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MAYONNAISES FROM FRESH OR FROZEN EGG YOLK WITH RAPESEED AND SESAME OILS -THE INFLUENCE OF EGG YOLK FREEZING AND STORAGE TIME AND OILS RATIO

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MAYONNAISES FROM FRESH OR FROZEN EGG YOLK WITH RAPESEED AND SESAME OILS -THE INFLUENCE OF EGG YOLK FREEZING AND STORAGE TIME AND OILS RATIO

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Abstract. The rheological behavior of some mayonnaise varieties prepared from liquid egg yolks, fresh or frozen, whose oily phase is made up of mixtures of sesame oil and rapeseed oil was studied in the current paper. The study examined the influence of the freezing time of the egg yolk, of the ratio between the two types of oil, as well as of the storage time, on the rheological parameters (apparent viscosity, consistency coefficient, flow behavior index). It has been shown that all types of mayonnaise present non-Newtonian behavior (pseudoplastic), because the values of the flow behavior index established from the specific mathematical models (Ostwald de Waele and Herschel-Bulkley) are sub-unit, and the apparent viscosity decreases with the increase of the shear rate. Mayonnaises prepared from frozen egg yolks and those with an oily phase in which sesame oil is predominant, have a higher consistency. The oxidation stability was evaluated by determining the acid values, which increase slightly with the freezing time of the egg yolk and with the amount of sesame oil in the oily phase. From the color tests carried out in the CIELAB color space, the characteristic parameters L^* , a^* and b^* were determined and the lightness of the mayonnaise was assessed.

Keywords: egg yolk, mayonnaise, rheological behavior, viscosity, CIELAB.

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Introduction

Mayonnaise is a semi-solid and oil-in-water emulsion which traditionally contains egg yolk (liquid, frozen, dried), whole eggs (liquid, frozen, dried) or any of the yolk products in combination with liquid of frozen egg white, oil (30-65% in low fat mayonnaise and 75-80% in full fat mayonnaise), salt, sugar or sweeteners (sucrose) and vinegar (4.5% acetic acid) [1,2]. In certain recipes, spices or natural flavoring (mustard flour, white pepper), monosodium glutamate, sequestrants to preserve color and/or flavor, citric or malic acid, crystallization inhibitors (lecithin, polyglycerol esters of fatty acids) may still be occasionally included [2].

The main emulsifying agent is the yolk, which controls the texture and stability of mayonnaise, the emulsifying capacity and stabilizing properties being provided by its lipoprotein and phospholipid (lecithin) content [3-5]. In addition, secondary nonionic emulsifiers such as mono and diglycerides obtained by transesterification of refined oils [1], soy milk [6], enzyme-modified milk proteins [7] can be used to enhance emulsion stability and improve its rheological properties.

Yolk freezing causes gelation which negatively alters its emulsifying ability. The removal of this disadvantage can be achieved by the addition of peptides from egg yolk/egg white proteins hydrolysis. Thus, the addition of 5% hydrolyzed egg yolk proteins successfully inhibited gelation because the hardness of the frozen yolk becomes comparable to that of the yolk treated with 10% salt [5]. In order to inhibit the gelation of frozen egg yolk long-term stored at -18°C , antigelation agents (NaCl, sucrose, neutral protease and their combinations) can also be used, added before freezing [8].

The increase of freezing storage time of egg yolk can alter the properties of mayonnaise, mainly the decrease in the heating stability of the mayonnaise. Moreover, as the freezing storage time of the yolk increases, the mayonnaise tends to become lighter, and its redness and yellowness values decrease. [3].

Changing the consistency/texture of mayonnaise can be done by adding thickening agents: modified starch, xanthan gum and combination of these, guar gum, locust bean gum, carrageenan, gelatin [9], microfibrillated cellulose, chemically modified or native waxy

corn starch [10], octenyl succinic anhydride (OSA) modified starches from wheat, corn, waxy corn, potato, sweet potato, rice and kidney bean [11].

Storage time and temperature, along with the size of oil droplets, affected the rheological and viscoelastic properties of mayonnaise. The storage temperature affected the flow curves of the mayonnaise indicating that its structure is significantly affected, and the values of apparent viscosity, consistency index, yield stress, storage modulus and complex viscosity decreased with increasing droplet size [12].

The aim of this work was to characterize some types of mayonnaise prepared from fresh or frozen egg yolk and having as an oily phase mixtures of rapeseed oil and sesame oil, in different proportions. The rheological behavior of the mayonnaise types and the raw materials was investigated to determine the flow behavior parameters and their correlation with the freezing time of the egg yolk, the preservation time, and the composition of the oily phase. Oxidation stability (by determining the acid values) and color changes assessed from the variations of the L^* , a^* , b^* parameters of the CIELAB space were also evaluated.

Experimental

Materials

Egg yolks come from category A eggs, weighing between 53 g and 63 g, originating from Romania. The eggs were obtained from hens reared in batteries and fed on grain. As declared by the producer, the main nutritional values per 100g product are: energy - 139 kcal, protein - 12.5 g, carbohydrates - 0.6 g (of which sugars 0.0 g), fibers < 0.5 g, fats - 9.7 g (of which saturated fatty acids 3.0 g), salt - 0.4 g, sodium - 0.14 g.

Both rapeseed and sesame oil were purchased commercially, the rapeseed oil being refined and the sesame oil being obtained from the first cold pressing of the seeds (without solvent addition) and subsequent filtration. The commercially purchased food vinegar (Regal) was derived from the enzymatic oxidation of ethanol obtained from the wine industry (acetic concentration 90 g/L). Additionally, crystal white sugar (Agrana), extrafine gem iodized table salt (Salrom) and drinking water were used.

