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Research Article

Utilization of whey proteins for producing low-fat mayonnaise via complete and partial egg replacement

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Abstract
There is a worldwide demand for healthier foods. One common practice is the production of reduced-fat products in several categories. Whey proteins are popular as important food ingredients due to their essential amino acid content. This work intends to investigate the ability of whey proteins to be used to produce a low-fat mayonnaise. The present study aims to evaluate wholly or partially replacing eggs with whey protein concentrates as emulsifiers in low-fat mayonnaise and its impact on rheological, physicochemical, and sensory characteristics. To accomplish this aim, the researchers followed a quantitative approach by using the SPSS program to sort the findings based on the percentage and the frequency of the mayonnaise model .As a result, the moisture, ash, and fat percentages, along with the pH values for transactions (T1: the eggs were partially replaced (50%) with whey protein concentrates, T2: the eggs were completely replaced 100% with whey protein concentrates) when compared to those of the control treatment have been decreased while the protein and carbohydrates have been increased. This fact has been found in both treatments of partial and total replacement of the egg component with whey protein concentrates. Moreover, the texture study revealed that the properties of viscosity, hardness, adhesiveness, and fluctuation of susceptibility were increased. Additionally, the sensory evaluation scores of some of the studied characteristics in the replacement treatments decreased compared to those of the control.

Keywords: Egg replacement, Healthy foods, Low-fat mayonnaise, Physicochemical properties, Whey protein concentrate

INTRODUCTION

Fat is considered a fundamental element of foods and a traditional energy source with contributes to a sense of fullness. In addition to being a carrier of fat-soluble vitamins, it is also an essential source for supplying the body with essential fatty acids (Emadzadeh and Ghorani, 2015). Owing to shifts in lifestyle and the absence of an equilibrium between energy consumption and expenditure, there has been a global surge in obesity (Aganovic and Heinz, 2018). This rise can be attributed to the overindulgence in fat, a significant contributor to obesity. Thus, it is worth mentioning that excessive consumption of fats, which consist of saturated and hydrogenated fats, leads to harmful effects on health because there is a close relationship between fat consumption with chronic diseases (Astrup et al., 2011; Baum et al., 2012). Therefore, in the 1980s in Japan, attention has been paid to foods that prevent or reduce the incidence of chronic diseases in the elderly

(McConnon et al., 2002). Thus, functional foods are made with formulations that can be consumed as a meal and contain bioactive compounds that are believed to have significant health benefits (Aid et al., 2020).

Drawing on this fact, many efforts have been made to develop edible products with low fat. Moreover, the awareness of the negative impact of fats leads to paying great attention to the foods that give rise to certain diseases such as obesity, cardiovascular disease, and cancer (Shati et al., 2020: Mohammed and Mohamed, 2023). Although consumers want to buy functional foods they realize that they promote health and provide benefits not found in conventional foods (Mahmed et al., 2021), it seems that developing new food products becomes increasingly difficult because it must match consumer satisfaction with the taste of healthy foods. This stems from the desirability of fat in the enhancement of palatability and texture of food. As a result, the quest for food palatability and texture, among other attributes like emulsification, leads to the development of fat substitutes. These substitutes replace fat particles in food with analogous components, maintaining similar properties (Yashini, et al., 2021). In this context, numerous fat-free or low-fat food options have been introduced, such as sausages, cream, yogurt, and mayonnaise (Baker and Alkass, 2020).

