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Developing low-fat oleogels based on Monoacylglycerol and Bees Wax

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1. Introduction

Fat plays a crucial role in the internal network of several food products because it provides important sensory and textural qualities. However, fats used in processed food are hydrogenated fats or trans fats. The consumption of this type of fats has been associated to health risk, for that reason some regulations around the world have been adopted to minimize this problem. In 2018, the United Stated Food and Drug Administration published a statement calling for the removal of industrially generated artificial trans-fats from the food supply. Similarly, in 2019, the European Commission stablished a Regulation where specified the maximin limit of trans-fat consumption per 100 grams.

In other hand, fat substitutes in food are a need that has been growing over the years, due to the recent trend of leading a healthy lifestyle, where the consumption of foods that provide health benefits and the practice of some sport are sought. in order to avoid conditions such as overweight and obesity, which lead to suffering from certain cardiovascular pathologies. Among the alternatives for fat substitutes, oleogels represent a novel option. However, when replacing fat, it is critical to ensure that the replacement compounds can imitate the unique qualities of fats while retaining the desired sensory and textural features of the food product.

It is generally established that the amount of fat consumed, the makeup of the fatty acids, and the availability of bioactive micronutrients can all have an impact on how fat affects human health and nutrition. The primary goal of using oleogels in the food sector is to change the structure of the oils to create polymers with solid-like qualities while also giving products healthier fatty acid profiles. Owing to a shift in consumer awareness of the negative effects of solid fats on human health as well as suggestions made in dietary guidelines.

Oleogels have been studied in order to be a substitute for fat, being defined as structures that work by dispersing a structuring agent (oleogelator) in a continuous oily phase, in this case an edible liquid oil, forming a three-dimensional network without chemically altering said oil and forming a solid gel material (Özer & Çelegen, 2021). Oleogels are semi-solid or solid structures generated when liquid oils gel with a gelling ingredient such as a natural wax or a polymer. They can have textural features similar to fats, such as smoothness, creaminess, and mouthfeel.

Nevertheless, solid fats have a technological utility as food texture modifiers because the rheological and thermal behaviors of the crystalline structure may be adjusted, offering attractive functional qualities in a variety of food systems. And for that reason, to substitute (semi) solid fat with structured liquid oils, product quality must be reassessed and fulfill the needed quality patterns (Okuro, et al., 2020). To ensure that oleogels can effectively substitute fats in high-fat food products, the formulation and processing conditions must be optimized to achieve the appropriate texture. This may entail modifying the gelling agent concentration, the type of oil utilized, as well as the processing temperature and time. Analytical techniques like rheology can also be used to characterize the textural qualities of oleogels and their performance in food products.

Thus, for the development of oleogels, it is therefore necessary to evaluate some properties in order to present this product as a real alternative to use in a final product. For this reason, this work aims to develop low-fat oleogel based on two different oleogelators, Monoacylglycerol and Bee Wax and to evaluate their effects on spreadability and rheological characteristics.

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2. The goal of the thesis work

Trans-fatty acids are manufactured fats produced during the chemical process called hydrogenation, which is used to stabilize polyunsaturated oils and keep them solid at room temperature by preventing rancidity. Trans-fatty acids are unsaturated fatty acids which contain at least one double bond in its trans configuration. These could be particularly harmful to heart health and could increase the risk of developing some cancers. (Pipoyan et al., 2021)

In confectionary and bakery product one of the main ingredients implemented to improve the texture in final products is shortening. It has a greater melting point and can endure high heat without breaking down, it is frequently used in place of butter or margarine. However, because to the health risks associated with trans-fat consumption, several researchers have begun to study how to reformulate these products to limit or remove the usage of partially hydrogenated oils. Alternative fats, such as palm oil or coconut oil, are utilized in some circumstances instead, however nowadays oleogels are been developing as a potential alternative to improve food nutritional profiles.

For that reason, the goal of this study is to develop low-fat oleogel based on Monoacylglycerol and Bees Wax, and evaluating their effects on spreadability and rheological characteristics of the final product as a fat replacement for using in confectionary and bakery products, comparing their responses based on their gelling agent ratio.

3. Literature overview

3.1.Fats, oils and lipids

Fats, oils and lipids are essential nutrients that play important roles in human nutrition and food science. They are important sources of energy, essential fatty acids, fat-soluble vitamins, and flavor and texture in foods. They are composed of various organic compounds, which include fatty acids (FA), monoacylglycerols (MG), diacylglycerols (DG), triacylglycerols (TG), phospholipids (PL), eicosanoids, resolvins, docosanoids, sterols, sterol esters, carotenoids, vitamins A and E, fatty alcohols, hydrocarbons, and wax esters. (FAO, 2010).

Fats and lipids are critical components of the human body's homeostatic function. Lipids play an important role in many of the body's operations. They are organic molecules that are soluble in organic solvents but insoluble in polar solvents like water (Ahmed et al., 2022). According to their chemical structure, lipids can be classified as simple, compound, and associated. Within the simple lipids are those that are made up of glycerol and fatty acids such as fats, which are generally of animal origin and at room temperature present a solid state; oils, from plant and marine sources that are characterized by being liquid under ambient conditions; and the waxes, which are esters of long-chain acids with high molecular weight alcohols, can be of animal (beeswax), vegetable (carnauba wax) and mineral (paraffins) origin (Arredondo, 2022).

Oils and fats used for food are mainly made up of triglycerides. These mainly present three classes of fatty acids: saturated (SFA), monounsaturated (MUFA) and polyunsaturated triglycerides (PUFA). In general, fats contain a higher proportion of saturated fatty acids, which have a linear three-dimensional structure that allows them to fit orderly in space, thus presenting a high melting point. However, oils generally have a higher proportion of unsaturated fatty acids. Unsaturated fatty acids have C=C double bonds, and in some very particular cases they may also have triple bonds, and they may have one or more unsaturations along the carbon chain (Giacomozzi, 2020).

Astrup et al., (2020) mention that in food it is important to distinguish between fat and fatty acids. Saturated fat foods are those that are mainly lipid and solid at the temperatures at which they are typically stored and consumed. Butter and butter-fat are examples, as are dairy-derived fats found in cheese, animal fats like tallow and lard, and plant oils like cocoa butter (chocolate), coconut oil, palm and palm kernel oils. These fats are solid because they are predominantly composed of "saturated fatty acids," where "saturated" refers to a specific chemical structural attribute of fatty acids. SFAs have chemically defined structures, whereas saturated fats are complicated chemical combinations of all main SFAs in varying quantities, as well as a variety of other fatty acids.

Structural properties of semi-solid fat products are based on saturated and trans fatty acids (TFAs). Trans fatty acids, also known as trans fats, are unsaturated fatty acids that are commonly found in processed foods, fried foods, and baked goods. TFAs have long been employed in food manufacture because to the difference in melting point between saturated and unsaturated fats at ambient temperature. However, growing epidemiologic and biochemical evidence suggests that trans fats in the diet constitute a significant risk factor for cardiovascular events, as well as cancer and diabetes.

Trans fatty acids are mostly the product of industrial processes such as the hydrogenation of fats (Tarté et al., 2020). This process consists of making liquid vegetable oils more solid and stable at room temperature to prevent rancidity of unsaturated fatty acids by adding hydrogens to remove double bonds and make saturated fats. However, it has been reported that hydrogenated fat has negative health effects. (Arredondo, 2022).

According to Islam et al., (2019) trans fats are thought to be nutritionally ineffective. Unlike other types of unsaturated fats, trans fats have been shown to increase the “bad” cholesterol (LDL cholesterol) and decrease the “good” one (HDL cholesterol). Several studies have found that a 2% increase in daily TFA energy consumption is related with a 23% increase in the risk of cardiovascular disease. They have also been shown to lower blood lipids and lipoproteins, increasing the risk of cardiovascular disease. In addition, excessive trans-fat consumption has also been associated with an increased risk of type 2 diabetes and certain types of cancer, such as breast cancer and colorectal cancer.

Due to the health risks associated with trans fats, many countries have implemented regulations to limit their use in food manufacturing. In the United States, the Food and Drug Administration (FDA) has banned the use of partially hydrogenated oils in food products (Saghafi, Naeli, et al, 2019). In Europe, since 2019, the European Commission adopted a Regulation regards to trans-fat, other than trans-fat naturally occurring in fat of animal origin, where stablished to include a maximum limit of 2 grams of trans fat per 100 grams of fat in food intended for the final consumer and food intended for supply to retail excluding trans-fat naturally occurring in fat of animal origin (European Commission, 2019).

3.2.Shortening

Shortening is a crystal-structured fat-based food ingredient. Some industries employ the hydrogenation process to enhance the content of saturated fatty acids in shortening, which has the potential to produce trans fatty acids (Subroto & Nurannisa, 2020). Vegetable oils are often hydrogenated, or solidified, to create shortening, a solid vegetable fat. Shortening is a cooking ingredient that helps produce crumbly, flaky, and tender baked goods. As shortening is totally fat, as opposed to butter and lard are about 80% fat content, it produces extremely delicate cakes, cookies, and pie crusts (Marcus, 2013).

Shortening can be classified as the naturally occurring fats that are solid at room temperature. Its composition can range from a natural fat to mixtures of oils with hard fats to liquid oils that have undergone hydrogenation to mixtures of oils that contain emulsifiers, antioxidants, metal scavengers, and antispattering agents (Demirkesen & Mert, 2020).

According to Goh et al., (2019) shortening is a semisolid viscoelastic food product that contains both liquid and solid fats. Shortening's role in cake products is to give lubricity and aeration. When fats are added to the mixing stage, they might combine with the liquid in the ingredients to generate an emulsion. Furthermore, the fat crystals quickly encircle air gaps in cake batter, trapping air bubbles. When lipids are heated during baking, they melt and release gas, providing an aerated structure to the finished items.

Shortening plays a crucial role in the cake baking process as it helps in forming stable emulsions that can endure the heat of baking. These emulsions facilitate aeration by incorporating small air cells into the plastic shortening phase during batter-mixing. By doing so, air bubbles get entrapped in the continuous phase of the emulsion at room temperature instead of remaining in the aqueous phase. (Atchley, 2022).

All soft wheat products contain shortening, which is generally used to create a soft, tender bite. If it is small or nonexistent, the result resembles bread more. (Atwell & Finnie, 2016). Shortening allows the aeration process during baking. During the baking process, fat crystals melt, and the oil gets exposed over the internal surface of the cells, providing an extra interface for expansion. The air bubbles expand, serving as nuclei for leavening gases, and move from the fatty phase to the aqueous phase structure. As a result, a fine and smooth texture and a high volume are obtained in the final bakery product (Pycarelle et al., 2020).

Shortening's role in cake baking is crucial in creating a stable emulsion that facilitates aeration, providing a fine and smooth texture and a high volume in the final product. During mixing, fat crystals get covered with an interfacial layer of adsorbed protein. This also helps in stabilizing the emulsion and in creating a uniform structure in the cake (Demirkesen & Mert, 2019).

3.3.Oleogel

Organogels are three-dimensional structures made from an organogelator or gelling agent and a continuous liquid phase that, depending on their nature, can be classified as hydrogel (if you have a polar liquid) or organogel (if you have a nonpolar liquid) (if you have an organic solvent). If the organic solvent is an edible liquid oil, it is referred to as an oleogel (Jimenez-Colmenero et al., 2015).

Oleogels consist of a continuous liquid phase (liquid oil edible, > 90%), which is structured thanks to the action of an oleogelator or gelling agent (of low or high molecular weight or of a polymeric nature) through the formation of a three-dimensional network that results in a solid, similar to a gel, with viscoelastic properties similar to a hydrogenated fat or a naturally saturated fat, thus producing a structured fat without modifying the chemical properties of the oil (Aguilar-Zarate et al., 2019).