Preparation of the mayonnaise samples

Egg yolks, fresh or frozen for various periods of time at -18°C in an upright freezer and subsequently rapidly thawed into a Samsung Microwave Oven MS23K3515 with Quick

Defrost function, salt, sugar, vinegar and water were mixed for 3 minutes at a lower mixer speed (640 rpm), at 25°C . Under more intense stirring (1100 rpm), the oily phase was added dropwise over 12 minutes. The obtained samples were kept in the refrigerator at $4\div 5^{\circ}\text{C}$, in closed jars. The composition of each type of mayonnaise is shown in Table 1, and that of the oily phase is shown in Table 2. Mayonnaise series were coded as follows: M1-M5 (made with fresh yolk), M1_20-M5_20 (made with frozen yolk 20 days), M1_48-M5_48 (made with frozen yolk 48 days).

Table 1

| The composition of mayonnaise. | |
|--------------------------------|-----------------|
| Ingredients | Weight (g/100g) |
| Egg yolk | 13 |
| Oily phase | 70 |
| Vinegar | 1.5 |
| Water | 8.5 |
| Salt | 4.0 |
| Sugar | 3.0 |

Table 2

| The composition of oily phase of all mayonnaise series. | | |
|---|----------------------------|--------------------------|
| Symbol | Rapeseed oil-RO (wt. %) | Sesame oil-SO (wt. %) |
| M1 | 100 | 0 |
| M2 | 75 | 25 |
| M3 | 50 | 50 |
| M4 | 25 | 75 |
| M5 | 0 | 100 |

Characterization methods

The physico-chemical properties were determined following AOAC methods [13]. The acid values were measured according to AOAC Method 972.28 [13] and expressed as mg KOH/g oil. For each experiment, in a 100 mL Erlenmeyer flask, weighed with a precision of 0.001 g a quantity of 1-3 g of fat sample, adding 20 mL of solvent (hexane for the two oils, water for egg yolk/mayonnaise) and 1-2 drops of 1% alcoholic solution of phenolphthalein. Next, the mixture was stirred for sample dissolution and the obtained solution was titrated with KOH solution 0.1 M until the appearance of a pink color that persisted for 30 seconds. A blank sample was also titrated to determine the KOH consumption of the solvent. The density was measured using the pycnometer method according to AOAC Method 920.213 [13].

The rheological measurements for egg yolk/mayonnaise were carried out under thermostatic conditions, at different temperatures

ranging from 2°C to 35.5°C, using a Rheotest-2 rotational viscometer (Rheotest Medingen GmbH Germany), with the system vat-drum S/N. The device allows the measurements of the torsion moment appeared due to the ring-shaped substance layer placed between a fixed cylinder and a rotating one with known revolution. The torsion moment is correlated with the shear stress τ , while the revolution and the ring-shaped layer thickness determine the shear rate $\dot{\gamma}$. Shear rate values were changed in the range 0.333÷243 s⁻¹.

The dependence $\tau = f(\dot{\gamma})$ can be described by two mathematical models: the power model (Ostwald de Waele), Eq.(1) and Herschel-Bulckley model, Eq.(2). The dependence between the apparent viscosity η_a and the shear rate $\dot{\gamma}$ is described by Eq.(3) [14-16].

$$\tau = K \cdot \dot{\gamma}^n \quad (1)$$

$$\tau = \tau_0 + K \cdot \dot{\gamma}^n \quad (2)$$

$$\eta_a = K \cdot \dot{\gamma}^{n-1} \quad (3)$$

where: K – consistency coefficient (Pa·sⁿ);
 n – flow behavior index (dimensionless);
 τ_0 – yield stress (Pa).

The color tests were performed with a FRU WR10 portable photocolimeter (Shenzhen Wave Optoelectronics Technology Co.,Ltd, China), standard illuminant D65 (white light), 10° angle. The obtained data were presented by CIELAB space which is three-dimensional and covers the entire range of human color. It describes color by means of three parameters: L^*

denotes the lightness ranging from 0% (black) to 100% (white), a^* value ranges from – (greenness) to + (redness) and b^* ranges from – (blueness) to + (yellowness) [17-19]. To avoid the formation of air bubbles in the mayonnaise, the measuring cells must be completely full.

Results and discussion

Next, we present the conclusions and interpretations of the experimental studies conducted using the previously described methods. These studies encompassed the examination of color in the CIELAB color space, including the interpretation of the determined parameters, as well as the investigation of rheological behavior and stability over time for the mayonnaise types under consideration. The density at 25°C and the values of the cartesian parameters (L^* , a^* , b^*) of the CIELAB color space, for rapeseed and sesame oil, are shown in Table 3.

For both oils, the dependence of shear stress τ with shear rate $\dot{\gamma}$ is linear, which corresponds to a Newtonian behavior. The slope of the lines represents the dynamic viscosity of oils which decreases with increasing temperature. The rheological equations obtained at five temperature values using the TableCurve 2D program, as well as the activation energy of the viscous flow E_a are presented in Table 4. In the case of fresh yolk, the dependence $\tau = f(\dot{\gamma})$ can be described by Eq.(1). The particular forms of the rheological equations are shown in Table 5 and demonstrate that the yolks involve the flow of a non-Newtonian fluid, more precisely, a pseudoplastic fluid behavior ($n < 1$).

