–6. The obtained results indicate that the tumbling conditions significantly influenced the tendinous-tenderness index, which is consistent with [3,12]. The graphic forms of the approximation function in the figures take into account the influence of only two out of four (T, α, τ, ω) variable parameters of the tumbling process. The parameters not included in the figures are taken as constants with an average value from the test program (values in bold in the list of test program parameter values). Due to the nature of the assumed values of the parameters of the test program, the values of the approximation functions in the corners of the graphs are unreliable (in this field, there is no coverage of the test points, the function has the nature of extrapolating the values). In the approximation figures, a circle or oval indicates the extent of the field adopted for the analysis. The lines indicate the basic analyzed cross sections and the ranges of the nature of the variation of the parameters of the test program settings and the obtained values of the tendinous-tenderness index ($K_{Z\text{-}S}$). The green fields in the figures illustrate the favorable areas of low tendinous in favor of the tenderness values, obtained as a result of tumbling.

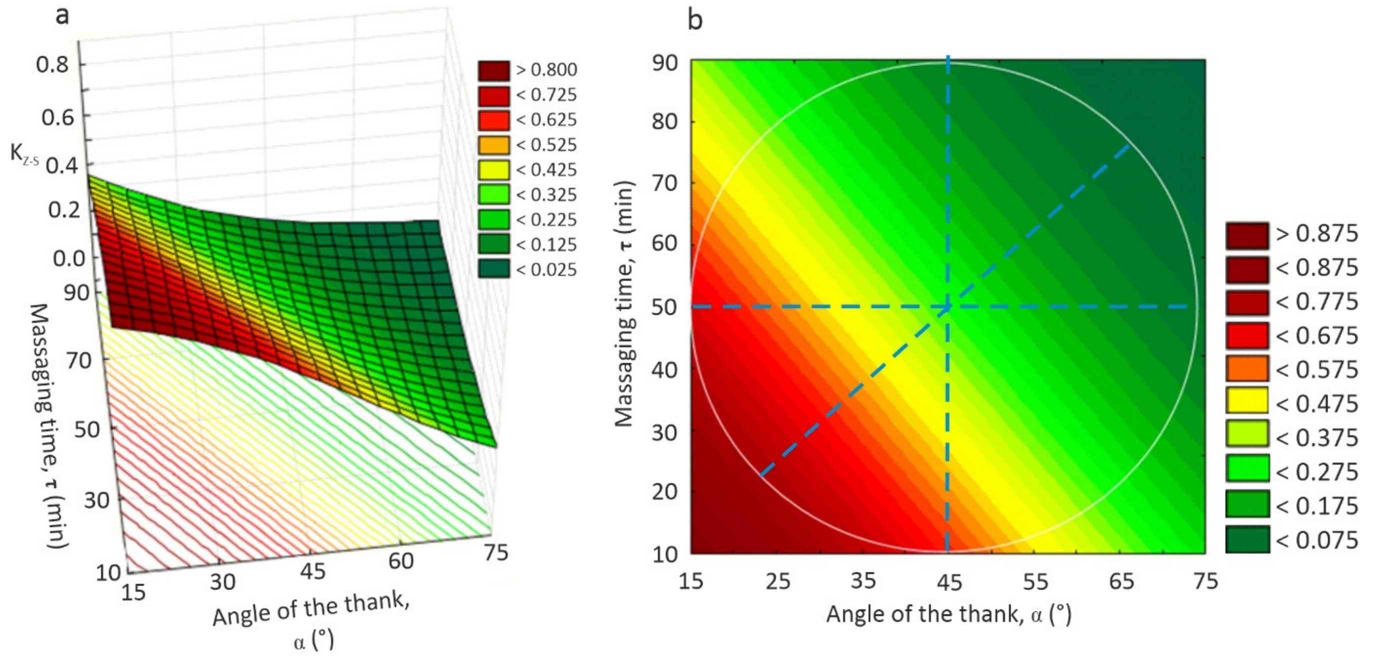

Figure 3. Diagrams of the tendinous-tenderness index $K_{Z\text{-}S}$ function, depending on the angle (α) and the time (τ): (**a**) spatial diagram, (**b**) contour plot.