To produce healthy foods, the producers must follow the international standards of mayonnaise. The international specifications of mayonnaise argues that 50% of vegetable oils should be included to provide the functions of the fat phase. Therefore, Vegetable oils become one of the main components which is of necessary to produce a water-in-oil emulsion. This process is closely related to the sensory, physical and mechanical properties of mayonnaise (Abed and Khairy, 2023). As a result, many undesirable changes in the physical, chemical, and sensory quality of the mayonnaise could occur after removing the fat, as it is crucial to the texture, flavor, color, lubrication, and stability of food. Therefore, developers face significant barriers in their path to produce new mayonnaise variations, including those with more plant-based ingredients and lower calories. This is because fat affects the rheological properties and sensory properties of foods such as flavor, mouthfeel, and texture. Hence, it becomes difficult to reproduce sensory properties in formulations without fat (Rojas-Martin et al., 2023) . However, based on certain researchers' claims selecting particular fat substitutes in precise amounts offers the potential to achieve a consistency akin to traditional mayonnaise. As claimed by Abed et al., (2024) the possibility of manufacturing mayonnaise by replacing sunflower oil with pumpkin seed oil and improving the shelf life and physicochemical properties of mayonnaise by increasing the replacement ratios. To accomplish this objective, texture improvers or fat replacers need to be incorporated to preserve the texture and sensory qualities of the product. Moreover, AbdulHadi (2022) points out the importance of whey proteins and their vital role in manufacturing products that reduce cholesterol and triglycerides. Eggs are known for their gelatinous properties, foam formation, and emulsification, and they play a major part in food processing. The most essential uses of eggs in the food industry can be summarized in three forms, which are liquid eggs that solidify or coagulate when subjected to heat treatment for the sake of producing solid cake products. Secondly, the foam formation (ability to retain air) to produce products with low air content, such as marancuama. The third use is as phospholipid emulsifiers, which are found in egg yolks and lipoproteins, which are used in the manufacture of both salad dressings, and sausages (Abu-Salem and Abou-Arab, 2008).

In addition, powdered milk serves as a structural component in mayonnaise by enabling milk proteins to swell and fill voids when exposed to moisture. This augmentation in water retention enhances the structural cohesion of all the elements composing mayonnaise (Katsaros et al., 2020; Saygili et al., 2021). Another claim, which is reported by Mohammad (2018) indicates he possibility of replacing egg yolks with lupine protein isolate in manufacturing models of low-calorie mayonnaise.

As earlier argued, the process of developing new food products is becoming increasingly difficult, because these developed products must meet consumer satisfaction, especially concerning the taste of these healthy foods. Within this domain, functional foods offer numerous health advantages beyond their nutritional value, particularly those with reduced fat content (Nashmi and Naser, 2022; Miele et al., 2010).There are numerous studies in which plant-based products sed in the manufacture of dairy products, such as dried fruits or natural sweeteners, are added during the production of ice cream (Hasan et al., 2020; Saadi et al., 2022). Vegetable oils and cardamom are just two examples of what is used in the cheesemaking process (Saadi, 2018; Salih et al., 2021). Sour milk manufacturers may add things like dry mushroom powder, stabilizers, or even different types of milk to this mix (Alkaisy et al., 2023; Saadi et al., 2022; Al-Bedrani et al., 2023). The present study seeks to evaluate the impact of wholly or partially replacing eggs with whey protein concentrates as emulsifiers in low-fat mayonnaise on its rheological, physicochemical, and sensory characteristics.

MATERIALS AND METHODS

Materials

It is worth mentioning that the following materials are used in preparing the mayonnaise mixture, Oil, Egg, Water, Sugar, Vinegar, Mustard, Salt, White pepper,

Table 1. Components of different mayonnaise model mixes

Components	Control C	T1	T2
Oil	70ml	52.5 ml	35 ml
Egg	10g	5g	0
Water	0ml	5ml	5ml
Sugar	2.5g	2.5g	2.5g
Vinegar	5ml	5ml	5ml
Mustard	0.3g	0.3g	0.3g
Salt	1.5g	1.5g	1.5g
White paper	0.5g	0.5g	0.5g
WPC	0	5.0g	10g
Starch	0	2.5g	2.5g

T1: the eggs were partially replaced (50%) with whey protein concentrates; T2: the eggs were completely replaced 100% with whey protein concentrates

and Starch. All ingredients have been obtained from local markets, except the *Whey Protein* Concentrate (WPC) which has been obtained from the Iranian company Golshad.

Methodology

Mayonnaise manufacturing

Mayonnaise was made based on Johary et al. (2015) method, which includes three mixtures. The first mixture which was made according to the standard method for manufacturing mayonnaise with the standard ingredients for mayonnaise is considered as a control sample C. Next in the treatment, the eggs were partially replaced (50%) with whey protein concentrates, which are in treatment T1. Finally, the eggs were completely replaced 100% with whey protein concentrates to represent treatment T2. They are packed in 200 ml plastic containers then the samples are placed in the refrigerator to cool and preserve at a temperature of (5±1) °C until the required tests are conducted within 1, 7, and 14 days.

