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Effect of Frozen to Fresh Meat Ratio in Minced Pork on Its Quality

Igor Tomasevic [1,*,†], Franziska Witte [1,†], Rike Elisabeth Kühling [1], Lisa M. Berger [2], Monika Gibis [2], Jochen Weiss [2], Anja Röser [3], Matthias Upmann [3], Eike Joeres [1], Andreas Juadjur [1], Ute Bindrich [1], Volker Heinz [1] and Nino Terjung [1,*]

1 DIL German Institute of Food Technologies, Prof.-v.-Klitzing-Str. 7, 49610 Quakenbrueck, Germany
2 Department of Food Material Science, Institute of Food Science and Biotechnology, University of Hohenheim, Garbenstr. 25, 70599 Stuttgart, Germany
3 Meat Technology, Department of Life Science Technologies, University of Applied Sciences and Arts, Campus Allee 12, 32657 Lemgo, Germany
* Correspondence: i.tomasevic@dil-ev.de (I.T.); n.terjung@dil-ev.de (N.T.); Tel.: +49-54-3118-3319 (N.T.)
† These authors contributed equally to this work.

Abstract: The meat industry is typically using a mixture of fresh and frozen meat batters for minced meat production. Our goal was to find the exact threshold for fresh to frozen meat ratio capable of controlling the meat temperature during processing, but without having an adverse effect on the sensory quality of minced pork. To achieve this, the percentage of frozen meat used for the minced pork production was increased from 0% (control) to 50% (maximum) in 10% increments. To keep the minced meat temperature in control and make the processing resistant to fat smearing, the addition of 30% of frozen meat to the meat batter is sufficient. The soluble protein content, instrumental cutting force, and the sensory perceived firmness, juiciness, and inner cohesion were not affected by the addition of frozen meat. However, it has contributed to a significant increase of the drip loss and the amount of non-intact cells (ANIC). With the addition of frozen meat into the minced pork, the compliance to ANIC regulation by the German regulatory authorities is technologically (practically) almost impossible.

Keywords: ground pork; non-intact cells; texture

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Citation: Tomasevic, I.; Witte, F.; Kühling, R.E.; Berger, L.M.; Gibis, M.; Weiss, J.; Röser, A.; Upmann, M.; Joeres, E.; Juadjur, A.; et al. Effect of Frozen to Fresh Meat Ratio in Minced Pork on Its Quality. *Appl. Sci.* **2023**, *13*, 2323. https://doi.org/10.3390/app13042323

Academic Editors: Antonio Valero and Roberto Anedda

Received: 20 December 2022
Revised: 4 February 2023
Accepted: 7 February 2023
Published: 10 February 2023

1. Introduction

Post-industrial working time regimes deregulated the eight-hour working day and "free-weekend" model, while diversifying not only the length but also the pattern of the so called "normal" working times. We already know that working hours have a strong association to everyday life, work-life interaction, diet patterns, and health [1]. The increased working load and frequently changing working patterns of the contemporary life style has led to the general lack of consumers' willingness to prepare and cook meals at home and especially for the younger generations [2]. In a modern food-consumption era, we are witnessing an increase in the production and sale of ready-to-eat meals that are developed, including minced meat as one of the key ingredients. Supermarkets all over the world are jam-packed with frozen and easy-to-prepare Spaghettis, Pasta Bolognese, Lasagnas, Meatballs, Chili Con Carne, or Greek Moussakas. Moreover, fast-food restaurants and street food parlors, in any major city in the world, are selling Burgers, Cevapi, Meat Buns, Meat Burek, Empanadas, Quesadillas, Shepherd's Pies, Lahmacun—Turkish Meat Pizzas, and other great tasting meals, that cannot be made without minced meat, in record numbers. Therefore, it is not a surprise that the global minced meat market was worth $66.3 billion in 2021, and it is expected to grow at a considerable annual rate (>3%) from 2022 to 2030 [3]. This makes research regarding different aspects of minced meat quality relevant and important, and especially if its findings can be clearly translated into practical applications.

In minced meat production, meat is subjected to four major processing steps: pre-mincing of meat muscles or meat cuts, mixing, mincing, and forming into a tray [4]. Meat mincing is a process in which meat cuts with largely intact cellular structures are reduced in particle size, usually with the help of the cutting set consisting of pre-cutter(s), perforated disc(s), and rotating knife(s). Mincing involves a crude disruption of cellular structures of muscle and fat cells together with a mechanical disruption of well-ordered fibrillar structures of myofibers and connective tissue sheets [5]. Therefore, mincing itself increases the sensory tenderness, enhances the amount of solubilized proteins and water binding capacity (WBC), and results in a lower cookout time but with an increased cooking loss, compared to fresh meat [5–7].

