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Research of the rheological properties of mayonnaise with adding pumpkin and rice oils to replace sunflower oil

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Abstract

The influence of ingredients and homogenization process parameters on the rheological properties of mayonnaise with pumpkin and rice oils added was investigated in this work. Various types of vegetable oils: sunflower, pumpkin and rice were used to make mayonnaise. The mechanical process of mayonnaise homogenization was carried out at room temperature. The preparation of mayonnaise was carried out on a laboratory model homogenizer with a rotor speed range of 3500-24000 rpm. Rheological measurements were carried out on a rotary viscometer with concentric cylinders at temperatures of 25 °C and 10 °C. The following rheological parameters were calculated from the data obtained: apparent viscosity, consistency index and flow index. The investigation results revealed that the main ingredients influenced the rheological properties of mayonnaise with pumpkin and rice oils added. Empirical flow curves were described by the Herschel-Bulkley model with a high degree of adequacy.

Keywords: mayonnaise; rheological properties; water-in-oil emulsion; homogenization.

Practical Application: This present work has three main practical applications: enable the pumpkin and rice oils as a functional ingredient into a mayonnaise system; provide knowledge and understanding of the rheological and textural properties of mayonnaise with pumpkin and rice oils added; give insight into the influence of process parameters and composition of the oil phase on rheological properties of mayonnaise.

1 Introduction

Mayonnaise is one of the most widely used sauces in the world. It is a mixture of a semi-solid water-in-oil emulsion obtained by emulsifying of vegetable oil with other ingredients such as egg yolk, vinegar, mustard (Singla et al., 2013). According to the standard, mayonnaise must contain at least 50% of vegetable oil, which makes up the product fat phase. The authors (Muadiad & Sirivongpaisal, 2022) found out that edible vegetable oil is used as the main ingredient to create this type of water-in-oil emulsion, contributing to the organoleptic and physical- and mechanical properties of mayonnaise in a specific way. The mayonnaise oil content has a significant effect on rheological properties such as yield stress, storage modulus and loss modulus (Bredikhin et al., 2022a; Yildirim et al., 2016). The use of vegetable oils different types in various combinations allows achieving the desired composition of fatty acids and tocopherols, which are natural antioxidants and can improve mayonnaise nutritional and organoleptic properties (Kostyra & Barylko-Pikielna, 2007). The production of mayonnaise with a fat phase, consisting of a mixture of edible vegetable oils, such as sunflower oil, enriches the product with a high content of essential linoleic acid and cold-pressed pumpkin seed oil with oleic acid and gamma-tocopherol (a natural antioxidant) and contributes to its better stability (Gorji et al., 2016; Hasenhuettl & Hartel, 2008; Narsimhan & Wang, 2008). Cold pressed pumpkin seed oil enhances mayonnaise organoleptic properties through its aroma and color.

Milk powder, egg powder and vegetable phospholipids are used as emulsifiers (Lužaić et al., 2022). In addition, milk powder acts as a structurant as well, since milk proteins are capable of swelling in the presence of moisture. This allows increasing the water-holding capacity and providing a structuring effect on all the components that make up mayonnaise (Katsaros et al., 2020; Saygili et al., 2022).

The emulsifying ability of egg yolks is mainly due to the presence of phospholipids, high and low density lipoproteins. Vinegar, salt, sugar and mustard are added to mayonnaise as flavoring agents. Lutein, phycocyanin and other compounds (Alvarez-Sabatel et al., 2018), processed beet (Raikos et al., 2016) and fruit components (pulp) (Izidoro et al., 2008) provide oxidation stability, as well as the specific taste and color of mayonnaise. This increases consumer interest in new food products.

Mustard powder is a flavoring agent. The proteins it contains provide emulsification and structure formation too. Mustard powder should be dry, have a pungent allyl oil scent and not darken. Mustard paste should not feel musty and not characteristic of fresh mustard bitterness and rottenness.

Acetic acid improves the taste and bactericidal properties of mayonnaise. Water is required to dissolve salt and sugar as well as to dissolve and swell milk proteins and other recipe components.

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The nutritional value of mayonnaise is determined by the content of vegetable oil and the fact that it is a direct type of emulsion, easily absorbed by the body (Primacella et al., 2019).