According to Chuliá et al. (2022), Oleogels are colloidal systems defined as structures solid or semi-solid gel-type, in which the oil is immobilized in a three-dimensional network constituted by a structuring agent or combination of agents. That is, they are gels in which the dispersed phase is oil and the continuous phase is a network structure made up of the structuring agents. Oleogels are capable of providing a consistency and firmness similar to that of solid fats without affecting their original composition in unsaturated fatty acids.

For the preparation of oleogels, a low concentration of oleogelator is combined with a high amount of oil, and through an appropriate process, which can be heating (above the melting point), stirring and cooling. The oleogelator molecules are dispersed in the oily phase, assembling into these structures, three-dimensional by Van der Waals forces, such as hydrogen bonds, as well as ionic interactions and covalent bonds (Wijaya, Sun, Vermeir, Dewettinck, Patel & Van der Meeren, 2019).

Oleogels have primarily been advocated in the food industry as fat alternatives to obtain healthier foods with lower saturated/trans fatty acid content. They have recently been proposed as delivery vehicles for bioactive lipophilic compounds and lipolysis modulators during digestion (Plazzotta et al.,2020). Oleogels have been researched and produced as a viable replacement to traditional fats such as animal fats, tropical oils, margarine, and shortenings. Their ability to imitate the technical functions of traditional fats is key to their effectiveness as a fat substitute (Calligaris et al., 2022).

3.3.1. Oleogelation

Oleogelation is a recent approach used by researchers to convert liquid vegetable oil into a solid like gel using organogelators in order to create novel food ingredients with the functionality of fats and the nutritional profile of liquid oils. Oleogels can be created from a wide range of structuring agents, which will result in different gelation mechanisms on a nano and micro scale, as well as specific macroscopic features (Pușcaș et al., 2020).

According to Chen & Zhang (2020) different types of structurants with different gelation mechanisms have been suggested for the fabrication of oleogels. However, Martins et al., (2018) mention there are four well know gelation methods and these are:

- Fatty acid crystallization: This mechanism involves the long hydrocarbon chains in fatty acids, which are able to develop crystalline structures at a certain concentration. These structures are strong enough to retain the oil phase and promote solid structuring upon cooling.

- SAFIN's or self-assembled fibrillar networks: This mechanism involves the one-directional crystalline growth that originates at the same nucleation point, resulting in a 3D self-assembled fibrillar network. This mechanism is commonly used to create structured oleogels.
- Polymeric networks: This mechanism involves the use of polymers that cross-link or entangle between them to form a network that will entrap the oil phase. This can be performed through direct and indirect methods forming a gel. This mechanism is commonly used to create polymer-based oleogels.
- Reverse spherical micelles: This mechanism involves amphiphilic molecules that are dissolved in non-polar media, forming a three-dimensional network with a jelly-like structure. This mechanism is commonly used to create surfactant-based oleogels.

The figure 1 presents the classification of oleogel formation mentioned previously. A. corresponds to Fatty acid crystallization, B. to self-assembled fibrillar networks, C. to polymeric networks and D. to reverse spherical micelles.

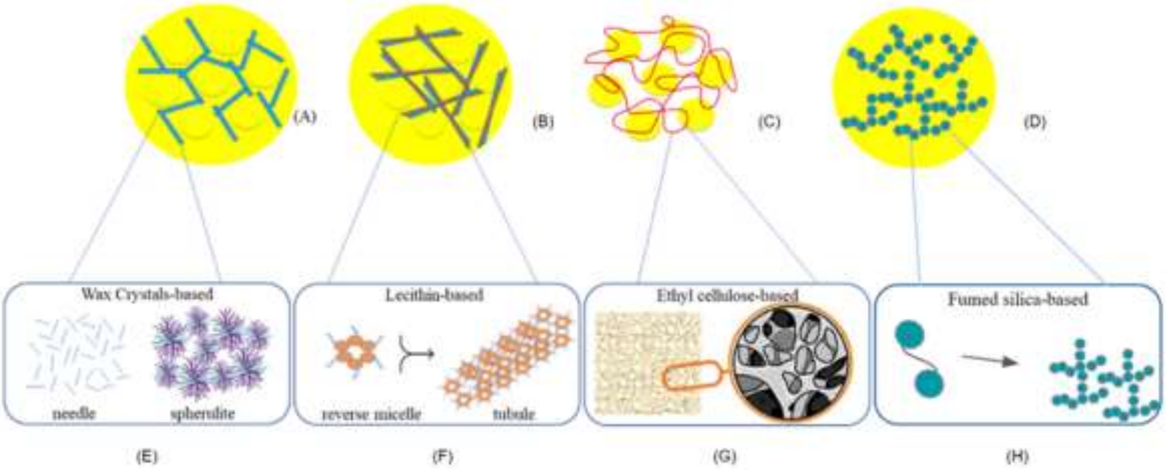

Figure 1. Examples of the classification of oleogel formation

(Da Silva, 2023)

The choice of mechanism for creating oleogels will depend on the specific application and the desired properties of the final product. Each mechanism offers different advantages and disadvantages, and careful consideration should be given to the selection of oleogelator and the method of formation to ensure the best results. Figure 2 shows a general method for oleogel production.

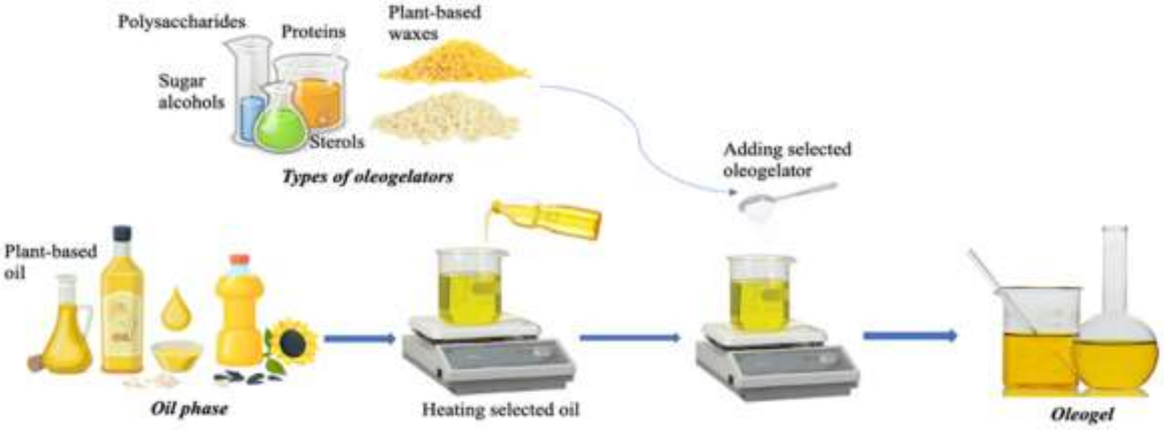

Figure 2. General method of oleogel preparation

(Da Silva, 2023)

According to Chuliá et al., (2022), one of the common oleogelification techniques is the emulsion template approach, however authors mention that oleogelation method to choose, depends on the type of oleogelator we are using, when the structuring agents are hydrophobic in nature, direct dispersion methods are used and when they are mainly hydrophilic in nature, indirect methods are used.

In direct methods, the structuring agent has good dispersibility in oil, so it can be directly contacted and interact with the oil to be structured. The general procedure consists of directly dissolving, normally at high temperatures (above its glass transition temperature (Tg)), the structuring agent in the oily phase. While staying above the Tg, it becomes more flexible and adopts a more extended and open conformation. Subsequently, the solution is cooled and the structuring molecule returns to a more rigid state that induces precipitation. This process facilitates the formation of intermolecular bonding zones, resulting in a three-dimensional polymer network that physically entraps the liquid oil phase. Direct dispersion of structuring agents in the oil occurs via specific molecular mechanisms, such as sheet crystallization or self-assembly (normally seen with low molecular weight structurants).

In indirect methods, structuring agents with low dispersibility in oil are used, such as hydrocolloids, therefore, in order to achieve the formation of the polymeric network required for gelation to occur, it is first necessary to disperse the hydrocolloids in an aqueous phase. This favors the unfolding of the hydrocolloid chain and, after the emulsification process, the hydrocolloid adopts a conformation capable of trapping oil droplets. Some of the most widely used indirect methods are the "emulsion template approach" that has already been discussed above or sorption in solid structures forming cryogels or aerogels (Chuliá et al., 2022).

According to Calligaris et al., (2022) indirect oleogelation methods refer to a process where the network forms first in the presence of water. Following that, water is removed, resulting in the production of an oleogel or the formation of a porous substance capable of absorbing additional oil. And they mention that the most promising indirect techniques are:

a) Emulsion-template approach, in which the starting material is an emulsion and the water phase is removed by drying.
b) Solvent exchange procedure, in which the starting material is a hydrogel and the solvent is progressively removed by changing the solvent polarity; and
c) Dried-template approach, in which the oleogel is obtained by oil absorption into a dried porous template made from a hydrophilic polymer.

3.3.2. Oleogelators

Regarding to Pușcaș, et al, (2020), there are numerous publications describing different formulations of oleogels and their rheological behavior, solid fat content, thermal behavior, microscopic structure, and textural properties due to the existence of various organogelators and oleogelation techniques. These properties are critical for assessing the compatibility of organogelators with the vegetable oils used in oleogelation, selecting the best oleogels for specific food processing conditions, and understanding some of the possible influences on oleogel formation that may occur due to food composition and other food ingredients.

According to Martins et al (2018), the properties of oleogels can be tailored to meet the specific requirements of different food applications, depending on the desired physical characteristics of the product. For example, the texture, viscosity, and stability of oleogels can be adjusted by varying the type and concentration of the structurant used.

Different types of structurants can be used to form oleogels, such as natural waxes, polymers, and proteins. Each structurant has a unique molecular structure and physical properties, which will influence the final properties of the oleogel. For example, some structurants may form a network with small, tightly packed crystals, resulting in a stiff and brittle texture, while others may form a more flexible, elastic network with larger crystals, resulting in a softer texture. (Hwang & Winkler-Moser, 2020)

Oleogelators are classified into two groups, low- and high-molecular weight oleogelators (LMOGs and HMOGs) (Figure 3). Fatty acids, fatty alcohols, waxes, wax esters, sorbitan esters, phytosterols, and mono- and diglycerides are examples of LMOGs. They are self-assemble to form an oil-binding crystal network. Some oleogelators function by co-assembling or self-sorting two components into distinct assemblies, such as fatty acids and fatty alcohols, lecithin and sorbitan tristearate, phytosterols and γ-oryzanol, lecithin and tocopherol, sucrose esters and lecithin, and oleic acid with sodium oleate (Hwang, 2020).

LMOGs’ structures are formed by the hierarchical assembly of molecules governed by weak physical molecular interactions such as hydrogen bonding, van der Waals forces, electrostatic interactions, dipole forces, and hydrophobic forces. Those assemblies form 3D architectures such as ribbons, rods, fibers, and sheets. The gelling mechanism is based on aggregation processes initiated by external forces such as temperature and shearing (Chuliá et al., 2022).

HMOGs are polymers, such as proteins and polysaccharides, capable of forming a three-dimensional network through interactions such as hydrogen bonding. The structuring properties of these polymers will largely depend on the molecular weight, conformation, and concentration of the polymer. Some HMOG are used for direct dispersion, such as polymers of a hydrophobic nature. An example would be ethylcellulose, which has the ability to immobilize oil by dispersing it directly. However, these oleogels have low oxidative stability due to the high temperatures used to induce gelation (>135-140°C in the case of ethylcellulose) (Davidovich-Pinhas, 2019).

The oleogelators can also be classified according to their origin, being natural or synthetic, those that are made of vegetable fibers are quite abundant in nature, since they are present in leaves, stems, fruits, seeds and other parts of plants, in addition to they can degrade in a short time. Within these fibers we can find cellulose, hemicellulose and lignin (Arredondo, 2022).

