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Treball Final de Grau

Development of three salad dressings: a vinaigrette, a sweet salad dressing and a vegan salad dressing

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January 2019

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En primer lloc, voldria agrair al meu tutor, el Dr. José María Gutiérrez, per la seva dedicació i paciència al llarg d'aquest projecte. Per altra banda, donar les gràcies a la meva família i amics per fer-me costat durant aquests anys.

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SUMMARY

Formulated product development consists in transforming one or more needs detected in the society, into a commercial product. In this work the development of three salad dressings with different flavour, aroma and texture has been carried out.

With the emergence of new eating habits, the consumption of salads has increased and with this, the demand for salad dressings. The mixture of flavours and textures that can be offered in a dressing is so diverse that being successful in this industry will not be easy. That's why three salad dressings, with clear differentiations between each other, have been developed. The three condiments developed are a vinaigrette, a sweet salad dressing and a dressing with similar attributes to a mayonnaise but vegan and therefore without products of animal origin in its composition. For all of them, a generic recipe has been proposed, contemplating variations in their compositions, after having studied the market and having defined its quality criteria. In spite of being different in flavour and texture, the three salad dressings are oil-in-water emulsions and therefore, the characteristics of the product will be directly linked to the stability of the emulsion obtained and its rheological behaviour.

Finally, a manufacturing process and its processing method have been designed to produce about 1.000-1.500 tons of each of the dressings per year. On the other hand, the necessary equipment has been selected. In addition, a brief description of the main design variables and the operating conditions have been detailed, as well as the factors to be taken into account in order to ensure that the food product obtained is safe and free of pathogenic microorganisms to be consumed. Furthermore, and due to the differentiation in the viscosities of the salad dressings obtained, a distribution of the plant where the three dressings would be manufactured, have been proposed.

Keywords: Product development, salad dressing, quality criteria, emulsion, emulsion stability, rheological behaviour, manufacturing process design.

RESUM

El desenvolupament de productes formulats consisteix en convertir una o diverses necessitats detectades a la societat, en un producte comercial. En aquest treball s'ha dut a terme el desenvolupament de tres salses per amanida amb diferent sabor, aroma i textura.

Amb l'aparició de nous hàbits alimentaris, el consum d'amanides ha augmentat i amb això, la demanda de salses per amanida. La barreja de sabors i textures que poden oferir-se en una salsa és tant divers que tenir èxit en aquesta indústria no serà fàcil. És per això, que s'han desenvolupat tres salses ben diferents entre elles. Les tres salses desenvolupades són una vinagreta, una salsa per amanida dolça i una salsa amb característiques semblants a la maionesa però vegana i per tant sense productes provinents dels animals. Per totes elles, se n'ha proposat una recepta genèrica, contemplant variacions en les seves composicions, després d'haver estudiat el mercat i definit els seus factors de qualitat. Malgrat ser diferents en sabor i textura, les tres salses són emulsions d'oli en aigua i per tant, les característiques del producte obtingut aniran directament lligades amb l'estabilitat de l'emulsió obtinguda i el seu comportament reològic.

Finalment s'ha dissenyat un procés de fabricació i el seu mètode d'operació per a produir unes 1.000-1.500 tones de cada una de les salses a l'any. Per altra banda, s'han seleccionat els equips necessaris, s'ha fet una breu descripció de les principals variables de disseny i les condicions d'operació, així com també, dels factors a tenir en compte perquè el producte alimentari obtingut sigui segur i lliure de microorganismes patògens per ser consumit. A més a més, i degut a la diferenciació en les viscositats de les salses obtingudes, s'ha proposat una distribució de la planta on es fabricarien les tres salses.

Paraules clau: Desenvolupament del producte, salsa per aminada, factors de qualitat, emulsió, estabilitat de l'emulsió, comportament reològic, disseny del procés de fabricació.

1. INTRODUCTION

Dressings or condiments are an essential part of the food. Nowadays, any ingredient can be good to produce a dressing. A wide variety of dressings are used on salads to enhance their palatability and desirability (Ford et al. 2003). The market of salad dressings is growing as more exotic flavours are introduced. The mixture of flavour and textures is so diverse that there are dressings for all interests and consumers. The range of options is so great that the consumer is demanding and will buy the salad dressing that best suits his needs. The industries, therefore, will have to innovate, adapting to new times if they do not want to be left behind in sales.

The appearance of new eating habits is an important factor to keep in mind for the industries for the production of their condiments. A clear example is veganism, a practice that rejects the consumption of any food of animal origin (including, therefore, milk, eggs or honey). The awareness of society with climate change, overproduction of meat or the precarious conditions under which animals live in the food industry are some of the factors which directly influence in the increase of the demand for vegan products. In recent years, sales of vegan dressings have skyrocketed.

At present, the food industry has managed to bring the flavour and texture of processed dressings to that of traditional home-made sauces. With all this, the global demand for processed salad dressings has increased considerably and, therefore, also, the figure of the engineer and product engineering. Product engineering includes all stages since the need is detected until the product formulated is ready to be sold. The main objective of an industry that manufactures salad dressings will be to design a product that satisfies the needs of the consumer in terms of appearance, taste and texture; conceptualizing the product, analysing the criteria and quality indexes, selecting the ingredients and the microstructure of the product and designing its manufacturing process.

In addition, the industries will seek that the plant cover as much production as it is necessary, as well as being flexible enough to make changes in production if necessary.

On the other hand, it will be important to understand the mechanics of the fluids with which one works, its rheology and properties of the final mixture that will be obtained. The enormous structural differences and physicochemical properties of the different ingredients that make up a salad dressing is one of the other challenges for the engineer, as well as, for the design and selection of equipment. All this previous knowledge applied to reduce the necessary experimentation can be understood as the product design, first stage in the development of products.

It will be necessary to know and deepen in the unitary operations that may be needed. The main process for the production of any dressing will be the mixture or emulsification of ingredients to achieve a chemically and physically stable mixture. The necessary equipment in the processed condiments industry will basically be: storage systems of the different ingredients, mills, homogenizers, emulsifiers and sterilizers (or other operations at temperature or pressure that eliminate pathogenic microorganisms), among others.

Having said that, the increase in the demand for salad dressings, and the diversification in this demand, lead us to the main objective of this work; the development of different types of salad dressings.

2. OBJECTIVES

The final goal of this work is the development of three families of salad dressings to be manufactured at the same plant. Three generic and representative recipes of each type of condiment will be defined and their production process will be designed, selecting the necessary equipment. The three salad dressings that will be developed will be different to be able to satisfy the needs of consumers with different tastes and interests.

For the preparation of these formulated products, we must choose the product we want to develop after having studied what the market offers and deciding what needs we want to satisfy with our product. We need to decide the ingredients of the formulated product that will give the desired requirements and finally design the chemical process that fits with the product we make and select the equipment needed. This procedure can be divided into four sections (C. Wibowo and K.M. Ng, 2001):

Product conceptualization: it is about detecting the needs to satisfy. A thorough analysis of similar products in the market is made. Main characteristics of the product are defined.

Quality criteria: once the product has been conceptualized and its characteristics and properties have been detailed, it is necessary to identify their quality criteria (different for each type of salad dressing) which will allow us define the product formulated and see if it fulfils or not the needs to satisfy, as well as if it is competitive with the current market and convince, therefore, the consumer.

Product formulation: At this point we will focus on the formulation of the salad dressings, we need to do a thorough analysis and select the necessary ingredients and their quantity in the product formulated, as well as to define which microstructure will have the product that meets the factors and quality index detailed before. All the ingredients for the generic and representative recipe for each of the three sauces as well as its proportions in the product will be definitely chosen.

Design of the manufacturing process and equipment selection: At this point the production process of the three condiments selected will be designed, detailing the unit operations and the necessary equipment. The distribution of the plant will also be proposed.

Although a generic recipe for each salad dressing will be detailed, more condiments may be produced with modifications to the generic within the same section, since the characteristics and structure, as well as their industrial process, will be similar for each of the families of salad dressings. Therefore, a wide range of salad dressings could be produced in the same industrial plant.

3. PRODUCT CONCEPTUALIZATION

According to C. Wibowo and K.M. Ng (2001), The first step when developing a product is the conceptualization of the product. It occurs in the initial design activity, it's time to decide the scope of the project and define the product. At this point, it must be clear the aim of the product formulated that you want to produce and what are the needs that you want to satisfy.

Innovation and creativity are both important to succeed in the development of a new product. That's why it is important to make a market research of the different brands to see what they offer. Market research will allow us to understand the supply and demand as well as the different recipes that industries have for a similar product. So, after this deep investigation in the market, we will be able to select one or more of the main ingredients in the product that will make the difference with the already existing products and that we think that will make us succeed in the industry. Apart from the main ingredients, container that will be used will be selected.

The product that is wanted to be developed is a salad dressing. Dressing is an oil-in-water emulsion, in which the total flavour has been shown to be a combination of aroma, taste and mouthfeel (McClements and Demetriades, 1998).

A research in the market of the different salad dressings ready to be sold have been done and, in the following table, we find a summary of the most common condiments for salads that have been found. They are split in three different groups of salad sauces; vinaigrettes on the one hand, sweet salad dressings on the other and finally, viscous dressings such us mayonnaise or similar. In the left column we see the type of dressing and the brand. In the middle column, we find the main ingredients of the condiment. Only the principle ingredients that differentiate the three salad dressing families each other are detailed; later in the selection of the ingredients all the additives will be specified. Finally, in the last column, we find a valour of its viscosity going from 1 (very low viscosity) to 3 (high viscosity like a mayonnaise), this number, obviously, is a visual measure of the viscosity which helps us define the products.

Table 3.1. Vinaigrettes found in the market

VINAIGRETTES		
Dressing	**Ingredients**	**Viscosity**
Salsa vinagreta Balsámica **Babyfresh**	water, balsamic vinegar (25%), apple juice, alcohol vinegar, extra virgin olive oil (2,5%), starch, salt, sugar, additives	1
Vinagreta **HACENDADO**	water, sunflower oil (28,6%), alcohol vinegar (9,5%), mustard, egg yolk, starch, sugar, salt, additives	2
Vinagreta Gourmet **Florette**	water, sunflower oil, wine vinegar (14%), citric acid, mustard sauce, starch, salt, sugar, additives	2
Vinagreta enselada vegana (take-away salad) **Carrefour**	extra virgin olive oil, balsamic vinegar, wine vinegar, grape juice	1
Vinagreta balsàmica (take-away salad) **verdifresh**	water, olive oil, balsamic vinegar, sugar, salt, additives	1
Vinagreta amanides pollastre i pinya (take-away salad) **AMETLLER ORIGEN**	extra virgin olive oil (70%), balsamic vinegar (30%)	1
Crema de vinagre balsámico de manzana **HACENDADO**	apple vinegar, grape juice, apple juice, starch	1
Vinagreta balsámica Modena y miel **Florette**	water, balsamic vinegar, (5%), honey (3%), vegetal oil, sugar, salt, additives	2

Table 3.2. Sweet salad dressings found in the market

SWEET SALAD DRESSINGS		
Dressings	**Ingredients**	**Viscosity**
Salsa miel y mostaza **HACENDADO**	water, sunflower oil, honey (15%), alcohol vinegar, egg yolk, mustard (2%), salt, sugar, additives	2
Aderezo de mango y albahaca **HACENDADO**	olive oil (30%), wine vinegar, balsamic vinegar, basil (0,07%), salt, sugar, additives	2
Salsa mostaza y miel con arándanos **Babyfresh**	water, vegetal oil, mustard sauce (4%), wine vinegar, honey powder (2%), dry cranberries (2%), egg yolk, starch, salt, sugar, additives	2
Salsa agridulce **HACENDADO**	water, alcohol vinegar, apple vinegar, tomato, modified starch, sugar	2
Salsa miel y mostaza **Florette**	water, dextrose, vegetal oil, cider vinegar, honey (5%), mustard sauce (5%), soya sauce, modified starch, additives	2
Salsa de soja dulce **AIKO**	Water, Glucose-fructose syrup, sugar, sugar syrup, soya, additives	1

Table 3.3. Mayonnaise and high viscous salad dressings found in the market

VISCOUS SALAD DRESSINGS		
Dressing	**Ingredients**	**Viscosity**
Ligeresa original **Ligeresa**	water, soybean oil (25%), wine vinegar, egg yolk, starch, sugar, salt, additives	3
Mayonesa **HACENDADO**	Water, sunflower oil (64%), egg yolk (5%), wine vinegar, lemon concentrate (0,2%), starch, sugar, salt, additives	3
Mayonesa Bio **Eco Cesta**	Water, sunflower oil (77%), egg yolk, alcohol vinegar, (8,8%), mustard sauce, sugar, salt, additives	3
Mayonesa **Musa**	Water, sunflower oil, wine vinegar, egg yolk, salt, additives	3
Salsa sin huevo y sin lactose **Musa**	Water, sunflower oil, vinegar, starch, mustard, salt, sugar, additives	3
Mayonesa **YBARRA**	Water, sunflower oil (65%), egg yolk, wine vinegar, concentrated lemon juice, sugar, salt, additives	3
Mayovegana **Bio D'Atenea**	Water, sunflower oil, wine vinegar, garlic, lemon juice, beer yeast, mustard, potato and turmeric protein, sugar, salt	3
Sin huevo **Flora**	Water, soybean oil (36%), alcohol vinegar, mustard sauce, lactose and milk proteins, concentrated lemon juice, starch, sugar, salt, additives	3
Salsa César ***HACENDADO***	Water, sunflower oil, cheese, onion, alcohol vinegar, egg yolk, mustard, sugar, salt, starch	3

After this research, it has been decided to produce three different salad dressings with a diverse aroma, flavour and texture. They will be elaborated in a plant with three parts differentiated, one for each family of salad dressing. The target market will be anyone who love salads with different flavours. As they all are mixtures of immiscible liquids (oil and water), emulsion will be the appropriate delivery vehicle. Indeed, as mentioned before, McClements and Demetriades, (1998) conclude dressings are oil-in-water emulsions.