Determination of rheological properties is an important criterion for food products quality (Mezger, 2002), including products that are water-in-oil emulsions (mayonnaise, sauces, margarine). Knowing these products rheological properties is important for developing a certain consistency of mayonnaise (Liu et al., 2007), for quality control during production, for storage, transportation (Heydari et al., 2021). The rheological properties of mayonnaise are mainly determined by the proportion and composition of the oil phase, the presence of emulsifiers, stabilizers and thickeners (Kantekin-Erdogan et al., 2019). The quality of water-in-oil emulsions, primarily their stability and viscosity, is aff ected by the process of homogenization (Aganovic et al., 2018), by the dispersion of vegetable oil droplets in the continuous water phase, by the egg yolk (Yang et al., 2020), the type of carbohydrates (Patil & Benjakul, 2019; Shen et al., 2011), as well as the milk component proportion and type (Dybowska, 2008). Fat droplets are mechanically dispersed in the continuous aqueous phase of vinegar, and the action of a natural emulsifier from egg yolks (phospholipids, proteins) provides greater stabilization of the entire system in products of this emulsion type (Castellani et al., 2006; Laca et al., 2010; Thaiudom & Khantarat, 2011).

The homogenization process parameters (rotor speed, duration) and the choice of the rotor-stator system, which forms the fat phase droplets of a larger or smaller diameter, provide different stability of medium, play an important role in the formation of a water-in-oil emulsion (Bredikhin et al., 2022b; Kumar et al., 2021).

This article shows the influence of the composition (type of milk component, carbohydrates and egg yolk), as well as the homogenization process parameters (rotor speed, duration) on the rheological properties of mayonnaise with pumpkin and rice oils added at measuring temperatures of 10 °C and 25 °C.

2 Materials and methods

2.1 Materials

The following ingredients were used to make a mayonnaise with pumpkin and rice oils added: oil phase (refined sunflower oil, cold-pressed pumpkin oil and refined rice oil); egg yolk, carbohydrates (glucose, fructose, lactose, sucrose, inulin, acacia honey), acetic acid, sea salt, mustard, milk component (whole milk powder, skimmed milk powder, whey powder), tartaric acid, distilled water, banana puree (Table 1).

The fat phase of mayonnaise consisted of refined sunflower oil (Sloboda, Russia), cold-pressed pumpkin seed oil (Organic brand), and refined rice oil (Tayra, Thailand). Vinegar, sea salt and mustard were bought at a local store. Egg yolk was purchased from a private supplier and was prepared both fresh and pasteurized. The dairy component comprising whole milk powder (proteins 26.3%, sugar 39.8%, fat 26%), skimmed milk powder (fat content 1.5%) was purchased from the Tagris company, and whey powder (milk fat in the amount of 2%, protein 12-14%, lactose 74%) was manufactured by the Vita-Max company. The carbohydrates glucose, sucrose, fructose, lactose, tartaric acid and inulin were bought from the Novaprodukt company and acacia honey was purchased from a private supplier. Tartaric acid was added to regulate the mayonnaise acidity. The fruit component (banana puree) was prepared by peeling a banana, cutting it into pieces and chopping it by stirring to obtain a homogenized sample.

Table 1. Recipe for the preparation of mayonnaise with the pumpkin and rice oils added.

Composition	Sample	
	Share (%)	Weight (g)
Refined sunflower oil	45	135
Cold pressed pumpkin seed oil	10	30
Refined rice oil	10	30
Pasteurized egg yolk	6.2	18.6
Dry whey	3.5	10.5
Glucose	3.8	11.4
Acetic acid	4	12
Sea salt	0.9	2.7
Mustard	1	3
Tartaric acid	0.1	0.3
Distilled water	11	33
Banana puree	4.5	13.5
TOTAL	100	300

2.2 Mayonnaise preparation

The preparation of mayonnaise samples with the addition of pumpkin and rice oils was carried out in the traditional way in the laboratory at room temperature in the amount of 300 g for each sample. The preparation of mayonnaise was carried out on the laboratory homogenizer of the Ultra Turrax T25 IKA model with the rotor speed range of 3,500-24,000 rpm. A rotor-stator system (type S25 D-14 G-KS) was used to make the mayonnaise. A control mayonnaise sample was prepared with a 65% fat phase consisting of a mixture of refined sunflower oil, cold-pressed pumpkin seed oil and refined rice oil as well as other listed ingredients (Table 1).

Samples were prepared by the required ingredients pre-weighing and adding of ½ part sunflower oil, fresh egg yolk, vinegar, water, and other ingredients. Then the homogenizer was turned on and the rest of the sunflower oil, pumpkin and rice oils were slowly added. The mixture was homogenized for 3 min at the rotor speed of 10,000 rpm. Mayonnaise samples were prepared at room temperature. After that, the rheological properties measurement was carried out. Other mayonnaise samples were prepared in the same way. The exception was that some ingredients were varied depending on each sample recipe and the homogenization process parameters.

