SCIENTIFIC AND PROFESSIONAL SECTION

The effect of extra virgin olive oil and lemon juice on rheological properties of mayonnaise

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Summary

Rheological properties are important quality parameters of mayonnaise. This study examined the effect of the addition of extra virgin olive oil and fresh lemon juice on the rheological properties and the change in color of mayonnaise. The effect of refrigerated storage time of mayonnaise on its rheological properties was also examined. The mechanical process of homogenization of mayonnaise was carried out at 12 000 r/min. for 5 minutes at room temperature. Mayonnaise samples contained 75% oil with different proportions of sunflower oil and extra virgin olive oil. Rheological tests were carried out in a controlled rotational viscometer (DV- III + Digital Rheometer - Brookfield Engineering Laboratories, USA) with concentric spindles, at temperatures of 10°C and 25°C. The obtained data were used to calculate the following rheological parameters: consistency coefficient, flow behavior index and apparent viscosity. The results of the research show that the addition of extra virgin olive oil and lemon juice affects the rheological properties and the color of mayonnaise. The addition of extra virgin olive oil into the oil phase of mayonnaise reduces shear stress, apparent viscosity, consistency coefficient and color change at 25°C and 10°C. Refrigeration of mayonnaise for 14 days leads to changes in rheological parameters.

Key words: *sunflower oil, extra virgin olive oil, rheological properties, mayonnaise*

Introduction

Mayonnaise is a wide consumption product. It is a semi-solid oil-in-water emulsion made from edible vegetable oil, egg yolk, acetic and/or other edible organic acid, mustard, salt, sugar, allowed additives, with or without spices or spice extracts (Anon., 1999). Mayonnaise must contain at least 75% vegetable oil, which makes up its oil phase (Anon., 1989; Anon., 1999). Vegetable oils have an important function in an emulsion; they contribute to the taste, the appearance, the texture and the sustainability of the emulsion in a very specific way (McClements and Demetriades, 1998). Rheological properties represent important quality parameters of oil-in-water emulsion products (sauces, toppings, mayonnaise). Knowledge of the rheological properties of these products is important in creating a certain consistency of mayonnaise (Štern et al., 2001) and in controlling product quality during production, storage and transportation (Juszczak et al., 2003). The rheological properties of mayonnaise, as well as of salad dressings and sauces are mainly determined by the ratio and the composition of the oil phase and the presence of emulsifiers, stabilizers and thickeners (Wendin and Hall, 2001). The quality of oil-in-water emulsions, primarily their stability and viscosity, is affected by the process of homogenization (Wendin et al., 1999), by the dispersion of vegetable oil droplets in the continuous water phase, by the egg yolk (Guilmineau and Kulozik, 2007; Xiong et al., 2000; Laca et al., 2010) and the type of carbohydrates (Ruiling et al., 2011). In this type of emulsions, oil droplets are mechanically dispersed in the continuous water phase of vinegar and the natural emulsifier in the egg yolk is used to increase the stability of the entire system (Kiosseoglou, 2003; Castellani et al., 2006). The use of different edible vegetable oils or a combination of vegetable oils may enhance the nutritional and sensory traits of mayonnaise (Kostyra and Barylko-Pikielna, 2007). The addition of extra virgin olive oil into the oil phase with sunflower oil changes the composition of fatty acids, whereby the ratio of monounsaturated oleic fatty acid and natural antioxidants increases, resulting in greater stability of mayonnaise in the face of oxidative spoilage (Koprivnjak, 2006; Koprivnjak, 2008). Rheological behavior of mayonnaise is a reoccurring subject of research, since it influences consumer attitudes not only by its composition, consistency and taste but also by its use in salads, with chips and in other dishes (Franco et al., 1995; Akhtar et al., 2005; Abu-Jdayil, 2003).

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This study examined the effect of the addition of extra virgin olive oil and fresh lemon juice on the rheological properties and the change in color of mayonnaise. The effect of refrigerated storage time of mayonnaise (14 days) on its rheological properties was also examined. All the mayonnaise samples contained a 75% oil phase with different ratios of sunflower oil and extra virgin olive oil.