The gradual reduction in meat particle sizes while mincing, typically from 18 mm over to 9 mm, then 5 mm and finally to 2.8 mm, requires a lot of mechanical energy that is, because of the friction between the meat and moving parts of the cutting set, transforms into heat. The effect of heat on meat proteins, in general, is significant, and it can lead to aggregation and coagulation of sarcoplasmic proteins and unfolding, protein-protein associations, and gelation of myofibrillar proteins. Heat also prompts the denaturation and shrinkage of collagen fibers [8]. For minced meat, whose structure is no longer anisotropic, heating leads to the loss of water, a denser product with increased elasticity, and enhanced sensorially perceived toughness [9]. Meat itself is an excellent feeding medium for a vast number of different microorganisms, some of them pathogenic, and as long as it remains undisrupted, its interior is practically sterile. However, while mincing, the meat surface area is greatly increased and the microorganisms present on it are distributed through the mince. Although, preventing the rise of meat temperature while mincing and its immediate chilling to 0–2 °C retards or inhibits microbial growth with a significant effect on the shelf-life of minced meat [10].

To keep the meat processing temperature in control, and under the values that might negatively affect its texture, WHC, sensory quality, and shelf-life, the meat industry is using a mixture of fresh and frozen meat for minced meat production. However, frozen meat undergoes a range of (negative) quality changes, especially its physical properties. These changes are mainly related to the water content of meat and the formation of ice crystals within muscle fibers during freezing, that physically damage the ultrastructure of the meat [11]. This leads to a subsequent water loss [12] that is directly proportional to the WHC of muscle proteins, and this reduced water content then changes key quality parameters such as color and texture [13]. Lower redness values in frozen pork meat were reported by Alonso et al. [14] and Hansen et al. [15], while there is a general consensus in the literature that meat tenderness increases and shear force values decrease with freezing [16].

The hypothesis of this investigation was that the addition of frozen meat will significantly and undesirably affect the quality of minced pork. The aim was to find the exact threshold for fresh to frozen meat ratio that will be capable of controlling the meat temperature during processing but without having an adverse effect on the sensory quality of minced pork. To the best of our knowledge, this important and very applicable issue for the minced meat industry has never been explored before.

2. Materials and Methods

2.1. Minced Meat Processing

Dices (approximately 5 × 5 × 5 cm) of fresh deboned pork shoulder (*Mm. supraspinatus, deltoideus, omotransversarius, trapezius*) were delivered on the production day for fresh meat, whereas frozen meat dices were delivered a week in advance (Landschlachterei G.H. Diekmann, Essen Oldenburg, Germany). The fresh meat delivery temperature was approximately 3 °C, and pH values were around 5.7. The frozen meat delivery temperature was around −18 °C. To investigate the effect of fresh/frozen meat ratio in minced pork production on its quality, the percentage of frozen meat used was increased from 0% (control) to 50% (maximum) in 10% increments. One day prior to production, frozen meat was tempered to −12 °C to mimic the typical conditions in industrial processing. Minced pork was produced in 40 kg batches, once per day and on six different days to attain six replicates in total. Mixing of the fresh and frozen meat into the homogeneously distributed batches was performed manually and conducted by the same person for all replicates. The minced meat production line consisted of a meat mincer (MD 114, Maschinenfabrik Seydelmann KG, Aalen, Germany), vacuum filling machine (VF 838 S, Albert Handtmann Maschinenfabrik GmbH & Co. KG, Biberach an der Riß, Germany) equipped with the inline grinding systems GD 451 (5-pieces) & GD 452 (3-pieces), and modified atmosphere packaging machine (J. Pack Srl, Val Brembilla BG, Italy). The production and packaging procedure was identical to the one described in the work of Witte, Sawas, Berger, Gibis, Weiss, Röser, Upmann, Joeres, Juadjur, Bindrich, Heinz, and Terjung [4]. Before and after each mincing step, the pH value and temperature were checked for unusual discrepancies (n = 10) (testo 208, Testo SE & Co. KGaA, Lenzkirch, Germany). Minced meat was stored at approx. 2 °C for two days after production and before analysis (Figure 1).