Estimation of the chemical composition of mayonnaise samples

To estimate the percentage of moisture, ash, fat, and protein, the researchers follow the method that is found in AOAC (2005) and the carbohydrate has been calculated mathematically, based on Ihokoronye's and Ngoddy's (1985) method.

(% carbs = 100 - % (fat + ash + moisture + protein) Eq.1

Physical tests for mayonnaise

Estimating PH has been done by using the method AOAC (2005) by inserting the sensor of a Romanian (HANNA Instruments Microprocessor) pH meter (model 211).

Emulsion stability measurement

The process of ascertaining the emulsion's stability followed the guidelines provided by Rahbari et al. (2015) where each sample, which has 15 grams, is transferred into 15 ml tubes, initially marked as F1. These tubes underwent centrifugation at 5000 x g for 30 minutes, whereupon the upper- fat layer was extracted and weighed, labeled as F2. The emulsion's stability has been computed using the formula:

Emulsion stability % = f2/f1 x 100 Eq. 2

Measurement of heat stability of the emulsion

The thermal stability of the emulsion is assessed by following the method which is described by Rahbari et al. (2015), in which a 15-gram sample is placed in test tubes where its weight denoted as (F1), and then it is heated in an oven at 50°C for 48 hours. After heating, the sample is centrifuged at 3000 x g for 10 minutes. The top fat layer is then removed and its weight denoted as (F2). Finally, the thermal stability is calculated using the formula:

Heat stability % =f2/f1 x 100 Eq. 3

Viscosity estimation

The apparent viscosity of the mayonnaise samples is gauged at a temperature of 10°C utilizing a Brookfield DVII+ viscometer (Brookfield Engineering Lab Inc., Stoughton, Mass). This procedure adhered to the method which is delineated by Donkor et al. (2007), with slight modifications. An axial spindle No. 4 is employed, set to 10 revolutions per minute, with a sample volume of 150 ml. After mixing the sample by stirring it ten times clockwise and ten times counterclockwise, the spindle is allowed to rotate within the sample for 60 seconds. The viscosity measurement is recorded in centipoise units.

Texture analyses

Texture analyses of mayonnaise treatments are done by using (Brookfield CT3 Texture Analyzer) texture analyzing device and the hardness, and cohesiveness is measured. The measurement was done according to

Bonczar et al. (2002) method by using a plastic cylinder with a diameter of 2 cm, which is pressed on the product at a force of 5 g in order to enter at a depth of 2cm at speed of 1 mm/sec.

Sensory evaluation

Sensory evaluation of the mayonnaise models is conducted after manufacturing by 11 panelists, and the evaluation form for sensory attributes (flavor, color, scent, general acceptability which is proposed by Johary et al. (2015).

Statistical analysis

The Statistical Analysis System (SAS, 2018) software is employed to analyze the impact of various factors on parameters. To compare the means and identify significant differences, the Least Significant Difference (LSD) test, a form of Analysis of Variation (ANOVA), was used.

RESULTS AND DISCUSSION

Chemical composition

The data presented in Table 2 revealed that notable discrepancies in moisture content between the control and the group of treatments were subjected to either partial or complete substitution of the egg component. Thus, the control treatment had the highest moisture percentage, of 17.462%. This finding aligns closely with the results of Satriawan et al. (2022) who claimed that the moisture content in the control sample of low-fat mayonnaise was 19.05%, the T1 treatment is 12.340% and the T2 was 10.675.

In both treatments, the substitution with whey protein concentrate correlated directly with the increase in the added amount compared to the control treatment due to the total solid, which will rise as an effect of adding whey protein concentrate in the form of a dry (solid) powder. Therefore, a reduction in moisture will be found. Also, low-fat mayonnaise is The fat that works with vinegar to increase moisture content has been lost compared to full-fat mayonnaise, and this outcome aligns with Abd El-Salam et al. (2009) and Firebaugh and Daubert, (2005) findings indicate that the emulsifying ability of whey proteins comes from their distinct properties, including their ability to absorb two different phases of liquids, namely the water and fat phases.