Materials and Methods

Materials

The following materials were used to make mayonnaise:

- Refined edible sunflower oil
- Extra virgin olive oil
- Alcohol vinegar (9% acetic acid)
- Chicken egg yolk (pasteurized)
- Distilled water
- Table salt
- Mustard
- Tartaric acid (acidity regulator)
- Glucose
- Freshly squeezed lemon juice

Refined edible sunflower oil was obtained from the IPK Oil Factory Čepin. Extra virgin olive oil, alcohol vinegar (9% acetic acid), table salt and mustard were purchased in a local shop. Liquid chicken egg yolk (pasteurized) was obtained from EL-CON Foods Ltd. in Zlatar Bistrica. Glucose was obtained from Claro-prom Ltd. in Zagreb and tartaric acid from Alkaloid Skopje.

Preparation of the emulsion

The samples of mayonnaise used in this research were prepared in a traditional way, without the use of conservatives, in laboratory conditions, each sample weighing 300 g. The samples contained a 75% oil phase of sunflower oil or of a mixture of sunflower oil and extra virgin olive oil in the ratios 70:30 and 50:50. The first three samples were oil-in-water emulsions made from the ingredients in the following ratios: distilled water (8.4%), alcohol vinegar (4%), pasteurized liquid egg yolk (8%), table salt (1%), mustard (1%), glucose (2.5%) and tartaric acid (0.1%) as acidity regulator. The fourth sample contained the above mentioned ingredients with 10% freshly squeezed lemon juice instead of alcohol vinegar and water. The mayonnaise samples were produced in the laboratory homogenizer D-500 (Wiggenhauser, Germany-Malaysia) with the rotor rotation speed of 10 000 - 30 000 °/min. The 15 mm diameter rotor and the 20 mm diameter stator were used (model HA, SC4-27). In total, four samples of mayonnaise were produced, by homogenization at the rotation speed of 12 000 r/min. for 5 minutes. The first step in the preparation of the samples was the weighing of the necessary ingredients. ½ of sunflower oil was poured into the glass, and egg yolk, vinegar, distilled water and other ingredients were added. The homogenizer was turned on and the rest of the sunflower oil (or olive oil) was added slowly, and then homogenized for 5 minutes at 12 000 r/min. All the ingredients were at room temperature when used. Some of the samples were used to determine rheological properties and some were stored in a refrigerator (+4° C) to test the influence of storage during 14 days on the rheological properties and color of mayonnaise.

Table 1 **Recipes for the preparation of mayonnaise samples**

Ingredients	Sample 1 (g)	Sample 2 (g)	Sample 3 (g)	Sample 4 (g)
Sunflower oil	225	157.5	112.5	112.5
Extra virgin olive oil	0	67.5	112.5	112.5
Egg yolk	24	24	24	24
Distilled water	25.2	25.2	25.2	7.2
Alcohol vinegar (9%)	12	12	12	0
Salt	3	3	3	3
Mustard	3	3	3	3
Tartaric acid	0.3	0.3	0.3	0.3
Glucose	7,5	7.5	7.5	7.5
Lemon juice	0	0	0	30

The mass of each sample was 300 grams.

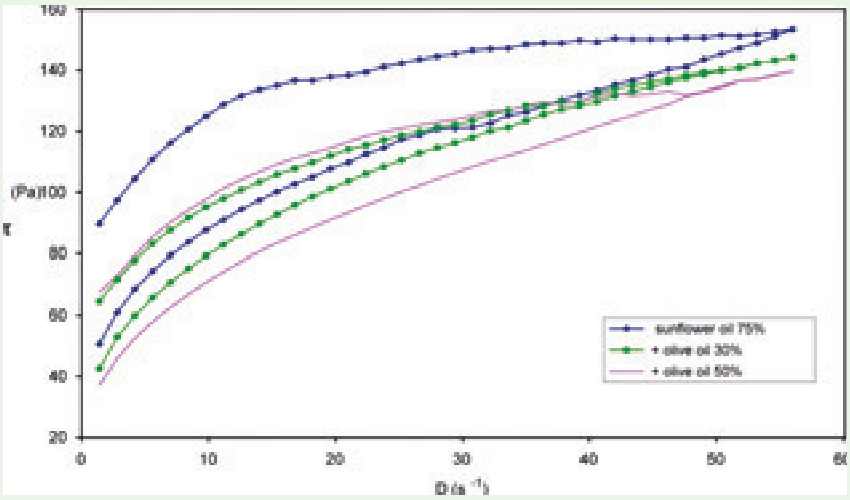

Figure 1. **The relation of shear stress and shear rate in mayonnaise with the addition of 30% and 50% olive oil (on the 0th day), at 25° C**

