Assessment of the cavitation effect on colour attributes of chilled pork with different autolysis during brining

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Abstract. The study assesses the effect of low-frequency ultrasonic pre-treatment of slightly saturated 3% brine on colour attributes of chilled pork after 24 h salting. The results obtained are used to formulate recommendations to stabilise surface and intramuscular colouration in normally autolysed, PSE- and DFD-defective pork by cavitational disintegration of liquid sodium chloride-based salting media. Cavitational pre-activation of 3% brine using a submersible low-frequency sonication technique is recommended as a method to optimise colour attributes in normally autolysed pork and meat with inner and surface DFD defects. Prior cavitational activation of 3% brine was shown undesirable with PSE meat due to a reduced steadiness of the component a* (degree of redness) in the CIELab colour system.

1. Introduction

Along with taste, flavour and consistency, the colour of meat and meat products is an important indicator of their quality and safety. A spot visual inspection of the colour attributes of a meat product allows not only the appraisal of its presentation but also apprehension of inadequate biochemical processes that have occurred over post-slaughter handling of meat. For a long time, the Russian meat market was supplying products with the two adverse handicaps of autolysis: pale, soft, exudative (PSE) and dark, firm, dry (DFD) meat. Since recently, however, the national food market has been increasingly offering meat with PSE signatures but of an untypical bright pink colour, so-named RSE meat (standing for “red, soft, exudative”) [1]. According to current estimates, the share of exudative meat (including RSE) in the national meat industry reaches 40-47% and exceeds by an average of 7% the share of DFD meat, thus exacerbating affairs with the identification of raw meat stock and quality assurance of meat products [2, 3].

Application of nitrite salt in the meat industry to brine raw meat with PSE, RSE and DFD defects, particularly in sausages, does not provide for a stable pink colour of the final product. Furthermore, modern production formulas widely adopt food additives (protein substances of vegetable and animal origin, hydrocolloids, starches, etc.) that cause deterioration of the colour of any meat product, including those manufactured from normal (NOR) meat, due to a reduced content of the main colouring pigment of meat, myoglobin. The practice of correcting colour with food dyes has become most common owing to its high productivity and cost effectiveness [4]. In Russia, the industry legally regulates 38 food dyes of different origin and colour under TR CU (EAC) 029/2012 “Safety Requirements for Food Additives, Flavours and Technological Aids” [5]. Nevertheless, the usage of food dyes raises concerns among
healthcare professionals and often receives a negative perception by consumers. In the outcome, the problem of colour preservation in raw meat throughout its storage life using safe technologies is timely and demands novel developments and innovations in the field.

Current research and development of alternate methods of colour preservation in raw meat focus on modified atmosphere packaging (HIOX MAP and CO MAP), vacuum and skin packaging [6–9], usage of the citric acid cycle intermediates (lactate, succinate, pyruvate, malate) [10, 11], nitrite-embedded films [12, 13], antioxidants [14, 15] and physical methods (treatment with high hydrostatic pressure [16], air cold plasma [17], ultrasound [18–21], etc.).

Sonochemistry has attracted particular interest as a perspective approach for colour preservation in the meat industry. There exist opposing opinions on the direct and indirect effects of sonication on meat. Some works advocate its preserving effect on chilled meat pigmentation [21], whilst alternative views report evidence for a neutral [18] to negative impact of cavitation [19]. Noteworthy, the majority of studies address the ultrasonic effects on the colour of cattle meat, with little attention paid towards sonochemical influence on the muscle tissue colouration in other meat types, including pork.

This study aims to elucidate the indirect (due to pre-activation of sodium chloride-based brines) effect of cavitation treatment on colour stability in chilled NOR pork and abnormally autolysed pork with PSE and DFD defects.

2. Materials and methods

In analyses, we sampled the longissimus muscle (l. dorsi) in three types of meat: NOR pork, DFD- and PSE-defective pork, with samples in each type assigned between the experimental and control groups (figure 1).