On the one hand, a **vinaigrette** will be developed. As find in the market, vinaigrettes are the product most used as a salad dressing. The main problem in the vinaigrettes is its viscosity; while homemade vinaigrettes present low viscosity, since they basically are a mixture of oil and vinegar, the big manufacturers add thickeners and stabilizers, to get a higher viscosity to increase the stabilization of the dressing and its shelf life. However, as we can see in table 3.1, salads that are exposed in the supermarkets to take away, usually bring a low viscous vinaigrette with them to make the costumer feel like if he was taking a homemade salad with its respective homemade vinaigrette.

In this project, the vinaigrettes that will be produced will be a mixture of vinegar, water and oil that can also contain spices and flavourings, including solid flavourings and colorants. Although the recipe will be basically the traditional composition, it has been decided to use, in addition, ginger oil and other vegetable oils like sesame oil because of its good properties for health. Compare to other oils, ginger oil, facilitates digestion and can help to prevent digestive problems. However, it has a strong flavour, that's why it will be mixed with other oils to make the mixture softer in terms of taste. So, a vinaigrette with little modifications to the traditional composition will be developed. The main distinction will be the use of oils with healthy properties in the oil phase of the vinaigrette.

The vinaigrette developed will have a low viscosity, and because of that, it will readily separate to multiple phases; specifically, a water phase (essentially vinegar), an oil phase, and solid phase (if solids are added). Immediately before to be poured to the salad, the dressing will have to be vigorously agitated. Although previous patents and vinaigrettes in the market use gum as a thickener which makes an increasing in the viscosity of the dressing, in our vinaigrette, no thickener will be used to prevent the separation of ingredients. Thickeners clearly alter the texture of the dressing but the consumers of this kind of dressing are, in dead, used to visually seeing the dressing in the container, separated into the multiple phases. A little quantity of emulsifying agent can be used to remain the dressing dispersed for a short period of time after agitation, to permit dispensing and use.

As a container for the vinaigrette, a 250 ml glass bottle will be used. The condiment has a low viscosity and a limited stability, it readily separate in multiple phases, that's why it will have to be agitated immediately prior to use. The glass bottle will be elongated, higher than wide; with a narrower upper part forming a hole through which the sauce will be dispensed. The glass will be coloured but not completely opaque in order to let the costumer see the different phases separated before agitation.

On the other hand, a **sweet salad dressing** will be produced, for those who prefer sweetness in a condiment, and to give extravagant flavour to the salad. Because of the honey, egg or mustard that are usually added, these dressings usually present a higher viscosity than vinaigrettes.

Despite of the fact that this salad dressing will be sweeter than vinaigrettes, the composition will be similar. It will basically be an oil-in-water emulsion. However, Mustard or egg will be used as emulsifier, to get a compact emulsion. In addition, thickeners will be used to give a higher stability and viscosity. The dressing will be pourable for a long time after its manufacture because of the higher viscosity and emulsion stability that will be obtained. Our sweet salad dressing will contain, water, vinegar, oil, honey and mustard or egg (as the main ingredients in the salad dressing). However, it's been decided to use royal jelly in a mixture with honey. Royal jelly with a similar taste to the honey and also deriving from bees, is a multivitamin compound that can give an extra healthy point to the sweet salad dressing. Royal Jelly and honey has the same texture and rheology so it will not be a problem to mix them to give sweetness and consistence to the condiment. Other Ingredients that can be used to provide sweetness to the condiment will be fruit -like berries- and fruit jam.

Because of the properties of this salad dressing, and the viscous liquid that will be obtained, a 250 ml squeeze bottle constructed of a transparent flexible plastic which has a container and a cap for containing and dispensing the condiment, will be used as a container for the sweet salad dressing.

Finally, because of the growth of environmental consciousness and critic spirit with the food industry for animal exploitation, the trend of veganism has increased in recent years and thus the demand for vegan products. However, after exploring the composition of high viscous dressings (Table 3.3) we've noticed that most of them, like *mayonnaise* and *Caesar sauce*, have eggs on their recipes. It is difficult to find vegan products, with recipes that do not contain ingredients that come from animals, in the group of high viscous salad dressings. In addition, people who consider themselves vegan, are great consumers of salads since they do not eat anything of animal origin, therefore, developing a high viscous vegan salad dressing is a good way to succeed in the market of salad dressings. So, a viscous **vegan salad dressing** will be produced.

To produce the vegan dressing any component originating from animals will not be used. In particular, vegan emulsions therefore, do not contain any components that are obtained from animal or animal's products such as milk or eggs. The aim is to create a dressing with similar properties to a mayonnaise but without using egg as emulsifier. An emulsion of oil and water will be produced and a good substitute for the eggs will be the mustard flour or similar components that will be discussed in later chapters. However, more ingredients may be added to the salad dressing to give the desired flavour.

Because of the properties of this salad dressing, and the viscous product that will be obtained, a 250 ml squeeze bottle constructed of a transparent flexible plastic which has a container and a cap for containing and dispensing the condiment, will be used as a container for the vegan salad dressing.

The three big families of salad dressings developed, will be produced in a specific place of the plant that will be designed. So, the plant, will present three main parts with its particular processing units.

As seen in the previous explanation of the three families of salad dressings that will be produced, viscosity is the main property that differentiates the salad dressings families each other and it will take big importance in the selection of the equipment for the production of the condiments. While the vinaigrette will be a low viscous solution, the sweat dressing will be more viscous and the vegan sauce will be the most viscous. It is important to point out, that vegan salad dressing will be specified as a viscous salad dressing, that usually include eggs or milk on their recipes, because producing a vegan vinaigrette or a vegan sweet salad dressing will not be a big inconvenience. Indeed, most of the vinaigrettes can consider themselves totally vegan, and honey from the sweet salad dressing can be easily replaced; however, it's difficult to find a viscous salad dressing similar to a mayonnaise without eggs and milk on it.

This difference in the viscosity of the three families of salad dressings will enable us to separate the plant that will be designed, not only for kind of salad dressing but for the viscosity of the sauce that is being produced. So, although the sweet salad dressings produced will have a specific viscosity, if it's decided to produce a sweet dressing containing sweet soybean and free of thickeners –for example- which will have less viscosity, it will be elaborated in the part of the plant where vinaigrettes are done, with the appropriate equipment to produce a low viscous product.

4. QUALITY CRITERIA

According to *C. Wibowo, K.M. Ng* (2001) the next step towards realization of a product is to identify the desired performance in terms of quality factors.

The quality factors or quality criteria of a formulated product are the requirements that the product must achieve which on the one hand will satisfy the needs that have been detected and on the other will make it attractive and different from its competitors. Depending on product form or delivery system, the desired quality factors can be different. Additional quality factors may need to be specified after the ingredients are selected in the next step, and cannot be anticipated at the moment.

Some of the quality factors will be quantified by quality index. Quality index are properties that we can measure to evaluate each one of the quality criteria that has been stablished. In this chapter, various studies and tests will be mentioned to help as decide which quality criteria are appropriate for the three salad dressings that are going to be developed. However, it will be in the next chapter, *Product formulation*, were the information will be discussed to select the suitable ingredients for the formulated product.

The most important aim when developing a salad dressing is to achieve the desired flavour which will make the product attractive and longed for by the costumer. On the other hand, the texture of the condiment will also be important since the visual effect and the feeling the costumer will have once the salad dressing is on his mouth are also parameters to take into account to develop the best salad dressing. The quantity and quality of the ingredients used to give the desired flavour, emulsifier used for the oil-in-water emulsion, thickeners which will determined the viscosity of the condiment and other additives such as flavourings and colorants, will all be important in the final result of its flavour and texture and thus to the quality of the salad dressing developed.

For the development of the three salad dressings, the quality factors to be taken into account will be mainly; flavour and aroma on the one hand and texture and stability of the product obtained on the other. Texture of the condiment will basically depend on its emulsion stability and the viscosity obtained. Among all kind of quality factors that *C. Wibowo and K.M. Ng (2001)* talk about, sensorial quality factors, which coincide with functional quality factors, physical quality factors (product stability) and rheological quality factors, will be useful for the present work.

The present chapter is divided in three big parts first: the sensory analysis for flavour, aroma and fluidity; emulsion stability; and finally, rheology. However, other quality factors that don't fit in any of these groups, will be defined and summarize in the last section of this chapter where the quality criteria for all the salad dressings will be displayed.

4.1 SENSORY ANALYSIS

In this section we will talk about the flavour, aroma and fluidity of the salad dressings which will be quantified with sensory analysis. Sensory analysis of food is an effective instrument for quality control and acceptability of a food.

Sensory analysis is defined as "the scientific discipline used to measure, analyse and interpret reactions to those characteristics of food and other substances, which are perceived by the senses of sight, smell, taste, touch and hearing" (Institute of US food). Sensory analysis is a very useful discipline to know the organoleptic properties of food, as well as products of the pharmaceutical industry, cosmetics, etc., through the senses, that's why it is important that the senses are well developed to emit an objective and not a subjective result.

The sensory evaluation is innate in man since from the moment that a product is tested, a judgment is made about it, if it likes or dislikes, and describes and recognizes its characteristics of taste, smell, texture, etc.

The basic or main tool to carry out the sensory analysis are the people; instead of using a machine, the measuring instrument is the human being, since the human being is sensitive, and a machine can't give the results that are needed to carry out an effective evaluation.

To execute the sensory analysis of the food, it is necessary to give the right conditions (time, space, environment) so that these do not negatively influence the results, the tasters must be well trained, which means that they must develop more and more all their senses so that the results are objective and not subjective. The selection of the tasters can be done considering the ISO Standard 8586: 2012, which considers both selection and training of the judges who will taste each quality criteria.

In sensory analysis judges are selected after different tests that candidates have to pass if they want to be part of the final group of panellists. Recognition tests and threshold tests are performed to ensure the judges are competent. Finally, the tasters are selected and trained before carrying out the sensory analysis of the product.

For the current work, flavour, aroma and fluidity of the salad dressings will be measured by sensory analysis by 10 panelists.

Flavour

From the Latin "sapor", flavour is the sensation produced by food or other substances in taste. This impression is largely determined by the sense of smell, apart from the response of the palate and the tongue to the chemical components.

The flavour identification test is currently regulated for the ISO 3972, a document that recommends not only the identification of the basic flavours (sweet, salt, sour, bitter) but also introduces the umami flavour.

After the flavour recognising and threshold test have been done and judges are well trained, the 10 judges selected will be given 15 mL of each salad dressing that is wanted to be tested, and will have to select one of the basic flavours.

Table 4.1. Proposed sensory analysis for Flavour

FLAVOUR	Sour	Bitter	Salt	Sweet	Umami	No Identified flavour
Salad dressing						

For the present work, where three salad dressings are developed, the results expected in terms of quality index for the quality factor of flavour and which will show that the elaboration of the three salad dressings are satisfactory is the next:

Table 4.2. Expected results for sensory analysis for Flavour

FLAVOUR	Sour	Bitter	Salt	Sweet	Umami	No Identified flavour
Vinaigrette	X					
Sweet salad dressing				X		
Vegan salad dressing	X					

Aroma

Aroma is a distinctive, pervasive, and usually pleasant or savoury smell.

Similar to the flavour sensory analysis, 10 tanners will evaluate the aroma of the salad dressing to qualify the quality criteria of aroma. We will differentiate between fruity/sweet aroma and vinegary/sour aroma. In addition, there will be an option for those salad dressings that the taster can't associate to the fruity or vinegary aroma, "neither fruity nor vinegary". All the tasters will fill with a cruise (x) the aroma they feel in each salad dressing.