Rheological properties

Rheological tests of the mayonnaise samples were carried out in a controlled rotational viscometer, model DV- III+ Digital Rheometer - Brookfield Engineering Laboratories (USA), with concentric spindles SC4-27. The viscometer was connected to a computer with the Rheocalc 3.2 software, which controls tests of rheological properties of mayonnaise and processes the obtained data. Tests of rheological properties of freshly made mayonnaise (on the 0^{th} day), as well as of mayonnaise stored in a refrigerator (+4°C) for 14 days, were carried out at the temperatures of 25°C and 10°C (consumption temperature, temperature after removal from the refrigerator). The thermostat TC-501P (Brookfield Engineering Laboratories) was used to keep the temperature of the mayonnaise samples constant during testing in the viscometer. The tests measured the dependence of shear stress (t) and apparent viscosity (μ) on shear rate (D), at shear rates ranging from 1.4 s^{-1} to 56 s^{-1} at upward measurement and from 56 s^{-1} to 1.4 s^{-1} at downward measurement. On the basis of this dependence, fluid type was determined. All the tested mayonnaise samples displayed *non-Newtonian* characteristics and were therefore pseudo plastic fluids with smaller or larger thixotropic loops. The values of the rheological parameters consistency coefficient (k) and flow behavior index (n) were calculated in the Microsoft Excel program, with the application of linear regression analysis.

The rheological parameters consistency coefficient (k) and flow behavior index (n) were thus calculated according to the Ostwald-Reiner power law:

$$\tau = k \cdot D^n$$

τ – shear stress (Pa)
D – shear rate (s^{-1})
k – consistency coefficient ($Pa \cdot s^n$)
n – flow behavior index

The apparent viscosity (μ) of the mayonnaise samples was calculated by the formula:

$$\mu = k \cdot D^{n-1}$$

Color measurement by the instrumental method

The color of the examined mayonnaise samples was measured with the tristimulus colorimeter Minolta CR-300. This type of chromameter measures light reflected from the surface of an object (sample). Reflected light is measured by placing the measuring head onto the glass surface of the sample dish, with the xenon lamp pulsating light vertically onto the object surface. Light is reflected and measured by six highly sensitive silicon photocells. The measured data are computer recorded and expressed in five different colorimetric systems (XYZ; Yxy; Lab; LCh; Hunter lab). Two systems of color measurement were used (Lab and Hunter Lab). The results were detailed in the Lab system, since its values are close to those perceived by the human eye.

L*- the value which defines lightness or darkness; if L* = 100, the color is white; if L* = 0, the color is black

a*- this value can be positive or negative; if positive, the color is red; if negative, the color is green

b*- this value can also be positive or negative; if positive, the color is yellow; if negative, the color is blue

The measurement was carried out by placing the mayonnaise samples in the glass cuvette of the instrument, taking care that no air bubbles are formed in the samples. The color was measured instrumentally and the obtained data were further processed.

Results and Discussion

Table 1 shows the recipes for the preparation of the mayonnaise samples used to examine rheological properties and color change.

The results of the research on the rheological properties of standard or full-fat mayonnaise (75% oil) with the addition of extra virgin olive oil and lemon juice are shown in Figures 1 and 2 and in Tables 2, 3 and 4. Rheological tests were carried out at the temperatures of 25° C and 10° C on freshly made mayonnaise samples (on the 0^{th} day), and during storage of the samples in a refrigerator (+4° C) for 14 days. Figure 1 shows the relation between shear stress and shear rate in freshly made mayonnaise with the addition of 30% and 50% olive oil (on the 0^{th} day) measured at the temperature of 25°C. Upward and downward measurement of the rheological properties of mayonnaise was carried out at the range of shear rates from 1.4 s^{-1} to 56 s^{-1}. The addition of olive oil (30% and 50%) and the decrease in the ratio of sunflower oil in the oil phase of mayonnaise resulted in lower shear stress values and a smaller thixotropic loop area (Figure 1). It may be observed that all the mayonnaise samples, being oil-in-water emulsions, represent *non-Newtonian*, pseudoplastic systems with smaller or larger thixotropic loop areas.