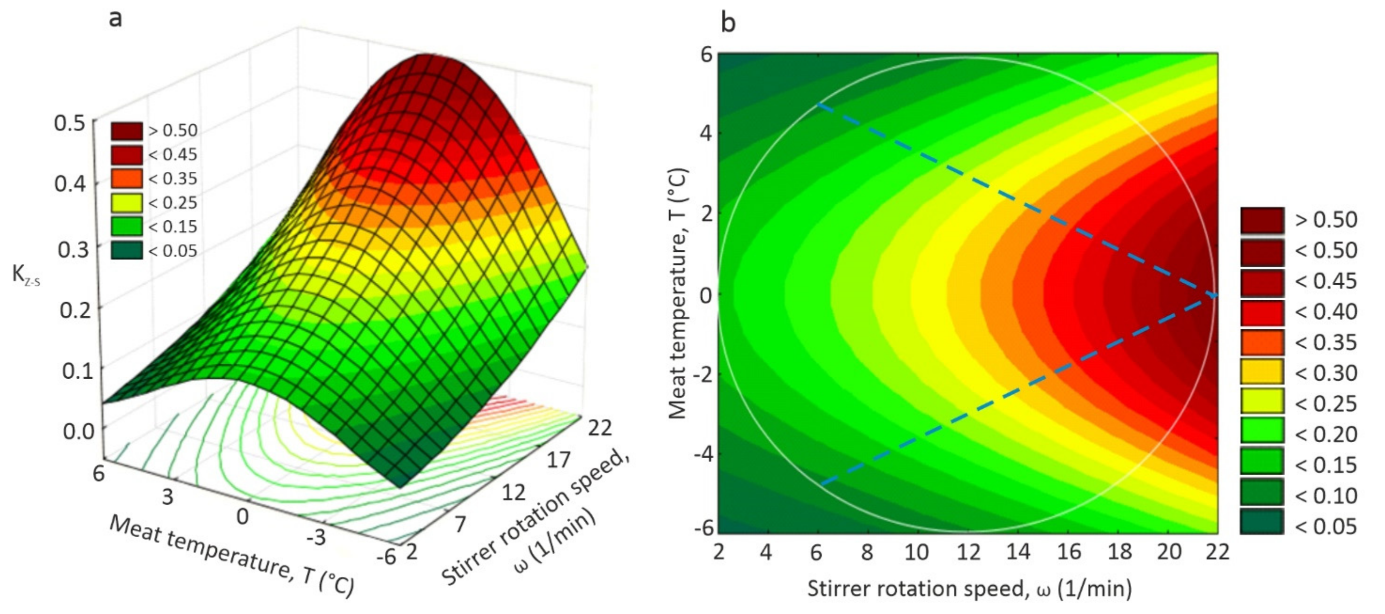

Figure 4. Diagrams of the tendinous-tenderness index $K_{Z\text{-}S}$ function depending on the agitator speed (ω) and the temperature (T): (**a**) spatial diagram, (**b**) contour plot.