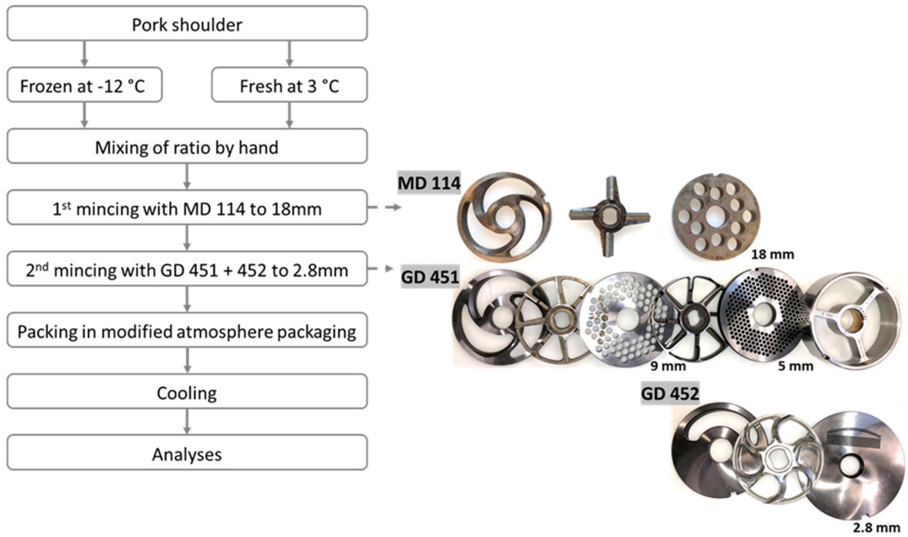


Figure 1. Flow chart of the minced pork production process with photographs of the grinding systems used.

2.2. *Analyses of Proximate Composition*

2.2.1. Fat

Fat content of minced pork with 0/100 and 50/50 frozen to fresh meat ratios was analyzed as described by Baune et al. [17]. Results were expressed as the triglyceride content per 100 g sample and examined in a single analysis per replicate, resulting in n = 6. Fat contents of minced pork with 10/90 to 40/60 frozen to fresh meat ratios were interpolated.

2.2.2. Protein

Minced pork with 0/100 and 50/50 frozen to fresh meat ratios were examined for crude protein in a single analysis (n = 6) and for soluble protein in a triple analysis (n = 18) per replicate. The procedures followed, and calculations conducted for protein content were already reported in Witte, Sawas, Berger, Gibis, Weiss, Röser, Upmann, Joeres, Juadjur, Bindrich, Heinz, and Terjung [4].

2.2.3. pH Values

Values of pH were established in triplicate from all solutions made for soluble protein content analyses (n = 18) with a Seven-Easy pH meter (Mettler Toledo, Columbus, OH, USA).

2.2.4. Moisture

Moisture content was analyzed with a method previously described by Witte et al. [18]. It was calculated per 100 g and examined in a technical triplicate for each minced pork replicate, resulting in n = 18.

2.3. Determination of Drip Loss

To determine the drip loss of raw minced pork meat, the Grau and Hamm [19] method was used after slight modification as described in Witte, Sawas, Berger, Gibis, Weiss, Röser, Upmann, Joeres, Juadjur, Bindrich, Heinz, and Terjung [4]. All analyses were performed in triplicate for each minced meat replicate, resulting in n = 18 per method applied.

2.4. Histological Analysis of Amount of Non-Intact Cells

Histological analyses were conducted at the Laboratory of Raw Material Science Animal of the University of Applied Sciences and Arts (Lemgo, Germany). The trials were organized according to the procedure of Friedelsheimer et al. [20]. Sample preparation, dehydration, staining, evaluation with a microscope slide scanner, equipment used, and calculation of the amount of non-intact cells (ANIC) were performed in the exact same fashion as described in the work of Witte, Sawas, Berger, Gibis, Weiss, Röser, Upmann, Joeres, Juadjur, Bindrich, Heinz, and Terjung [4]. In total, four out of the six minced pork replicates were analyzed for ANIC (n = 32).

2.5. Sensory Analyses

2.5.1. Instrumental

The cutting force of cooked meat balls (approx. 30 g), formed manually, was measured. Five meatballs were made from each minced pork replicate (6) and were cooked in an oven (Joker B, Eloma GmbH, Maisach, Germany) at 150 °C until an internal temperature of 78 °C was reached and then cooled to room temperature before analysis. Meatballs were placed in a slot and were cut through by the razor blade with a constant speed of 2 mm/s. The maximum force (N) to cut through the meatball was recorded (n = 30). The instrument used for all the analyses was a Texture Analyzer (TA-XT2) with the corresponding software (Texture Expert Exceed) (Stable Micro Systems Ltd., Guildford, UK).

2.5.2. Trained Panel

For sensory evaluation of minced pork, meatballs were prepared as described in Section 2.5.1 for the textural analysis of cooked meatballs. A panel, trained and validated in line with the recommendations of Djekic et al. [21], consisted of ten assessors and used an 11-point-scale to evaluate cooked meatballs. The rating of firmness, juiciness, inner cohesion, and inner structure was carried out using a questionnaire according to DIN 10969 [22] with a scale from 0 to 10 with 0.25 steps. On this scale 0 means soft, dry, fine inner structure, and loose cohesion, while 10 means firm, juicy, rough inner structure, and strong cohesion.