2.3 Rheological properties

The rheological properties of freshly prepared mayonnaise samples with pumpkin and rice oils added were measured on a Brookfield rotary viscometer with concentric cylinders.

The viscometer was connected to a computer equipped with Rheocalc 3.2 software, which controlled rheological properties measurement and processed the data obtained. The study of mayonnaise samples rheological properties was carried out at temperatures of 25 °C and 10 °C. Maintaining of the samples constant temperature during the viscometer measurement was carried out with a thermostat model TC-501P from Brookfield. The dependence of shear stress (τ) and apparent viscosity (μ) on shear rate (D) in the range of rates 2.15-136.6 1/s (increasing measurement) and 136.6-2.15 1/s (reverse measurement), as well as the thixotropy phenomenon i.e. the ability to restore viscous and plastic properties after the load removal and deformation cessation were investigated in the work.

The type of mayonnaise rheological model was defined according to the experimental data obtained. The studied samples were determined to have non-Newtonian properties and belong to a pseudoplastic liquid type. The calculated values of rheological parameters-consistency index (k) and flow index (n) were obtained with Microsoft Excel with the application of the linear regression method.

Equation 1 describes the stepwise Ostwald-Rainer law used to calculate rheological parameters.

$$\tau = k \cdot D^{n} \quad (1)$$

τ is the shear stress in Pa; D is the shear rate in 1/s; k is the consistency index in Pa·s^n; n is the flow index.

Equation 2 was used to calculate the apparent viscosity of mayonnaise samples

$$\mu = k \cdot D^{n-1} \quad (2)$$

μ is the apparent viscosity in Pa·s.

3 Results and discussion

The research results of ingredients influence on the change in rheological properties, measured at temperatures of 25 °C and 10 °C when preparing mayonnaise with the addition of pumpkin and rice oils, are given in Figures 1-2 and in Tables 2-4.

The relationship between shear stress and shear rate for mayonnaise with pumpkin seed oil and rice oil, at 25 °C, is shown in Figure 1.

The tested mayonnaise samples exhibit non-Newtonian, pseudoplastic and thixotropic properties. The empirical flow curves are described by the Herschel-Bulkley model with a high degree of adequacy.

The influence of the milk component on the rheological parameters of mayonnaise prepared for 3 minutes at the rotor speed of 10,000 rpm measured at 25 °C and 10 °C is shown in Table 2.

A control mayonnaise sample prepared from whey powder had an apparent viscosity of 2.391 Pa·s, a consistency factor of

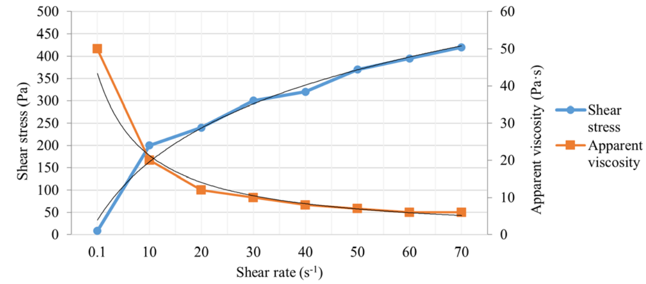

Figure 1. Flow curves of mayonnaise with pumpkin and rice oils added at 25 °C.

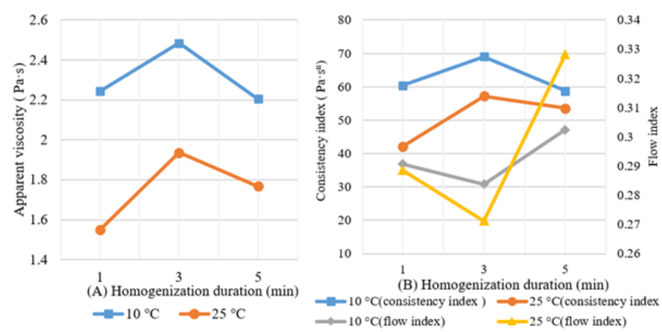

Figure 2. The effect of homogenization duration on the rheological properties of mayonnaise with pumpkin and rice oils added.

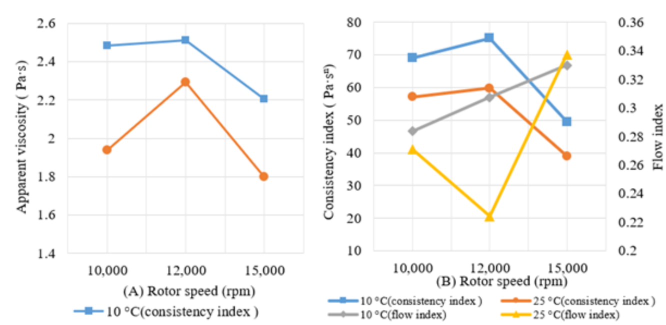

Figure 3. The influence of the rotor speed on the rheological properties of mayonnaise with the addition of pumpkin and rice oils.