Table 3

Density and L^* , a^* , b^* parameters for sesame oil and rapeseed oil.

| Oil type | Density (kg/m ³) | L^* | a^* | b^* |
|----------|------------------------------|-------|-------|-------|
| Sesame | 925 | 53.85 | 0.75 | 38.67 |
| Rapeseed | 892 | 54.81 | -2.16 | 18.69 |

Table 4

Rheological equations ($\tau = \eta \cdot \dot{\gamma}$) and the activation energy of viscous flow for sesame oil and rapeseed oil.

| Oil type | 2°C | 5°C | 10°C | 15°C | 25°C | E_a (kJ/mol) |
|----------|--|--|--|--|--|-------------------|
| Sesame | $\tau = 0.1794 \cdot \dot{\gamma}$ ($R^2 = 0.9986$) | $\tau = 0.1559 \cdot \dot{\gamma}$ ($R^2 = 0.9999$) | $\tau = 0.1212 \cdot \dot{\gamma}$ ($R^2 = 0.9986$) | $\tau = 0.0940 \cdot \dot{\gamma}$ ($R^2 = 0.9997$) | $\tau = 0.0622 \cdot \dot{\gamma}$ ($R^2 = 0.9992$) | 32.3 |
| Rapeseed | $\tau = 0.1879 \cdot \dot{\gamma}$ ($R^2 = 0.9994$) | $\tau = 0.1615 \cdot \dot{\gamma}$ ($R^2 = 0.9999$) | $\tau = 0.1244 \cdot \dot{\gamma}$ ($R^2 = 0.9994$) | $\tau = 0.0959 \cdot \dot{\gamma}$ ($R^2 = 0.9999$) | $\tau = 0.0614 \cdot \dot{\gamma}$ ($R^2 = 0.9978$) | 34.7 |

Table 5

Rheological equations ($\tau = K \cdot \dot{\gamma}^n$) for fresh egg yolk.

| | 2°C | 10°C | 25°C | 35.5°C |
|--|--|---|--|---|
| | $\tau = 2.07 \cdot \dot{\gamma}^{0.873}$ ($R^2 = 0.999943$) | $\tau = 1.22 \cdot \dot{\gamma}^{0.876}$ ($R^2 = 0.99994$) | $\tau = 0.52 \cdot \dot{\gamma}^{0.921}$ ($R^2 = 0.999791$) | $\tau = 0.30 \cdot \dot{\gamma}^{0.95}$ ($R^2 = 0.999919$) |

This type of behavior is also confirmed by the variation of the apparent viscosity η_a , Eq.(3), which decreases with shear rate - shear thinning behavior, as seen in Figure 1. From the particular forms of the rheological equations presented in Table 5, it can be seen that increasing the temperature leads to a decrease in the consistency coefficient K , as well as to an increase in the flow behavior index n , which tends to 1 and corresponds to a possible Newtonian behavior.

Since the composition of mayonnaise includes both salt and sugar, their effect on the rheological behavior of the egg yolk was studied, in the concentration range 1÷5 wt.%. At 25°C, the dependence $\tau = f(\dot{\gamma})$ for egg yolk with added salt or sugar is shown in Figure 2. It is observed that both the addition of sugar and,

especially, that of salt lead to an increase in the shear stress values and, implicitly, in the apparent viscosity. This fact is also demonstrated by the values of the consistency coefficient K and the flow behavior index n , Figures 3 and 4.

The rheological behavior of mayonnaise was studied at 25°C, after different storage periods in the refrigerator. Thus, for the set of mayonnaises prepared from fresh egg yolk (M1-M5), after 4 days of preparation, the dependence $\tau = f(\dot{\gamma})$ is shown in Figure 5. It is observed that the dependence $\tau = f(\dot{\gamma})$ is non-linear, the rheological behavior being non-Newtonian. The corresponding rheological equations can be described both by Eq.(1), as well as by Eq.(2).

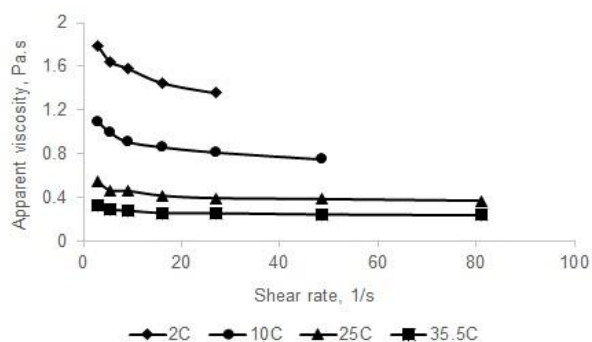


Figure 1. Apparent viscosity vs. shear rate for fresh egg yolk.

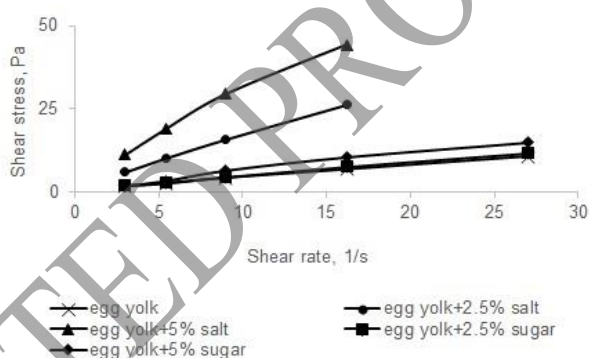


Figure 2. Shear stress vs. shear rate for fresh egg yolk with salt/sugar content at 25°C.

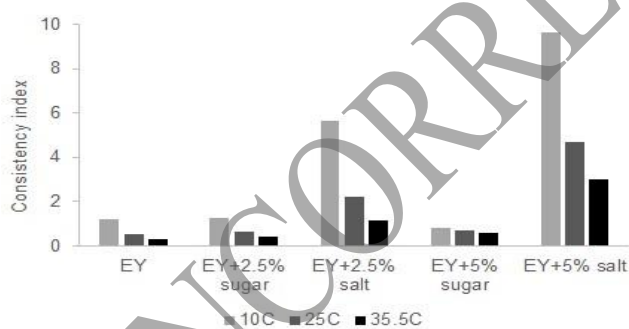


Figure 3. Consistency index for fresh egg yolk with salt/sugar content.