2.6. Statistics

Data were tested for normal distribution using the Shapiro-Wilk test and the Brown-Forsythe test for equal variance with a significance of $\alpha = 0.05$. If tests were passed, data were analyzed for significant differences using One-Way Analysis of Variance (ANOVA) and Tukey's multiple comparison test with a significance level of $\alpha = 0.05$. If neither the normality nor equal variance test was passed, an ANOVA on ranks with Tukey's multiple comparison test was conducted with a significance level of $\alpha = 0.05$. Statistical analyses were also conducted using SigmaPlot 14.0 (Systat Software Inc., San Jose, CA, USA).

3. Results and Discussion

3.1. Temperature during Processing

The coalescence instability of pork fat when subjected to different degrees of comminution and subsequent heating is a known fact. When pork fatty tissue is disintegrated and friction-heated during the production of minced meat, it can be found in roughly two forms. First, the fat remains in its natural fat cells as a single cell or in aggregates. Second, the fat can be squeezed out of the cell and dispersed into the surrounding meat batter in the form of small droplets or larger fat pools. The latter phenomenon is known as "fat smearing" [23]. Smeared fat may trigger all kinds of problems in minced meat. First, the texture deteriorates as otherwise buttery and savory fat becomes distorted because it was heated and "broken" into liquid, leaving a dry, "sandy" consistency behind [24]. With an increased amount of fat smearing, the energy applied during comminution dissipates more and more as viscous energy (heat), leading to a less efficient mincing of the that-far non-disintegrated fat tissue [23]. It also adversely affects the efficiency and effectiveness of cleaning and disinfection procedures established for meat mincing equipment.

When minced pork, in our investigation, was produced exclusively from fresh meat chilled at 3 °C, the meat temperature at the end of the first mincing cycle remained almost unaffected (Figure 2a). However, during the second mincing cycle, additional energy dissipated into heat increased the end meat temperature to 5.4 °C (Figure 2b). This led to a small to moderate appearance of fat smearing on the surface of minced pork (Scheme 1a). When the frozen to fresh meat ratio was altered, by the gradual addition of frozen meat, this made the batter easier to handle as it became more rigid, while remaining pliable. By adding just 10% of frozen meat, the end-product temperature was decreased to 1.5 °C, and the 30/70 frozen to fresh meat ratio resulted in a harder and more resistant to smearing fat tissue (Scheme 1b) because its temperature by the end of the second mixing cycle was well below 0 °C (Figure 2b). Meat was also comminuted more cleanly and regularly, with virtually no connective tissue wrapping itself around the cutting heads. However, by tempering the final temperature of minced pork to −1 °C, and with the addition of 50% of frozen meat, it appeared that it has lost a bit of its flexibility and became slightly brittle, as it shattered into smaller fragments when comminuted (Scheme 1c). No fat smearing or drips formed at cut surfaces, were observed when the highest 50/50 frozen to fresh meat ratio was utilized, since the below zero temperatures immediately re-froze any exude almost immediately.

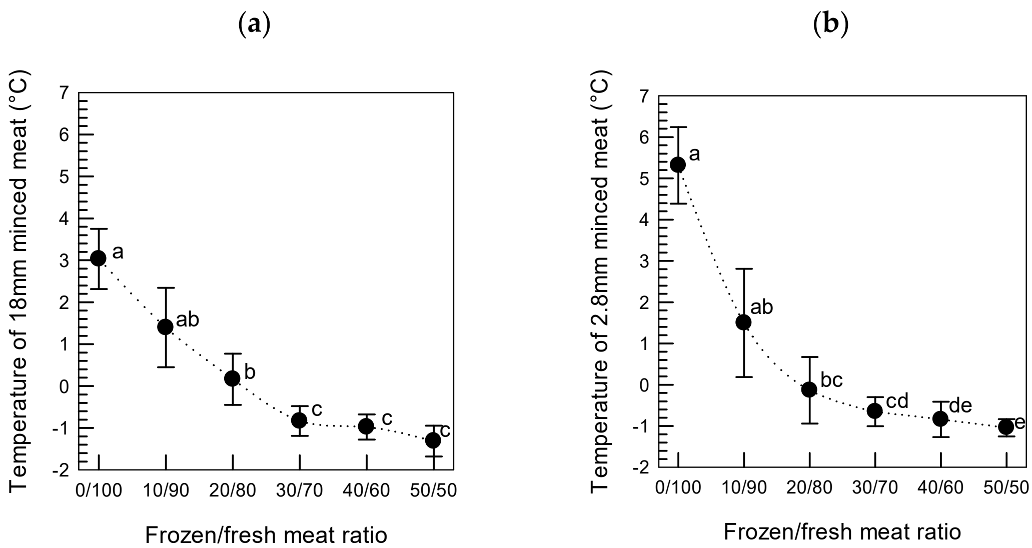
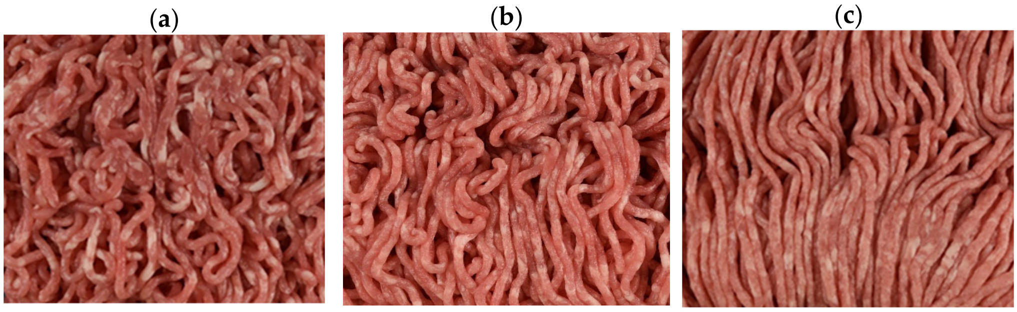