In compliance with the state standard, brine was prepared with tap water (GOST P 51232-98) and food-salty water (GOST P 51574-2018), with NaCl concentration 3%. Depending on equipment, sonication time was 8 to 10 min.

Ultrasonic treatment of the brine was performed with submersible transducers of the “Volna” series (figure 2) and flow-type bath devices of the RKU (original “PKY”, transliterated) series (figure 3). The “Volna” UZTA-0.4/22-OM (original “УЗТА-0,4/22-ОМ”) device has the following technical characteristics: vibration frequency 22 ± 1.65 kHz, maximal power consumption 400 W, power control range 30-100%. In this trial, we used the earlier estimated optimal parameters of 180 W for power level and 5 min for sonication time [22].

![DFD (Ph= 6.70)](image1)
![NOR (Ph= 5.70)](image2)
![PSE (Ph= 4.13)](image3)

Figure 1. Test samples of DFD, NOR and PSE pork.
According to an earlier dissertation study [23], the RKU flow cavitation reactor was calibrated for optimal performance as follows: ultrasonic pressure amplitude $0.20 \text{ MPa}$, intensity $20 \text{ KHz}$, productivity $5 \text{ L/min}$.

Colour stability was measured with a method for colorimetric control of the surface and internal layer in the CIELab colour system. The CIELab schema quantifies the three colour components: L, degree of lightness; a, degree of redness; b, degree of yellowness. Values of L*, a* and b* in the CIELab colour space were obtained with a “Spectron” spectrocolorimeter (Figure 4) equipped with the reflection and measuring units. Measurements were performed with a standard D65 light source.

The degree of colour stability ($Y$) measures the ability of a meat system to sustain the primary colour characteristics (L, a, b) under exposure to ultrasound. It was estimated with formulas 1–3 proposed in the dissertation research by L.A. Veretov [24].

$$Y_L = (1 - \frac{|L_1 - L_2|}{L_1}) \times 100\%,$$

where $L_1$ is degree of lightness in the control, %; $L_2$ is degree of lightness in the experiment, %

$$Y_a = (1 - \frac{|a_1 - a_2|}{a_1}) \times 100\%,$$

where $a_1$ is degree of redness in the control, %; $a_2$ is degree of redness in the experiment, %
\[ Y_b = (1 - \frac{|b_1 - b_2|}{b_1}) \times 100\% \]  

(3)

where \( b_1 \) is degree of yellowness in the control, \%; \( b_2 \) is degree of yellowness in the experiment, %.

Samples in the control group (no. 1, 5, 9) were not exposed to brine and, hence, to any cavitation treatment.

Samples in the experimental NOR (no. 2), PSE (no. 6) and DFD (no. 10) groups were treated for 1 day in 3% brine with no cavitation.

Samples in the experimental NOR (no. 3), PSE (no. 7) and DFD (no. 11) groups were treated for 1 day in 3% brine pre-activated with a submersible low-frequency ultrasonic probe.

Samples in the experimental NOR (no. 4), PSE (no. 8) and DFD (no. 12) groups were treated for 1 day in 3% brine pre-activated in a flow-type low-frequency ultrasonic bath.

3. Results and discussion

Experiment results are presented in tables 1, 2 and 3.

Table 1. Experimental measurements of colour characteristics of chilled raw pork (I. dorsi) with normal autolysis (NOR).