Wiguna et al. (2023) indicate that the upper limit of the moisture percentage in mayonnaise is 30%. These results are also in the same line as those mentioned by Satriawan et al. (2022), who demonstrated that there was a decline in the moisture percentage of low-fat mayonnaise, which was added to a whey protein with 15%, and reached 15.81% compared to the control treatment, which had a humidity of 19.05%. Firebaugh and Daubert (2005) also point out that the emulsifying ability of whey proteins depends on several factors, including pH, ionic strength, and total protein component. The findings of this paper align with those of Aziznia et al. (2008), who stated that the reduced moisture in fat-free mayonnaise comes from the higher total solids raised by increasing the added amount of whey protein.

Regarding the fat content, Table 2 shows that the control sample had a fat percentage of 40.87%, while the T1 treatment had 33.892%, and the T2 treatment had 28.74%. The data reveals that the fat ratio decreased in the two whey protein concentrate samples, and this decrease was directly proportional to the increased added amount compared to the control. This reduction is likely due to substituting the fat-rich egg component with whey protein concentrates, which are fat-free, along with lowering the oil content in the initial mixture. This adjustment aligns with the product's low-fat requirement, having a fat percentage of 25% for T1 and 50% for T2. Substantial variations in fat content have been observed between the replacement treatments and the control.

Regarding the protein content, as indicated in Table 2, the percentage ranged from 5.469% to 9.950%. This demonstrates notable disparities between the replacement treatments and the control. The data showed that a direct correlation between the increase in protein ratio and the added amount of whey protein concentrate in the substitution samples. This might be aligned with what Satriawan et al. (2022) who indicated an increase in the protein percentage in low-fat mayonnaise treatments to which whey protein concentrate has been

Table 2. Chemical composition of mayonnaise samples

Treatment	Moisture%	Fat%	Protein%	carbohydrates	Ash %	pH
Control (C)	17.462	40.87	5.469	35.61	0.195	4.34
T1	12.340	33.892	7.563	45.32	0.885	4.25
T2	10.675	28.74	9.950	49.91	0.725	4.13
LSD value	2.501*	4.833*	1.976*	5.017*	0.337*	0.362NS
*($P \leq 0.05$)						

Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates.

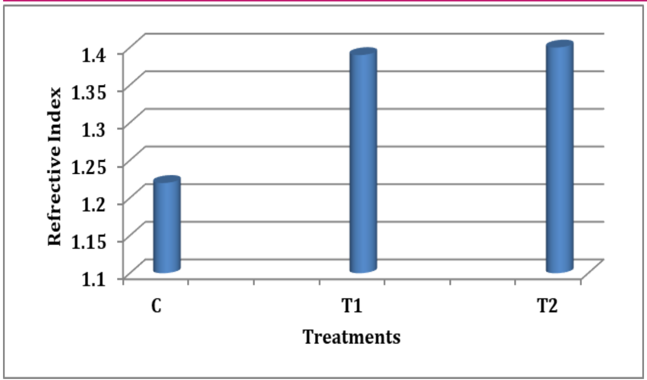

Fig. 1. *Refractive index values of mayonnaise treatments, LSD Value =0.193 NS Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates*

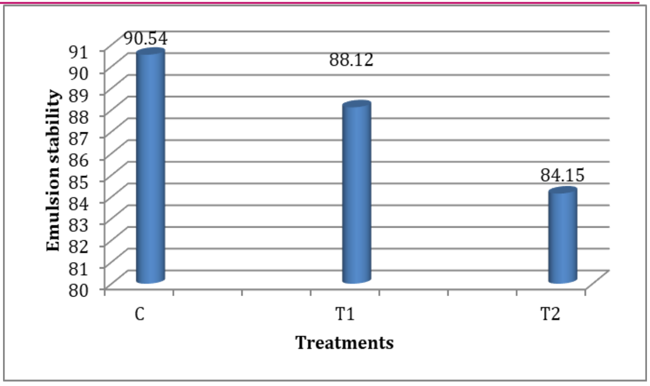

Fig. 2. *Emulsion stability for the different mayonnaise treatments, LSD Value =4.189 * Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates*

added. This also aligns with Al-Darwash et al. (2014), who noted that protein-based ingredients elevate the solids and increase the protein content. Therefore, adding more whey protein concentrate leads to an increase in the protein percentage in the mayonnaise.