Figure 2. Temperature of 18 mm-minced meat after the first mincing step (**a**) and 2.8 mm-minced meat after the second mincing step (**b**) (n = 30) (mean ± standard deviation) of minced meat with varying frozen to fresh meat ratios. Different letters indicate significant differences ($p < 0.05$).



Scheme 1. Photographs of raw minced meat with a 0/100 (**a**), 30/70 (**b**), and 50/50 (**c**) frozen to fresh meat ratio.

3.2. Proximate Composition and Water Holding Capacity

The results of a proximate composition analysis for the minced pork samples (Table 1) revealed no significant influence of the addition of frozen meat on fat (~13 g/100 g), protein (~18 g/100 g), or even moisture content (~69%) of the end-product. Meat loses moisture during the freezing process because its exterior is subjected to heat and mass transfer exchange with the environment. The difference between the water vapor pressure on the meat surface and that in the air bulk of a freezing chamber is the driving force for the meat dehydration (loss of moisture) [25]. However, time is the most important factor in this process because the longer the storage time, the greater the losses due to evaporation. This effect has a greater influence in the case where the chamber has a greater airspeed [26]. The fact that there was no statistically significant difference ($p > 0.05$) in moisture content between the minced pork samples in our investigation, made exclusively from fresh meat and with the addition of 50% of frozen meat (Table 1), can be explained by the really short time of frozen storage. It seems that the period of only one week was not long enough to significantly decrease the moisture content of frozen pork meat, compared to the fresh one.

Table 1. pH value, fat, protein, soluble protein, and moisture content as well as drip loss (mean ± standard deviation) of minced meat with varying frozen to fresh meat ratios (n = 18).

Frozen /Fresh	pH Value	Fat (g/100 g)	Protein (g/100 g)	Soluble Protein (%)	Moisture (g/100 g)	Drip Loss (%)
0/100	5.83 [a] ± 0.10	13.48 [a] ± 1.69	18.07 [a] ± 0.62	34.94 [ab] ± 1.04	68.12 [a] ± 2.50	15.18 [a] ± 1.83
10/90	5.76 [a] ± 0.17	13.11 [a] ± 0.37	18.23 [a] ± 0.67	35.83 [ab] ± 1.06	68.94 [a] ± 1.86	15.94 [ab] ± 2.05
20/80	5.73 [a] ± 0.18	13.20 [a] ± 0.22	18.19 [a] ± 0.61	34.69 [a] ± 1.53	69.10 [a] ± 1.38	17.39 [ab] ± 1.26
30/70	5.84 [a] ± 0.16	13.30 [a] ± 0.68	18.15 [a] ± 0.58	35.83 [ab] ± 1.55	68.78 [a] ± 1.62	18.30 [bc] ± 0.90
40/60	5.85 [a] ± 0.14	13.39 [a] ± 1.18	18.11 [a] ± 0.58	36.17 [b] ± 1.50	68.70 [a] ± 1.52	19.93 [cd] ± 1.61
50/50	5.87 [a] ± 0.16	13.02 [a] ± 0.86	18.27 [a] ± 0.75	36.09 [ab] ± 1.87	69.01 [a] ± 1.49	21.63 [d] ± 1.75

[abcd] Different letters indicate significant differences ($p < 0.05$) for each parameter.