Furthermore, oleogels can be made from a combination of different oleogelators. The use of multiple oleogelators can offer several advantages, such as improved gel strength, better temperature stability, and increased flexibility in formulation. When combining different oleogelators, it is important to consider their compatibility and how they will interact with each other. Some oleogelators may be more compatible than others, and certain combinations may result in synergetic or antagonistic effects on the final oleogel properties. In addition to oleogelators, other ingredients may also be added to the formulation, such as antioxidants or emulsifiers, to improve the stability and shelf-life of the oleogel. The amount and type of these ingredients will depend on the specific application and the desired properties of the oleogel (Huang et al., 2022).

Hwang (2020) mentions that one of the most current advances in the field of oleogel is the investigation of binary and ternary systems of distinct oleogelators, as well as the addition of a co-oleogelator, in order to improve the properties of oleogels and mitigate the downsides of each oleogelator. Natural wax oleogels, for example, have a higher melting point than traditional solid fats, which might result in an unattractive waxy mouthcoating.

The final application of the oleogels will also influence the choice of structurant and formulation conditions. For example, in bakery applications, a soft and pliable oleogel may be desired to replace traditional fats, while in confectionery products, a firmer and more stable oleogel may be necessary. Overall, the properties of oleogels can be tailored to meet the specific needs of different food applications, based on the desired physical characteristics and the type of structurant used (Da Silva et al., 2023).

3.3.3. Oil phase in oleogels

Oleogels can be made from a variety of vegetable oils, such as: soybean oil, high oleic sunflower oil, olive oil, and palm oil. Because of their composition, availability and cost. These oils are commonly used as they are widely available, cost-effective, and have unique fatty acid compositions that can influence the physical and chemical properties of the resulting oleogel. For example, soybean oil is rich in linoleic acid, which can produce an oleogel with a soft and pliable texture. High oleic sunflower oil has a high oleic acid content, which can result in a firmer and more stable oleogel. Olive oil has a high content of monounsaturated fatty acids, which can result in a soft and spreadable oleogel. Palm oil contains a high proportion of saturated fatty acids, which can produce a firmer and more structured oleoge (Chaves et al., 2018).

According to Hwang (2020), the quality of the oil, as well as minor oil components like polar components have a big impact on the characteristics and appearance of the oleogel network. Thanks to the study carried out by Scharfe et al. (2019), gel characteristics were examined as a function of oil permittivity, which indicated both the quantity and quality of polar minor chemicals present in the oil. The authors postulated that minor polar components interact with the ferulic acid moieties of γ-oryzanol to produce tougher gels at low polar component concentrations. The interaction became saturated at larger concentrations, and the extra polar components had a detrimental effect on the gel strength. For this result is necessary to choose properly the oil phase to develop an oleogel.

Sunflower oil has gained popularity, because its fatty acid composition is very similar to olive oil, in addition to the fact that if it is consumed frequently it can provide various benefits to human health, such as reducing the risk of cardiovascular diseases and stones. bile, in addition to reducing triglycerides, cholesterol and blood pressure, all this due to its high content of oleic acids (Da Silva, et al., 2019). Due to its characteristics, sunflower oil has been incorporated into oleogels used for bakery products, reducing saturated fatty acids by about 65%, improving nutritional content and not intervening in the rheological properties of these products (Arredondo, 2022).

In other hand, Canola oil is one of the most used and researched for the replacement of animal fat in meat products, including it within an oleogel in order to add it to a meat product. This oil is highly prized because it has a very low level of saturated fatty acids and substantial amounts of monounsaturated fatty acids and polyunsaturated fatty acids compared to other vegetable oils (Alejandre et al., 2019). Furthermore, this oil has been used to develop oleogel as an alternative to shortening in baked goods (Jang et al., 2015).

3.3.4. Oleogels applications

Oleogels have a wide range of potential applications in confectionery, bakery, dairy and meat industry. Their versatility has led to their use in a variety of food products, such as chocolates, confectionery fillings, ice creams, cream cheese, frankfurters, emulsions, biscuits, muffins, and cakes (Demirkesen, & Mert, 2020).

According to Manzoor et al., (2022) the development of oleogels has benefited the bakery industry the most, where it is used as a substitute for shortening and spread to produce products with trans-free fats and a reduced amount of saturated fat. Oleogels also produce heat-resistant products, which is particularly useful in bakery applications. It helps in combating the challenge of oil leakage in various products, resulting in a more stable and desirable product.

Another significant application of oleogels is their ability to act as carriers for lipophilic bioactive substances. This means that oleogels can be used to incorporate health-promoting compounds such as vitamins, antioxidants, and other bioactive ingredients into food products, which can offer additional health benefits to consumers. Therefore, oleogels have the potential to play an essential role in the development of healthier food products that meet the increasing demand for functional and health-promoting foods (Pinto et al., 2021).

According to Da Silva et al., (2023) oleogels can be used as a replacement in the following industries:

- Confectionery industry: oleogels can be used as a replacement for traditional fats in chocolate products, resulting in improved texture and stability. They can also be used as fillings in confectionery products, providing a creamy and smooth texture.
- Bakery industry: oleogels can be used as a replacement for traditional fats in products such as biscuits, muffins, and cakes, resulting in a softer and more tender texture. They can also be used in doughs and batters, improving their machinability and reducing the need for additional processing steps.
- Dairy industry: oleogels can be used as a replacement for traditional fats in products such as cream cheese, resulting in a lower-fat product with improved spreadability and texture. They can also be used in ice creams, providing a creamy and smooth texture while reducing the amount of saturated fats.
- Meat industry: oleogels can be used as a replacement for traditional fats in products such as frankfurters, resulting in improved texture and reduced saturated fat content.

3.4.Monoacylglycerols

Mono- and diacylglycerols (MAG and DAG) are popular emulsifying agents that are used in food products or generated through lipolysis in fermented goods like dry sausages. They are essential in maintaining the texture of the final food product by binding lipophilic and hydrophilic components together (Rodríguez et al., 2014).

The food industry worldwide primarily utilizes mono- and di-acylglycerols along with their organic acid derivatives as emulsifiers, which are produced by glycerolysis or interesterification of fats or oils with glycerol. Hydrogenated vegetable oils (e.g., soybean, rapeseed, cottonseed) and animal fats (e.g., lard, tallow) are commonly used as raw materials. The equilibrium mixture resulting from glycerolysis typically contains 40-50% monoacylglycerols, 30-40% diacylglycerols, and 10-20% triacylglycerols, which is the standard composition of many commercially available mono- and di-acylglycerols (Krog, 2011).

According to USFA (2019) mono- and diglycerides are composed of glyceryl mono- and diesters, along with small amounts of triesters, which are derived from edible sources such as fats, oils, or fat-forming acids. The most common fatty acids found in mono- and diglycerides include lauric, linoleic, myristic, oleic, palmitic, and stearic acids. To produce mono- and diglycerides, glycerin is reacted with fatty acids or triglycerides in the presence of an alkaline catalyst. The resulting product is then further purified to obtain a mixture containing at least 90 percent glycerides, as well as free fatty acids and glycerin.

MAG and DAG are compounds with both hydrophilic and hydrophobic properties, allowing them to serve as emulsifiers that create stable and uniform emulsions. These two compounds constitute around 75% of the global production of food emulsifiers. MAG is commonly used in bakery, margarine, milk, and confectionery products, mainly for its emulsifying and stabilizing properties. For food applications, high-purity MAG is preferred because it exhibits better emulsifying properties compared to a mixture of various acylglycerols. Typically, a 0.5% by weight MAG is used as an emulsifier to create a stable emulsion. Additionally, MAG can form complexes with starch to enhance the quality of bread, such as its firmness and hardness. MAG and DAG function as emulsifiers that can prevent fat bloom, which is a known issue in chocolate products, as emulsifiers can help inhibit susceptibility to this problem (Subroto, 2020).

3.5.Bees Wax

Beeswax is a wax that is found in nature and is primarily secreted by honeybees of the species A. mellifera. Its main purpose is to be used in constructing honeycombs. The composition of unhydrolyzed beeswax consists of around 71% esters, 15% hydrocarbons, 8% free fatty acids, and 6% other components. The melting temperature of natural beeswax ranges from 62 to 65 °C, and it is brittle when cold but has high plasticity and is inert. Beeswax provides protection against corrosion, abrasion, and moisture loss, and it is one of the most commercially useful waxes available. Commercially, beeswax is used in various applications such as metal castings, candle making, cosmetics, textiles, varnishes, and food processing. The latter will be discussed further in the subsequent parts (Lan, 2019).

According to Coppock (2021), beeswax is a chemical mixture that is secreted by the wax glands of honeybees located in their abdomen. The bees secrete beeswax as a liquid between 12-18 days of age, which hardens on exposure to air. Beeswax is primarily used to create the foundation and hexagonal cells of the honeycomb, which serve as the breeding ground and storage for honey and pollen. The hexagonal cells also cradle the larvae, and are storage cells for pollen and honey. The entire wax foundation provides support to the working bees. In beekeeping, foundations are provided on which bees can build wax hexagonal cells. Wax is incredibly strong and approximately 100g of wax is used to construct all the cells in one Langstroth deep frame.

The chemical composition of wax varies depending on the genus and species of bees. Beeswax from A. mellifera is estimated to consist of over 300 different compounds. The primary groups of compounds found in beeswax include alkanes, free fatty acids, monoesters, diesters, and hydroxy-monoesters. Fatty alcohols and hydroxy-diesters are minor constituents. Beeswax is purified using various methods such as hot water extraction, steam extraction, and centrifugation. The yellow beeswax obtained by pressure filtration is considered pure, while the white beeswax obtained after bleaching.

Bee wax has been shown to have excellent physicochemical properties, such as high melting point, good emulsifying capacity, and low water solubility, making it a suitable ingredient in food formulations. One of the most common uses of beeswax in the food industry is as a glazing agent. Beeswax is used to create a shiny coating on confectionery, fruit, and vegetables, giving them an attractive appearance and improving their shelf life. It has also been used as a coating material for cheeses to improve their texture and prevent moisture loss during storage (Mandu et al., 2020).

Beeswax has also been studied for its potential as an alternative to synthetic food additives. For example, it has been shown to have antioxidant properties, which can help prevent lipid oxidation in food products. It has also been found to have antimicrobial properties, which can help prevent spoilage and extend the shelf life of food products. Another potential application of beeswax in the food industry is as a fat replacer. Beeswax-based oleogels have been developed as a low-fat alternative to traditional shortening, which can reduce the saturated fat content of food products. These oleogels have been shown to have similar physicochemical properties to traditional shortening and can be used in a variety of applications, including baked goods and fried foods (Abdolmaleki, 2022).

4. Materials and methods

4.1.Materials

For the present study High oleic sunflower oil (HOSO) was used as oil phase to produced oleogels. HOSO was obtained from the Hungarian factory Bunge Zrt. As oleogelator, two materials were employed: Distilled Monoglyceride and Bee wax. Distilled Monoglyceride or Mono- and diglycerides of fatty acids (E471) was gotten thanks to KUK Hungária Kft, the product was from a Danish brand, Danisco. And Bee wax from a cosmetics website (Humanity store), and it was originated from Netherlands.

4.2.Preparation of the samples

To develop oleogel formulations having minimum saturation level and reducing waxes taste, three samples of oleogel were prepared by fatty acid crystallization as gelation mechanism. All of the samples were produced with the same oil phase, but with different gelling agents concentrations (table 1).

Monoacylglycerol-Bee wax (MAG-BW) based oleogels were formulated from High oleic sunflower oil (80%), MAG and BW at three different concentrations (5, 10, 15%). The samples were produced in 150 grams. HOSO, MAG and BW were weighed into a 500-ml Biker using a VWR precision balance. HOSO was heated at 70°C using magnetic stirring (500 rpm). Then MAG and BW were added consecutively by homogenizing using ULTRA-TURRAX (13500 (min^{-1})) for 10 minutes until completely dissolved. All the samples were cooling down by ice water bath and stirring using ULTRA-TURRAX (13500 (min^{-1})) and after that storing at room temperature and analyzed within the next 48 hours.