As for the percentage of carbohydrates, it ranged between 35.61 - 49.91%. The results indicated that carbohydrate percentage escalates proportionally with the amount of whey protein concentrate used when related to that of the control due to the whey protein concentrates containing a percentage of the sugar lactose during the preparation process and this causes an increase in its concentration in these treatments.

Finally, the percentage of ash ranged between 0.725-1.589 %. The ash percentage decreased proportionally with the increase in whey protein concentrate. This reduction might be attributed to the egg component, especially its fat part, containing many mineral elements that are not found in whey protein concentrates.

Physical properties

The data presented in Table 3 illustrates the pH levels, which varied from 4.13 to 4.34, with the control treatment registering the highest value of 4.34. This result is close to what Evanuarini and Susilo (2020) found when estimating the pH value for the control treatment of low-fat mayonnaise fortified with bananas, which amounted to 4.43, although it is lower than what was found by Abed and Khairy (2023), who indicated that the pH values of mayonnaise reached 7.8 when producing mayonnaise by replacing sunflower seed oil with pumpkin seed oil.

Its lowest value was for the total replacement treatment with whey protein concentrates treated

The lowest pH value of the treatment T2 (treatment with complete eggs substituted (100%) with whey protein concentrates) is attributed to the properties of WPC, which are characterized by more acidic properties than those of egg proteins and contribute to increasing the mayonnaise mixture's buffer capacity. This is similar to what has been found by Aziznia et al. (2008). The finding also aligns with the results those are reported by Yeganehzad et al. (2007), who indicate that the reason for the reduction in pH values for fat-free yogurt treatments with whey protein concentrates comes from an increase in the percentage of citrates and phosphates in the yogurt mixture which is a result from an expansion in the milk's total solids.

Refractive index

Fig. 1 presents the refractive index measurements for the various mayonnaise samples, showing a lower refractive index of the control treatment than the refractive index of the two replacement treatments. It is also clear that the complete replacement of the egg component with whey protein concentrate has increased the refractive index value compared to the partial replacement and the control sample. The constitution of whey protein, characterized by a high refractive index compared to egg protein and fat, might cause the above-mentioned elevation (Lafta et al., 2019).

Emulsion stability

Lee et al. (2013) stated that the stability of mayonnaise emulsion is affected by several factors, the most important of which are the oil content, egg yolk content, proportionality between oil and water, preparation method, temperature, viscosity, size of fat particles, type of emulsion, concentration, and distribution ratio.

The results in Fig. 2 and 3 show the emulsification stability of the mayonnaise models and the emulsification stability to heat, respectively. Partial replacement of the egg component with whey protein concentrates treated with T1 increased the ability to emulsify and its stability to heat. This may be due to the presence of a portion representing 50% of the egg component with a high emulsification ability due to the presence of phospholipids in it, which increases this ability. On the contrary,

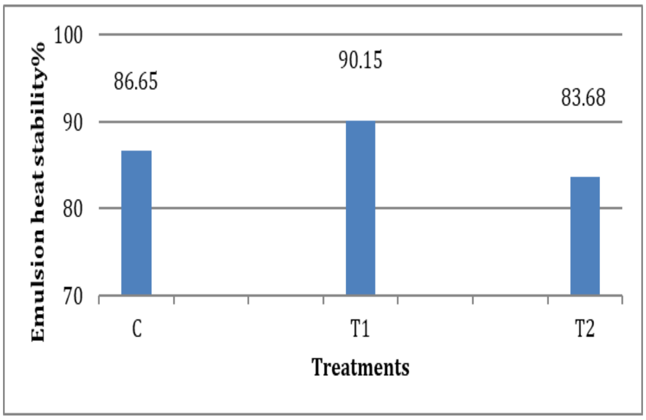

Fig. 3. *Emulsion heat stability for the different mayonnaise treatments, LSD Value =4.572 *Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates.*