Many investigations have attempted to determine the effect of freezing on pork meat drip loss. Important factors on drip loss that have been reported so far are the freezing rate, freezing time, frozen storage temperature, and pH [27]. The latter was the same for both fresh minced pork and all the different frozen to fresh meat ratios used for minced pork production in our investigation. All meat was frozen and stored in the same way before the minced pork production, so none of those considerations might explain the significant differences between drip losses for fresh (0/100) minced pork (15.18%) and the drip loss (21.63%) of minced pork made from 50% of frozen meat (50/50) (Table 1). However, we already know that the drip loss for frozen meat is confirmed as being higher than that of fresh (unfrozen) meat [28]. Therefore, the higher the share of frozen meat that was used to produce minced pork in our investigation, the higher the drip loss was observed, while the content of soluble proteins also increased slightly, although not statistically significant ($p > 0.05$) because of the relatively high standard deviations detected (Table 1). Lastly, our results are supporting the hypothesis of Tyszkiewicz, Kłossowska [28] of a higher drip loss with an increasing amount of non-intact muscle fibers (ANIC).

3.3. Sensory Analysis

Instrumental textural (sensory) measurements of a cutting force (using a knife blade as an impression of top front teeth) give us an objective indication about the firmness of a product. In this investigation, when cooked meat balls made entirely from fresh minced pork with varying frozen to fresh minced pork ratios were put up to this instrumental sensory analysis, no statistically significant differences ($p > 0.05$) between cutting forces were observed (Figure 3). Since there was only a negligible increase in the soluble protein content in between the different frozen to fresh minced pork ratios (Table 1), this led to a similar quantity of intermolecular protein interactions during the cooking of the meat balls and resulted in a similar firmness of the end-products. Sensory firmness analysis of the cooked meat balls performed by the trained panelists confirmed the instrumental findings. The panelists also could not observe the differences in firmness between samples, and their average scores were set right in the middle of an 11-point scale (Figure 4a), irrespective of the ratio of frozen to fresh meat used for the preparation of cooked meat balls.

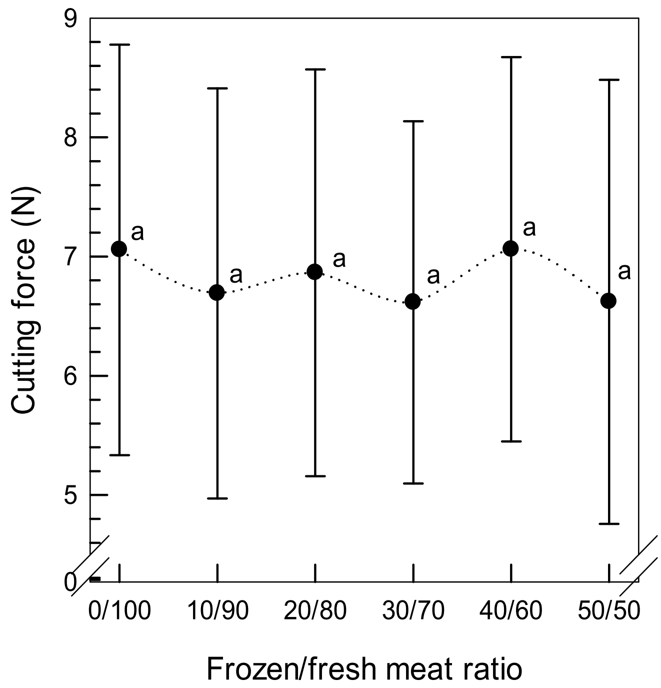


Figure 3. Cutting force (n = 32) (mean ± standard deviation) of minced meat with varying frozen to fresh meat ratios. Different letters indicate significant differences ($p < 0.05$).

Firmness and juiciness are inversely interrelated. The firmer the cooked pork meat, the dryer it gets [29]. The perception of juiciness is also highly dependent on the fat content that is released while chewing the meat products [30]. Since there was no difference in instrumentally measured and sensory perceived firmness, and the fat content was almost identical for all frozen to fresh ratios of minced pork (Table 1), it was surprising that the juiciness was also assessed as not significantly different by the panelists (Figure 4b). Inner cohesion was also rated similarly to firmness and juiciness and in the middle of an 11-point scale (Figure 4c), where 0 meant loose and 11 meant strong inner cohesion. The only sensory parameter that was significantly affected by the addition of frozen meat into the minced pork meat batter was the inner structure of cooked meat balls. The panelist assessed the inner structure of cooked meat balls made entirely of fresh meat as rougher compared to the ones made with the addition of at least 30% of frozen meat (Figure 4d). The higher the ratio of frozen meat utilized to produce minced pork, the finer the inner structure of the cooked meat balls was made, as perceived by the sensory panelists.