| Sample No. | CIELab component | Value | Deviation, %* | Colour stability in units of \( L, a, b \) \((Y_L, Y_a, Y_b)\), %b |
|------------|------------------|-------|---------------|-------------------------------------------------|
| Control (1) | SURFACE Lightness, L | 57.51 | - c | 
| | Redress, a | 3.52 |  |
| | Yellowness, b | 9.86 |  |
| | CUT Lightness, L | 58.02 |  | 
| | Redress, a | 3.48 |  |
| | Yellowness, b | 10.12 |  |
| 3% NaCl (2) | SURFACE Lightness, L | 62.72 | ↑ 8.77 | ↑  |
| | Redress, a | 1.88 | ↓ 66.67 | 33.33 |
| | Yellowness, b | 5.66 | ↓ 44.44 | 55.56 |
| | CUT Lightness, L | 52.16 | ↓ 10.34 | 89.66 |
| | Redress, a | 5.86 | ↑ 66.67 | ↑ |
| | Yellowness, b | 8.48 | ↓ 20.00 | 80.00 |
| 3% NaCl + cav. (submersible transducer) (3) | SURFACE Lightness, L | 57.93 | 0 | 100.00 |
| | Redress, a | 3.75 | 0 | 100.00 |
| | Yellowness, b | 11.12 | ↑ 22.22 | ↑ |
| | CUT Lightness, L | 60.02 | ↑ 3.45 | ↑ |
| | Redress, a | 4.25 | ↑ 33.33 | ↑ |
| | Yellowness, b | 10.96 | 0 | ↑ |
| 3% NaCl + cav. (flow bath) (4) | SURFACE Lightness, L | 63.20 | ↑ 10.53 | ↑ |
| | Redress, a | 2.21 | ↓ 33.33 | 66.67 |
| | Yellowness, b | 5.21 | ↓ 44.44 | 55.56 |
| | CUT Lightness, L | 55.08 | ↓ 5.17 | 94.83 |
| | Redress, a | 4.63 | ↑ 33.33 | ↑ |
| | Yellowness, b | 7.91 | ↓ 30.00 | 70.00 |
Table 2. Experimental measurements of colour characteristics of chilled raw pork (l. dorsi) with the PSE defect of autolysis.

| Sample No. | CIELab component | Value | Deviation, %<sup>a</sup> | Colour stability in units of L, a, b (Y<sub>L</sub>, Y<sub>a</sub>, Y<sub>b</sub>), %<sup>b</sup> |
|------------|------------------|-------|---------------------------|--------------------------------------------------|
| **SURFACE** |                  |       |                           |                                                  |
| Control (5) | Lightness, L     | 63.57 |                           |                                                  |
| Control (5) | Redness, a       | 0.74  |                           |                                                  |
| Control (5) | Yellowness, b    | 10.16 |                           |                                                  |
| **CUT**    |                  |       |                           |                                                  |
| Control (5) | Lightness, L     | 63.08 |                           |                                                  |
| Control (5) | Redness, a       | 1.94  |                           |                                                  |
| Control (5) | Yellowness, b    | 10.87 |                           |                                                  |
| **SURFACE** |                  |       |                           |                                                  |
| 3% NaCl (6) | Lightness, L     | 68.92 | ↑<sup>d</sup> 8.42      | ↑                                                 |
| 3% NaCl (6) | Redness, a       | 1.91  | ↑<sup>d</sup> –        | ↑                                                 |
| 3% NaCl (6) | Yellowness, b    | 5.93  | ↓<sup>c</sup> 41.63    | 58.37                                             |
| **CUT**    |                  |       |                           |                                                  |
| 3% NaCl (6) | Lightness, L     | 59.86 | ↓<sup>c</sup> 5.10    | 94.90                                             |
| 3% NaCl (6) | Redness, a       | 3.00  | ↑<sup>d</sup> 54.64    | ↑                                                 |
| 3% NaCl (6) | Yellowness, b    | 10.64 | ↓<sup>c</sup> 2.11    | 97.88                                             |
| **SURFACE** |                  |       |                           |                                                  |
| 3% NaCl + cav. (submersible transducer) (7) | Lightness, L | 68.21 | ↑<sup>d</sup> 7.30      | ↑                                                 |
| 3% NaCl + cav. (submersible transducer) (7) | Redness, a | 0.61  | ↓<sup>c</sup> 7.56    | 82.44                                             |
| 3% NaCl + cav. (submersible transducer) (7) | Yellowness, b | 4.66 | ↓<sup>c</sup> 54.13    | 45.87                                             |
| **CUT**    |                  |       |                           |                                                  |
| 3% NaCl + cav. (submersible transducer) (7) | Lightness, L | 60.16 | ↓<sup>c</sup> 4.63    | 95.37                                             |
| 3% NaCl + cav. (submersible transducer) (7) | Redness, a | 0.86  | ↓<sup>c</sup> 55.67    | 44.33                                             |
| 3% NaCl + cav. (submersible transducer) (7) | Yellowness, b | 9.70 | ↓<sup>c</sup> 10.76    | 89.24                                             |
| **SURFACE** |                  |       |                           |                                                  |
| 3% NaCl + cav. (flow bath) (8) | Lightness, L | 70.59 | ↑<sup>d</sup> 11.04     | ↑                                                 |
| 3% NaCl + cav. (flow bath) (8) | Redness, a | 0.46  | ↓<sup>c</sup> 37.84    | 62.16                                             |
| 3% NaCl + cav. (flow bath) (8) | Yellowness, b | 5.00 | ↓<sup>c</sup> 50.78    | 49.22                                             |
| **CUT**    |                  |       |                           |                                                  |
| 3% NaCl + cav. (flow bath) (8) | Lightness, L | 62.88 | ↓<sup>c</sup> 0.30    | 100.00                                            |
| 3% NaCl + cav. (flow bath) (8) | Redness, a | 2.43  | ↑<sup>d</sup> 25.26    | ↑                                                 |
| 3% NaCl + cav. (flow bath) (8) | Yellowness, b | 10.77 | ↓<sup>c</sup> 0.92    | 99.08                                             |