Table 2. The influence of milk component on the rheological properties of mayonnaise with pumpkin and rice oils added.

Sample	μ* (Pa·s)	k (Pa·s^n)	n	μ* (Pa·s)	k (Pa·s^n)	n
	25 °C			10 °C		
Skimmed milk powder	2.229	46.87	0.3005	2.712	54.84	0.3095
Whole milk powder	2.343	55.21	0.2744	2.999	67.11	0.2863
Dry whey	2.391	57.18	0.2710	3.055	69.09	0.2838

*Apparent viscosity at shear stress of 77.82 s^{-1}.

Table 3. The influence of carbohydrates type on the rheological parameters of mayonnaise with pumpkin and rice oils added.

Sample	μ* (Pa·s)	k (Pa·s^n)	n	μ* (Pa·s)	k (Pa·s^n)	n
		25 °C			10 °C	
Glucose	2.392	57.16	0.2712	3.052	69.06	0.2837
Fructose	1.997	39.05	0.3172	2.464	55.62	0.2842
Sucrose	2.425	58.63	0.2685	3.024	70.15	0.2780
Lactose	2.748	68.48	0.2615	3.031	77.51	0.2556
Inulin	2.801	69.36	0.2630	3.051	78.92	0.2530
Acacia honey	2.755	65.14	0.2736	3.047	77.28	0.2575

*Apparent viscosity at shear stress of 77.82 s^{-1}.

Table 4. The egg yolk effect on the rheological parameters of mayonnaise with the addition of pumpkin and rice oils.

Sample	μ* (Pa·s)	k (Pa·s^n)	n	μ* (Pa·s)	k (Pa·s^n)	n
		25 °C			10 °C	
Fresh egg yolk	2.656	65.64	0.2634	3.144	73.52	0.2761
Pasteurized egg yolk	2.391	57.15	0.2711	3.054	69.09	0.2838
Whole egg powder	2.504	54.23	0.2937	3.116	71.24	0.2813

*Apparent viscosity at shear stress of 77.82 s^{-1}.

57.18 Pa·s^n and a flow index of 0.2710 measured at 25 °C. A lower apparent viscosity of 2.229 Pa·s^n, a consistency factor of 46.87 Pa·s^n, and a higher flow index of 0.3005 were obtained when using skimmed milk powder in the preparation of mayonnaise compared to using whole milk and whey powder. From the results obtained, it can be concluded that the use of whey powder gives a higher consistency and viscosity of mayonnaise with the addition of pumpkin and rice oils compared to using other dairy ingredients, measured at 25 °C. In addition, the same phenomenon of change in the rheological parameters as at 25 °C is observed when measuring the rheological properties of these samples at 10 °C. Higher values of rheological parameters compared to the measurement at 25 °C were obtained when measuring the rheological properties at 10 °C. This proved the effect of temperature on rheological properties.

The influence of carbohydrates type on the rheological parameters of the mayonnaise obtained during the 3-minute homogenization and the rotor speed of 10,000 rpm measured at 25 °C and 10 °C is shown in Table 3.

A control mayonnaise sample was prepared with glucose. The research results show that the application of glucose and fructose monosaccharides in the preparation of these mayonnaise samples results in lower values of apparent viscosity and consistency index compared to the application of sucrose and lactose disaccharides, inulin and acacia honey. The use of fructose gives the lowest apparent viscosity and consistency of mayonnaise. The application of Inulin provides the highest mayonnaise consistency of 69.36 Pa·s and the apparent viscosity of 2.801 P·s, as well as the lowest flow index of 0.2630 measured at 25 °C. The authors of the work (Alvarez-Sabatel et al., 2018) found out that the content of vegetable oil and inulin affects the stability and rheological properties of mayonnaise obtained by homogenization in the rotor-stator system, as well as homogenization under high pressure. The same effect of ingredients on rheological parameters was observed when measuring the rheological properties of these mayonnaise samples with pumpkin and rice oils at 10 °C.

The research results of egg yolk effect on the rheological parameters of mayonnaise with the addition of pumpkin and rice oils, prepared for 3 minutes of homogenization and the rotor speed of 10,000 rpm, measured at 25 °C and 10 °C, are presented in Table 4.