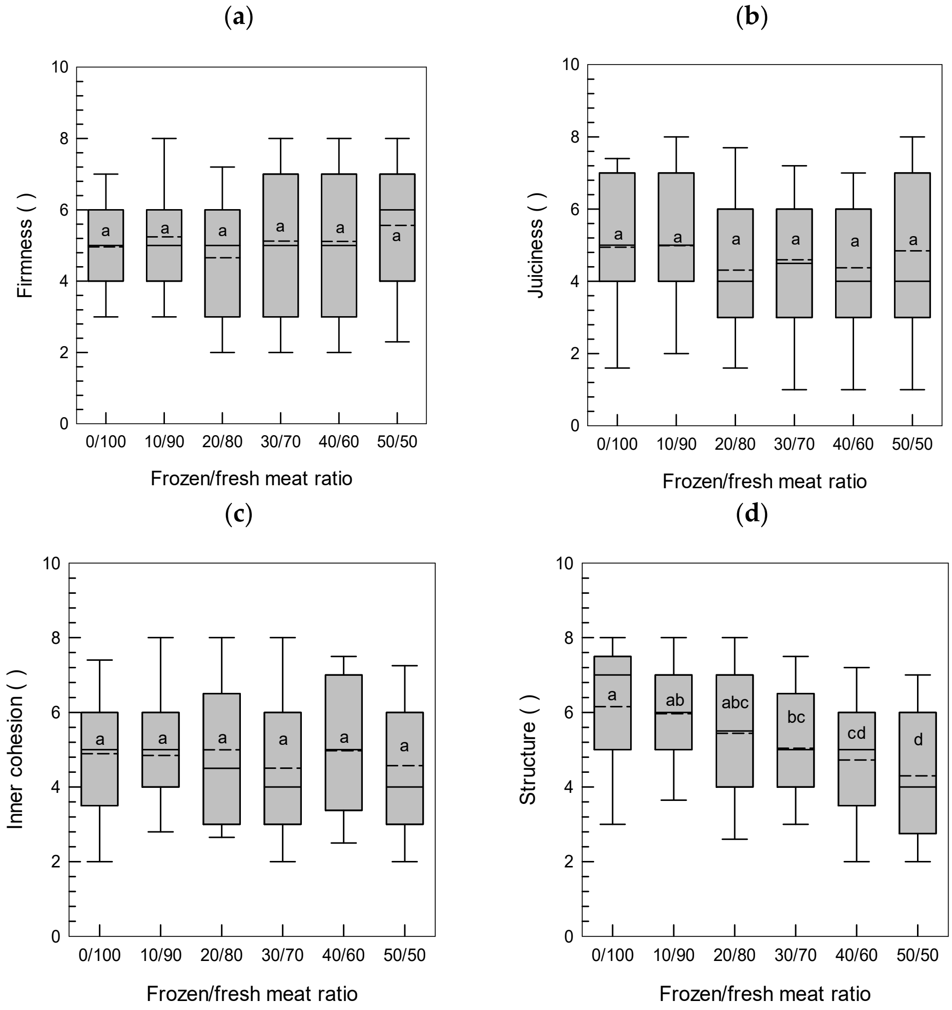


Figure 4. Boxplots of sensory evaluation of (**a**) firmness, (**b**) juiciness, (**c**) inner cohesion, and (**d**) inner structure (n = 96) of cooked meatballs consisting of varying frozen to fresh meat ratios; 0 means soft, dry, loose cohesion, and fine structure, whereas 10 means firm, juicy, strong cohesion, and coarse inner structure. Dotted line marks mean, full line marks median, box marks lower and upper quartile, and whiskers mark distance until lower and upper extreme. Different letters represent significant differences ($p < 0.05$) for each parameter.

3.4. Amount of Non-Intact Cells

When a mechanical force is applied to the muscle fibers, the well-ordered fibrillar structures and connective tissue are disrupted, making proteins and intramuscular substances open for extraction [31], and the amount of non-intact muscle fibers (ANIC) is significantly increased [32,33]. The amount of ANIC negatively influences the quality and functionality of minced meat and is, therefore, officially restricted to 20% vol. in Germany [4,34].

The lowest amount of ANIC (30%) in our experiment was observed for the minced pork made exclusively from fresh meat chilled at 3 °C (Figure 5). This result is in concurrence with the investigation of Witte, Sawas, Berger, Gibis, Weiss, Röser, Upmann, Joeres, Juadjur, Bindrich, Heinz, and Terjung [4] where lower amounts of ANIC also could not be registered when the two step mincing process was utilized. We already know that the first step increases the amount of ANIC by a factor of 2.4, and that the second step raises it further by a factor of 2.7 [32]. In terms of the meat mixing and forming of minced meat under pressure, the results are contradicting. The results of Beneke [33] suggest that these processing steps are crucial for the muscle fiber disintegration, while the reports of Berger, Witte, Terjung, Weiss, and Gibis [32] have not provided evidence that they have a significant influence on the ANIC formation. Presumably, the more gentile mixing and lower pressures applied during forming diminish the negative effect of these processing steps. This also explains why only 6% of artisanal-produced and almost 45% of industrial-produced minced meat had an ANIC over the regulatory limit in Germany [35].