<sup>a</sup> Deviation (%) estimated for all CIELab components across all treated samples.

<sup>b</sup> Colour stability (Y<sub>L</sub>, Y<sub>a</sub>, Y<sub>b</sub>, %) in treated samples estimated only for CIELab components (L, a, b) that exhibited a declining trend.

<sup>c</sup> Deviation and stability not estimated in the PSE control group, because it provides a reference to derive estimates in treated samples.

<sup>d</sup> The «↑» sign marks a growing trend.

<sup>e</sup> The «↓» sign marks a declining trend.
### Table 3. Experimental measurements of colour characteristics of chilled raw pork (l. dorsi) with the DFD defect of autolysis.

| Sample No. | CIELab component | Value | Deviation, %* | Colour stability in units of L, a, b (Y_L, Y_a, Y_b), %b |
|------------|------------------|-------|---------------|--------------------------------------------------------|
| Control (9) | SURFACE Lightness, L | 44.58 | _c |  |
|            | Redness, a       | 12.55 | _c |  |
|            | yellowness, b    | 9.28  | _c |  |
|            | CUT Lightness, L | 46.92 |   |  |
|            | Redness, a       | 13.67 | _c |  |
|            | yellowness, b    | 9.84  | _c |  |
| 3% NaCl (10) | SURFACE Lightness, L | 56.8  | ↑ d 27.27 | ↑ |
|            | Redness, a       | 6.48  | ↓ e 50.00 | 50.00 |
|            | yellowness, b    | 10.7  | ↑ 11.11 | ↑ |
|            | CUT Lightness, L | 45.78 | ↓ 2.17 | 97.73 |
|            | Redness, a       | 15.45 | ↑ 15.38 | ↑ |
|            | yellowness, b    | 10.73 | ↑ 11.11 | ↑ |
| 3% NaCl + cav. (submersible transducer) (11) | SURFACE Lightness, L | 43.51 | ↓ 2.27 | 97.73 |
|            | Redness, a       | 10.3  | ↓ 14.16 | 85.84 |
|            | yellowness, b    | 8.14  | ↓ 09.55 | 90.45 |
|            | CUT Lightness, L | 42.44 | ↓ 8.70 | 91.30 |
|            | Redness, a       | 11.90 | ↓ 15.38 | 84.62 |
|            | yellowness, b    | 8.45  | ↓ 11.11 | 88.89 |
| 3% NaCl + cav. (flow bath) (12) | SURFACE Lightness, L | 53.77 | ↑ 20.45 | ↑ |
|            | Redness, a       | 5.40  | ↓ 58.33 | 41.67 |
|            | yellowness, b    | 8.57  | ↓ 11.11 | 88.89 |
|            | CUT Lightness, L | 42.89 | ↓ 8.70 | 91.30 |
|            | Redness, a       | 13.88 | 0    | 100.00 |
|            | yellowness, b    | 09.60 | 0    | 100.00 |

a Deviation (%) estimated for all CIELab components across all treated samples.

b Colour stability (Y_L, Y_a, Y_b, %) in treated samples estimated only for CIELab components (L, a, b) that exhibited a declining trend.

c Deviation and stability not estimated in the DFD control group, because it provides a reference to derive estimates in treated samples.

d The «↑» sign marks a growing trend.

e The «↓» sign marks a declining trend.