Table 1. Component of the oleogel formulations

	Component of the formulations		
	MAG %	BW %	HOSO %
Oleogel 1	15	5	80
Oleogel 2	10	10	80
Oleogel 3	5	15	80

MAG: Monoacylglycerol, BW: Bees wax, HOSO: High oleic sunflower oil

4.3.Rheological analysis

A rheometer (Anton Paar MCR 302 rheometer, Austria) was employed in order to carry out rheological measurements in oleogel samples. A parallel plate geometry with a diameter of 50 mm was used for this study to avoid slippage in the samples with 1 mm gap. Dynamic oscillatory tests, including amplitude sweep, frequency sweep, and temperature sweep tests, were carried out to examine the viscoelastic properties of the samples, using the method carried out by Naeli et al., (2022), and Anton Paar RheoCompass software was used to calculate rheological parameters. Rheological measurements were made in triplicate for each sample of oleogels, which were perfomed 48 hours after preparation.

4.3.1. Amplitude sweep

Amplitude sweep is a type of rheological measurement in which the applied stress or strain amplitude is altered over a range of values while the frequency or time of application remains constant. The material's response to the changing amplitude is then measured, often in terms of complex modulus or viscosity. In practice, amplitude sweeps can be used to describe the behavior of dispersions, pastes, and gels.

This test was performed at the strain amplitude of 0.01–1000% and constant frequency of 1 Hz and temperature of 25 °C to determine the following parameters:

a) Linear viscoelastic range (LVE or (γLVE))
b) Structural strength G’ at LVE point (G’LVE),
c) Crosspoint of G’ and G” (where G’ is equal to G”)

4.3.2. Frequency sweep

Frequency sweep tests are a type of rheological measurement that is commonly used to study the viscoelastic properties of materials, including polymers and dispersions. In a frequency sweep, the material is subjected to oscillatory deformation at different frequencies while measuring the corresponding stress response.

The test was performed at the frequency sweep of 0.628 to 314 rad/s at a constant strain of 0.02% (LVE) and a temperature of 25 °C. and the results were plotted in a graph with the angular frequency displayed on the x-axis, while the storage modulus G' and loss modulus G" are presented on the y-axis, with both axes logarithmically scaled (Figure 5).

4.3.3. Temperature sweep

Temperature sweep tests, are a type of rheological test that are commonly used to study the viscoelastic properties of fats and other food materials as they undergo heating and cooling processes. The temperature sweep test was performed in the temperature range of 10 – 80 °C, at a rate of 0.08 °C per minute, at the constant frequency of 1 Hz and a constant strain of 1 %, this value was stablished based on the LVE as determined by stress sweep measurements.

4.4.Spreadability test

In food industry spreadability tests is used for evaluating the quality and consistency of spreads like margarine or peanut butter. These tests can help to determine the optimal formulation of a product, identify potential issues with texture or consistency, and provide valuable information for quality control. The test involves applying a force to the sample and measuring the extent to which it spreads or flows over a surface. This measurement is typically represented as an area or a curve on a graph.

The three oleogel samples were tested using a Stable Micro Systems Texture Analyzer TA.XT Plus (manufactured by Stable Micro Systems in Godalming, UK) with a TTC Spreadability Rig (HDP/SR) was used to place the gel sample to prevent air entry and ensure a smooth upper surface, and a 90° cone probe was installed above the gel surface. A load of 20 g force was applied to each sample, which was then placed between the top and bottom cones. Each oleogel sample underwent five replicate analyses at room temperature.

4.5.Statistical analysis

Every analysis was repeated three times and the obtained results are presented as means ± the standard deviation. One-way analysis of variance test (ANOVA) and Tukey's method were applied to assess the results at a significance level of $p < 0.05$. And Minitab 19 statistical software was used to perform the statistical analysis.

5. Results and discussion

5.1. Rheological properties

5.1.1. Amplitude sweep analysis.

The LVE, or linear viscoelastic region, is the range of strain within which a material's response to applied stress is linearly proportional. The strain sweep test is used to determine the LVE in oscillatory rheological experiments by applying a range of small strains and measuring the resulting stress response, in order to provide valuable information regarding the structure and technical aspects of fatty systems, including as spreadability and gel network strength. This test can be used to optimize formulations and improve product performance (Naeli et al., 2022).

The limiting value of the LVE region was calculated in terms of the strain γL as a percentage, with a tolerance range of deviation for G' of 5 %, this was selected according to the standards ISO 6721-10. Results are presented in table 2. Frequently, the G' and G" values within the LVE region are also evaluated. If in the amplitude sweep test G' > G", the sample displays a gel-like or solid structure and can be referred to as a viscoelastic solid substance. However, if G" > G', the sample shows a fluid structure and can be classified as a viscoelastic liquid (Figure 3). Figure 4 presents flow curves for the three oleogel samples developed. All of them exhibit evident shear thinning behavior, with viscosity decreasing as shear rate increases.

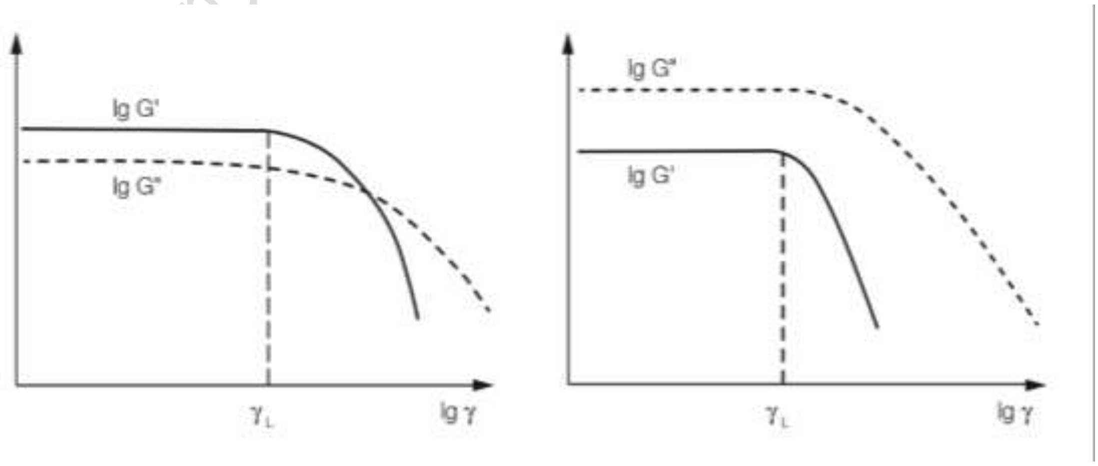

Figure 3. Amplitude sweeps results, Left: G' > G" in the LVE region, Right: G" > G' in the LVE region.

(Anton Paar, 2023).

The strain sweep rheograms can be divided into two regions: a linear viscoelastic region, where G' and G" are practically constant and structural deformation is reversible (small deformation), and a non-linear region, where G' and G" begin to decrease as strain increases (large deformation). Figure 4 shows that in all of the samples, G' was greater than G" before the cross point, showing that they behaved solidly in the LVE.

As we can see in the figure 4, all samples revealed a significant drop in G' and G" close to a strain of 1%, These unexpected deviations were a little bit more pronounced in two of our oleogel samples, MAG:BW 75:25 and MAG:BW 25:75. Thus, both samples presented similar behaviors. However, the MAG:BW based oleogel sample with the proportion of 25:75 was the closest one to the strain of 1% and MAG:BW based oleogels with the same gelling agent ratio had the lowest G' among the three samples.

Acording to Joyner (2019) a high value of G' at low strain means the sample has a tendency to retain their initial shapes. Nevertheless, if there is a swift drop in G' at higher strains, it suggests that the sample has good spreadability characteristics. Thus, as we can notice in figure 4 our three oleogel samples presented these charactheristics.

The γLVE and G'LVE data in the LVE and the cross point of G' and G" are shown in Table 2. The γLVE of MAG:BW (25:75) based oleogel sample was higher than the other two samples, indicating a greater LVE range in oleogel samples. The wider LVE range means that the viscoelastic properties of MAG:BW(25:75) based oleogel sample is elevated, enabling it to maintain its structure even at higher strain values, and it exhibits greater abilities. However, the difference between the three samples was not significative.

The cross point as the rheological index, the point at which the storage modulus (G') and loss modulus (G") are the same. At higher shear, the viscous portion will dominate and the sample flows. The sample with the higher cross point was MAG:BW (25:75), MAG:BW ratio 50:50 got a close result, nevertheless oleogel sample with the lowest bees wax ratio got the lowest storage modulus.

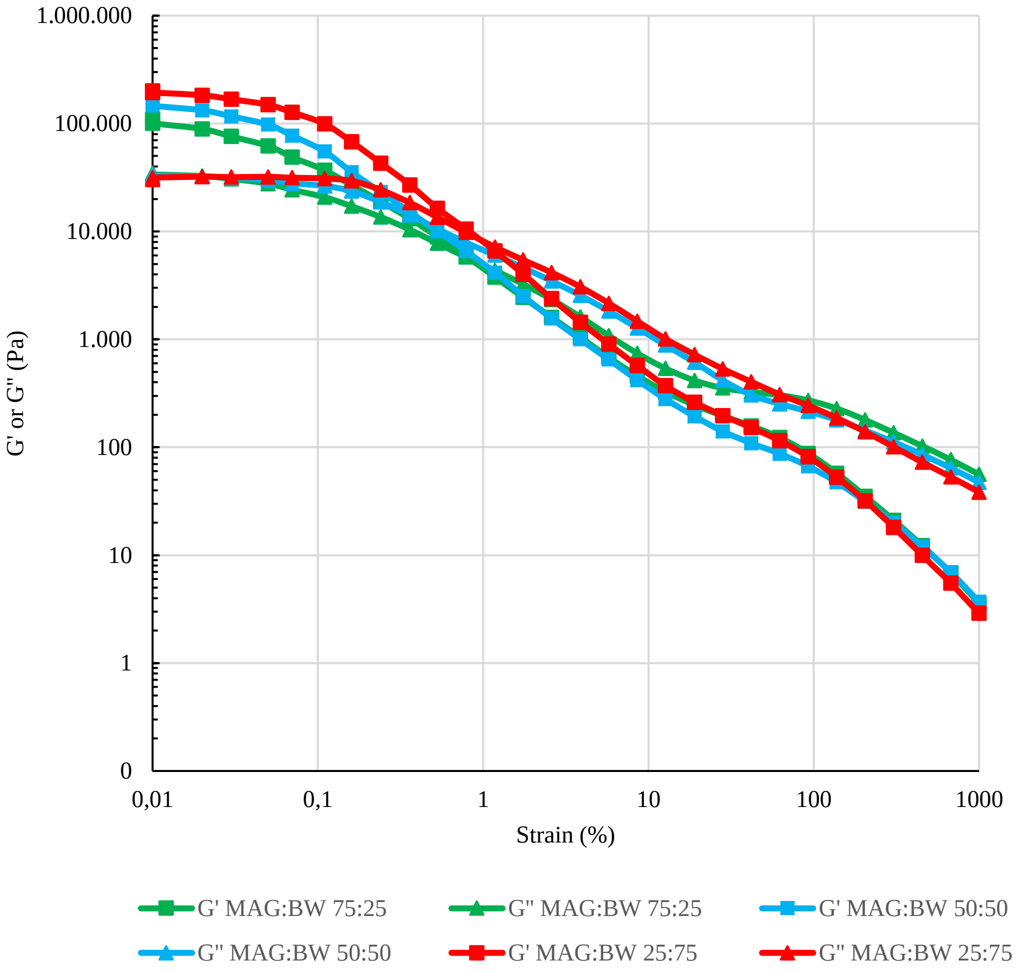

Figure 4. Amplitude sweep curve of MAG:BW based oleogel samples

Table 2. Parameters related to amplitude sweep test of the MAG-BW based oleogel samples

	Shear strain at LVE γLVE (%)	Structural strength G’LVE (Pa)	Cross point G’= G’’ (Pa)
Oleogel 1 MAG:BW (75:25)	0,01 ± 0,001	103968,00 ± 7083,42	5592,43 ± 739,25
Oleogel 2 MAG:BW (50:50)	0,01 ± 0,00	148453,33 ± 10500,57	12377 ± 863,61
Oleogel 3 MAG:BW (25:75)	0,02 ± 0,002	191757,71 ± 121706,91	14956,4 ± 7973,05

MAG: Monoacylglycerol, BW: Bees wax. Data are presented as mean standard deviation

Table 3. P value results from one-way analysis of variance

ANOVA	
Response	P value
γLVE	0,204
G’LVE	0,495
G’= G’’	0,193

One-way analysis of variance test (ANOVA) was applied with a significance level of p < 0,05 in all of the three-response evaluated during amplitude sweep test, p value was greater than the level of significance as can be seen in table 3. It means there are differences between our samples in every response.