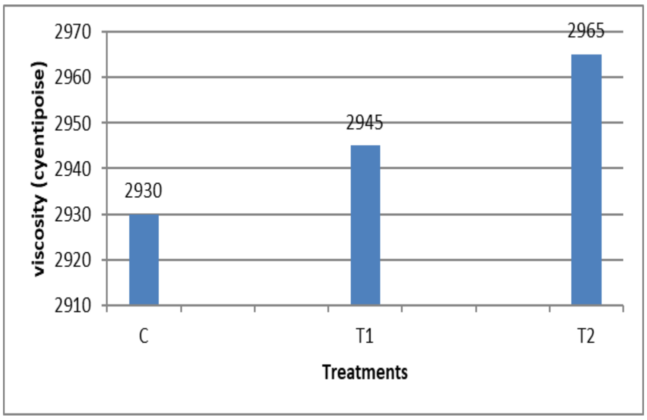

Fig. 4. *Viscosity values for the different mayonnaise treatments, LSD Value =28.544 *Hardness; Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates.*

the total replacement of the egg component with whey protein concentrates led to a decrease in the emulsification ability of the T2 treatment to the control specimen as an effect of the decrease in the emulsification ability of whey proteins compared to eggs, a result conforms to that of Johary et al. (2015) which states an increase in the heat stability of the emulsion for low-calorie mayonnaise models manufactured by replacing the emulsifying agent egg yolk with some types of gums Basil Seed Gum and Tracaganth Gum, and indicated that the use of emulsifiers, including gums, proteins, and polysaccharides, leads to an increase in viscosity, which slows down It reduces the rate of migration of oil droplets by reducing the repulsion between those droplets. This leads to increasing the stability of the colloidal system and providing emulsions with a smaller and more stable particle size. The instability of the emulsion may be due to low viscosity (Nikzade et al., 2012). Rojas-Martin et al. (2023) explains that the stability of mayonnaise samples is improved, especially in those in which the protein isolate has been completely replaced with egg yolk. It also linked with what is stated by Roller and Jones (1996) who indicated that whey proteins perform an emulsifying function, which leads to improving the functions of fat substitutes. They attributed the process of protein fragmentation within emulsified product blocks to the imitation of whey proteins of droplets of real fat in the water-in-oil mixture. The process of protein fragmentation is attributed to the imitation of real fat droplets in a water-in-oil mixture, where whey proteins perform an emulsifying function, which leads to improving the functions of fat substitutes.

In a study conducted by Hashemi et al. (2018), it was shown that adding lysozyme and Arabic gum to the mayonnaise mixture leads to an interaction between both proteins and polysaccharides with oil and water to act as an emulsifier and thus increasing the emulsifying stability of mayonnaise. Lee et al. (2013) also indicated an increase in the emulsifying ability of mayonnaise by increasing the content of xanthan gum. Yalmanci et al. (2023) also denoted that whey protein isolates, when added in by 5% and bacterial exogenous polysaccharides by 2%, improved low-fat mayonnaise's emulsifying stability properties. Whey proteins are mainly composed of the proteins beta-lactoglobulin and alpha-lactobumin. It can stabilize emulsions, especially the beta-lactoglobulin protein, at a pH of 7, which carries a negative charge, leading to a relatively strong electrostatic repulsion between the droplets. In fact, the electrical neutralization point for this protein is 5.2. It has been proven through particle size measurements that emulsions stabilized by this protein are sensitive. Thermal treatments higher than 70°C lead to denaturation, while temperatures lower than that make the protein structure unopened; therefore, effective sites are not available to increase interactions and attractive interactions (Kim et al., 2002). In general, proteins encompass various functional clusters and specialized formations linked to their physicochemical attributes, which can be altered (for instance, via molecular conformational changes and chemical alterations) in the course of creating nanostructures used as nano-delivery systems. Moreover, proteins exhibit stronger interactions at the water-oil junction compared to the water-air junction (Santiago et al., 2008). After proteins are absorbed, emulsions can be stabilized by electrostatic forces (Dalgleish, 2006).