Table 2 illustrates that increased ratios of extra virgin olive oil in the oil phase of freshly made mayonnaise resulted in changes of its rheological parameters compared to the mayonnaise containing only sunflower oil in the oil phase (75%). Apparent viscosity (μ - at the shear rate of 56 s^{-1}) and consistency coefficient (k) values were lower and flow behavior index values (n) higher when measured at the temperature of 25°C. On the basis of the obtained data, it may be surmised that extra virgin olive oil added into the oil phase of mayonnaise reduces its viscosity and consistency, but increases rheological stability since it produces a smaller thixotropic loop area. This occurs because the addition of extra virgin olive oil into sunflower oil creates an oil mixture with a different composition and properties, which causes the difference in viscosity of this oil-in-water emulsion.

The effect of refrigerated storage time on the rheological properties of the mayonnaise samples containing sunflower oil (75% oil phase) and of those containing mixtures of sunflower and olive oil, measured at 25° C, is illustrated in Figure 2 and Table 2. Figure 2 shows that shear stress values increased during the 14 days of storage, but the thixotropic loop area was reduced, signifying that the system grew more rheologically stable. This observation is in accordance with the research results obtained by Laca (2010), illustrating that a larger thixotropic loop area means greater rheological instability of mayonnaise.

It was also noted that the values of the rheological parameters apparent viscosity (μ) and consistency coefficient (k) increased during refrigeration of the mayonnaise samples for 14 days at +4° C, in comparison with the freshly made samples tested on the 0th day (Table 2). During 14 days of storage, the mayonnaise with the oil phase containing a mixture of sunflower and olive oil in the ratios 50:50 (Sample 3) displayed a smaller increase in viscosity and in consistency than the samples containing only sunflower oil and those containing 30% olive oil.

The results of the rheological tests of the mayonnaise samples carried out at 10° C are expressed in rheological parameters in Table 3. By measurement of rheological properties at 10° C, higher apparent viscosity and consistency coefficient values were obtained than by measurement at 25° C. However, during refrigeration for 14 days, all samples examined at 10° C displayed an increase in apparent viscosity, but a decrease in consistency values, expressed as consistency coefficient (k).

With the addition of fresh lemon juice in mayonnaise (Sample 4), apparent viscosity and consistency values rose during refrigeration for 14 days.

Table 2 **The effect of extra virgin olive oil and lemon juice addition and of storage time (+4° C) on the rheological parameters of mayonnaise, at 25° C**

Sample	the 0th day				the 14th day			
	k ($Pa.s^n$)	n	m (mPa.s)	R^2	k ($Pa.s^n$)	n	m (mPa.s)	R^2
1. Mayonnaise with 75% sunflower oil	76.846	0.1444	2740	0.99547	88.028	0.2147	3355	0.99377
2. Mayonnaise with 70% sunflower oil and 30% olive oil	67.525	0.2084	2710	0.99671	74.423	0.2021	3125	0.98305
3. Mayonnaise with 50% sunflower oil and 50% olive oil	61.422	0.2046	2495	0.99095	61.575	0.2043	2515	0.99133
4. Mayonnaise with 50% sunflower oil and 50% olive oil + lemon juice	58.403	0.2223	2630	0.99180	68.422	0.2248	3085	0.99641

k – consistency coefficient ($Pa.s^n$)

n – flow behavior index

m - apparent viscosity at 56 s^{-1} (mPa.s)

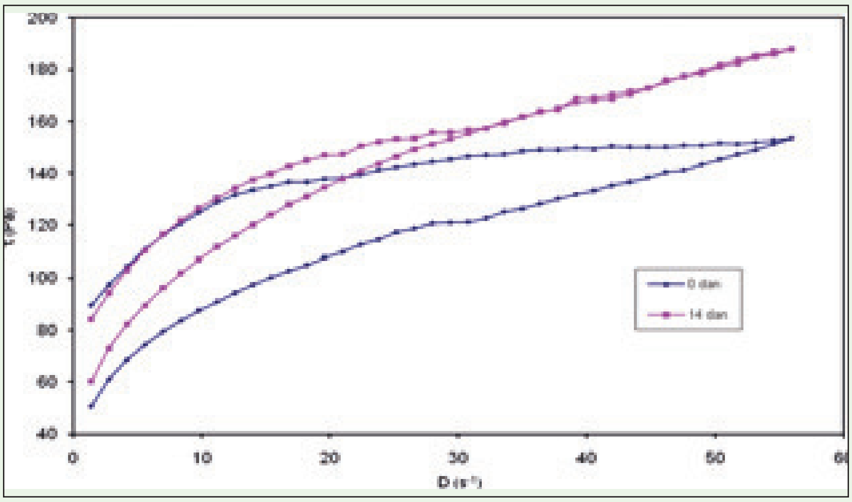

Figure 2 **The effect of refrigerated storage time (+4°C) on the rheological properties of mayonnaise containing 75% sunflower oil, at 25°C**