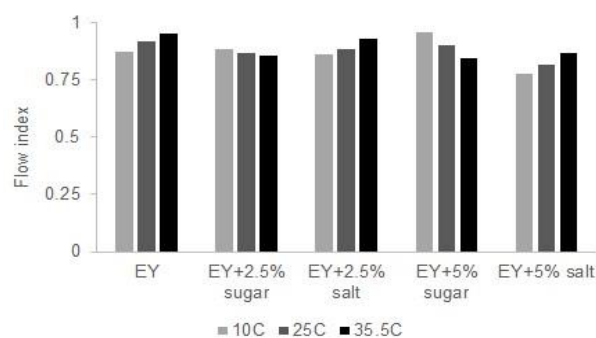


Figure 4. Flow behavior index for fresh egg yolk with salt/sugar content.

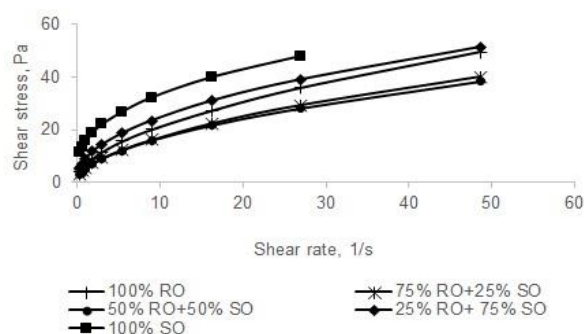


Figure 5. Shear stress vs. shear rate for mayonnaise prepared from fresh egg yolk, at 25°C.

The flow behavior parameters, at 25°C for both models are presented in Table 6 and Table 7. It can be observed that, after the same storage period, the mayonnaises with the oily phase containing 75% and 100% sesame oil have the highest consistency coefficients and the highest apparent viscosities (samples M4 and M5). At 25°C, the variation of the consistency coefficient K , of the flow behavior index n , yield stress τ_0 and of the apparent viscosity η_a (calculated at 9 s^{-1} and 16.2 s^{-1}), with the increase in the preservation time to 25, respectively 53 days is presented in Tables 8, 9 and 10.

The change in the apparent viscosity values, calculated based on the flow parameters of Ostwald de Waele model (Tables 6 and 8) at 2 shear rate values, for samples M1-M5, depending on the refrigeration time, is shown in Figure 6.

Table 6

Flow behavior parameters of mayonnaise after 4 days of preservation - power law model.

| Mayonnaise | $K (\text{Pa} \cdot \text{s}^n)$ | n | R^2 |
|------------|----------------------------------|-------|---------|
| M1 | 6.46 | 0.522 | 0.99959 |
| M2 | 5.19 | 0.525 | 0.99981 |
| M3 | 5.00 | 0.524 | 0.99988 |
| M4 | 8.83 | 0.449 | 0.99985 |
| M5 | 15.5 | 0.340 | 0.99887 |

Table 7

Flow behavior parameters of mayonnaise after 4 days of preservation - Herschel-Bulkley model.

| Mayonnaise | $\tau_0 (\text{Pa})$ | $K (\text{Pa} \cdot \text{s}^n)$ | n | $\eta_a (\text{Pa} \cdot \text{s})$ | | R^2 |
|------------|----------------------|----------------------------------|-------|-------------------------------------|-----------------------|---------|
| | | | | 9 s^{-1} | 16.2 s^{-1} | |
| M1 | 0.987 | 5.71 | 0.550 | 2.234 | 1.691 | 0.99990 |
| M2 | 0.472 | 4.83 | 0.542 | 1.818 | 1.378 | 0.99992 |
| M3 | 0.142 | 4.89 | 0.529 | 1.753 | 1.326 | 0.99989 |
| M4 | 0.181 | 8.68 | 0.453 | 2.629 | 1.903 | 0.99986 |
| M5 | 3.490 | 12.1 | 0.395 | 3.590 | 2.459 | 0.99989 |

Table 8

Flow behavior parameters of mayonnaise after 25 and 53 days of preservation - power law model.

| Mayonnaise | 25 days | | | 53 days | | |
|------------|----------------------------------|-------|---------|----------------------------------|-------|---------|
| | $K (\text{Pa} \cdot \text{s}^n)$ | n | R^2 | $K (\text{Pa} \cdot \text{s}^n)$ | n | R^2 |
| M1 | 8.86 | 0.501 | 0.99954 | 19.5 | 0.499 | 0.99991 |
| M2 | 7.72 | 0.518 | 0.99923 | 10.07 | 0.509 | 0.99866 |
| M3 | 11.46 | 0.467 | 0.99891 | 21.44 | 0.412 | 0.99888 |
| M4 | 20.94 | 0.372 | 0.99821 | 44.56 | 0.272 | 0.99985 |
| M5 | 30.79 | 0.232 | 0.99429 | - | - | - |

Table 9

Flow behavior parameters of mayonnaise after 25 days of preservation - Herschel-Bulkley model.