Table 4.3. Proposed sensory analysis for Aroma

AROMA	Vinegary/sour	Fruity/sweet	Neither fruity nor vinegary
Salad dressing			

For the present work, the results expected for this quality criteria and which will show that the elaboration of the three salad dressings are satisfactory in terms of aroma quality factor is the next:

Table 4.4. Expected results for sensory analysis for aroma

AROMA	**Vinegary/sour**	**Fruity/sweet**	**Neither fruity nor vinegary**
Vinaigrette	X		
Sweet salad dressing		X	
Vegan salad dressing	X		

Fluidity

Fluidity is the ability of a substance to flow easily. Although when talking about emulsion, physicochemical analysis and tests are done to characterize the emulsion, its stability, viscosity and rheology –parameters that directly affect to the product fluidity-, listening to the costumer's feelings about the fluidity of the product obtained is a good way to see if consumers understand the idea of the product in the same way as the manufacturer.

In this case, 10 judges will make a visual and taste analysis and will score on a scale of 1 to 10 depending on their feelings about if the condiment is liquid, 0; or very dense, 10. Low values in the fluidity scale means the condiment easily flows (low viscosity) and high values, implies that the product hardly flows (high viscosity). All the tasters will fill with a cruise (x) their opinion about condiment fluidity after tasting it.

Table 4.5. Proposed sensory analysis for fluidity

FLUIDITY	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Salad dressing											

For the present work, where three salad dressings with different viscosities are developed the result expected for this quality criteria and which will show that the elaboration of the three salad dressings are satisfactory will be low values for the vinaigrette, intermedium values for the sweet salad dressing and high values for the vegan salad dressing.

4.2 EMULSION STABILITY

As explained in previous chapters of this work, the three salad dressings that will be developed will be oil-in-water emulsions. Although more ingredients will be added to the condiment, the emulsion obtained thanks to the emulsifiers and thickeners (if required) will basically characterize the properties of the dressing obtained.

First of all, it is convenient to define and explain what an emulsion is. An emulsion is a thermodynamically unstable dispersion of several immiscible liquids. Usually the emulsion is constituted by two phases; one containing a polar compound (like water or vinegar) and the other containing a non-polar compound (usually oil). One of the phases is dispersed in the other phase, its droplets are dispersed in the homogeneous phase. If oil is dispersed in water, the emulsion in an oil-in-water emulsion, on the contrary, if water droplets are added to oil, it is a water-in-oil emulsion. On our work, as said before, the salad dressings will all be oil-in water emulsions.

The interfacial tension in the interphase between the oil and the water phases must be overcome if a stable oil-in-water emulsion is wanted to be formed. Despite of the fact that agitation can reduce this interfacial tension for a short time, an emulsifying agent must be employed to provide stability enough to the emulsion.

According to the AOCS (American Oil Chemists' Society) Emulsifiers work by forming physical barriers that keep droplets from coalescing. A type of surfactant, emulsifiers contain both a hydrophilic (water-loving, or polar) head group and a hydrophobic (oil-loving, or nonpolar) tail. Therefore, emulsifiers are attracted to both polar and nonpolar compounds. When added to an o/w emulsion, emulsifiers surround the oil droplet with their nonpolar tails extending into the oil, and their polar head groups facing the water.

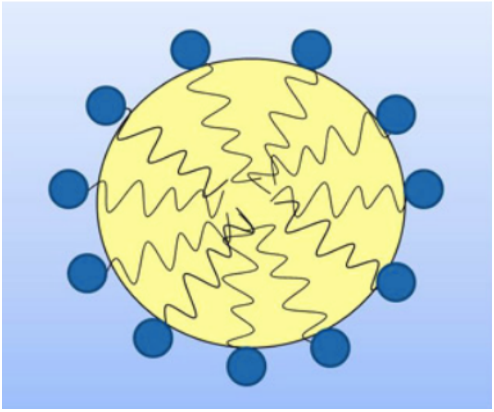

Figure 4.1. When a surface-active emulsifier is used to combine water and oil, the polar head group (shown in the blue circle) is attracted to water, while the non-polar tail (wavy black line) is attracted to oil, allowing the water and oil to combine. Source: The Lubrizol Corp. (Wickliffe, Ohio, USA)

Although, as emulsions are inherently thermodynamically unstable, understanding the theoretical factors influencing emulsion stability is critical to formulate the best emulsion.

In an emulsion, some phenomena which will go against emulsion stability can occur. The processes that can alter negatively the emulsion stability are:

- Gravitational separation: creaming and sedimentation
- Flocculation
- Coalescence
- Ostwald Ripening

Gravitational separation

It is the migration of the dispersed phase of an emulsion caused by the action of gravity and buoyancy without droplet size variation.

Buoyancy is an upward force exerted by a fluid that opposes the weight of an immersed object (oil droplet in this case). When dispersed phase density is greater than that of the fluid in which it is submerged, droplets tend to sink (sedimentation). If the density is either less dense than the homogeneous phase or is shaped appropriately (as in a boat), the force can keep the droplets afloat (creaming)

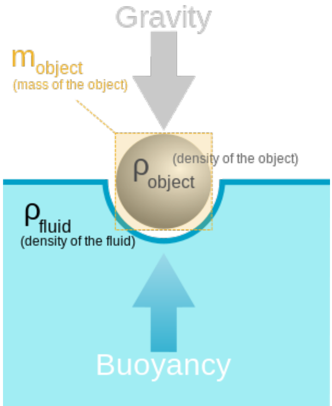

Figure 4.2. The forces at work in buoyancy.
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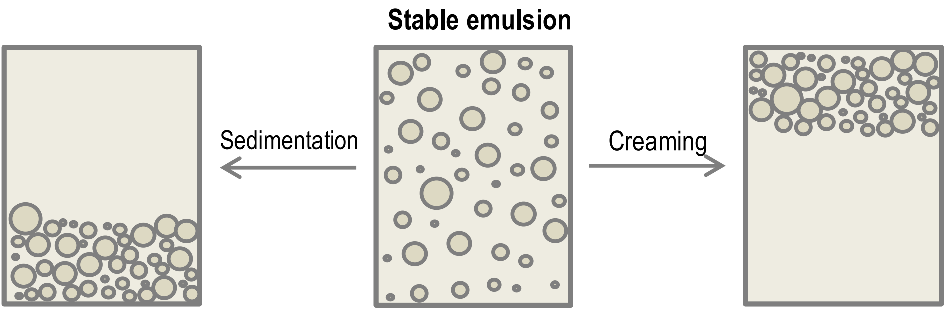

Figure 4.3. Sedimentation and creaming process

If we talk about isolated droplet, is good to define its terminal velocity (Stokes equation).

$$v = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} gR^2 \qquad \text{(eq 1)}$$

where g is the gravitational acceleration (m/s^2), R is the radius of the spherical particle. ρ_p is the mass density of the particles (kg/m^3), ρ_f is the mass density of the fluid (kg/m^3) and μ is the dynamic viscosity (kg/(m·s)). v will be positive if $\rho_p > \rho_f$ and negative if $\rho_p < \rho_f$. So sedimentation and creaming will be produced respectively.

So according to the Stoke's equation, to retard the gravitational separation, and maximize the stability of the emulsion we need to minimize the droplets radius (R) and increase the continuous phase viscosity (μ). This can be achieved through the use of the appropriate emulsifier and thickening agents.

Flocculation

Flocculation is a process wherein colloids come out of suspension in the form of floc or flake, either spontaneously or due to the addition of a clarifying agent. According to the IUPAC definition, flocculation is a process of contact and adhesion whereby the particles of a dispersion form larger-size clusters.

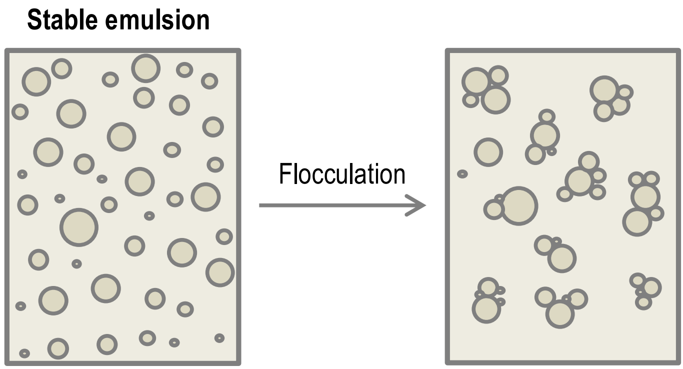

Figure 4.4. Flocculation process

We can describe if flocculation is produced or not thanks to the DLVO theory. The **DLVO** was established by **D**erjaguin, **L**andau, **V**erwey, and **O**verbeek in the 1940s (Derjaguin and Landau 1941, Verwey and Overbeek 1948) and describes the case where van der Waals forces are present in combination with electrostatic forces.

The theory explains the aggregation of aqueous dispersions quantitatively and describes the force between charged surfaces interacting through a liquid medium. It combines the effects of the Van der Waals attraction and the electrostatic repulsion due to the so-called double layer of counterions.

According to DLVO:

$V_T = V_A + V_R$

V_T – Total energy potential between particles

V_A – Attraction between particles due to van der Waals, mostly London Forces

V_R – Repulsion between particles due to the electrical double layer of co-ions and counter ions at the surface of a particle

Although DLVO present a complex mathematic model, we can easily say that the best way to avoid flocculation providing emulsion stability is by minimizing the attractive forces between the dispersed droplets, whether provoked by van der Waals or electrostatic force, by minimizing droplets size and maximizing distance between them. The selection of the emulsifier will be important to prevent emulsion from flocculation. On the other hand, maximizing the homogenous phase viscosity is a good way to immobilize the dispersed phase droplets avoiding them to approximate each other.

Coalescence

Coalescence is the phenomena that occurs when two or more individual droplets of the dispersed phase merge to form a bigger droplet

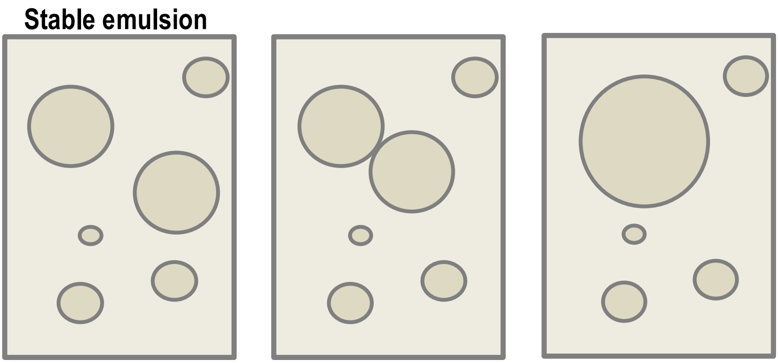

Figure 4.5. Coalescence process

The principle aims to avoid coalescence and ensure emulsion stability –similar to flocculation- is to reduce attraction and droplet contact and increase repulsion between droplets and resistance of membrane rupture. on the one hand, to reach the desire repulsion and decrease droplet contact, droplet size must be minimized and viscosity maximize through the use of thickeners or gelling agents. On the other hand, polymeric emulsifiers can be used to increase resistance of membrane to rupture.

Ostwald Ripening

Ostwald ripening causes the diffusion of droplets from smaller to larger droplets due to their internal activity difference. For a given interfacial tension, γ, the activity inside an emulsion droplet of radius r is proportional to γ/r (Laplace). The activity of dispersed material is greater for smaller droplets than larger droplets.

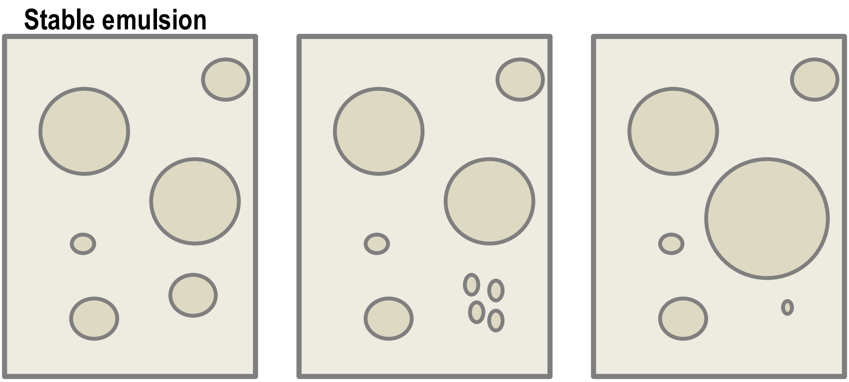

Figure 4.6. Ostwald ripening process

Ostwald Ripening process is somewhat difficult to model. A good enough approximation is *the LSW (Lifshitz-Slyozov-Wagner)* model which stated that droplet enlargement due to Ostwald Ripening, v, can be determined by:

$$v = \frac{dr^3}{dt} = \frac{8\,\gamma\,D\,c\,V}{9RT} \cdot f(\varphi) \qquad \text{(eq 2)}$$

Where r is average radius; γ, interfacial tension; D an oil diffusion coefficient; c, concentration (or solubility); V molar volume; t is time and $f(\varphi)$ a function depending on dispersed phase volum fraction, φ, that reflects the fact that higher volume fractions, φ, tend to show faster ripening

(Abbott, 2016) To avoid Ostwald Ripening phenomena and thus the increase of emulsion stability:

- The polydispersity of droplet radius should be minimized, to make the activity similar for all droplets

- The dispersed volume fraction, φ, should be controlled as it affects directly to the Ostwald Ripening phenomena.