In other hand, table 4 shows confidence interval at 95% applied in our three MAG:BW based oleogel samples. Confidence intervals allow us to approximate, once the value of the variable in the sample has been calculated, between what range of values is the inaccessible real value of the variable in the population, with a degree of uncertainty that we can determine. Following figures present the different responses evaluated in our three oleogel samples in terms of confidence intervals (CI), during the amplitude sweep test. As we can observe in figure 5, 7 and 9, oleogel sample with MAG:BW ratio of 25:75 presented the highest means in every response evaluated during the amplitude sweep test, it means high bees wax contain gives a higher and good response in oleogels.

Furthermore, Tukey's method was applied and comparison's results of every response are presented in figures 6, 8 and 10. With this method, we can understand that there is much more difference between OG1 and OG3 in all of the responses, that between the other pairs, OG2:OG1 and OG3:OG2. Comparison's results from the last two pairs mentioned do not differ significatively in of the response, in the case of the storage modulus at the Linear viscoelastic range. Evaluating these results according to BW contain in our oleogel samples we can say a good response can be obtain from the ratio of 50 to 75 BW contain but not less than that.

Table 4. Confidence Intervals of responses evaluated in MAG-BW oleogel samples during amplitude sweep test

Confidence interval (95%)			
Response	OG 1	OG 2	OG 3
γLVE	(0,011015; 0,015658)	(-22143; 230079)	(-2698; 13883)
G'LVE	(0,011796; 0,016439)	(22342; 274565)	(4086; 20668)
G'= G''	(0,01383; 0,01785)	(82542; 300973)	(7776; 22136)

OG 1: MAG:BW (75:25), OG 2: MAG:BW (50:50), OG 3: MAG:BW (25:75)

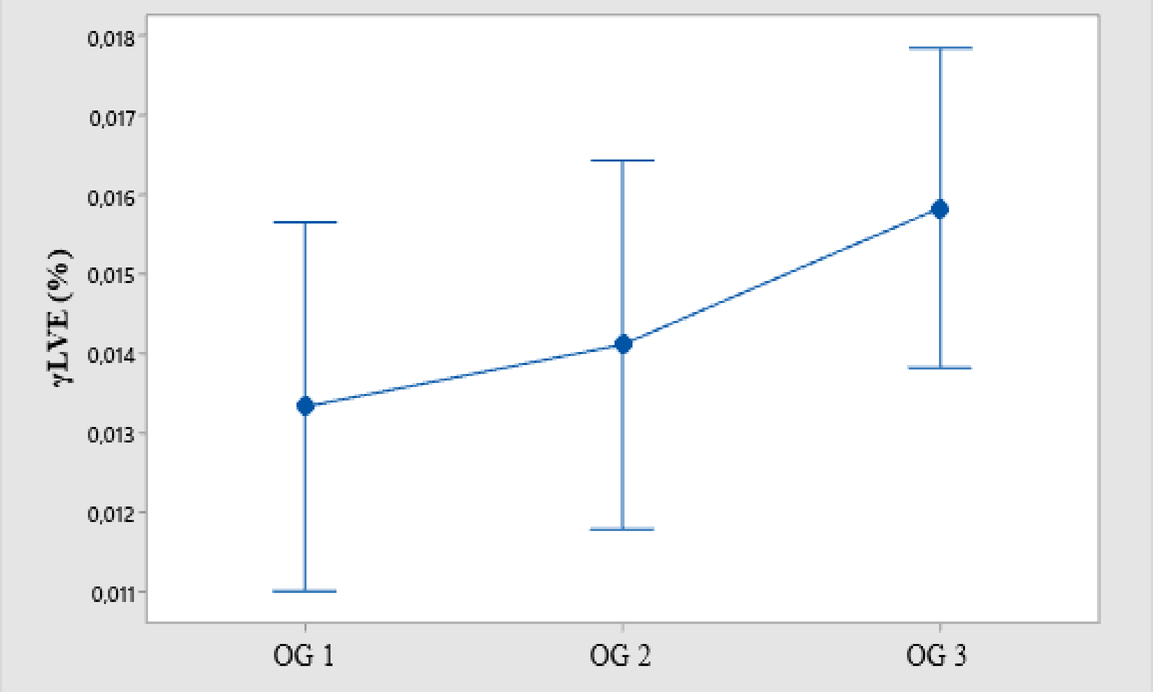

Figure 5. Shear strain at Linear Viscoelastic Range

OG 1: MAG:BW (75:25), OG 2: MAG:BW (50:50), OG 3: MAG:BW (25:75)

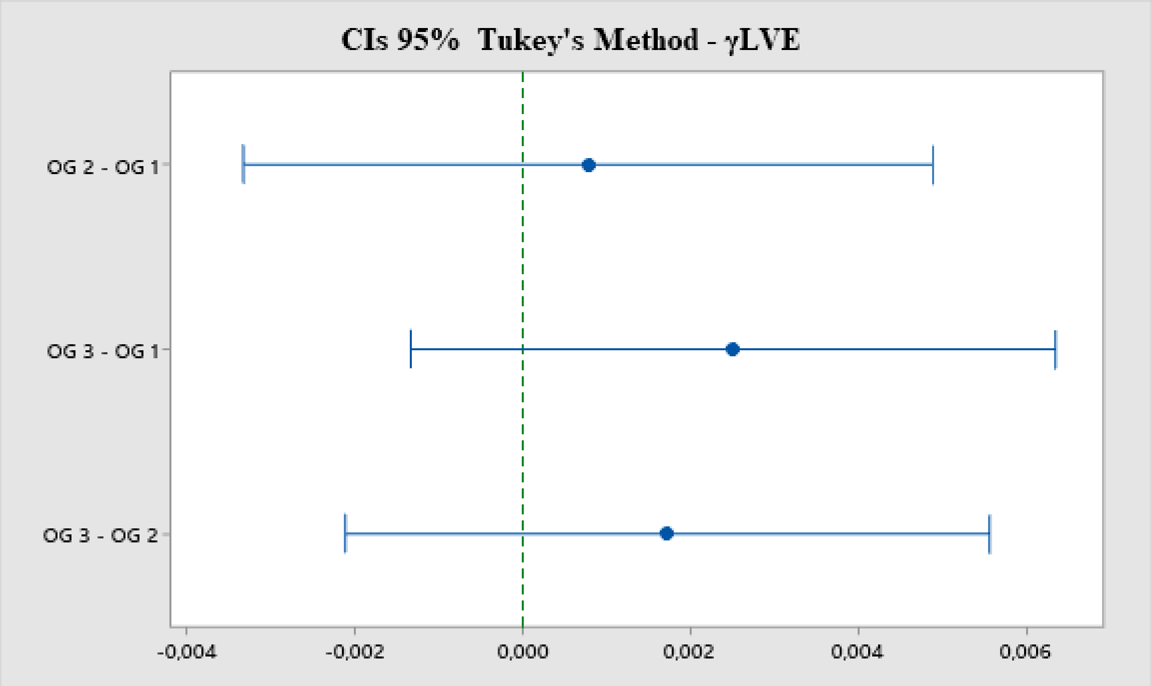

Figure 6. Tukey’s method results for the response: Shear strain at Linear Viscoelastic Range

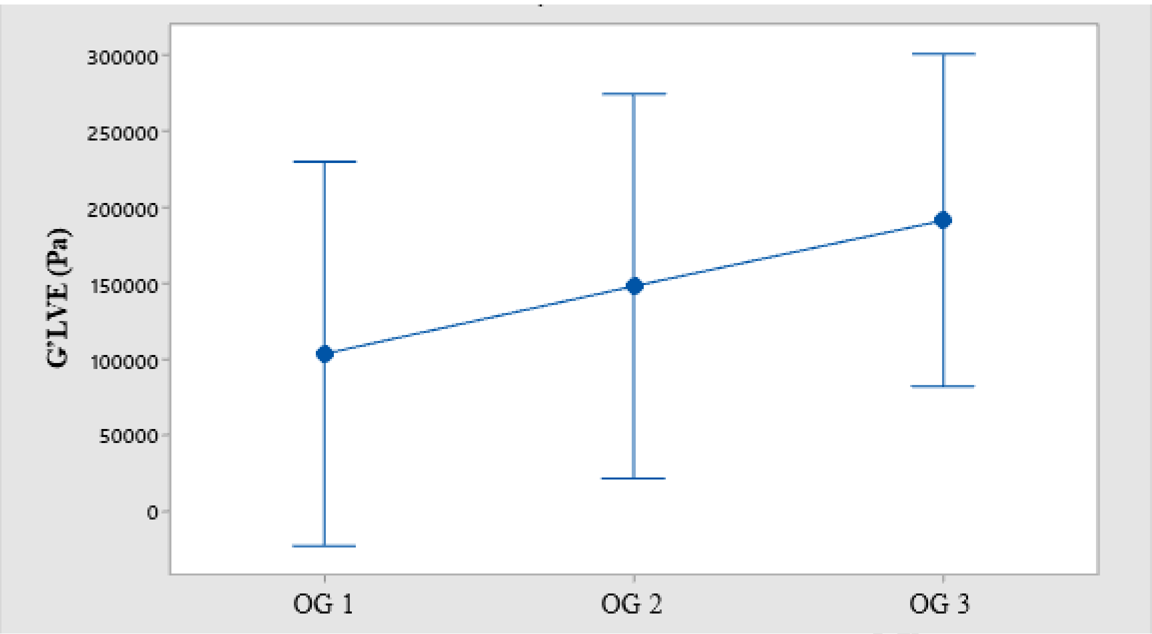

Figure 7. Storage modulus at Linear Viscoelastic Rang

OG 1: MAG:BW (75:25), OG 2: MAG:BW (50:50), OG 3: MAG:BW (25:75)