| Mayonnaise | $\tau_0 (\text{Pa})$ | $K (\text{Pa} \cdot \text{s}^n)$ | n | $\eta_a (\text{Pa} \cdot \text{s})$ | | R^2 |
|------------|----------------------|----------------------------------|-------|-------------------------------------|-----------------------|---------|
| | | | | 9 s^{-1} | 16.2 s^{-1} | |
| M1 | 1.30 | 7.72 | 0.536 | 2.93 | 2.20 | 0.99993 |
| M2 | 1.52 | 6.42 | 0.565 | 2.64 | 2.00 | 0.99994 |
| M3 | 2.53 | 9.19 | 0.522 | 3.50 | 2.58 | 0.99988 |
| M4 | 5.51 | 15.49 | 0.449 | 5.23 | 3.68 | 0.99989 |
| M5 | 14.55 | 15.92 | 0.390 | 5.78 | 3.81 | 0.99944 |

Table 10

Flow behavior parameters of mayonnaise after 53 days of preservation - Herschel-Bulkley model.

| Mayonnaise | $\tau_0 (\text{Pa})$ | $K (\text{Pa} \cdot \text{s}^n)$ | n | $\eta_a (\text{Pa} \cdot \text{s})$ | | R^2 |
|------------|----------------------|----------------------------------|-------|-------------------------------------|-----------------------|---------|
| | | | | 9 s^{-1} | 16.2 s^{-1} | |
| M1 | 1.06 | 18.43 | 0.518 | 6.51 | 4.88 | 0.99998 |
| M2 | 2.22 | 7.99 | 0.576 | 3.39 | 2.59 | 0.99985 |
| M3 | 4.26 | 17.09 | 0.482 | 5.95 | 4.30 | 0.99982 |
| M4 | 3.67 | 40.83 | 0.298 | 9.14 | 6.00 | 0.99989 |
| M5 | - | - | - | - | - | - |

Data in Tables 9 and 10 and in Figure 6 show that for each type of mayonnaise, the increase in the refrigeration time leads to an increase in the apparent viscosity, and this one is lower at higher values of the shear rate. Also, at the same refrigeration time, mayonnaises with 75%, respectively 100% sesame oil in the oily phase (samples M4 and M5), have the highest values of the apparent viscosity.

The influence of the freezing time of egg yolks on the rheological behavior of mayonnaise was studied for an exposure at -18°C for 20 and 48 days. Thus, for mayonnaise prepared from egg yolks frozen for 20 days (M1_20-M5_20), the dependence $\tau = f(\dot{\gamma})$ at 25°C, after 4 days from preparation, is shown in Figure 7. It is found that these mayonnaises also have non-Newtonian behavior, the dependence $\tau = f(\dot{\gamma})$ being non-linear. The direction of variation of the shear stress and, implicitly, of the apparent viscosity is similar to that of mayonnaises prepared from fresh egg yolks – the highest values correspond to mayonnaises in which the oily phase contains 75% or, respectively, 100% sesame oil (M4_20 and M5_20), followed by those prepared wholly with rapeseed oil (M1_20). Also, increasing the freezing time of egg yolks used in the preparation of mayonnaise leads to an increase in their flow parameters (Figure 8, Tables 6 and 11), in accordance with [3].

The variation of the L^* , a^* , b^* coordinates from the CIELAB color space depending on the percentage of sesame oil present in the oily phase, after 7 days of preservation of mayonnaise prepared from fresh egg yolks, respectively frozen yolks for various periods of time, is presented in Table 12. It is observed that, for the same composition of the oily phase, the mayonnaises prepared from fresh egg yolks show darker colors, with the L^* parameter having the lowest values. Also, increasing the freezing time of the egg yolks leads to a slight increase in the L^* values, which corresponds to lighter mayonnaise colors, in accordance with [3]. For each type of egg yolk used, the lightest colors show the mayonnaises

whose oily phase contains only sesame oil or only rapeseed oil.

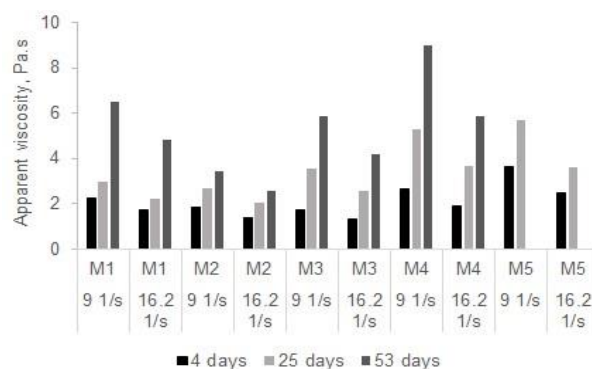


Figure 6. Variation of apparent viscosity as a function of refrigeration time.

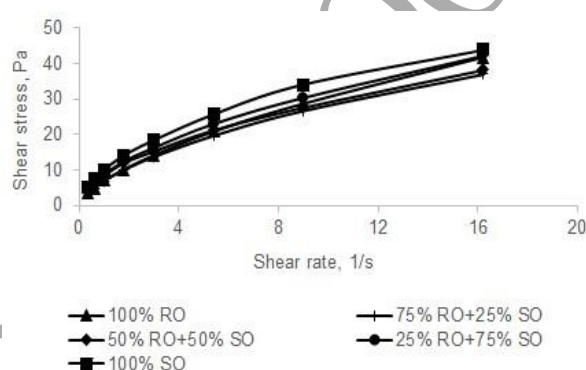


Figure 7. Shear stress vs. shear rate for samples M1_20-M5_20.

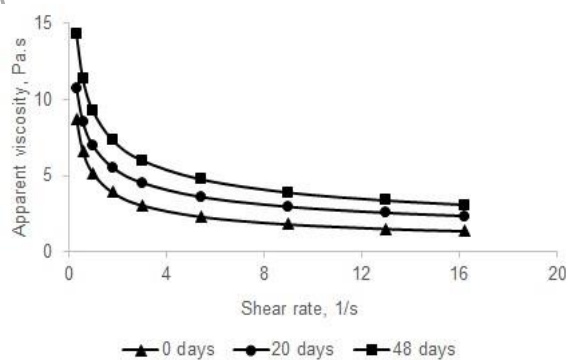


Figure 8. The apparent viscosity of mayonnaise with 25% sesame oil, at 25°C, depending on the freezing time of the egg yolks.