Instrumental measuring of color change in the examined mayonnaise samples with different ratios of extra virgin olive oil in the oil phase during refrigeration is shown in Table 4. The addition of olive oil (30% and 50%) lead to an increase in the negative value of the parameter (-a), i.e. olive oil caused change of color toward green. The value of the parameter (L) gradually decreased, i.e. the color grew darker. The value of the parameter (+b) increased, signifying change of color toward yellow. During refrigeration for 14 days the values of the parameters (L) and (-a) decreased, whereas the parameter (+b) showed no significant changes.

The mayonnaise samples with sunflower oil (75%) had the highest (L) values, i.e. instrumental measurements showed that their color was the lightest.

Table 3 **The effect of extra virgin olive oil and lemon juice addition and of storage time (+4° C) on the rheological parameters of mayonnaise, at 10° C**

Sample	the 0th day				the 14th day			
	k ($Pa.s^n$)	n	m (mPa.s)	R^2	k ($Pa.s^n$)	n	m (mPa.s)	R^2
1. Mayonnaise with 75% sunflower oil	98,471	0,1822	3755	0,99348	95,051	0,2319	4430	0,99972
2. Mayonnaise with 70% sunflower oil and 30% olive oil	89,659	0,1539	3095	0,98545	87,171	0,2064	3931	0,98437
3. Mayonnaise with 50% sunflower oil and 50% olive oil	86,932	0,1748	3010	0,99294	83,180	0,2695	3905	0,99549
4. Mayonnaise with 50% sunflower oil and 50% olive oil + lemon juice	84,582	0,2027	3405	0,99431	89,362	0,2821	3978	0,99357

k – consistency coefficient ($Pa.s^n$)

n – flow behavior index

m - apparent viscosity at 56 s^{-1} (mPa.s)

Table 4 **The values of color parameters in mayonnaise samples with different ratios of extra virgin olive oil**

Sample	L	a	b
		the 0th day	
1. Mayonnaise with 75% sunflower oil	81.30	- 2.39	+ 16.23
2. Mayonnaise with 70% sunflower oil and 30% olive oil	80.21	- 4.19	+ 22.07
3. Mayonnaise with 50% sunflower oil and 50% olive oil	79.20	- 5.01	+ 25.25
4. Mayonnaise with 50% sunflower oil and 50% olive oil + lemon juice	78.62	- 5.19	+ 26.45
		the 14th day	
1. Mayonnaise with 75% sunflower oil	76.74	- 1.86	+ 16.51
2. Mayonnaise with 70% sunflower oil and 30% olive oil	75.24	- 3.15	+ 21.62
3. Mayonnaise with 50% sunflower oil and 50% olive oil	74.33	- 3.80	+ 24.96
4. Mayonnaise with 50% sunflower oil and 50% olive oil + lemon juice	73.31	- 3.84	+ 25.17

L (L = 100 white; L = 0 black)

a (- a = green; + a = red)

b (- b = blue; + b = yellow)

Conclusion

All the mayonnaise samples displayed *non-Newtonian,* pseudoplastic flow with a certain thixotropic loop area.

The examined samples displayed different rheological properties, depending on the ratio of extra virgin olive oil and fresh lemon juice added.

The addition of extra virgin olive oil in the oil phase of mayonnaise reduced shear stress, apparent viscosity and consistency coefficient at the temperatures of 25° C and 10° C.

During storage in the refrigerator for 14 days, mayonnaise containing sunflower oil (75%) in the oil phase displayed an increase in shear stress, apparent viscosity and consistency coefficient at the temperature of 25°C. At the temperature of 10° C consistency coefficient was lower.

During 14 days of refrigeration, apparent viscosity and consistency coefficient values increased in mayonnaise containing 30% and 50% extra virgin olive oil in the oil phase, at 25° C. At 10° C viscosity was higher and consistency slightly lower.