- Interfacial tension, γ, should be minimized searching the best surfactant as emulsifier, one that brings the formulations close, but not too much as this greatly increases coalescence.

- Select an oil with low solubility, c, in water. If the oil used has a high solubility in water, a small fraction of insoluble oil can be added to stop Ostwald ripening

In the following lines, quality criteria related with emulsion stability for the vinaigrette, the sweet salad dressing and the vegan salad dressing will be shown. Different studies and tests will be analysed in order to have some data which will allow as in determining the quality factors for each condiment. Later, in the formulation of the product, all the information will be deeply examined to select the most suitable ingredients.

VINAIGRETTE

As said previously, a traditional vinaigrette is going to be developed, with the required taste and texture. The intention is to develop an oil-in-water emulsion obtained by agitation, which will be stable for a short period of time. The two phases (three if solids added) will be perfect visible before agitation, but after shaking, the emulsion will become dispersed and remained dispersed for a short period of time, to permit dispensing and use, and after that time, it will revert to the traditional multiple phases form. To achieve stability for a short time after hand-shaking a small quantity of emulsifier is required.

Some patents have been analysed to ensure that is possible to develop a vinaigrette with these conditions. The patent carried out by *D.E. Miller and C.E. Werstak* (U.S. Pat. No. 4,451,493) resides in a packaged, flavoured, non-homogenized oil-and-water salad dressing essentially free of thickening agents and proteins, which has limited stability on hand shaking of the composition, the term "emulsion stability' means free of any visibly discernible separation of phases with a little amount of a polyglycerol ester with a high HLB value. With little quantities of polyglycerol ester, emulsion can be stable for 15, 30 and 60 minutes (U.S. Pat. No. 4,451,493). Other patents such us US. Pat. No. 4,120,900 which use polyoxyalkaline propylene glycol ester as emulsifier, show also, that with little quantity of emulsifier, the vinaigrette can remain dispersed for almost 10 minutes after agitation. These researches will provide us information about quality criteria and indexes which will help us on the selection of the emulsifier and its quantity in the final formulation of the vinaigrette and will be later analysed in the formulation of the product.

After checking that is possible to produce a vinaigrette with the previous appreciations, the quality factors for the vinaigrette that is going to be developed can be deduced in terms of emulsion stability:

- Two phase differentiated in normal conditions (oil and water phases).

- No visibly separation of phases for 30 minutes after hand shaking of the composition.

SWEET SALAD DRESSING

The sweet salad dressing that is going to be developed will, as well as the vinaigrette, be an oil-in-water emulsion. However, in contrast to the vinaigrette, an emulsion with high stability for a long period of time is wanted to be produced. The emulsifier used will be powerful enough to reach the desired stability and viscosity in the salad dressing.

As seen in the market research, mustard is usually used as emulsifier in sweet condiments, in particular, is the mustard seed, the emulsifying agent. Other natural powders are being investigated to find their place in the salad dressing industry as emulsifying agents. Gums like xanthan or guar that usually act as thickening agents are also used as emulsifiers.

Y.Wu, et. al (2015) analyses the emulsifying properties of water soluble yellow mustard mucilage (WSM) and compared it with other emulsifiers used in food industries such as gum Arabic and citrus pectin. *A.V. Nushtaeva (2016)* showed in his studies that natural powders like cinnamon, mustard and ginger present good emulsifying properties to provide oil-in-water emulsions stability against coalescence and sedimentation. *G. Bortnowska, et. al (2014)* talk about pregelatinized potato starch as a good emulsifying and stabilizing agent in salad dressings. In all studies emulsions remain stable for a long time with little quantity of emulsifiers.

On the other hand, the influence of freeze-thaw cycle on emulsion was determined by *Y.Wu, et. al (2014)* using gum Arabic, pectin and mustard seed as emulsifier. A higher concentration was related to a better emulsion stability for all polysaccharides after freeze-thaw treatment. All this studies agree in the point that the smaller is the droplet size of the dispersed face, the higher is the stability of the emulsion.

With all these references and data threatened it's easy to say that natural powders can be useful to act as emulsifiers and give the desired emulsion stability to the sweet salad dressing. Later, in the formulation of the product, all he information will be threatened deeply to select the appropriate emulsifying agent. We can extract our own quality criteria for the sweet salad dressing in terms of stability:

- The emulsifier used is solid (powder) and natural
- The emulsion remains stable (no phase separation) for 24 months
- The emulsion has to exhibit good stability and resistance at freeze-thaw cycles.
- Droplet sizes of less than 5 microns

VEGAN SALAD DRESSING

Vegan salad dressing is a particular case when talking about quality criteria and index. The main goal when developing this salad dressing is to make it the most similar to a commercial mayonnaise containing egg as possible. Being the most similar to an egg yolk mayonnaise would be one quality factor when developing this condiment. Although in the previous point it has been showed that mustard seed, ginger powder and cinnamon powder (all of them natural and not coming from animals) can be good emulsifying agents, we don't have enough information about the viscosity obtained and how similar to a mayonnaise it would be. That's why another study which compares vegan emulsion to commercial mayonnaise will be analysed to select later, in the formulation chapter, the best emulsifier that provides the desired flavour, aroma and viscosity to the vegan salad dressing, making it the most similar to the traditional mayonnaise.

In traditional mayonnaise egg is used as emulsifier. Egg yolk contains amino acids and lipids which permit it to act as emulsifier. The reduction of surface tension is due to the lecithin (phosphatidylcholine) contained within the egg yolk. This amphiphilic molecule has two ends, one hydrophobic and one hydrophilic, which minimizes the energy required to form an emulsion by reducing oil/water interfacial tension. In recent years the research on protein utilization as an alternative emulsifying agents has increased, to find other emulsifiers to replace the eggs.

In addition to all the information provided before, we will use the research made by Corneliaa, Siratantri and Prawita (2015) to help us select a natural gum as emulsifier instead of egg and the appropriate amount of it. Gum durian seed as egg yolk replacer to make vegan mayonnaise was studied. Previous studies revealed that the natural polymer of gum durian seed had emulsifying activity for oil in water (o/w).

The aim of this research was to determinate the best formulation on making mayonnaise using durian seed as emulsifier, and then compare it with commercial mayonnaise. The results obtained when comparing the emulsions obtained with commercial mayonnaise in terms of stability, colour, flavour, aroma, taste and texture were satisfactory.

Based on the analysis done, it can be concluded that apart from other natural powders mentioned before, gum durian seed has potential to be a good emulsifying agent for the vegan salad dressing. Quality criteria for our vegan salad dressing will be:

- The use of a natural and having no animal origin emulsifier.
- The emulsion remains stable (no phase separation) for 24 months
- The emulsion has to exhibit good stability and resistance at freeze-thaw cycles.
- Emulsifier used will provide to the condiment the most similarity with a commercial mayonnaise as possible.
- Droplet sizes of less than 5 microns

4.3 RHEOLOGY

Although when developing a formulated product, the main aim is always to satisfy the functionality of the product, perception quality factors like texture, smoothness or ease to pour take often importance in consumer satisfaction. Rheology of the product will determine all these parameters.

For the present work where three salad dressings with different viscosities are developed, while for the vinaigrette, rheological behaviour will be easily defined, for the sweet salad dressing and the vegan salad dressing, rheological quality factors will be significant and more difficult to model.

The vinaigrette developed will present phase separation in normal conditions and no phase separation after agitation for a period of time. However, the mixture obtained after agitation will present a low viscosity; thereby, the quality factor related to the rheological behaviour will be:

- The fluid obtained after agitation will be a Newtonian fluid

For the sweet salad dressing, the emulsion obtained will be viscous enough to not appear runny but being capable to be pourable out of the container. Products that don’t readily flow by gravity or appear runny but are easily poured out of a container should present a Yield point between 10 to 15 Pa (C. Wibowo, K.M. Ng, 2001). The Yield point is the point in the shear stress-shear rate curve which indicates the limit of the elastic behaviour and the start of plastic beginning.

The emulsion obtained in the vegan salad dressing will be viscous enough to not flow by gravity but capable to be pourable out of the container when squeezing the container. According to Wibowo (2001), if the product is not supposed to flow by gravity it should present a Yield point of above 20 Pa.

For a product to be easily pourable it should present low viscosity at high shear rates (when squeezing) and high viscosity at low shear rates (rich texture on the plate). With all this claims, vegan and sweet salad dressings should present a non-newtonian, pseudoplastic (also known as shear-thinning) rheological behaviour. Pseudoplastics are fluids whose viscosity decreases under shear strain.

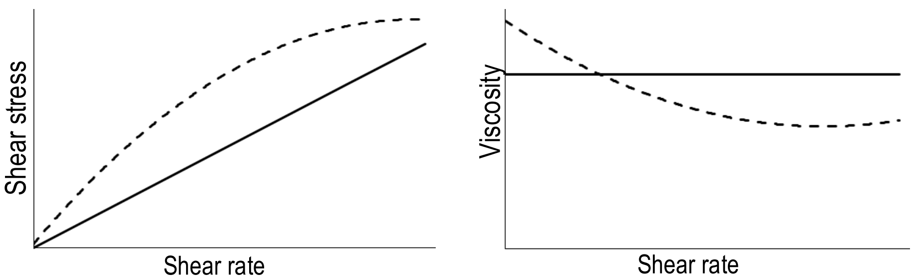

Figure 4.7. Shear stress and viscosity as a function of shear rate for Newtonian fluid (-) and pseudoplastic fluid (- - -)

Emulsifiers, stabilisers, thickeners and gelling agents will all affect in the rheological behaviour and stability of the emulsion and sometimes it is difficult to discern its function in the product.

Emulsifiers are substances which make it possible to form or maintain a homogenous mixture of two or more immiscible phases such as oil and water in a foodstuff. **Stabilisers** are substances which make it possible to maintain the physico-chemical state of a foodstuff;

stabilisers include substances which enable the maintenance of a homogenous dispersion of two or more immiscible substances in a foodstuff and include also substances which stabilise, retain or intensify an existing colour of a foodstuff. **Thickeners** are substances which increase the viscosity of a foodstuff. **Gelling agents** are substances which give a foodstuff texture through formation of a gel. (Regulation (EC) No 1333/2008)

Thickeners will be used to increase the emulsion viscosity, so, it will be important to select the mixture of thickening additives which will provide to the emulsion the desired rheological behaviour. Thickeners usually have extended molecular structures that not only increase the viscosity of continuous phase but contribute desirable texture and mouthfeel to the product (Saha and Bhattacharya 2010).

Thickening agents usually reduce flavour intensity without strongly influencing flavour character. This is usually because he macromolecules in the thickener affect the mobility and therefore the dynamic release of flavourants. (de Roos, 1997).

Xanthan gum, gum Arabic, guar gum and starch derivatives are usually used and mixed to reach a pseudoplastic behaviour with the appropriated viscosity to salad dressings. Xanthan gum, for example, is usually used in combination with other thickeners because it gives the desired rheological behaviour in sauces and salad dressings.

Wendin and Hall (2001) carried out a study were the rheological behaviour of several oil-in-water emulsions with 50/50 in weight xanthan gum and guar gum were analysed. All the samples with different thickener agent concentration showed a yield stress which increased with thickener agent concentration. Viscosity results were acceptable for a salad dressing in comparison to a commercial one.

D. Paraskevopoulou, D. Boskou and A. Paraskevopoulou (2006) studied the rheological behaviour of oil-in-water emulsions containing 1,5% of xanthan gum/propylene glycol algynate (PGA) on the one hand and and Xanthan gum/gum Arabic on the other. The flow curves giving viscosity, η, as a function of shear rate were characteristic for all the samples of shear-thinning behaviour (pseudoplastic). Measurement of viscosity of the salad dressing at various stages of storage indicates that increased viscosity contributes to an increased stability. The mixture of gum Arabic with xanthan show more stability in storage time than Xanthan/PGA.

So, the rheological quality factors of the sweet and vegan salad dressing have been determined:

- They will be Non-Newtonian fluids, pseudoplastic fluids with viscoelastic properties and yield stress.

- Sweet salad dressing should not appear runny but are easily poured out of a container, should present a Yield point between 10 to 15 Pa and vegan salad dressing should not flow by gravity (Yield point of above 20 Pa) but can be squeezed out of the container.