Table 11

Flow behavior parameters of mayonnaise prepared from frozen egg yolks, after 4 days of preservation- power law model.

| SO in oily phase (wt.%) | 20 days | | | | 48 days | | | |
|-------------------------|--------------------|-------|-------------------------------------|---------|--------------------|-------|-------------------------------------|---------|
| | $K (Pa \cdot s^n)$ | n | $\eta_a (at 9 s^{-1}) (Pa \cdot s)$ | R^2 | $K (Pa \cdot s^n)$ | n | $\eta_a (at 9 s^{-1}) (Pa \cdot s)$ | R^2 |
| 0 | 6.98 | 0.642 | 3.18 | 0.99979 | 8.36 | 0.655 | 3.92 | 0.99947 |
| 25 | 6.99 | 0.607 | 2.95 | 0.99967 | 9.28 | 0.606 | 3.90 | 0.99987 |
| 50 | 8.51 | 0.541 | 3.10 | 0.99970 | 8.84 | 0.608 | 3.73 | 0.99959 |
| 75 | 8.61 | 0.573 | 3.37 | 0.99953 | 11.08 | 0.576 | 4.36 | 0.99896 |
| 100 | 10.45 | 0.517 | 3.61 | 0.99578 | 16.13 | 0.515 | 5.56 | 0.99918 |

Table 12

| The parameters of CIELAB color space. | | | | | | | | | |
|---------------------------------------|--------------------------------|-------|-------|---|-------|-------|---|-------|-------|
| SO in oily phase (wt.%) | Mayonnaise from fresh egg yolk | | | Mayonnaise from 20 days frozen egg yolk | | | Mayonnaise from 48 days frozen egg yolk | | |
| | L^* | a^* | b^* | L^* | a^* | b^* | L^* | a^* | b^* |
| 0 | 58.47 | -0.69 | 16.38 | 65.97 | 0.85 | 22.54 | 68.32 | 1.11 | 24.00 |
| 25 | 58.07 | -0.54 | 16.60 | 65.64 | 1.31 | 23.87 | 67.09 | 1.42 | 24.38 |
| 50 | 56.57 | -0.39 | 17.16 | 65.66 | 1.31 | 23.66 | 67.41 | 1.40 | 24.75 |
| 75 | 55.10 | -1.09 | 14.43 | 64.16 | 1.97 | 24.00 | 67.82 | 1.31 | 24.49 |
| 100 | 61.95 | -1.50 | 16.46 | 66.49 | 2.18 | 25.36 | 68.64 | 1.28 | 24.03 |

Table 13

The total color differences (ΔE^*) of the mayonnaises compared to the color parameters of sesame oil.

| SO in oily phase (wt.%) | Mayonnaise from fresh egg yolk | Mayonnaise from 20 days frozen egg yolk | Mayonnaise from 48 days frozen egg yolk |
|-------------------------|--------------------------------|---|---|
| 0 | 22.80925 | 20.17626 | 20.60872 |
| 25 | 22.50683 | 18.93034 | 19.49232 |
| 50 | 21.71124 | 17.10732 | 19.44383 |
| 75 | 24.34185 | 17.97202 | 19.91349 |
| 100 | 23.74777 | 18.41115 | 20.81717 |

In addition, it can be observed that all mayonnaises, regardless of the composition of the oily phase and the type of egg yolk used, have lighter colors compared to fresh egg yolk ($L^* = 50.17$), sesame oil, respectively rapeseed oil (Table 3). Carotenoids pigments degradation with storage period is the main cause of mayonnaises lightness.

Egg yolk freezing causes a change in parameter a^* values from those negatives (corresponding to green spectra) to the positive ones (corresponding to red spectra). The values of the parameter b^* (yellowness) of mayonnaise increase with the increase in the freezing time of the egg yolk used in the preparation. Also, mayonnaises prepared with frozen egg yolk have lower b^* values than those of sesame oil (Table 3), of fresh egg yolk ($b^* = 28.52$), of egg yolk frozen for 20 days ($b^* = 29.25$), respectively frozen for 48 days ($b^* = 30.54$).

The total color differences ΔE^* between all mayonnaise samples and the color parameters of the sesame oil (Table 13) reveal that the highest values occur for mayonnaise made with pure sesame or rapeseed oil and the lowest ones with 50-50 percentage of these oils, regardless of whether the egg yolk is fresh or frozen.

The acid values for sesame oil, rapeseed oil and fresh/frozen yolk are presented in Table 14 and are consistent with data from the literature and legislative provisions [20-23], in the case of oils being dependent on the nature of the raw material and the way of obtaining it. The content

of free fatty acids in mayonnaise is an indicator of deterioration through hydrolytic processes. These processes take place with the participation of water in the aqueous phase and are favored by the enzymes present in the oils and by the time elapsed since preparation. Figure 9 shows the acid values for mayonnaise prepared from fresh egg yolk (M1-M5), after 7 days of preparation. It is found that the acid values increase by increasing the percentage of sesame oil in the sample.