The degree of redness (a*) in chilled meat can be associated with the concentration of myoglobin (Mb) or oxymyoglobin (OMb), which makes it a principal parameter in analyses. Figure 5 depicts the deviation pattern (%) of the component a* (degree of redness in the CIELab colour space) in treated samples of NOR, PSE and DFD pork with respect to corresponding control groups.
Figure 5. Deviation pattern (%) of the component a* (degree of redness in the CIELab colour space) in treated samples of NOR, PSE and DFD pork with respect to corresponding control groups.

The obtained results reveal certain patterns specific in meat with normal autolysis (NOR). Thus, a 24 h exposure of NOR pork in 3% NaCl saline reduces the a* value (CIELab redness) of its surface and amplifies it inside the meat layer (a decrease by 67% on the surface and increase of 67% in the cut with respect to corresponding control groups).

Prior cavitation activation of 3% NaCl saline with a submersible ultrasonic probe stabilises the redness value a* of the sample’s surface at the level of control and allows its increase in the cut by 33% compared to control samples.

Pre-cavitation of 3% brine in a flow low-frequency ultrasonic bath increases the redness level of the sample’s surface by 33% vs. treatment with non-activated 3% saline, which was not observed with cuts of NOR pork.

In trials with PSE pork, pre-cavitation of 3% brine with submersible probe-type sonication negatively affects pigmentation with myoglobins both on the surface and inside the layer; the redness value a* declines by 18% on the surface and by 56% in the cut compared to intact control samples.

Pre-activation of 3% brine in a flow ultrasonic bath entails surface discoloration in PSE pork with respect to the redness level; the value a* declined by 38% on the surface and by 25% in the meat cut compared to intact control samples.

Accordingly, brine agitation with a submersible probe provides for a 20% improved colour stability in meat with respect to flow-bath cavitation.

Experimental data in Figure 5 suggests that the optimal level of the CIELab redness component a* in PSE pork is reached for the meat surface and layer under brining in 3% saline with no prior cavitation.

Considering that DFD manifestations of abnormal autolysis, compared to PSE defects, provide for an untypical dark red colour of pork, the important concern in handling raw pork material is to decelerate the Fe(II)–Fe(III) valence transition that leads to oxidation of oxymyoglobin to metmyoglobin and further darkening of the muscle tissue.
Prior cavitation activation of 3% saline with submersible probe-type sonication allows diminishing of the redness degree \(a^*\) in the surface and layer of DFD pork by 14 and 15% compared to control untreated samples, respectively.

Prior cavitation activation of 3% saline in a flow ultrasonic device allows diminishing of the redness degree \(a^*\) in the surface of DFD pork by 58% with respect to the intact group and by 8% -- to samples preconditioned in non-activated brine. Changes in the redness degree inside the treated meat layer vs. the control were not observed.

The obtained results clearly show that the colour attributes of meat with normal autolysis can be optimised through preliminary activation of 3% brine with submersible probe-type sonication.

Prior cavitation activation of 3% brine is undesirable with PSE meat due to its negative impact on steadiness of the CIELab component \(a^*\) (degree of redness).

To stabilise the surface and intramuscular colour attributes of DFD meat, the primary recommendation is to apply prior cavitational activation of 3% brine using a submersible probe technique. It can be justified by feasible abatement of the myoglobin/oxymyoglobin to metmyoglobin oxidation rate. Likewise, preliminary flow-bath brine sonication can be recommended to decelerate brining-associated surface darkening in DFD meat.

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