Viscosity

The results of the viscosity test in Fig. 4 show that these values ranged between 2930 - 2965 centipoises, and their highest value is for treatment T2, in which the

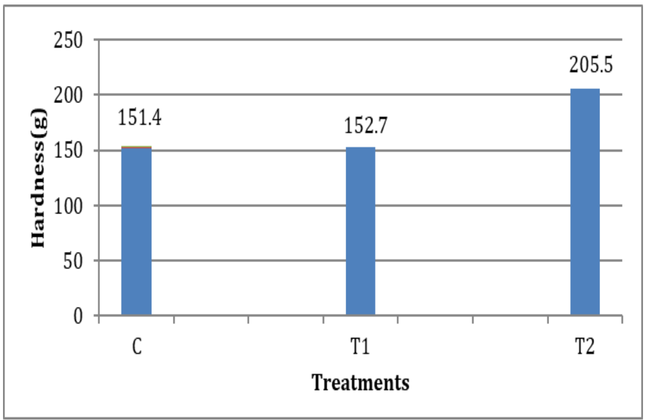

Fig. 5. *Hardness values for the different mayonnaise treatments , LSD Value =32.109 *Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates*

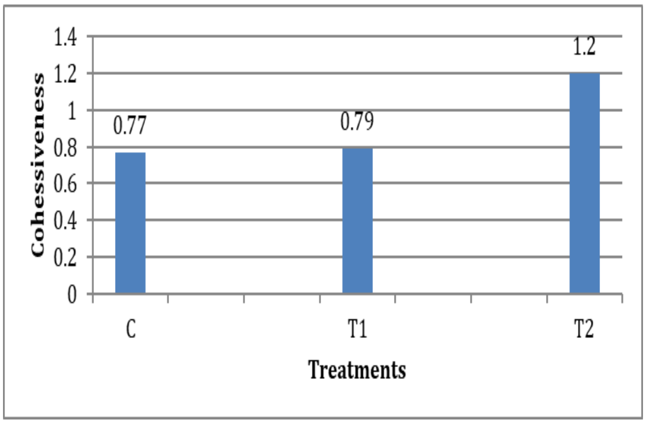

Fig. 6. *Cohesiveness values for the different mayonnaise treatments, LSD Value =0.237 *; Where: C = Control treatment, T1 = treatment with partial eggs substituted (50%) with whey protein concentrates, T2 = treatment with complete eggs substituted (100%) with whey protein concentrates.*

egg component has completely been replaced with whey protein concentrate, which is characterized by significant differences from the control treatment. This is followed by treatment T1, which had a viscosity value of 2945 centipoise compared to the control treatment, which is the least viscous, as its viscosity reached 2930 centipoise. The findings indicate that the viscosity of the replacement treatments rises compared to the control, with a direct correlation to the increased replacement ratio. This increase is likely attributable to the high water-absorption capacity of whey proteins, leading to an increased the mayonnaise emulsion's viscosity.

These results are similar to those of Satriawan et al. (2022), who agree with what Azizah et al. (2018) mentioned: that adding whey protein increases viscosity. Therefore, this is attributed to the whey protein acting as a surfactant, which increases the viscosity of the product. Since the protein content of the whey protein concentrate reaches 80%, it can act as a surfactant. Yalmanci et al. (2023) also conclude that adding a complex of isolated whey protein and bacterial exopolysaccharides as a substitute for fat in the production of low-fat mayonnaise improves the product's rheological properties. Heating a whey protein solution (as is the case in the manufacture of mayonnaise) can lead to a rise in viscosity and enhanced water-binding capacity. This occurs because the protein structure unfolds, exposing the formerly hidden locations to bind water and increasing the protein's occupied volume (Jayaprakasha and Brueckner, 1999). According to Chung et al. (2014), incorporating whey proteins that are microparticulated (MWP) in dressings and in low-calorie sauces as a substitute for fat will boost their viscosity levels.