Making mayonnaise with fresh egg yolk yielded a higher viscosity of 2.656 Pa·s and a consistency index of 65.64 Pa·s^n, as well as a lower flow index of 0.2634. When using whole egg powder in mayonnaise preparation, higher values of apparent viscosity and consistency were obtained compared to pasteurized yolk adding and a lower value of these parameters compared to fresh egg yolk adding. Similar results were observed when measuring the rheological properties of mayonnaise at 10 °C. But they were higher than the values obtained at 25 °C.

The research results of the influence of the homogenization process parameters (rotor speed, homogenization duration) on the rheological properties of mayonnaise with pumpkin and rice oils added are presented in Figures 1-2. The calculated values of the rheological parameter of the flow index (n = 0-1) show that the studied mayonnaise belongs to non-Newtonian fluids of the pseudoplastic type (Izidoro et al., 2007; Mancini et al., 2002).

Figure 2 shows the effect of homogenization duration (1,3 and 5 min) at the rotor speed of 10,000 rpm on the rheological properties of mayonnaise at 25 °C and 10 °C.

The results obtained showed that during 1 minute of homogenization, the apparent viscosity value of 1.548 Pa·s was obtained at the shear rate of 103.8 1/s (Figure 2A), the consistency coefficient of 42.14 Pa·s^n and the flow index of 0.2886 (Figure 2B). By increasing homogenization duration in mayonnaise preparation from 1 minute to 3 minutes, an emulsion with the higher viscosity of 1.936 Pa·s and the consistency of 57.16 Pa·s^n and the lower flow index of 0.2712 was obtained. A further increase in mayonnaise preparation time up to 5 minutes resulted in the structure destroying, causing a decrease in viscosity to 1.768 Pa·s (Figure 2A), the consistency index to 53.61 Pa·s^n and the increase in the flow index up to 0.3282 (Figure 2B). When measuring the rheological properties of mayonnaise with pumpkin and rice oils added at 10 °C, the same results were observed. But they were higher than the values obtained at 25 °C.

The influence of the homogenizer rotor speed (10,000, 12,000 and 15,000 rpm) on the rheological parameters of mayonnaise measured at temperatures of 25 °C and 10 °C for 3 minutes of preparation is shown in Figure 3.

The results of the calculated values of the samples rheological parameters show that the rotor speed also affects the rheological properties change. Increasing the rotor speed from 10,000 to 12,000 rpm increases the mayonnaise apparent viscosity up to 2.292 Pa·s and the consistency index up to 59.85 Pa·s^n (Figure 3A), and it also reduces the flow index to 0.2243 (Figure 3B), which means that the system becomes more stable, as it forms a large number of small fat droplets, which are finely dispersed in the emulsion aqueous phase. A further increase in the rotor speed up to 15000 rpm during the mayonnaise preparation leads to the formation of an emulsion with a lower apparent viscosity of 1.798 Pa·s (Figure 3A) and the consistency index of 39.05 Pa·s^n (Figure 3B) compared to rotor speeds of 10000 and 12000 rpm. This phenomenon can be explained by the increase in mayonnaise viscosity and consistency due to the increase in the homogenizer rotor speed to a certain value. However, with a further increase in the rotor speed, the stable structure of the water-in-oil emulsion is destroyed, i.e. the system is "diluted". This phenomenon can be seen by measuring the mayonnaise rheological properties at 10 °C.

4 Conclusion

The tested samples of mayonnaise with pumpkin and rice oils added belong to non-Newtonian systems, a pseudoplastic type of liquid. The rheological properties with a higher apparent viscosity and consistency index, as well as a lower flow index were obtained when using the dry whey milk component in mayonnaise preparation. The influence of carbohydrates type on mayonnaise rheological properties with pumpkin and rice oils added is also shown in the work. Mayonnaise prepared with Inulin has a higher apparent viscosity and consistency and a lower flow index than that one made with other sugars. The disaccharides used provide mayonnaise higher viscosity and consistency compared to monosaccharides. Mayonnaise with fresh egg yolk has a higher viscosity and consistency. The homogenizer rotor speed, as well as the homogenization duration at a constant speed, also affects the change in mayonnaise rheological properties. Higher viscosity and consistency as well as a lower flow index were obtained with the three minutes' homogenization time. The same phenomena are observed when measuring the rheological properties of mayonnaise with pumpkin and rice oils added at 10 °C, but the values of their parameters are higher than those obtained at 25 °C. Empirical flow curves with a high degree of adequacy are described by the Herschel-Bulkley model.

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