Table 14

Acid values (AV) of the main ingredients used for mayonnaise preparation.

| Main ingredient | AV (mg KOH/g) |
|-------------------------|---------------|
| Rapeseed oil | 0.872 |
| Sesame oil | 4.59 |
| Fresh egg yolk | 2.705 |
| Frozen egg yolk 20 days | 2.864 |
| Frozen egg yolk 48 days | 2.944 |

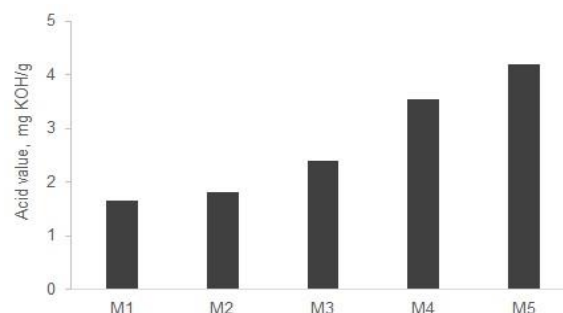


Figure 9. Acid values for mayonnaise prepared from fresh egg yolks, after 7 days of preservation.

This fact is most probably due to both the presence of lipases in the egg yolk, and especially to their presence in a larger quantity in the sesame oil obtained by cold pressing and subsequently only filtered, thus influencing the stability of acylglycerols. Also, for the same types of mayonnaise prepared from fresh egg yolks, the acid values increase with the increase in the storage time, Figure 10. These increases in the acid values are also due to the release of fatty acids following the hydrolytic processes previously mentioned.

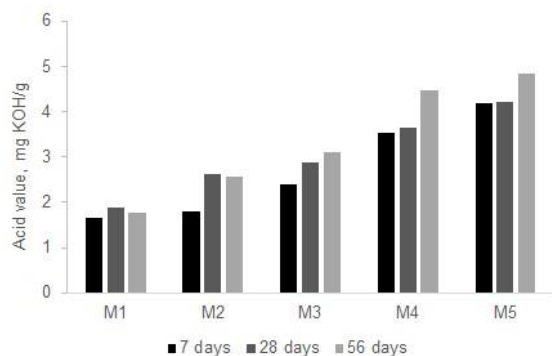


Figure 10. Acid values for mayonnaise prepared from fresh egg yolks, after 3 storage times.

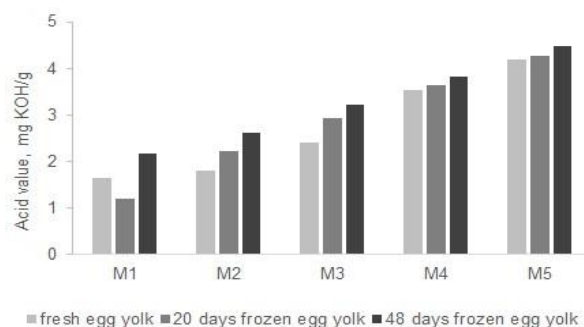


Figure 11. The acid values of mayonnaise according to the freezing time of the egg yolks.

In the case of mayonnaises prepared from egg yolks frozen for different times, the acid values increase with the increase in freezing time. Additionally, the acid values for these mayonnaises increase with the increase in the content of sesame oil, Figure 11. The observed variations (the increases are not large) originate from the same hydrolysis reactions with the formation of free fatty acids.

Conclusions

Mayonnaises with the oily phase (70 wt.%) consisting of mixtures, in different proportions, of rapeseed oil and sesame oil were prepared using egg yolks, fresh or frozen for different times.

The fresh yolk exhibits non-Newtonian behavior (pseudoplastic type) with subunit values of the flow behavior index and apparent viscosities that decrease with shear rate increasing. The addition of sugar, and particularly salt (concentrations between 1 wt.% and 5 wt.%) leads to an increase the shear stress value and, implicitly, an increase in apparent viscosity.

The consistency of mayonnaise prepared from fresh egg yolk increases with the increase in preservation time and in the content of sesame oil in the oily phase.

The apparent viscosity of mayonnaise increases with the increase in the freezing time of the egg yolk. Regardless of the freezing time, the types of mayonnaise with a high sesame oil content (100% or 75% in the oily phase) have the highest consistency.

The acid values of mayonnaise increase with the increase of the preservation time, of the sesame oil content and of the freezing time of the egg yolk.

Based on the color studies, it is found that the parameter L^* increases with the increase in the freezing time of the egg yolk, which proves that the lightest color is found in mayonnaises prepared with egg yolk frozen for 48 days. Also, the lightest color shows the mayonnaises whose oily phase consists only of sesame oil.

References

1. Kantekin-Erdogan, M.N.; Ketenoglu, O.; Tekin, A. Effect of monoglyceride content on emulsion stability and rheology of mayonnaise. *Journal of Food Science and Technology*, 2019, 56, pp. 443–450. DOI: <https://doi.org/10.1007/s13197-018-3506-2>
2. Duncan, S.E. *Fats: Mayonnaise*. Scott Smith, J.; Hui, Y.H. Eds. *Food Processing: Principles and Applications*. Blackwell Publishing: Oxford, 2004, pp. 329–341. <https://www.wiley.com/en-us/Food+Processing:+Principles+and+Applications-p-9780470290118>
3. Huang, L.; Wang, T.; Han, Z.; Meng, Y.; Lu, X. Effect of egg yolk freezing on properties of mayonnaise. *Food Hydrocolloids*, 2016, 56, pp. 311–317. DOI: <https://doi.org/10.1016/j.foodhyd.2015.12.027>
4. Chen, J.; Rosenthal, A. Eds. *Modifying Food Texture. Volume 1: Novel Ingredients and Processing Techniques*. Woodhead Publishing: Sawstone, 2015, pp. 27–49. DOI: <https://doi.org/10.1016/B978-1-78242-333-1.00002-4>
5. Primacella, M.; Wang, T.; Acevedo, N.C. Characterization of mayonnaise properties prepared using frozen-thawed egg yolk treated with hydrolyzed egg yolk proteins as anti-gelator. *Food*