It is clear from the tissue analysis results in Fig. 5 that the hardness values of the treatments replacing the egg component with whey protein concentrates has been increased in direct proportion to the added amount in relation to that of the control that is devoid of replacement. Adding concentrates of whey causes an increase in the proportion of solids. Thus, The total solid has been increased the hardness. This result was similar to Venus et al. (2021), who indicate a rise in hardness measurements belonging to the reduced-fat mayonnaise to which whey protein concentrates have been added with 0.3%. It is also in line with what Raymundo et al. (2002) said: adding proteins increases hardness and adhesiveness values. Venus et al. (2021) also indicate that the low-fat mayonnaise treatment supplemented with 0.4% whey protein concentrate and 0.5 tracacanth gums had high values of both hardness and adhesion. However, the findings presented in this study are contrary to those of Al-Bedrani et al. (2019), who observed a reduction in the hardness of processed cheese treatments produced from soft Iraqi cheese by adding whey protein concentrates. The results also highlight notable disparities in hardness between T2 and C samples.

Cohesiveness

The adhesion values for the different mayonnaise treatments, as shown in Fig. 7, ranged between 0.77-1.2, where the highest value is given for treatment T2, in which the egg component has completely been replaced with whey protein concentrates, followed by treatment T1. While the lowest adhesion value is given for the control treatment, which amounted 0.77. The outcomes reveal a significant elevation in the adhesion parameter, correlating with the rise in substitution rate. This phenomenon could be attributed to incorporating WPC in the production, which increases the adhesion ability due to the high ability of these proteins, which leads to binding the aqueous and fatty phases and to act as an emulsifier, which improves the adhesion properties. This corresponds with the results reported by Yang et al. (2022), which showed an increase in the adhesive qualities of low-fat mayonnaise fortified with whey proteins.

Sensory evaluation

Table 3 presents the findings from assessing the sensory characteristics of the mayonnaise models under the study. The results in the table show differences for the mayonnaise models in the grades given to the color attribute, as Model C (control treatment) excelled in all sensory attributes, including color, then comes Model T1, and finally, Model T2. As for flavor's control model outperformed the others, followed by the T1 and T2 models. The assessment of flavour and taste attributes reveals a notable similarity between the mayonnaise samples with added whey protein concentrates and the control sample.

This similarity arises because whey proteins possess distinctive flavor properties, making their flavor an essential factor, leading to utilising it more in various foods (Le Quach et al., 1998). Matumoto-Pintro et al. (2011) also indicated that increasing the rates of addition of substances containing α-lactalbumin or those come from protein materials that are partially hydrolyzed gives the fat-free food product fortified with them sensory characteristics that are completely identical to the full-fat product. Yang et al. (2022) also indicated an improvement in the fatty taste and mouth-fullness characteristics of low-fat mayonnaise supplemented with whey proteins. Whey proteins have a pure flavor compared to other proteins, such as soy protein, which has increased their ability to be used in various products.

In addition, these proteins can be manufactured in ways that make them contain the lowest possible percentage of carbohydrates, thus turning into a food with a lower carbohydrate rate, and high in protein (Kilara and Vaghela, 2018). For instance, it is incorporated into cereals for breakfast to enhance their protein content (Hazen, 2005). As for the evaluation of body and texture, the T2 model excelled and obtained the highest scores, then comes the T1 model, and finally, the control model, where the addition of whey protein concentrates leads to giving an elastic texture that is closest to a good texture, and this is consistent with what is found by Delikanli and Ozcan, (2014), who indicated that the addition of protein concentrates leads to significant differences in texture and consistency. The superiority of the control treatment C in the scores it obtained in the sensory evaluation. This is reflected in the general acceptability. The influence of WPC on the rheological traits of reduced-fat mayonnaise is related to its sulfur group content, which determines the extent and size of the cross-links present in it.

Conclusion

On the basis of mayonnaise treatments and statistical analysis, it was determined that whey protein, either as a partial or complete substitute for egg yolks, facilitates the production of low-fat mayonnaise by enhancing its rheological properties. Additionally, the complete replacement of egg yolks with whey protein resulted in a product with favorable rheological characteristics and improved health benefits. These findings confirm the feasibility of entirely replacing egg yolks and highlight the potential for identifying alternative emulsifiers, such as plant-based protein isolates with strong emulsifying properties, for producing healthier mayonnaise formulations. As a result, the researchers find that using whey protein either a partial or wholly substitute for egg yolks helps to manufacture the low-fat mayonnaise due to its features in improving the rheological properties of the product. Moreover, it increases the advantages of health by reducing the calories that are consumed by individuals.

Conflict of interest

The authors declare that they have no conflict of interest.

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