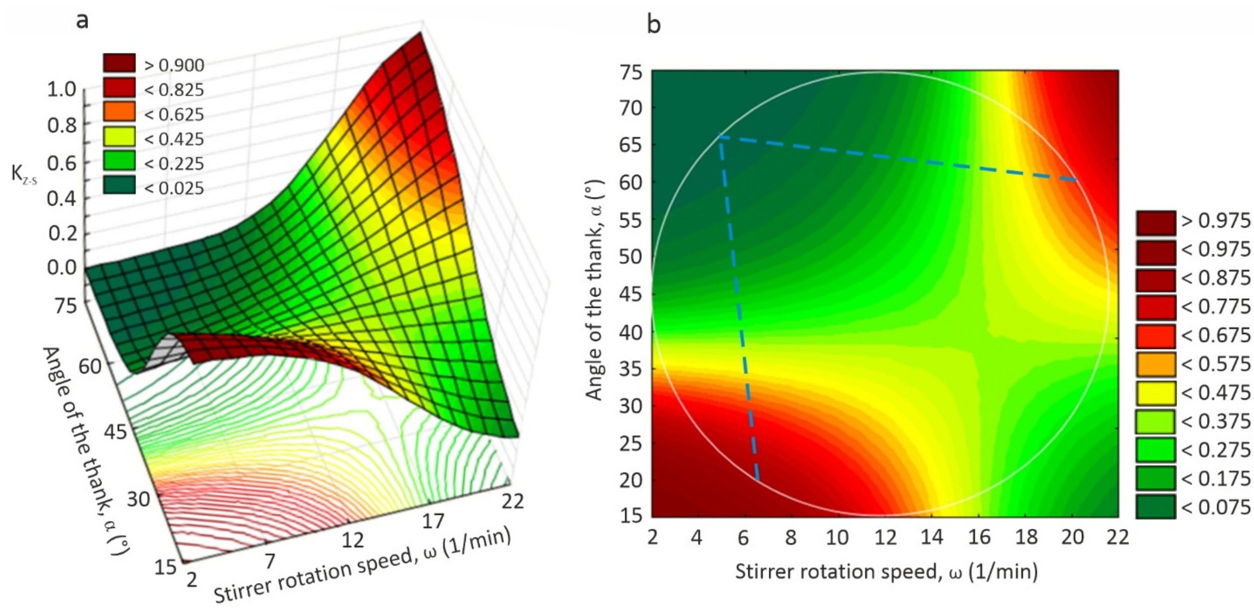

Figure 5. Diagrams of the tendinous-tenderness index $K_{Z\text{-}S}$ function, depending on the angle of inclination of the tumbler drum (α) and the rotational speed of the agitator (ω): (**a**) spatial diagram, (**b**) contour plot.

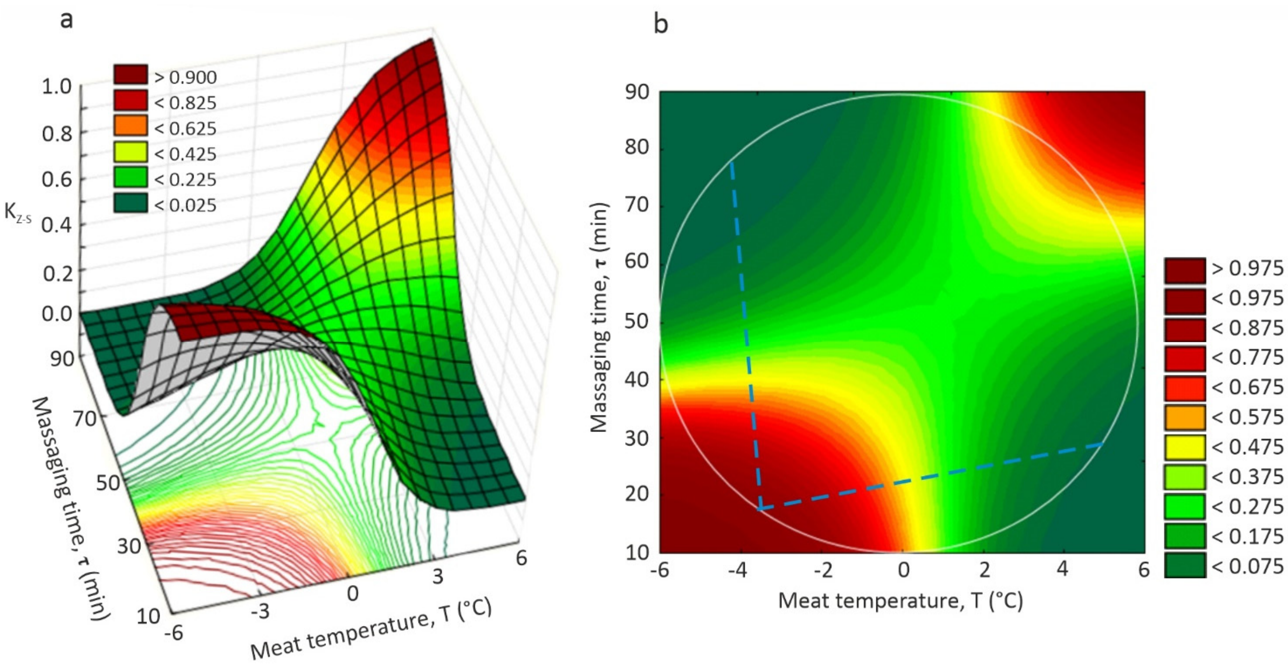

Figure 6. Diagrams of the tendinous-tenderness index $K_{Z\text{-}S}$ function, depending on the temperature (*T*) and the time (τ): (**a**) spatial diagram, (**b**) contour plot.