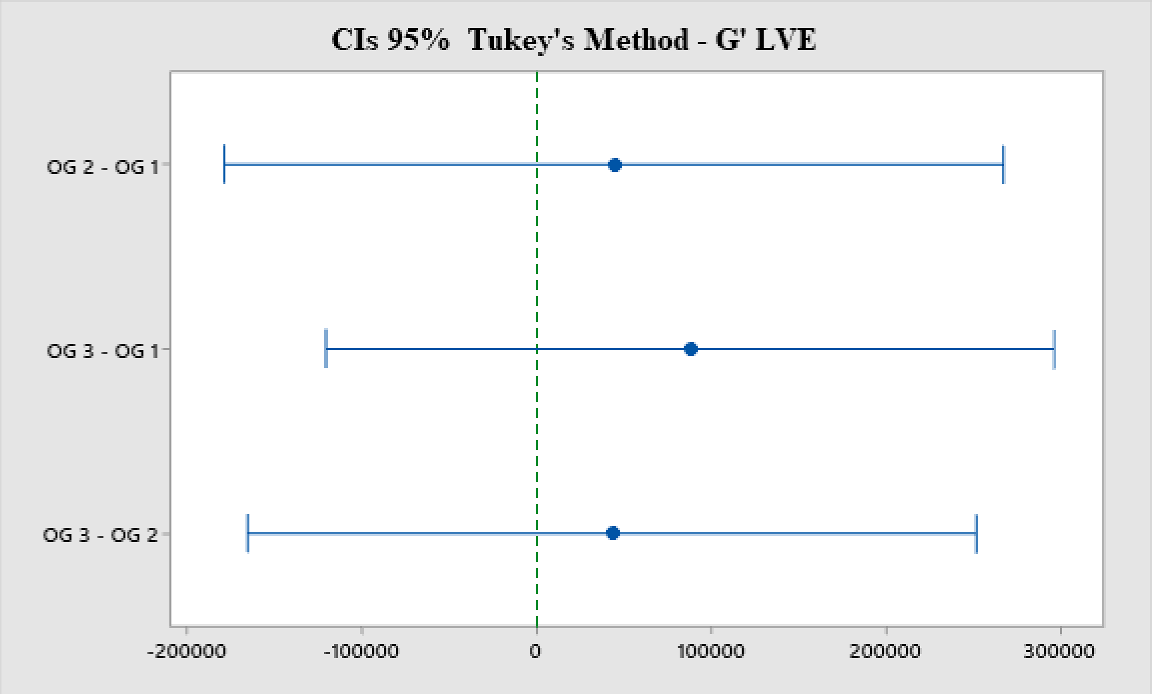

Figure 8. Tukey’s method results for the response: Storage modulus at Linear Viscoelastic Range

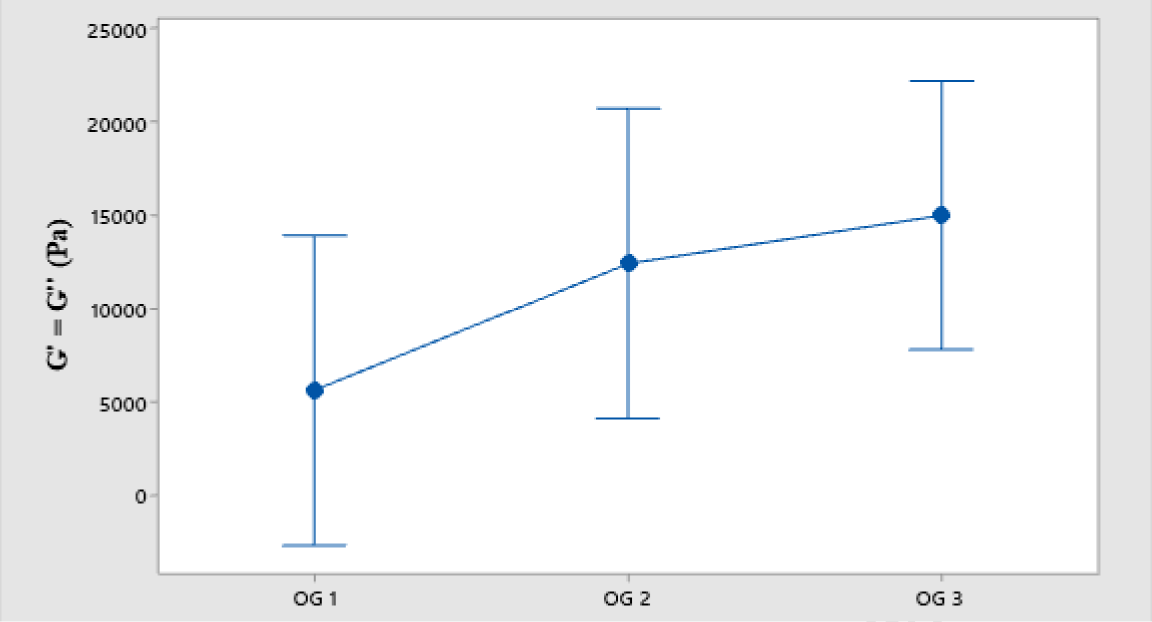

Figure 9. Cross point result obtained during amplitude sweep test

OG 1: MAG:BW (75:25), OG 2: MAG:BW (50:50), OG 3: MAG:BW (25:75)

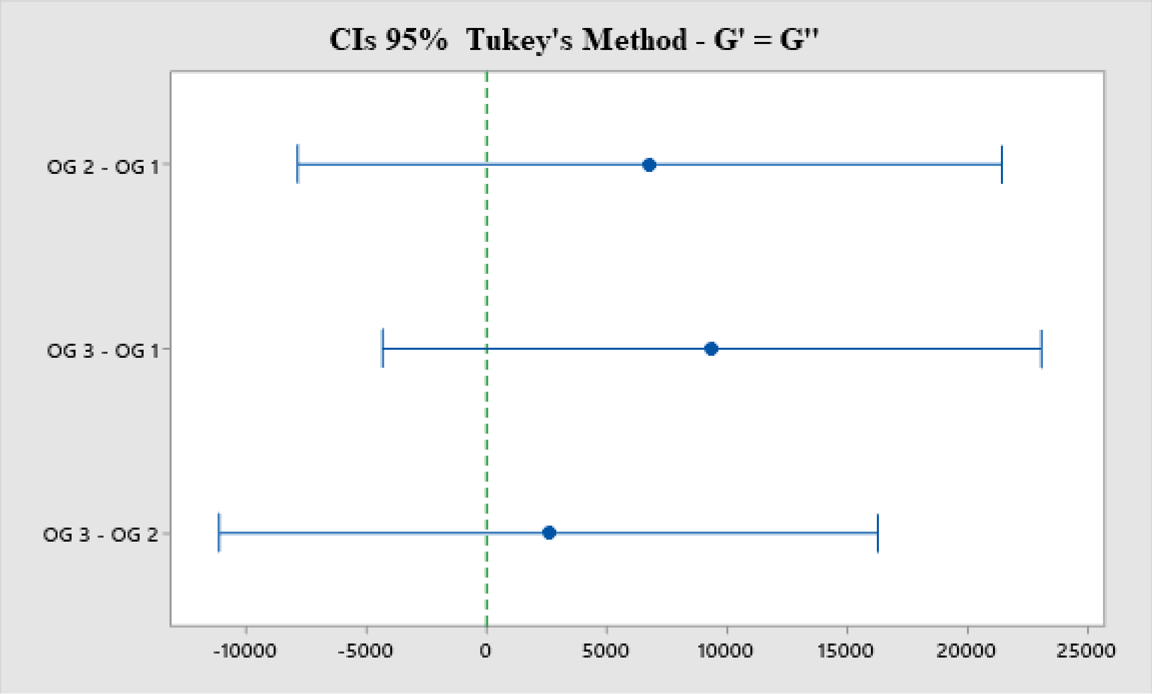

Figure 10. Tukey’s method results for the response: Cross point.

5.1.2. Frequency sweep analysis.

Frequency sweep is a method used to explore the linear viscoelastic properties of soft materials and is frequently used in rheological investigations to analyze complex fluids. The amplitude and temperature of the input signal are held constant throughout time while the frequency is squeezed in this test. The elastic (G′), viscous (G″), and phase angle properties of oleogels characterize their linear viscoelasticity. The value of G′ represents the stored energy and reflects the elastic behavior of the test material, whereas the value of G″ represents the dissipated energy and is linked with the viscous behavior of the test material (Huang et al., 2022).

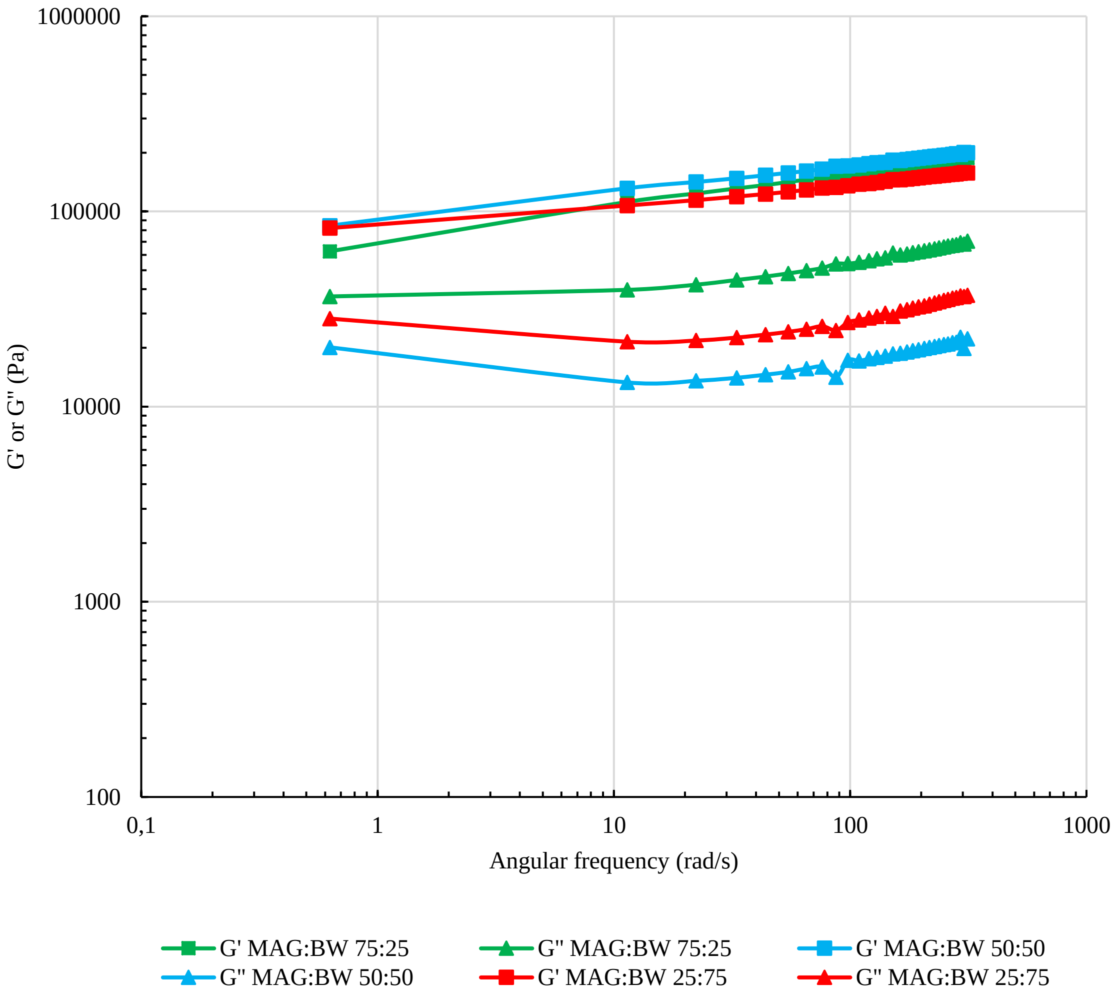

Figure 11. Frequency sweep curve of MAG:BW based oleogel samples

The frequency sweep rheograms of the samples are shown in Figure 11. All the samples presented higher G’ values than G” values during the frequency sweep test, indicating their solid-like (elastic) behavior. Both G’ and G” parameters shifted to higher values with the increase of frequency.

5.1.3. Temperature sweep analysis.

Dynamic temperature sweep studies can provide valuable information regarding the viscoelastic behavior of lipids as changed by heating/cooling cycles. During a dynamic temperature sweep test, the sample is subjected to a linear temperature ramp while measuring the corresponding changes in its viscoelastic properties, such as complex modulus, viscosity, and phase angle. As the temperature increases or decreases, the fat undergoes a transition from a solid-like to a liquid-like state or vice versa, depending on its composition and processing history (Naeli et al., 2022).