4.4 QUALITY FACTORS SUMMARY

Although several tests and studies have been analysed and we have had information enough to extract some of the quality factors which will determine the quality of the salad dressing that are going to be developed; there are some quality factors that don't fit in any of the big groups identified in the previous sections. These are related with personal requirements we decided at the beginning of the project when, for example, one of the objective defined was the use of oil with healthy properties in the vinaigrette. However, all these additional quality criteria will affect in the flavour, texture, stability, etc. of the final formulated product. In this point we summarize the quality factors for the three salad dressings related with flavour, aroma, emulsion stability, rheological behaviour and prerequisites or conditions set by us.

Table 4.6. Quality factors of the vinaigrette

VINAIGRETTE	
Sensorial quality factors	- Sour flavour - Acid/vinegary aroma - Flows easy, low values in the fluidity sensorial test
Stability quality factors	- No phase separation for at least 30 minutes after hand shaking of the product
Rheological quality factors	- Newtonian behaviour, flows by gravity
Other quality factors	- Oils with healthy properties in the oil phase - Visual phase separation in natural conditions

Table 4.7. Quality factors of the sweet salad dressing

SWEET SALAD DRESSING	
Sensorial quality factors	- Sweet flavour - Fruity/sweet aroma - Flows with difficulty, intermedium-high values in the fluidity sensorial test
Stability quality factors	- The emulsifier used is solid (powder) and natural - The emulsion remains stable (no phase separation) for 24 months - The emulsion exhibits good stability and resistance at freeze-thaw cycles. - Droplet sizes of less than 5 microns
Rheological quality factors	- Non-Newtonian, pseudoplastic fluid (shear-thinning behaviour) with viscoelastic properties and yield stress - Should present a Yield stress of 10-15 Pa - Does not feel runny but can be easily poured out of the container when squeezed
Other quality factors	- Honey as sweetening agent - Royal jelly as a component with healthy properties

Table 4.8. Quality factors of the vegan salad dressing

VEGAN SALAD DRESSING	
Sensorial quality factors	- Sour flavour - Acid/vinegary aroma - Flows with difficulty, high values in the fluidity sensorial test
Stability quality factors	- The emulsifier used is solid (powder) and natural - The emulsion remains stable (no phase separation) for 3 months - The emulsion exhibits good stability and resistance at freeze-thaw cycles. - Droplet sizes of less than 5 microns
Rheological quality factors	- Non-Newtonian, pseudoplastic fluid (shear-thinning behaviour) with viscoelastic properties and yield stress - Should present a Yield stress of above 20 Pa - Does not flow by itself (by gravity), but can be easily poured out of a container when squeezed
Other quality factors	- No products coming from animals in its composition - It should be the most similar to a commercial mayonnaise as possible; in terms of flavour, colour, texture and viscosity

5. PRODUCT FORMULATION

After all the research around the parameters that determine the characteristics and properties of the three salad dressings and once the quality criteria have been decided with each quality index quantified, the compounds that will form the formulated product can be selected and its optimum quantity too. The quantity of each ingredient has been determined not only by analysing studies but also by investigating the market of salad dressings. In the present chapter, a generic formulation for the vinaigrette, the sweet salad dressing and the vegan salad dressing will be proposed. The three formulations proposed will only be a basic recipe for each family of dressings; variations on each condiment will be considered.

While in the vinaigrette the aqueous phase will have more presence, in the sweet salad dressing quantity of both phases will be similar and in the vegan dressing the oil phase will present a bigger volume fraction. This volume fraction of the dispersed phase will directly affect in the viscosity of the product.

5.1 VINAIGRETTE

As explained in previous chapters, the vinaigrette developed will be an oil-in water emulsion containing oils with healthy properties in the oil phase and vinegar in the water phase as vinegars behaviour with oil is basically the same as water. Little quantity of emulsifier will be used to provide short period of time of no phase separation to the salad dressing to be pourable after agitation. Finally, other additives will be selected if needed.

Oil phase

The main distinction of the vinaigrette developed, will be the presence of oils with healthy properties in the oil phase. A mixture of ginger oil and sesame oil in olive oil will be prepared. Since ginger and sesame oil have a strong and distinctive taste only a little amount will be used. The oil phase will be composed by: 20% ginger oil, 10% sesame oil and 70% virgin extra oil.

Aqueous phase

The aqueous phase will be composed basically by Balsamic vinegar, a dark, concentrated and intensely flavoured vinegar made essentially from grape must and a small quantity of water.

Emulsifier

In the *U.S. Pat. No. 4,451,493* polyglycerol esters as emulsifying agent were tested. The emulsion contained 40% vinegar, 60% oil and from 0 to 3% of the emulsifier agent (polyglycerol ester) with high HLB valour. Above about 3% weight, off-flavours may be experienced.

Polyglycerol esters of fatty acids useful in the process of the present invention were polyglycerol monoesters such as octaglycerol monooleate (8-1-O) with a HLB value of about 13-16. The amount of polyglycerol ester employed as emulsifier went from 0,1 to 3% by weight

Four different formulations were prepared with the same quantity of oil (60%) and vinegar (40%) and different quantity of polyglycerol ester (PGE) employed. A control sample containing no octaglycerol monooleate was also prepared. The room temperature samples were subjected to hand-shaking similar to that required for a commercial oil-and-vinegar dressing. The results of the PGE added and the period of time each sample remained stable (the fat is dispersed in the aqueous phase) after agitation before reverting to separate oil-and-water phases is detailed in the next table.

Table 5.1. Period of time of stability at different PGE concentrations. (Miller et al. 1984)

60-40 OIL VINEGAR SALAD DRESSING	
PGE (8-1-O) concentration parts per weight	Approximate period without visual phase separation (minutes)
0 Control	Immediate phase separation
0,5	15
1,0	30
2,0	60
3,0	More than 60

Other emulsifiers coming from PGE were tested; with octaglycerol monostearate, excellent results were obtained similar to the octaglycerol monooleate. By contrast, the results were unsatisfactory when using triglycerol monoshortening (with a low HLB value) and ethoxylated mono-diglycerides.

A Canadian patent (Pat. No. 919,498) also used polyglycerol ester as emulsifying agent and conclude it give stability enough to the emulsion to be spray dried later. Other patents such us US. Pat. No. 4,120,900 which use polyoxyalkylene propylene glycol ester as emulsifier can be useful too. With a little quantity of it, the emulsion remained dispersed for 9 minutes after agitation.

The emulsifier selected for the vinaigrette will be octaglycerol monooleate as it provides the desired stability to the salad dressing to be stable for a short time while pouring. Octaglycerol monooleate (8-1-O) is polyglycerol ester specifically a polyglycerol monoester obtained by polymerization of glycerol with an alkaline catalyst, as exemplified in U.S Pat. No. 3,637,774 and then esterifying the polyglycerol obtained with fatty acids to obtain the final compound, the octaglycerol monooleate.

As seen in Table 5.1, little quantity of emulsifier provide stability enough to the salad dressing. It's been chosen to use 2% by weight of octaglycerol monooleate because as figure x shows, it's amount enough to give the vinaigrette, stability for 60 minutes without visual phase separation.

Final proposed composition

Next table details the proposal of the final formulation of the vinaigrette. It can be considered, the option to add other natural oils with healthy properties or solid particles like chia seeds or celery seed, minced garlic or spices like paprika or herbs.

Table 5.2. Proposed vinaigrette formulation (% by weight)

INGREDIENT	100
Water	7
Balsamic vinegar	50
Olive Oil	28
Ginger Oil	8
Sesame Oil	4
Octaglycerol monooleate	2
Salt	1

5.2 SWEET SALAD DRESSING

The sweet salad dressing will be an oil-in-water emulsion with sweetening ingredients in the aqueous phase which will give the desired flavour and aroma. Thickeners will be added to achieve the desired viscosity and rheological behaviour, as well as other additives like colourants or acidulants.

Oil phase

For the sweet salad dressing, sunflower oil will be used. In this case, the oil used will be a vegetal oil since olive, ginger and sesame oil (used in the vinaigrette) have a strong and distinctive taste and the sweet flavour can decrease if we use that kind of oils.

Aqueous phase

The main ingredient which will provide sweetness to the condiment will be honey. In dead, the honey used will be a mixture of honey and Royal jelly. Royal jelly, coming from beers too, is said to provide healthy properties such as stimulate the nervous system and strengthen the immune system. Honey and Royal jelly will not only act as flavourings but also will help in salad dressing texture. In dead, honey is a viscous product which will help in the increase of the viscosity of the sweet salad dressing, apart from providing its main function; sweetness to the condiment. 10% by total salad dressing weight will be used, containing 40% of Royal jelly and 60% of honey. Royal jelly and honey present the same structure and can be combined easily.

The aqueous phase will also contain water, apple vinegar and apple juice, contributing also in the sweetness of the salad dressing.

Emulsifier

One of the requirements suggested in chapter 4 was that the emulsifier was solid and natural. Solid insoluble nano/micro-sized particles are alternative types of stabilizers. Numerous studies have demonstrated that solid particles provide highly stable emulsions compared with emulsions stabilized using classical surfactant molecules. (A.V. Nushteava 2016)

An study carried pu by *Wu, Eskin, Cui, & Pokharel (2015),* analyse *the emulsifying properties of water soluble yellow mustard mucilage (WSM) and compares it with other emulsifiers used in food industries such as gum Arabic and citrus pectin.*

Yellow mustard mucilage, the dried layer on mustard seeds (*Sinapis alba, L.*) is readily extracted by water at room or elevated temperature. The objective of this study was to examine the emulsifying properties of WSM in oil-in-water emulsions in comparison to gum Arabic and citrus pectin. In addition to measuring the interfacial activities of the gum solutions, oil distribution, zeta-potential and freeze-thaw stability at different pH and temperature conditions.

Each sample solution was prepared with 5 concentrations for surface active compound. Aqueous solutions of gum which each respective concentration were prepared and then mixed with 10% (w/w) vegetable oil and homogenized.

Emulsion stability was measured over 21 days at room temperature (21ºC) by comparing the evolution of phase separation; the thickness of the serum layer and creamed phase were measured as percentages of total emulsion height in tubes of 34mm. The next graphic show the results obtained in different emulsifier concentration.

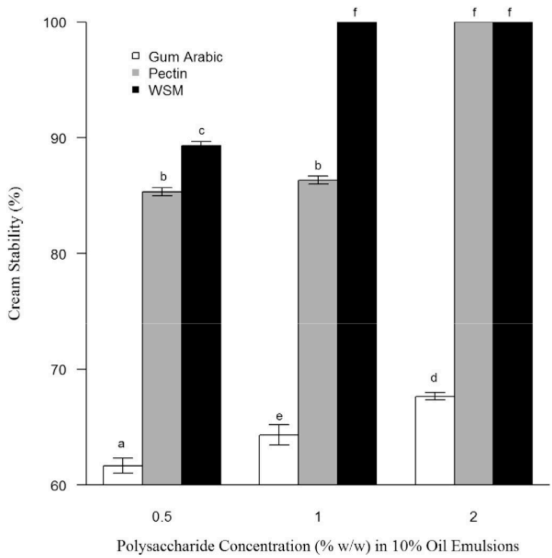

Figure 5.1. Emulsion stability after 21 days of storage at room temperature. (Wu et al. 2015)

Emulsion stability increases with the increase of polysaccharide concentration. The increase in gum concentration may lead to a better coverage on the droplet surfaces and promote long term stability of the emulsions by forming a thick protective layer around oil drops. According to the Stoke-Einstein equation, creaming is a complex function of droplet size, density difference and viscosity, as such, an increase in emulsifier/stabilizer concentration will affect all three of these parameters.

The WSM emulsions were the most stable among the three gum emulsions with both 1% and 2% exhibiting 100% cream stability after 21 days of storage. As said before, WSM is composed mainly of pectic polysaccharides and a small portion of cellulosic polysaccharides attached with methyl and ethyl groups. These hydrophobic groups may also contribute to the extraordinary stability of the WSM emulsions. Another study carried out by *A.V. Nushtaeva, 2016*, the emulsion stability of different natural insoluble powders in an oil-in-water emulsion was measured by preparing tubes in different natural powder and concentration and calculating the relative emulsion volume, V_{rem} as the relation between the volume of the aqueous phase, V_{em}, and the total volume of the emulsion after a period of time, V_{over}. The emulsion was aggregate (resistance against coalescence) when it didn't collapse after one or more days; the emulsion was considered stable against sedimentation when it did not exude any water or oil after one or more days. The next figure details the results obtained with concentration from 1 to 30% of mustard powder, ginger, cinnamon and their calculated values of $V_{rem,}$ where V_{rem}=1, the emulsion does not release water or oil and is therefore stable against coalescence and sedimentation.