- Hydrocolloids, 2019, 96, pp. 529–536. DOI: <https://doi.org/10.1016/j.foodhyd.2019.06.008>
6. Rahmati, K.; Tehrani, M.M.; Daneshvar, K. Soy milk as emulsifier in mayonnaise: physico-chemical, stability and sensory evaluation. *Journal of Food Science and Technology*, 2014, 51(11), pp. 3341–3347. DOI: <https://doi.org/10.1007/s13197-012-0806-9>
 7. Gaonkar, G.; Koka, R.; Chen, K.; Campbel, B. Emulsifying functionality of enzyme-modified milk proteins in O/W and mayonnaise-like emulsions. *African Journal of Food Science*, 2010, 4(1), pp. 16–25. DOI: <https://doi.org/10.5897/AJFS.9000118>
 8. Ma, Z.; Ma, Y.; Wang, R.; Chi, Y. Influence of antigelation agents on frozen egg yolk gelation. *Journal of Food Engineering*, 2021, 302, 110585, pp. 1–10. DOI: <https://doi.org/10.1016/j.jfoodeng.2021.110585>
 9. Caballero, B.; Finglas, P.M.; Toldra, F. Eds. *Encyclopedia of Food and Health*. Academic Press, 2016, pp. 669–676. DOI: <https://doi.org/10.1016/B978-0-12-384947-2.00449-9>
 10. Blok, A.E.; Bolhuis, D.P.; Arnaudov, L.N.; Velikov, K.P.; Stieger, M. Influence of thickeners (microfibrillated cellulose, starch, xanthan gum) on rheological, tribological and sensory properties of low-fat mayonnaises. *Food Hydrocolloids*, 2023, 136A, 108242, pp. 1–12. DOI: <https://doi.org/10.1016/j.foodhyd.2022.108242>
 11. Bajaj, R.; Singh, N.; Kaur, A. Properties of octenyl succinic anhydride (OSA) modified starches and their application in low fat mayonnaise. *International Journal of Biological Macromolecules*, 2019, 131, pp. 147–157. DOI: <https://doi.org/10.1016/j.ijbiomac.2019.03.054>
 12. Katsaros, G.; Tsoukala, M.; Giannoglou, M.; Taoukis, P. Effect of storage on the rheological and viscoelastic properties of mayonnaise emulsions of different oil droplet size. *Heliyon*, 2020, 6(12), e05788, pp. 1–8. DOI: <https://doi.org/10.1016/j.heliyon.2020.e05788>
 13. Latimer, G.W. *Official Methods of Analysis of AOAC International*. AOAC International: Rockville, 2023. <https://www.aoac.org/official-methods-of-analysis/>
 14. Miclăuș, A.; Pode, V. Particular cases of the flow of ideal and real fluids. *Rheology elements*. Casa Cărții de Știință: Cluj-Napoca, 2018, 142 p. (in Romanian). <https://www.casacartii.ro/editura/carte/cazuri-particulare-de-curgere-a-fluidelor-ideale-si-reale-elemente-de-reologie/>
 15. Schramm, G. *A Practical Approach to Rheology and Rheometry*. Thermo Electron: Karlsruhe, 2004, 268 p. <https://www.ifi.es/wp-content/uploads/2021/06/Rheology-Book.pdf>
 16. Falguera, V.; Velez-Ruiz, J.F.; Alins, V.; Ibarz, A. Rheological behaviour of concentrated mandarin juice at low temperatures. *International Journal of Food Science & Technology*, 2010, 45(10), pp. 2194–2200. DOI: <https://doi.org/10.1111/j.1365-2621.2010.02392.x>
 17. Luo, R. Ed. *Encyclopedia of Color Science and Technology*. Springer: Berlin, Heidelberg, 2015, pp. 1–7. DOI: https://doi.org/10.1007/978-3-642-27851-8_11-1
 18. Westland, S.; Ripamonti, C.; Cheung, V. *Computational Colour Science using MATLAB*. John Wiley, 2012, 240 p. DOI: <https://doi.org/10.1002/9780470710890>
 19. Bruhl, L.; Ubehend, G. Precise color communication by determination of the color of vegetable oils and fats in the CIELAB 1976 ($L^*a^*b^*$) color space. *European Journal of Lipid Science and Technology*, 2021, 123(7), pp. 1–9. DOI: <https://doi.org/10.1002/ejlt.202000329>
 20. Decision of the Government of the Republic of Moldova no. 434 of 27 May 2010 regarding the approval of the “Edible vegetable oils” requirements. Annex no. 3. (in Romanian). https://www.legis.md/cautare/getResults?doc_id=86300&lang=ro
 21. Codex Alimentarius International Food Standards – Standard for edible fats and oils not covered by individual standards CXS 19-1981. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B19-1981%252FCXS_019e.pdf
 22. Olasunkanmi, G.S.; Omolayo, F.T.; Olusegun, O.T. Fatty acid profile, physico-chemical and functional properties of oil and protein isolate simultaneously extracted from sesame (*Sesamum indicum*) seed. *Annals. Food Science and Technology*, 2017, 18(1), pp. 1–10. https://afst.valahia.ro/wp-content/uploads/2022/09/I.1_Saka.pdf
 23. Borchani, C.; Besbes, S.; Blecker, Ch.; Attia, H. Chemical characteristics and oxidative stability of sesame seed, sesame paste and olive oils. *Journal of Agricultural Science and Technology*, 2010, 12(5), pp. 585–596. <https://jast.modares.ac.ir/article-23-7694-en.pdf>