4. Discussion

From the course of the function in Figure 3, it can be seen that it is advantageous, due to the loss of tendinous, in favor of tenderness, to tumble using higher values of the angle of inclination of the tumbler tank (α) and the tumbling time (τ). The nature of the function course indicates a comparable beneficial effect for increasing the angle and increasing the time, on the tumbling effect. From the nature of the function's plot (Figure 3a), it can be seen that the highest intensity of change occurs in the middle range of the angle and time values. In the range of the average courses of variation, defined by the horizontal and vertical lines in Figure 3b, it becomes apparent that, for the unfavorable parameters of the tumbling process, the meat remains at the level of tendinous $K_{Z\text{-}S}$ = 0.65, while with favorable tendinous parameters decrease to the level of $K_{Z\text{-}S}$ = 0.2 (the tendinous difference in favor of tenderness, by a value of 0.45). The maximum range of the coefficient difference ($K_{Z\text{-}S}$) is illustrated by the diagonal line and is 0.6. The results coincided with the results of Mirade et al. [3] who showed that the tumbling mechanical effect, related to the device used, and the time of tumbling, are most impacted on the mass transfers. The vacuum is less important, in this respect.

The range of variation of the tendinous-tenderness index $K_{Z\text{-}S}$, as a function of the meat temperature T and the rotational speed of the tumbler drum ω (Figure 4), shows a slight influence of these factors on the effect of the tumbling process. There is a range of $K_{Z\text{-}S}$ values from 0.15 to 0.45, i.e., the difference between the favorable and unfavorable tumbling conditions is 0.3. Similar results were obtained by Kim et al. [12], who did not find a significant difference in hardness, between 3 °C and −3 °C, using the same amount of tumbling time ($p > 0.05$). The form of the function shows an unfavorable optimum of tumbling conditions on the obtained tendinous-tenderness index for the temperature of the massaged meat T = 0 °C. The most favorable results for meat tumbling are obtained with lower (minus) and higher (plus) meat temperatures and a low value of the rotational speed of the tumbler. The largest range of variation in the $K_{Z\text{-}S}$ index, with values ranging from 0.47 to 0.12 (a difference of 0.35), is illustrated by the lines in Figure 4b.

The graphical illustration of the function in Figure 5 shows the significant coupling of the influence of the angle of inclination of the tumbler drum (α) and the rotational speed (ω). A favorable tendinous-tenderness minimum value occurs diagonally across the field of variation of α and ω. It is most favorable to use a large value of the angle α (characterizing the intensive nature of the impact on the meat) and a small value of the speed ω (characterizing the low-intensity nature of the impact on the meat). However, favorable effects on the tumbled meat are also obtained with a small value of the tank angle (α) (characterizing the low-intensive nature of the effect on the meat) and a high value of the speed ω (characterizing the intensive nature of the effect on the meat). The simultaneous use of the following α and ω settings is not favorable: the small values (low-intensive tumbling) and high values (very intensive tumbling). The maximum change in the tendinous-tenderness obtained, is illustrated by the lines in Figure 5b. The value of the difference in the tendinous-tenderness index $K_{Z\text{-}S}$, for the favorable and unfavorable tumbling conditions, is 0.6, and can be considered as significant.

Similar to Figure 5, in Figure 6, the graphical form of the approximation function shows the coupled effect from the temperature (T) and the time (τ). The fields of the favorable influence on the tumbling effect occur at a higher temperature (T) and a concomitant short amount of tumbling time (τ), and at lower temperature (T) and a concomitant extended tumbling time (τ). Kim et al. [12] reported that the improvement of textural properties, due to tumbling condition, is greatly associated with the degree of the myofibrillar protein solubility. The most unfavorable tumbling conditions are a low meat temperature and a short amount of time. The maximum range of differences in the favorable and unfavorable effects shown in the figure of the obtained tendinous-tenderness index, is 0.62—significant.

5. Conclusions

The values of the coefficient of determination R^2 = 0.30 and the correlation coefficient r = 0.55 prove the sufficient level of correlation of the approximation function to the measurement results.

The most favorable effects of the tendinous loss in favor of tenderness, determined by the tendinous-tenderness index, are obtained by tumbling: at a high angle of inclination of the tank, at a lower value of the rotational speed, for a longer amount of time, and not at a meat temperature around 0 °C.

Prior to the tumbling, the meat obtained from the chicken leg is characterized by a high tendinous (tendinous-tenderness index $K_{Z\text{-}S}$ = 1, this was confirmed in the previous study after the pretreatment process of marinating). Prior to tumbling, $K_{Z\text{-}S}$ is about 0.85, then as a result of the tumbling process, the tendinous-tenderness index is obtained at the level of $K_{Z\text{-}S}$ = 0.2. This means a significant loss of tendinous in favor of tenderness, by a difference of 0.65.

The study shows that the tumbling treatment makes it possible to improve the texture characteristics of the raw material for higher sensory acceptability, expressed in terms of a favorable loss of tendinous, which is not accepted by consumers, in favor of sensorily acceptable tenderness.

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