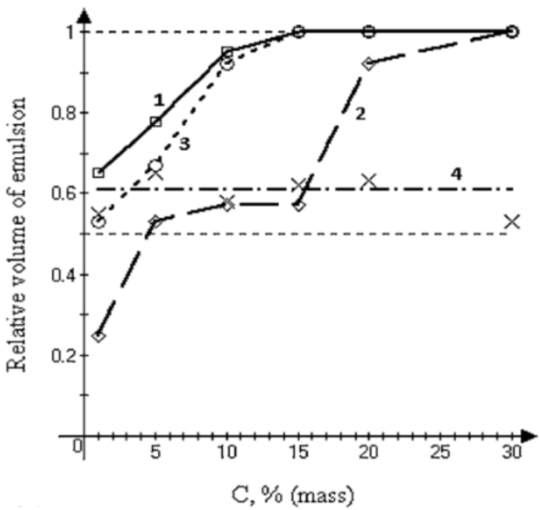

Figure 5.2. Dependence of the relative emulsion volume on the concentration of solid food powder-emulsifier 24 hours after the emulsions were prepared. 1:mustard 2:ginger, 3:cinnamon (Nushtaeva, 2016)

According to *Nushtaeva (2016),* mustard and cinnamon powder demonstrated the best protection against coalescence and sedimentation.

If we talk about surface tension, Wu, Eskin, Cui, & Pokharel (2015) verify with their study that the surface tension of WSM, gum Arabic were found to be concentration-dependent with a reduction in surface activity accompanying an increase in polysaccharide concentration. Based on this comparative study, WSM was the most surface-active material at all concentrations examined followed by gum Arabic and pectin.

On the other hand, according to Wu, Eskin, Cui, & Pokharel (2015), among the three polysaccharides, WSM demonstrated the significantly large magnitude of zeta-potential at all concentrations, which could be a factor contributing to the stability of WSM emulsions, directly related against coalescence phenomena. It was reported that emulsions with zeta-potential between -30 and +30mV tend to coagulate or flocculate, all the polysaccharide values tested were out of this interval.

Wu, Eskin, Cui, & Pokharel (2015) measured the droplet size, and mean droplet size was later used to represent the size distribution for mustard seed, Arabic gum and pectoin. The WSM emulsions yielded a larger droplet size than two other polysaccharides. However, droplet size increased significantly after heat treatment for all polysaccharides, except WSM.

It is also important, to see how emulsion behave in a temperature cycle to see its resistance at high or low temperatures or an abrupt temperature change, the influence of freeze-thaw cycle on emulsion was determined by Wu, Eskin, Cui, & Pokharel (2015) using the method described by *Gu et al. (2007).* The results presented in the Figure 5.3, show a higher concentration was related to a better emulsion stability for all polysaccharides after freeze-thaw treatment. When comparing the emulsions with the same polysaccharide concentrations, emulsions prepared with WSM showed the best stability. WSM has great potential as an ingredient in frozen food products.

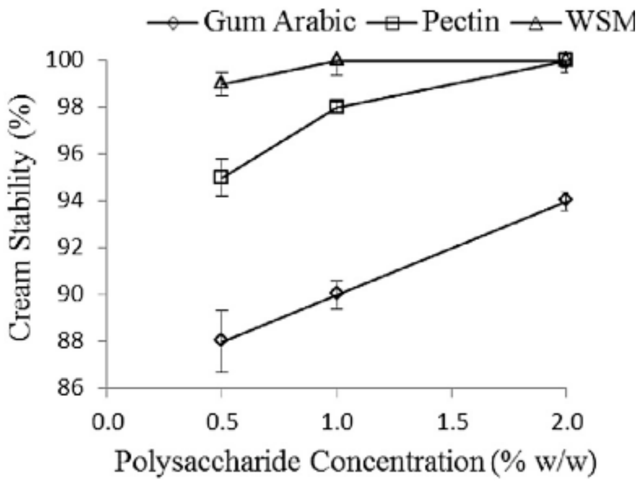

Figure 5.3. Freeze-Thaw stability of emulsion with various polysaccharides and concentrations.

Wu, Eskin, Cui, & Pokharel (2015)

After having compared the emulsifying properties of WSM with gum Arabic and citrus pectin, and Although cinnamon, ginger powder they all present also good properties to emulsify oil-in-water emulsions, mustard powder coming from the seeds of an herbaceous plant of the family of *Brassicaceae* (usually *sinapis alba*) will be used to emulsify our vegan salad dressing. WSM exhibited the best emulsion stability and highest surface activity. It also showed the highest zeta-potential and the best free-thaw stability. Little concentrations of WSM showed also great stability in all terms. In addition, fermentation was not observed in emulsions with mustard powders because mustard is natural preservative and antiseptic agent. The concentration of mustard powder used will be 5% ensuring good enough emulsion stability. Viscosity and thus emulsion stability will be increased with the addition of thickeners which will be discussed in the next point.

Additives

To obtain the desired viscosity and pseudoplastic behaviour in the sweet salad dressing thickeners will be used. Figure 5.4 shows viscosity as a function of shear rate of several hydrocolloid gums.

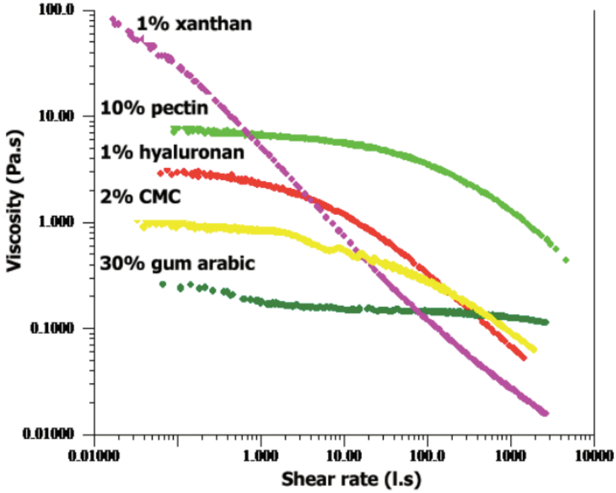

Figure 5.4. Shear flow viscosity of various hydrocolloid gums plotted as a function of shear rate. Measurements were carried out in distilled water at 25 o C. (food science and technology, 2009)

As shown in figure 5.4, to achieve pseudoplastic behaviour xanthan gum is the option to use as thickeners. Xanthan 1% shows a very high viscosity at low shear rate (deformation) and thus preferred as a thickener for emulsion, while its high shear thinning behaviour gives low viscosity when subjected to mixing or pouring.

On the other hand, in chapter 4 was also determined that according to C. Wibowo, K.M. Ng (2001), products that don't readily flow by gravity or appear runny but are easily poured out of a container should present a Yield point between 10 to 15 Pa

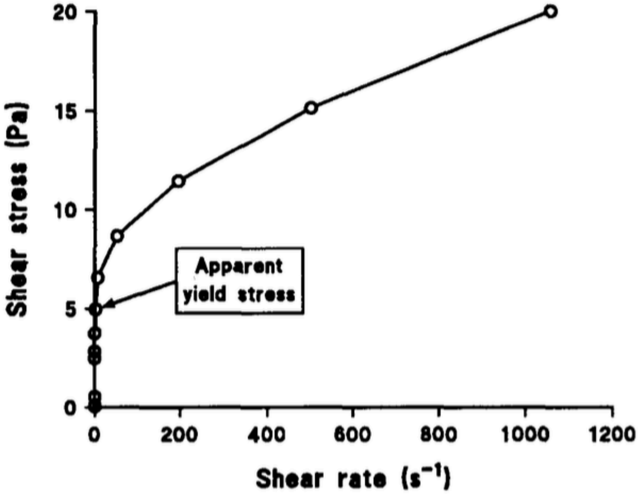

Figure 5.5. Flow curve of 5 g/L xanthan solution. Shear stress as a function of shear rate (Alan Parker et al. 1995)

As shown in figure 5.5, yield stress of 5 g/L xanthan gum solution is around 5 Pa. The previous flow curve, was determined for a xanthan solution of water. However, the emulsion yield point will depend not only of the gum added as a thickener but also of the emulsifier and the rest of the ingredients.

Tests and studies carried out by Allan Parker, et. al (1995) and *D. Paraskevopoulou, D. Boskou and A. Paraskevopoulou (2006)* obtained great results in terms of viscosity and stability of oil-in-water emulsion with little quantities of xanthan gum.

For all these evidences, 0,5% of xanthan gum will be used as a thickener.

Grazyna Bortnowska, et. al (2014) studied the behaviour of emulsions containing pregelatinized potato starch, giving great results in pseudoplastic behaviour with little quantities of the modified starch. Modified starch is a commonly used in salad drssings to give consistence ans stability to the emulsion. Bortnowska et al. (2014) evidenced that emulsions with less than 4% of pregelatinized potato starch presented a notable increase in emulsion stability. With all this evidences, it’s been decided to add 0,5% of pregelatinized potato starch, which in combination with xanthan gum will increase the viscosity of the salad dressing and thus its stability.

On the other hand, other additives will be added. Sulphite ammonia caramel (E-150d) presenting very mild flavour and aroma and rich dark colour will be added. A natural acidulant, citric acid (E-330), will also be added to regularize the acidity, keeping the pH between 2,5 and 4 which help prevent microbial growth. On the other hand, potassium sorbate (E-202) will be used as a preservative to extend the shelf life of the salad dressing.

Final proposed composition

Next table details the proposal of the final formulation of the sweet dressing. It can be considered, the option to add fruit jams or chopped fruit like strawberries or black berries to obtain a sweeter salad dressing.

Table 5.3 Proposed sweet salad dressing formulation (% by weight)

INGREDIENT	100
Water	15
Apple vinegar	12
Apple juice	12
Honey with Royal jelly	10
Sunflower oil	42
Mustard powder	5
Xanthan gum	0,5
Pregelatinized potato starch	0,5
Colourant E-150d	0,5
Acidulant E-330	0,1
Preservative E-202	0,1
Salt	1
Sugar	1,3

5.3. VEGAN SALAD DRESSING

The vegan salad dressing will be an oil-in-water emulsion as well, with similar properties that those in a traditional commercial mayonnaise in terms of taste, aroma and rheology. However, all ingredients used will not be of animal origin. Additives will be added to complete the desired conditions with this salad dressing.

Oil phase

For the vegan salad dressing, sunflower oil will be used. Similar to the sweet salad dressing, we will avoid the use of oils with strong tastes.

Water phase

The water phase will be composed by water, vinegar and lemon juice with around 40%, 30%, 30% respectively.

Emulsifier

As mentioned in chapter 4.2 the emulsifier used in the vegan salad dressing will have to be alike to a commercial mayonnaise. Although in 5.2 several emulsifying agents have been analysed, we will take special attention in a research done by Melanie *Corneliaa, Titri Siratantri, Retna Prawita* in 2015 *(The Utilization of Extract Durian (Durio zibethinus L.) Seed Gum as an Emulsifier in Vegan Mayonnaise).*

Gum durian seed as egg yolk replacer to make vegan mayonnaise was studied. Durian is a seasonal fruit that most popular in Southeast Asia, particularly Malaysia, Indonesia, Thailand, and Philippines. *Corneliaa, Siratantri and Prawita (2015)* prepared oil-in-water emulsions with 5 different concentrations of the emulsifier, gum durian seed.

Scoring mayonnaise organoleptic test were done using the method 7 scale by 70 trained panelists. The parameters assessed were sour flavour, sour taste, colour, texture and aftertaste. The graph below shows the results obtained in every parameter with each respective gum concentration analysed.

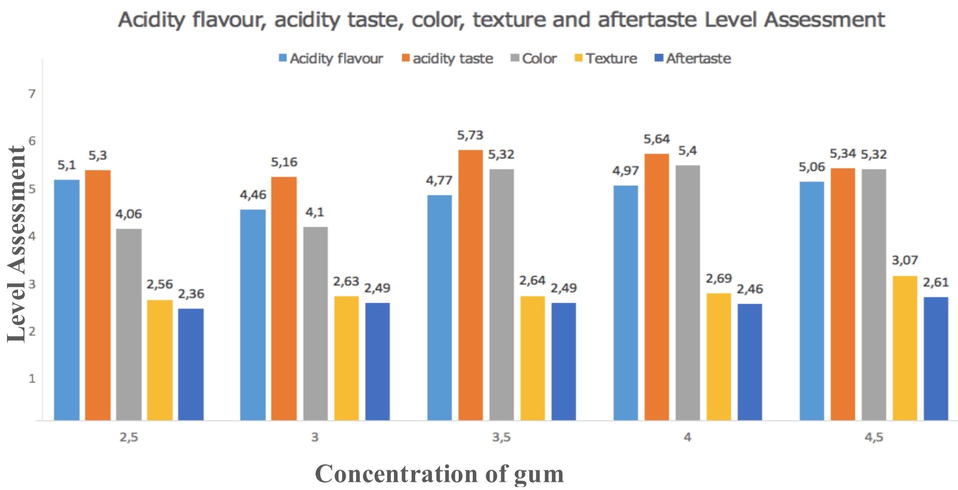

Figure 5.6. Level Assessment results at different gum durian seed concentrations. Corneliaa, Siratantri and Prawita (2015)

Based on statistical results, 4% of gum durian seed was chosen as best formulation and compared in a pair comparison test with commercial mayonnaise.