By analyzing the temperature-dependent changes in the sample's viscoelastic properties, one can obtain valuable information about its thermal behavior, including its melting and crystallization behavior, glass transition temperature, and phase behavior. This information can be useful for understanding how fats and other food materials behave during processing and storage, as well as for developing new products with desired properties (Joshi, 2017).

Figure 12 displays the impact of temperature on G’ and G” changes. It is evident that G’ and G” values decreased as temperature increased in all samples, indicating a decrease in elastic properties and an increase in viscous character. This trend of lipid systems is commonly observed. G’ remained higher than G” throughout the temperature range for all samples, and the viscoelastic nature of the samples did not transition from elastic to viscous.

A we can observed in the temperature sweep curve (figure 6), MAG:BW based olegel sample 75:25 presents a significance thermal behavior, G’ just started to decrease in a temperature range from 50°C to 60°C because of higher contain of MAG comparing to the other oleogel samples. Nevertheless, oleogel sample with the lowest MAG contain decreased a lower temperature range. This significant result evidences that MAG contain in oleogel samples is the factor that affect potentially the outcomes.

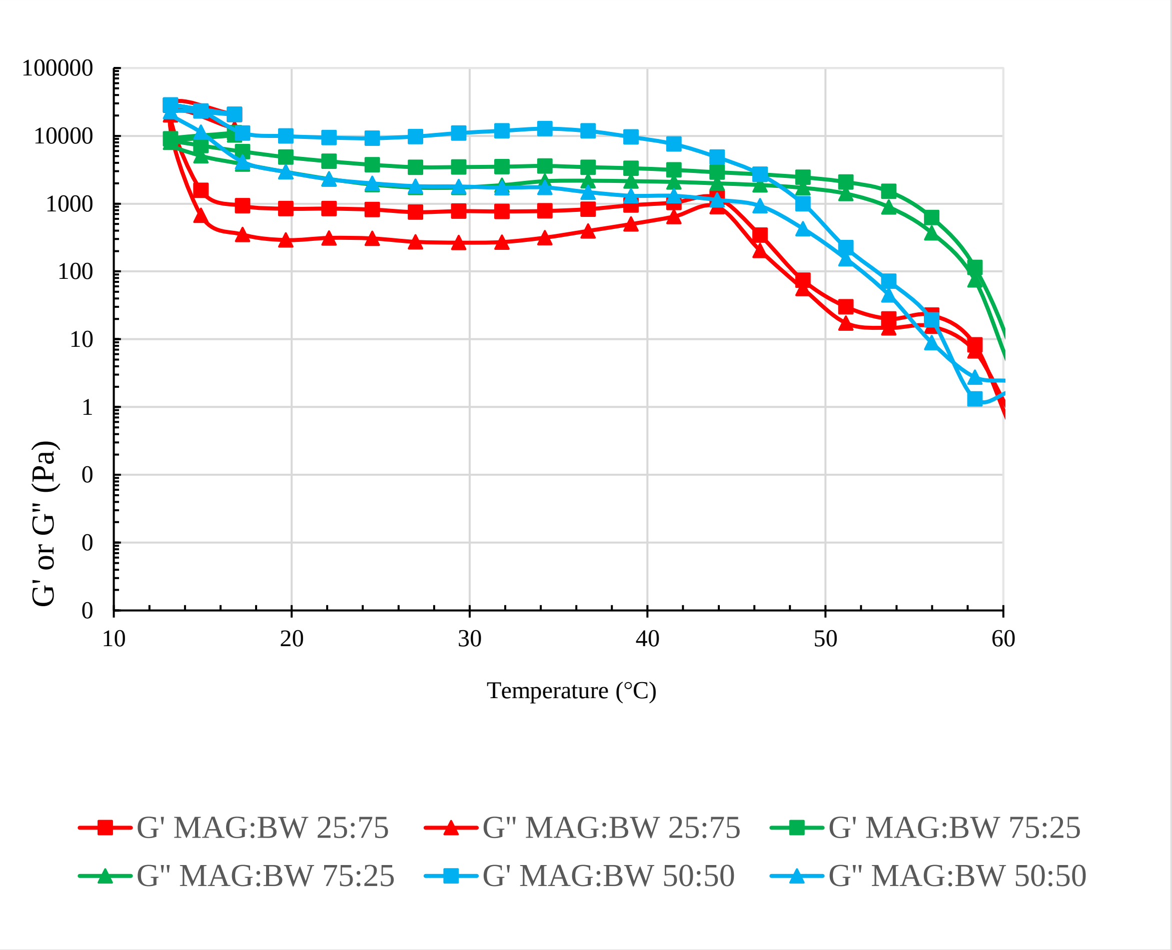

Figure 12. Temperature sweep curve of MAG:BW based oleogel samples

5.2.Spreadability test

Table 5 presents two parameters that were obtained from the test: spreadability. And firmness. Spreadability is measured by the mean area under the positive curve, where smaller values of the area indicate greater spreadability. Previous research has indicated that firmness is determined by the peak of the positive graph (Figure 13). These two parameters are crucial for evaluating oleogels as fat replacements in food products, oleogel should be firm enough to retain its shape and provide the desired texture, while also being soft enough to spread readily and evenly across the surface.

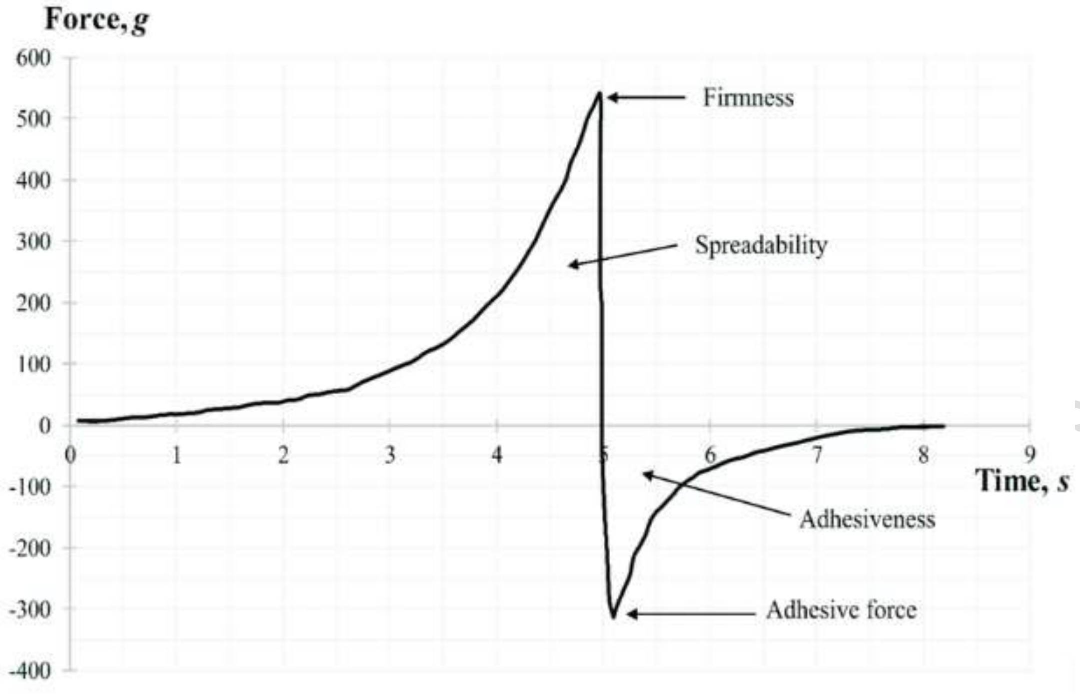

Figura 13. General parameters during Spreadability graph in textural analysis.

(Maslii et al., 2020)

With the results obtained in the mentioned test, gel firmness and spreadability were determined using the force-time graph (figure 14). Spreadability is related to a product's firmness, and the convenience of spreading is frequently associated with a loss of firmness. In this study, the results presented in table 5 demonstrate that an increase in the amount of BW in the ratio with less MAG, leads an increase in terms of firmness, thus, an increase of MAG in oleogel samples decreases firmness.

Oleogels with less amount of BW presented lowest peak values, however, according to Öğütcü & Yılmaz (2014) moderate levels of firmness and/or stickiness indicate excellent spreadability, as it would be extremely difficult to spread samples that are excessively firm or sticky onto a surface. It means oleogel sample with the highest peak does not present a good spreadability result comparing with other 2 oleogel samples.

As can be observed in the figure 14, oleogel sample with similar ratio of MAG and BW exhibited a nearly identical curve with the oleogel sample with highest MAG contain. It indicates that an increase of MAG from 50 to 75 in oleogel sample does not affect spreadability substantially; however in order to obtain a good result, percentage of BW should not exceed the ratio of 50.

Table 5. Spreadability test parameters of MAG:BW based oleogel samples

	Area under the Curve (g × sec)	Firmness (g)
Oleogel 1 MAG:BW (75:25)	1359,67 ± 74,08	1356,37 ± 103,77
Oleogel 2 MAG:BW (50:50)	1405,74 ± 76,18	1384,54 ± 92,97
Oleogel 3 MAG:BW (25:75)	2064,20 ± 94,11	1875,45 ± 97,07

MAG: Monoacylglycerol, BW: Bees wax. Data are presented as mean standard deviation

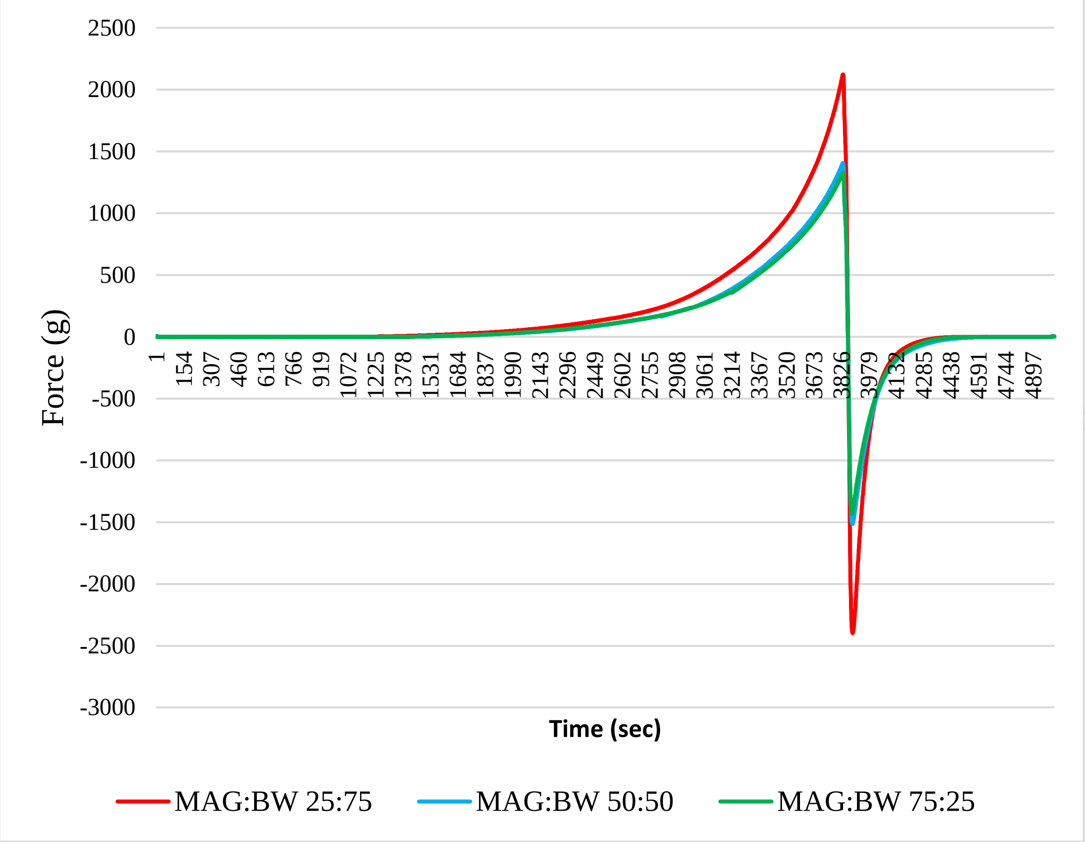

Figura 14. Spreadability graph in MAG:BW based oleogel samples

Spreadability results were also presented with standard deviations in table 5, and one-way analysis of variance was applied in terms of firmness in order to compare samples using Tukey's method. As can be observed in figure 15, OG3, (MAG:BW (25:75) does not share similar results when was compare between OG1 and OG2, it means OG3 means value are completely different. This significant difference can also be observed in Figure 16; the olegel sample with the highest BW content exhibited the maximum firmness with a mean value that was significantly different from the other samples.