The addition of fresh lemon juice and 50% extra virgin olive oil at preparation and refrigeration of mayonnaise for 14 days effected higher apparent viscosity and consistency coefficient values, at 25° C and 10° C.

The addition of extra virgin olive oil lead to an increase in the negative value of the parameter (-a), the color of mayonnaise changing toward green.

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Einfluss von Extra Vergine Olivenöl und Zitronensaft auf rheologische Eigenschaften von (Mayonnaise) Majonäse

Zusammenfassung

Rheologische Eigenschaften sind ein wichtiger Parameter für die Majonäsenqualität. In dieser Arbeit wurde die Zufügung von Extra Vergine Olivenöl und frischem Zitronensaft auf rheologische Eigenschaften der Majonäse und deren Farbenänderung untersucht. Es wurde auch der Einfluss der Lagerungszeit von Majonäse im Kühlschrank auf die Veränderung der rheologischen Eigenschaften untersucht. Der mechanische Homogenisationsprozess von Majonäse wurde bei 12 000 °/min in der Zeit von 5 Minuten bei Zimmertemperatur durchgeführt. Die Majonäse enthält 75% Öl mit verschiedenen Anteilen von Sonnenblumenöl und Extra Vergine Olivenöl. Die Messungen von rheologischen Eigenschaften wurden auf Rotationsviskosimeter (DV – III + Digital Rheometer – Brookfield Engineering Laboratories, USA) mit konzentrischen Zylindern bei Temperatur 10° C und 25° C vorgenommen. Aus den bekommenen Resultaten wurden rheologische Parameter, Konsistenzkoeffizient, Flüssigkeitsindex und scheinbare Viskosität gerechnet. Die Resultate haben gezeigt, dass die Zufügung von Extra Vergine Olivenöl und Zitronensaft rheologische Eigenschaften und Farbe von Majonäse beeinflussen. Durch die Zufügung von Extra Vergine Olivenöl in der Ölphase der Majonäse kommt es zu Verminderung der Gleitanstrengung (smično naprezanje), der scheinbaren Viskosität, des Konsistenzkoeffizients und der Farbenänderung bei 25° C und 10° C. Bei der Lagerung der Majonäse im Kühlschrank während 14 Tage kommt es zu Änderung der rheologischen Parameter.

Schlüsselwörter: *Sonnenblumenöl, Extra Vergine Olivenöl, rheologische Eigenschaften, Majonäse*

Influenza dell'olio extravergine di oliva e del succo di limone sulle caratteristiche reologiche della maionese

Somario

Le caratteristiche reologiche sono un parametro importante di qualità della maionese. Questo articolo presenta la ricerca dell'influenza di aggiunta dell'olio extravergine di oliva e del succo di limone appena spremuto sulle caratteristiche reologiche e sul cambiamento di colore della maionese. Anzi, è stata ricercata anche l'influenza del tempo di immagazzinamento della maionese nel frigorifero sulle caratteristiche reologiche. Il processo meccanico d'omogenizzazione della maionese è stato svolto a 12 000 giri/min e nel tempo di 5 minuti a temperatura ambiente. La maionese contiene il 75% di oli con varie percentuali di olio di girasole e olio extravergine di oliva. Le misurazioni di caratteristiche reologiche sono state fatte sul viscosimetro rotazionale (DV- III + Digital Rheometer-Brookfield Engineering Laboratories, USA) con i cilindri concentrici, alle temperature di 10 oC e 25 oC. Dai dati ottenuti sono stati contati i seguenti parametri reologici: coefficiente di consistenza, indice di scorevolezza e viscosità apparente. I risultati di ricerca hanno mostrato che l'aggiunta dell'olio extravergine di oliva e del succo di limone appena spremuto hanno influenza sulle caratteristiche reologiche e sul colore della maionese. Se l'olio extravergine di oliva viene aggiunto nella fase oleosa della maionese si riduce lo sforzo di taglio, la viscosità apparente, il coefficiente di consistenza e il cambiamento del colore ai 25 oC e ai 10 oC. Durante l'immagazzinamento della maionese nel frigorifero nel periodo di 14 giorni succedono i cambiamenti di parametri reologici.

Parole chiave: *olio di girasole, olio extravergine di oliva, caratteristiche reologiche, maionese*

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