(Corneliaa, Siratantri and Prawita, 2015) Pair comparison test was conducted to determine whether there is any difference between the best mayonnaise earlier stage research (vegan mayonnaise with addition 4% gum durian seed) with commercial mayonnaise and estimate the intensity difference.

Based on the average value of the pair comparison test, the mayonnaise with a concentration of 4% was considered to have better flavour but not taste than commercial mayonnaise. In terms of colour, the colour of vegan mayonnaise produced was not as white as commercial mayonnaise, but mayonnaise colour gum assessed as good with colour than commercial mayonnaise. Viscosity of vegan mayonnaise was considered better than commercial mayonnaise. Overall vegan mayonnaise with gum were not considered to have different characteristics with commercial mayonnaise.

Based on the analysis, durian seed gum could be used as an emulsifier for making a vegan salad dressing similar to a mayonnaise because it produced fairly stable emulsion, good texture, and fat droplet size was not too large.

Therefore, durian seed gum 4% will be used as emulsifier.

Additives

Although durian seed will provide to the condiment a high enough value of viscosity, dressing thickeners will be used to obtain the desired final viscosity and pseudoplastic behaviour in the vegan salad dressing. As well as in the sweet dressing, thickener will be used to increase the product viscosity and its stability. Xanthan gum 0,8% will be added and 0,5% of pregelatinized potato starch. More xanthan gum will be added, compared with the sweet salad dressing, since the viscosity of the vegan dressing is wanted to be higher.

As seen previously, the vegan salad dressing prepared with gum durian seed can present a distinctive colour, therefore, beta carotene (E-160a) as a colourant will be added. It is a yellow natural or synthetic additive usually used in commercial mayonnaise. As well as in the sweet salad dressing, a natural acidulant will also be added to regularize the acidity, citric acid (E-330). On the other hand, potassium sorbate (E-202) will be used as a preservative.

Final proposed composition

Next table details the proposal of the final formulation of the vegan salad dressing. It can be considered, as a variation of this vegan dressing, the option to develop a *vegan Caeser dressing* with similar composition to the vegan salad dressing produced.

Table 5.4. Proposed vegan salad dressing formulation (% by weight)

INGREDIENT	100
Water	15
Vinegar	10
Lemon juice	10
Sunflower oil	57
durian seed gum	4
Xanthan gum	0,8
Pregelatinized potato starch	0,5
Colourant E-160a	0,5
Acidulant E-330	0,1
Preservative E-202	0,1
Salt	1
sugar	1

6. DESIGN OF A MANUFACTURING PROCESS

The final stage of a formulated product development is the design of the manufacturing process. Process design establishes the sequence of chemical and physical operations; operating conditions; the duties, major specifications, and materials of construction of all process equipment, the general arrangement of equipment needed to ensure proper functioning of the plant; line sizes; and principal instrumentation. The process design is summarized by a process flowsheet, material and energy balances, and a set of individual equipment specifications. (James R. Couper, et al, 1998). However, in this work only the process flowsheet and the equipment selection to produce the three families of salad dressings will be executed. A processing method and a quantity production will be, also, proposed. The rest of the sections are beyond our scope.

For the current work, where three families of salad dressings are being developed, the process will be carried out as batch process. (P.N Sharrat, 1997) A batch process is one in which a series of operations are carried out over a period of time on a separate, identifiable item or parcel of material. This definition of batch processing includes what has been called 'semi-batch' production, during which material is added continuously to a batch over some period. This last appreciation will be useful for the sweet and vegan salad dressings where high viscous homogeneous emulsions will be obtained and the dispersed phase will be added accurately to achieve the desired stable oil-in-water emulsion.

Batch production generally has lower capital costs and offers flexibility to produce a variety of different product variations. Batch process for the salad dressings will be helpful since although one recipe for each family of condiment has been proposed, other product formulations can be opportune and working with batches will permit the manufacture of more variations of the acid, the sweet and the vegan salad dressings, which will allow the industry to grow and get to more consumers.

It has been decided to start manufacturing batches of 2 tons and hence the design of the equipment used will depend on this quantity produced. A normal workday of 8 hours would lead to do 2-4 batches per day. Working 5 days a week and counting 1 month of vocation would mean 240 days producing which will permit to manufacture around 1.000-1.500 tons per year of each salad dressing. Since the mass of the system will remind constant over time, to achieve a batch of 2 tones, the mass percentage proposed for all the ingredients in each salad dressing in chapter 5, will be adapted to tons and added to each agitated vessel. Although it has been decided to begin with batches of around 2 tons, depending on the demand, the quantity may be modified and adapted to the demand..

The process of converting two immiscible liquids into an emulsion is known as homogenization, and the mechanical device designed to carry out this process is called homogenizer. The creation of an emulsion directly from two liquids is known as the *primary homogenization*, whereas the reduction in size of droplets (if required) in the already existing emulsion is known as *secondary homogenization (McClemments, 2015).* Since the process flowsheet and the equipment required will be the same for the sweet and the vegan salad dressing and different for the vinaigrette, this manufacturing process design will be split in two groups:

- Design of a manufacturing process for the vinaigrette
- Design of a manufacturing process for the sweet salad dressing and the vegan salad dressing

Finally, a distribution of the plant will be proposed in the last point of this chapter.

6.2. DESIGN OF A MANUFACTURING PROCESS FOR THE VINAIGRETTE

6.1.1 Process flowsheet

For the vinaigrette, the process flowsheet is detailed in the next figure. Pre-mixing steps are used due to the various ingredients involved in the continuous phase and dispersed phase. Emulsification step is executed through mixing continuous and dispersed phase and no secondary homogenization is required since the salad dressing developed will be of the separating type and not very small droplet size is required.

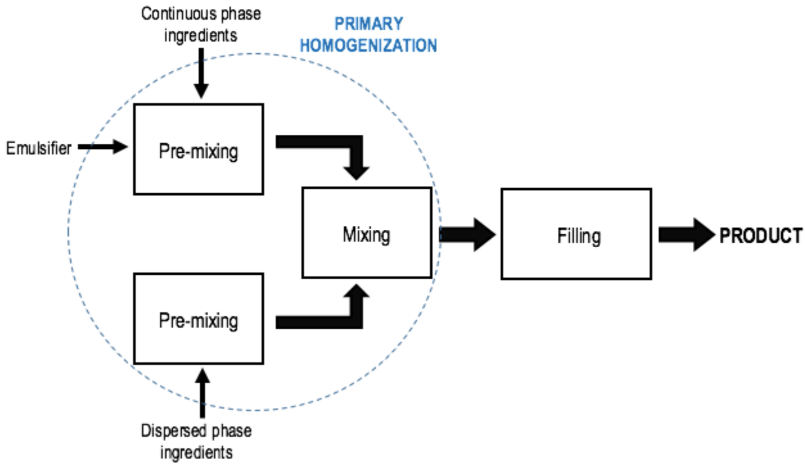

Figure 6.1. Process flowsheet for the vinaigrette

Pre-mixing

In this stage, the emulsifier, the octaglycerol monooleate, will be pre-mixed with the continuous phase (Miller et al. 1984), containing water, balsamic vinegar and salt. At the same time, the dispersed phase, containing olive oil, ginger oil and sesame oil will be premixed in a separated vessel.

Mixing

The pre-mixed continuous and dispersed phases will be finally emulsified. No secondary homogenization will be needed since the fluid obtained will present two phases in normal conditions and only will show one phase for a short period of time after hand-shaking, therefore homogenization would be useless and an economic waste. In addition, an extremely small droplet size is not required.

Filling

The vinaigrette is allowed to cool to room temperature and packaged in 250 ml glass bottles (as mentioned in chapter 3).

6.1.2 Selection of equipment units

Pre-mixing and mixing

For its low energy consumption and the great capacity that can be threatened (figure 6.2), agitated vessels will be used in the pre-mixing and mixing stages.

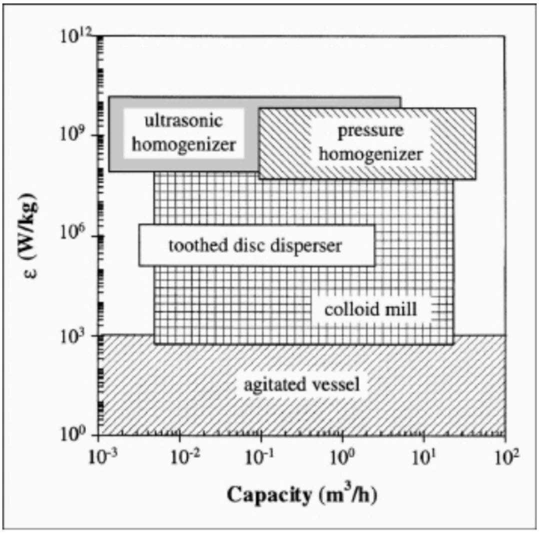

Figure 6.2. typical capacity and energy consumption for selected emulsification units

The vessels will contain a motor with an Impeller which will permit the mixing. Heat transfer surfaces such as helical coils will be installed inside the vessels and jackets (both side wall) so that the vessel wall can be used as heat transfer surfaces.

According to Wibowo (2001), the operating variable to take into account in agitated vessels is the agitation speed and vessel geometry, some of the equations and parameters are described in the chapter 6.2.2. However, for the manufacture of the vinaigrette, the emulsion will be obtained without great effort, indeed, hand-shaking will be enough to make the fluid pourable, so a simple mixing system will satisfy the required mixing power. The rotational speed of the impeller will be high because of the fluid with low viscosity obtained. Only a short time will be needed to make the emulsion stable for a short period of time and permit the filling stage to be executed. Both marine propeller and hydrofoil style impeller (figure 6.4) can be used to agitate the vessel since is the most economic for low shear applications, for turbulent flow and can be used at high speeds. (Couper et al 2012)

To produce batches of 2 tons, vessels of about 1.500L would be needed in the premixing stage. Later in the mixing stage, where both phases are mixed, the reactor should present a capacity of about 2.500L. *Pfaudler* or *De Dietrich* would be both industries with potential which would provide us the reactors needed, ensuring first, that the agitation system achieves the required characteristics.

6.2 DESIGN OF A MANUFACTURING PROCESS FOR THE SWEET SALAD DRESSING AND THE VEGAN SALAD DRESSING

6.2.1 Process flowsheet

For the sweet salad dressing and the vegan salad dressing, where intermedium and high viscous homogeneous condiments are being developed, the process flowsheet is detailed in the next figure. Pre-mixing step is used due to the various ingredients involved in the continuous phase. A pre-emulsion where water and oil phases are converted into a coarse emulsion that contains fairly large droplets, followed by a secondary homogenization step is needed to obtain the required droplet size (1-5 micrometres).

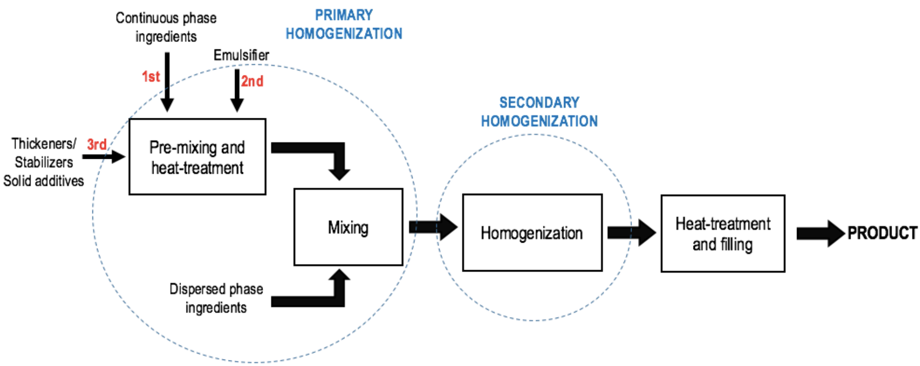

Figure 6.3. Process flowsheet for the sweet salad dressing and the vegan salad dressing

Pre-mixing and heat-treatment

In this stage, the emulsifier, will be pre-mixed with the continuous phase first and then thickeners and the rest of solid additives will be added and pre-mixed. Adding the emulsifier in the aqueous phase will lead to the formation of an O/W emulsion with fine droplet size size (Lin, 1993). On the other hand, phase inversion is an important issue in emulsion processing, according to Norato et al (1998) increasing continuous phase viscosity will prevent the emulsion from phase inversion, therefore thickeners will be added at this stage. The aqueous phase will undergo some kind of heat-treatment to in order to minimize viscosity and hence facilitate the mixing (Wibowo, 2001). In addition, heating the pre-mixture to about 80-100ºC permit the substance to be pasteurized (Hahn et al. 1979). The next table details the ingredients added in each step, being different for the sweet salad dressing and the vegan salad dressing, according to the product formulation proposed in chapter 5.