The results of the spreadability test can be correlated with those of the amplitude sweep test, which is also an essential test in terms of gel behavior for spreadability characteristics. The oleogel with the highest BW contained the highest values in both experiments. High values of stress response in the LVE region of a gel during an amplitude sweep test may indicate that the gel has a high level of cross-linking or network density, which contributes to its stiffness and rigidity. It is the same trait we observe when a sample exhibits the highest peak in the spreadability curve's force versus time graph. As a consequence of both tests, the MAG:BW 25:75 sample is the least spreadable.

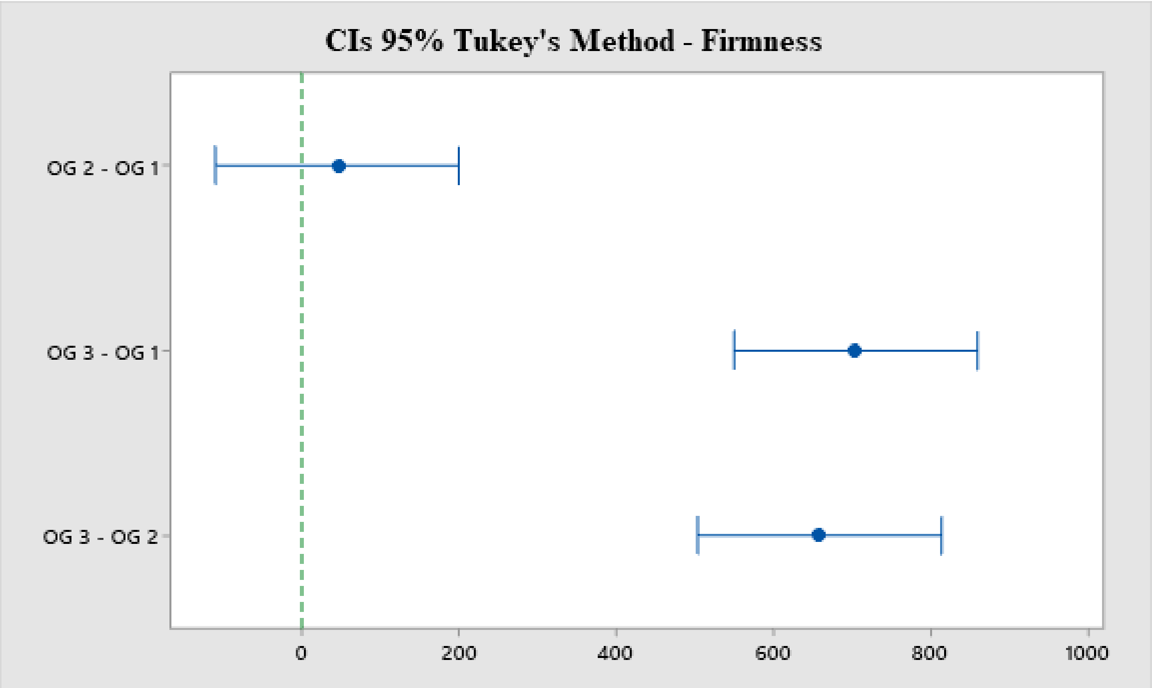

Figura 15. Tukey’s method results in response of Firmness during spreadability test

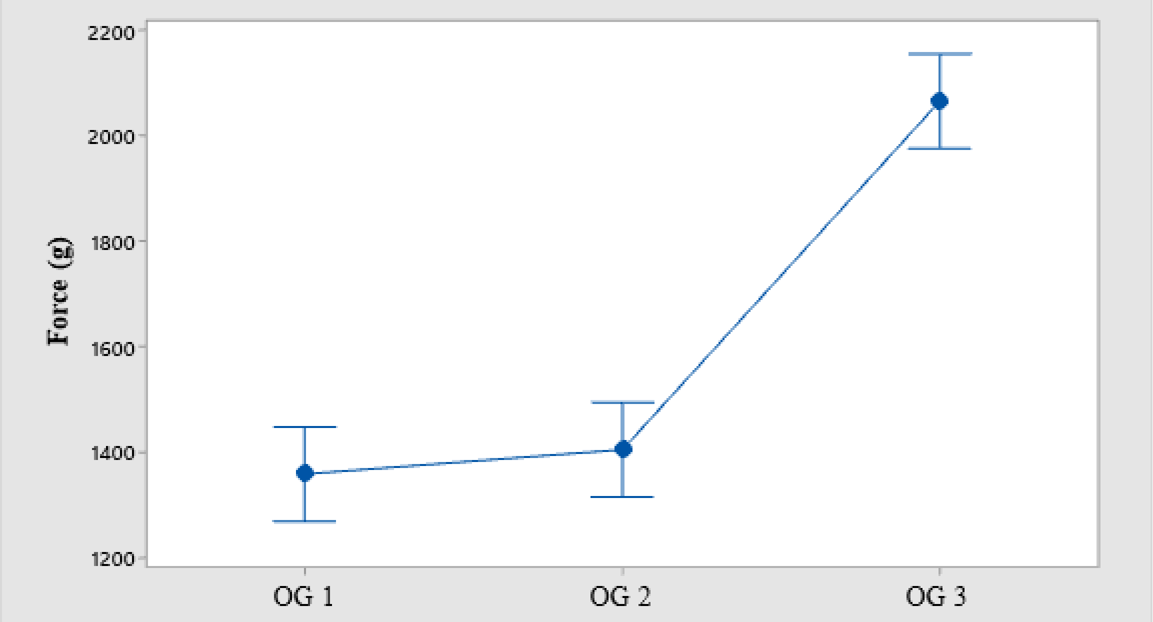

Figure 16. Firmness (force g) result from spreadability test performed in oleogel samples

OG 1: MAG:BW (75:25), OG 2: MAG:BW (50:50), OG 3: MAG:BW (25:75)

Summary

This study was conducted to investigate the rheological effect of mono-acilglycerol (MAG) and Bees Wax (BW) based oleogel in order to develop low-fat oleogels. For this purpose, three various binary mixtures of MAG-BW (20%) were added to the base oil (80% HOSO) at concentrations of 5, 10 and 15 % for each oleogelator, thus, with ratios of 75:25, 50:50 and 25:75.

Applying amplitude, frequency and temperature sweep test and also spreadability texture, the rheological and textural properties of the low-fat oleogel samples were found to be kind of similar between them. However, the oleogel samples with a high MAG contain showed best results, principle in terms of temperature sweep test and spreadability characteristics. The primary benefit of using MAG and BW together was the ability to produce oleogel samples that displayed favorable rheological behavior, maintain a structural strength without losing spreadability characteristics, in order to search for a potential use of these products in bakery and confectionary industry.

It is suggested that additional studies should be conducted to cover other important analyses, such as microstructure and sensory analysis. Future research should also quantify rancidity and solid fat content in order to optimize oleogels. In addition, it is crucial to evaluate their concluding responses to the use of oleogel samples as a fat substitute in bakery and confectionary products by assessing the quality of the final product.

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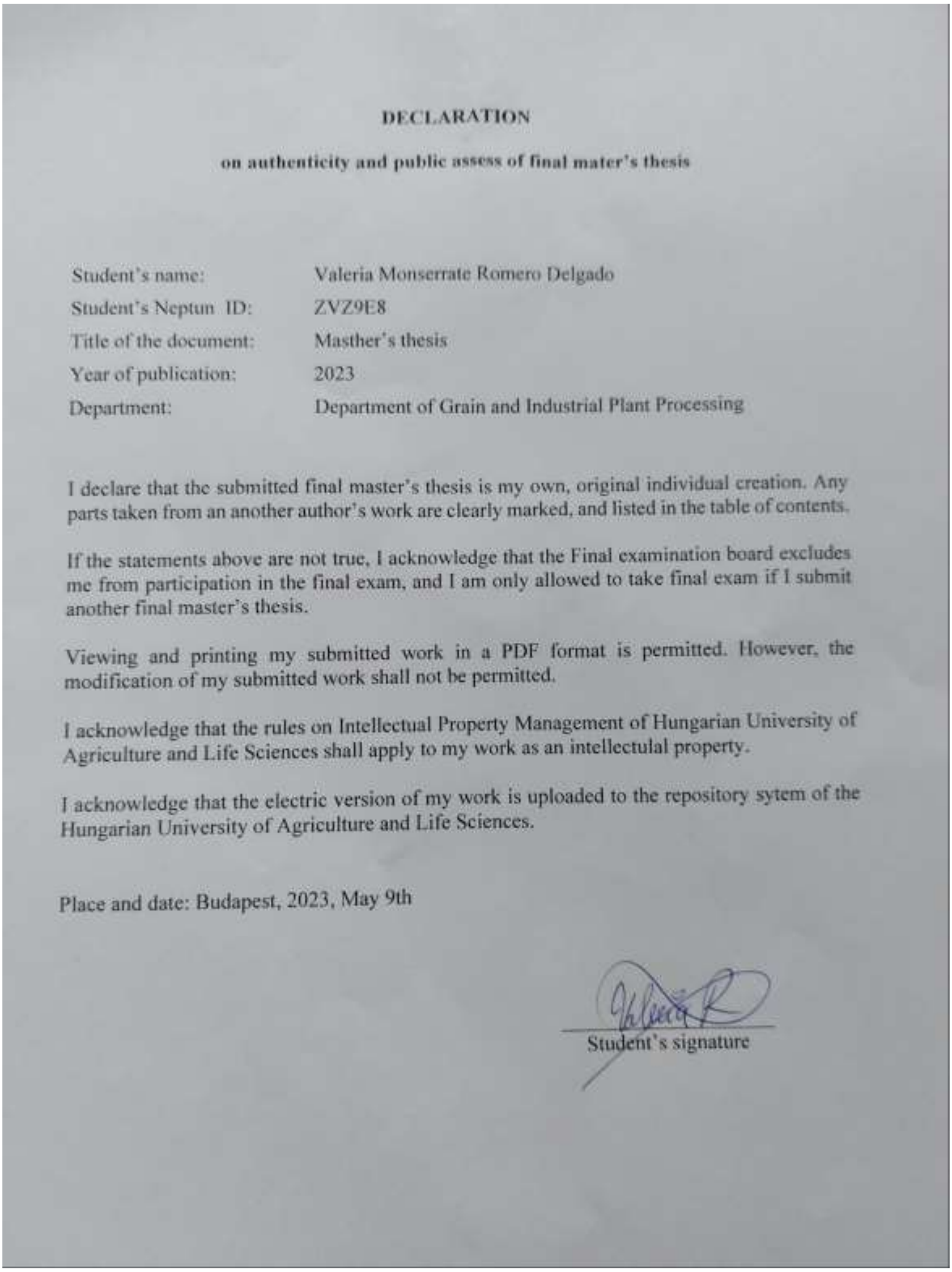
Valeria Romero Delgado

Statement



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