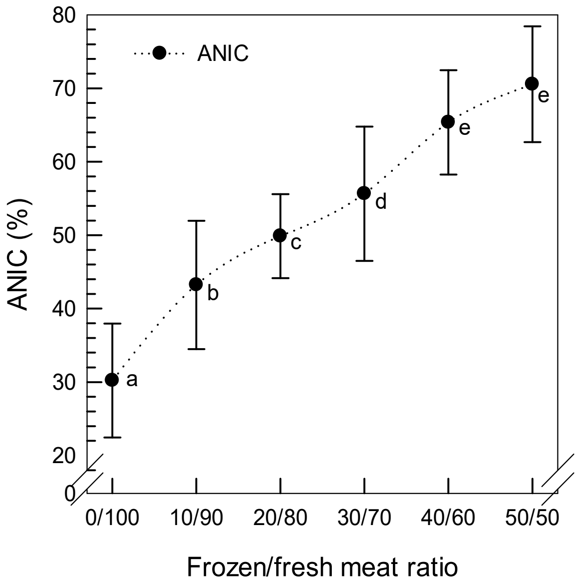


Figure 5. Amount of non-intact cells (n = 32) (mean ± standard deviation) of minced meat with varying frozen to fresh meat ratios. Different letters indicate significant differences ($p < 0.05$).

The amount of non-intact cells significantly ($p < 0.05$) increased with an increased portion of frozen meat added to the meat batter. The highest amount of ANIC was measured in the 50/50 frozen to fresh meat ratio with 70% vol. (Figure 5). This phenomenon could be explained by the effect of freezing on the microstructure of meat. Depending on the freezing rate, larger (slow freezing) or smaller (fast freezing) ice crystals out of the immobilized and free water will be formed [13] and they are capable of disrupting muscle cells [36]. It seems that the freezing of the meat used in our experiments led to the increased amount of ANIC in the minced pork. Therefore, the more frozen meat we added to the batter, the more ANIC was detected in the final product (Figure 5).

The higher standard deviations in Figure 5 might be caused by the differences in the unprocessed material (fresh and frozen meat), as the presented mean value is composed out of the four biological replicates made from different meat cuts, animals, and at different days. Additionally, meat samples may exhibit micro-regions or "mushy" regions where crystallization and/or solidification may take place in separated areas, rather than uniformly [37] and the fact that for the histological analyses of ANIC only one sample (meat dice of 2 × 2 cm) per biological replicate is taken, only adds up to the observed variations in the final results. Finally, we would like to concur with the conclusion of Hildebrandt and Jöckel [38] who acknowledged that with the addition of frozen meat into the comminuted meat products, an ANIC that is in compliance with German regulatory requirements is technologically (practically) impossible.

4. Conclusions

To keep the minced meat temperature in control and make the processing resistant to fat smearing, the addition of 30% of frozen meat to the meat batter is sufficient. However, our hypothesis that the addition of frozen meat will significantly and undesirably affect the sensory quality of minced pork needs to be rejected. Even the addition of 50% of frozen meat did not have any significant impact on instrumental cutting force nor the sensory perceived firmness, juiciness, and inner cohesion. In fact, the higher the ratio of frozen meat, the finer the inner structure of the cooked meat balls. Despite the high amount of ANIC, the sensory quality of minced pork remained unaffected. Lastly, the fact that we have used only the short-term frozen meat in our study represent its major limitation. Therefore, among other future developments of this line of research, the addition of meat that has been frozen and stored for longer periods of time on the quality of minced pork will be investigated.

Author Contributions: Conceptualization, I.T., F.W. and N.T.; methodology, F.W., A.R., M.U., A.J., U.B. and N.T.; validation, F.W.; formal analysis, F.W.; investigation, F.W., R.E.K., M.U., E.J., A.J. and U.B.; resources, F.W., M.U., A.J., U.B. and N.T.; data curation, F.W.; writing—original draft, I.T.; writing—review and editing, I.T., F.W., R.E.K., L.M.B., M.G., J.W., A.R., M.U., E.J., A.J., U.B., V.H. and N.T.; visualization, F.W.; supervision, N.T.; project administration, F.W., L.M.B., M.G., J.W. and N.T.; funding acquisition, F.W., M.G., J.W., V.H. and N.T. All authors have read and agreed to the published version of the manuscript.

Funding: This IGF Project of the FEI was supported via AiF within the program for promoting the Industrial Collective Research (IGF) of the German Ministry of Economics and Climate Action (BMWK) based on a resolution of the German Parliament. Project AiF 20384 N.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Most data are included in the article.

Acknowledgments: We would like to thank Julian Hoyer, Florian Singer, Frank Schilling, Berit Fitzner, and Frank Herkenhoff for their help as well as the chemistry lab for providing protein and fat results.

Conflicts of Interest: The authors declare no conflict of interest.

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