Table 6.1 Sweet and vegan salad dressings ingredients and its order of addition in the pre-mixing stage

	Sweet salad dressing	Vegan salad dressing
1st: continuous phase	Water, apple vinegar, apple juice, honey with royal jelly, preservative E-202	Water, vinegar, lemon juice, preservative E-202
2nd: emulsifier	Mustard powder	Durian seed gum
3rd: thickeners/stabilizers & solid additives	Xanthan gum, pregelatinized potato starch & Salt, sugar, acidulant E-330, colourant E-150d	Xanthan gum, pregelatinized potato starch & Salt, sugar, acidulant E-330, colourant E-160a

Mixing

In this stage, the aqueous phase, pre-mixed with the emulsifying agent and the rest of additives will be finally mixed and emulsified with the dispersed phase, the sunflower oil, feeding the vessel slowly with the sunflower oil. Adding the dispersed phase slowly gives time for the undesirable emulsion droplets to coalesce, so that a particular emulsion type would be preferred (Weiser, 1949). (Hahn et al. 1979) Both stages of homogenization of mayonnaise or similar salad dressing must be carried out at room temperature or less.

Homogenization

To reduce the droplet size so that the target is met, and the final emulsion formed, a secondary homogenization step is necessary..

Heat-treatment and filling

This is the final stage where the sweet salad dressing and the vegan salad dressing are heat-treated to inactive microbes prior to packaging and storing (*McClemments, 2015)*. The final emulsion can be heated up to 80-100 ºC to be pasteurized (Hahn et al. 1979). The products are finally to cool to room temperature and packaged in 250 ml squeeze bottles (as mentioned in chapter 3).

6.2.2 Selection of equipment units

When selecting the equipment units, for emulsions, we need to consider two opposing phenomena: droplet breakup and coalescence (Walstra, 1983, 1993; McClements, 1999). Droplet breakup depends on the balance between the disruptive forces generated by the equipment, which tend to pull the droplet the droplet apart, and the interfacial forces, which tend to keep it intact. Breakup occurs when the ratio between them, the Weber number (N_{we}) exceeds a critical value. On the other hand, coalescence is determined by the time for surfactant to migration and adsorption in the newly formed surfaces, as compared to the time interval between collisions. Coalescence is averted when the ratio between time adsorption and time collision is less than one. This ratio depends on the shear rate or density power (Walstra, 1983) related to equipment design and operation conditions. The total amount of energy supplied to an emulsion during the homogenization process is often referred as energy density, which has been definied as the energy input per unit volume of emulsion. (Schubert et al. 2003) and it can be given by the following equation (Walstra and Smulder, 1988).

$$E_v = P_v(t)\, dt \qquad \text{(eq 3)}$$

where P_v is the net power density and t, the duration of the homogenization procedure.

Droplet disruption only occurs when P_v exceeds some critical value. The values of E_v and P_v depend on the type of homogenizer used to create the emulsion (Walstra and Smulder 1988, Canselier et al. 2002, Schubert et al. 2003). The most commonly used correlation for shear rate or power density, E_v, for agitated vessels, in terms of impeller speed and fluid properties and geometry is the one proposed by Zwietering (1958), where C4 is a constant depending on vessel geometry, N is the rotational speed, D the impeller diameter and Np a dimensionless power number which directly depends on the Reynolds number.

$$E_v = C_4 N^3 D^2 N_p \qquad \text{(eq 4)}$$

The required blending time (t) in agitated vessels is also a function of the Reynolds Number (N_{Re})

In colloid mills, the shear rate depends on the rotational speed, rotor radius, and the gap width between the stator and the rotor. On the other hand, the energy consumption depends on the viscosity of the product, feed rate and temperature during processing. The capacity depends on the processed product (George D. Saravacos and A. E. Kostaropoulos, 2002).

Taking into account all these parameters and the properties of the final emulsion that is wanted to be obtained, equipment units and operating conditions could be defined.

On the other hand, although the equipment selected for the manufacture of the sweet salad dressing and vegan salad dressing is the same, its viscosity, and as a result, its rheological behaviour, present little differences. Therefore, the operating conditions will differ between them.

The materials used in food equipment should not interact with food and should be noncorrosive and mechanically stable. Stainless steel AISI 316 would be a good choice as is commonly employed when the acidity of the food product is high (George D. Saravacos and A. E. Kostaropoulos, 2002), which is the case of the vinaigrette, the sweet salad dressing and the vegan salad dressing.

Hygienic aspects of food processing equipment have been discussed by a lot of authors as well as regulated by strict hygienic standards and government regulations (George D. Saravacos and A. E. Kostaropoulos, 2002). Although, this is an issue beyond our scope, it is obvious that the process equipment selected in this chapter should be sterilized; opting for steam sterilization is a good choice as it is the most widely used method.

Although in the present work, separate devices have been selected to carry out primary and secondary homogenization, nowadays, units which achieve emulsions with stability enough and small enough droplet size are often used to concentrate both stages of homogenization process in one step. *Silverson* company is an example of a supplier offering primary and secondary homogenization in one unique device.

The unit equipment to produce both salad dressings will be mainly those used in the pre-mixing and mixing stages and in secondary homogenization.

Mixing and premixing

Due to the high viscosity of the fluids threatened, a high shear mixer will be used in the pre-mixing and mixing stages. When powders such as gums and thickeners are added to liquids they tend to agglomerate, and conventional agitators cannot readily break these lumps down, high shear mixers with the required power and operation condition can treat with high viscous fluids and facilitate the hydration of the thickeners.

High-shear mixer will, at first, allow the premixing of emulsifier, stabilizers and solid additives in the continuous phase and then the emulsification of the dispersed phase in the continuous phase. In batch high-shear mixers the components are fed from the top in the agitated vessel containing the mixer on a rotating shaft at the bottom of the tank. A high-shear mixer uses a rotating impeller or high-speed rotor, or a series of such impellers, usually powered by an electric motor, to "work" the fluid, creating flow and shear. High-shear impellers convert the majority of the energy of the motor to shear force. The *sawtooth impeller* type can be a good choice as impeller; it is extensively used to produced stable liquid-liquid emulsions (Couper et al 2012). In addition, according to Miner (1993), a propeller with high impeller-to-vessel diameter ratio (D/T) is preferred to achieve a more uniform shear rate distribution within the vessel, if the emulsion is highly viscous and shear-thinning.

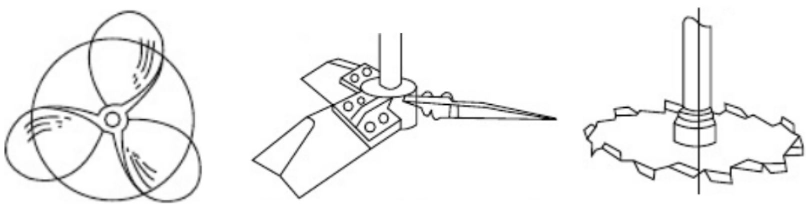

Figure 6.4. From left to right; Marine propeller, Hydrofoil impeller and sawtooth impeller representation. From Chemical Process Equipment Selection and Design - Couper et al. 2012 - 3th Edition)

As well as for the vinaigrette, heat transfer surfaces such as helical coils will be installed inside the vessels and jackets (both side wall) so that the vessel wall can be used as heat transfer surfaces.

Following the same criteria than for the vinaigrette, to produce batches of 2 tons, a vessel of about 1.500L would be needed in the premixing stage for the continuous phase. Later in the mixing stage, where both phases are mixed, the reactor should present a capacity of about 2.500L. *Pfaudler* or *De Dietrich* would be both industries which would provide us the reactors needed, ensuring first, that the agitation system achieves the required characteristics.

Homogenization

A colloid mill will be used in the secondary homogenization to reduce the droplet size. Colloid mill is the most cost-effective homogenizer device used in the food industry for medium and high viscous liquids. It usually contains a rotator and a stator which generates a shear stress in the gap and causes the larger droplet to be broken down into smaller ones, and generates a centrifugal force that causes the fluid to move from the centre to the periphery of the disks. The intensity of the shear stress can be altered by varying the thickness of the gap between the rotator and stator, varying the rotation speed or using disks that have roughened surfaces. (McClemments 2015). In colloid mills the rotation can achieve from 3.000 to 15.000 rpm. The more viscous a product is, the slower is the rotation of the disk and the pressure during homogenization lies between 1,5 and 3 bars (George D. Saravacos and A. E. Kostaropoulos, 2002).

To choose the most appropriate colloid mill, the company *Probst & Class (PUC)* would be useful. They offer a wide range of colloid mills and capable to threat with 34.000 l/h and operate both in line and batch.

6.3 DISTRIBUTION OF THE PLANT

The scope of this project was not only to develop a food product and design its manufacturing process but also to propose a distribution of the plant where the three dressings are supposed to be produced. As mentioned throughout the present project, the main distinction between the three condiments developed will not only be its flavour but also its viscosity. So, it is proposed to design the plant with three parts differentiated by the viscosity of the product produced. While the vinaigrette will be produced in the part where low viscous products are developed, the sweet salad dressing proposed in this work, will be manufactured in a section where products with intermedium viscosities are produced and the vegan dressing in the section of the plant where products presenting high viscosities are generated. This plant distribution will directly affects on the equipment units used and its operating conditions, being different for each section. Since variations in the generic recipe are considered, if a new composition of one of the families of dressings lead to a variation on its viscosity, its manufacturing process will be transferred in the appropriate section according to the viscosity of the product.

7. CONCLUSIONS

In this work, three types of salad dressing have been developed, defining their quality factors and indexes, selecting the appropriate ingredients and designing their manufacturing process in the final stage. In order to get to more consumers, the three families of salad dressings are widely different to each other in terms of taste, aroma and texture. The three salad dressings developed have been: a vinaigrette, a sweet salad dressing and a vegan salad dressing. Although one generic recipe (table 7.1) has been defined for each of them, the design of the equipment and the process is done thinking in the possibility of variations in the ingredients and quantity produced.

As the three condiments are basically mixtures of oil and water, emulsion as the delivery system has been studied. It has been important to understand the behaviour of an emulsion, its stability and how to modify its stability and rheological behaviour by using the pertinent emulsifier, thickeners and other additives. The emulsifiers and thickeners used have been selected after a deep research in the market and analysing several articles.

The **vinaigrette**, presenting sour flavour, shows low viscosity and separation of phases in normal conditions, it has to be vigorously agitated before consumption. The oil phase is composed by natural oils with healthy properties like sesame and ginger oil are. The **sweet salad dressing**, presenting sweet flavour, shows intermedium viscosity and no phase discernment for a long time. Honey and royal jelly are the main sweetener agents. The **vegan salad dressing**, presenting an acid flavour similar to a mayonnaise, shows high viscosity and no phase separation for a long time. No animal origin product has been used in the manufacture of the vegan salad dressing.

Table 7.1 shows not only the ingredients of the salad dressings but also the weight fraction of the oil phase and continuous phase, which directly affects in the viscosity of the product and the properties of the salad dressing produced.

Table 7.1. Composition of the vinaigrette, the sweet salad dressing and the vegan salad dressing

	Vinaigrette	**Sweet salad dressing**	**Vegan salad dressing**
Continuous phase	**(57%)** Water, balsamic vinegar	**(49%)** Water, apple vinegar, apple juice, honey with royal jelly, preservative E-202	**(35%)** Water, vinegar, lemon juice, preservative E-202
Dispersed phase	**(40%)** Sesame oil, ginger oil, olive oil	**(42%)** Sunflower oil	**(57%)** Sunflower oil
Emulsifier	Octaglycerol monooleate	Mustard powder	Durian seed gum
thickeners/ stabilizers & solid additives	Salt	Xanthan gum, pregelatinized potato starch & Salt, sugar, acidulant E-330, colourant E-150d	Xanthan gum, pregelatinized potato starch & Salt, sugar, acidulant E-330, colourant E-160a

To manufacture the vinaigrette, the main equipment needed is an agitated vessel. On the other hand, for the fabrication of the sweet and the vegan salad dressings a high shear mixer first and a colloid mill later to improve the homogenization is required. Stainless steel AISI 316 is the selected material for the reactors.

Finally, it has been decided to work in batches, producing 2 tons of each salad dressing each time, which will lead as to the production of around 1.000-1.500 tons per year of each dressing, considering changes in production if required.

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