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Vegetable Emulsions and Norwegian-Grown Pulses as Ingredients in Plant-Based Food Products: Effects on Quality Characteristics of Falafel

Grønnsaksemulsjoner og norskdyrkede proteinvekster som ingredienser i plantebaserte matvarer: Effekter på kvalitetsegenskaper i falafel

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Abstract

In the last few years, plant-based food products have increased in popularity both in Europe generally and Norway specifically. At the same time, the Norwegian Directorate of Health recommends a mainly plant-based diet with an increased consumption of vegetables for the general population. As many consumers wish to eat more sustainably, and much of the plant-based products available in Norway today are based on imported raw materials, there is a market for an increased and possibly innovative use of Norwegian vegetables and pulses as ingredients in plant-based products.

The present study aimed to determine the effects vegetable emulsions and Norwegian-grown pulses have quality characteristics in plant-based food products with focus on textural properties and water loss. Falafel, a traditional plant-based product, was used as a model product. Vegetable emulsions containing 10 % rapeseed oil were produced using typical surplus vegetables (carrot and onion) and rest raw material from the frozen vegetable industry (cauliflower). To determine possible new functional effects of vegetable emulsion as an ingredient, high pressure homogenization (HPH) treatment of the emulsions was utilised. The emulsions were incorporated in falafels based on either imported chickpeas, Norwegian-grown faba beans or Norwegian-grown yellow peas. Texture and water loss influence important quality characteristics in falafel and were thus measured instrumentally. In addition, informal sensory analyses were performed for comparison.

The results of the study showed that incorporating vegetable emulsions in falafels led to decreased water loss and some differences in texture, but no clear unfavourable effects. Variation of vegetable type resulted in differences in emulsion characteristics but did not have any significant effects on falafel texture and water loss. HPH-treatment of the emulsions led to increased firmness in falafel, but no changes in water loss. Falafels based on faba beans or yellow peas resulted in increased water loss compared to chickpeas. Additionally, faba beans resulted in textural changes in some cases. In conclusion, there is potential for including vegetable emulsions based on Norwegian surplus/rest raw materials, and possibly Norwegian-grown pulses, to create more nutritious and sustainable plant-based food products.

Sammendrag

Plantebaserte matvarer har i de siste årene økt i popularitet, både i Europa generelt og Norge spesielt. Samtidig anbefaler Helsedirektoratet et hovedsakelig plantebasert kosthold med økt inntak av grønnsaker for den generelle befolkningen. Ettersom mange forbrukere ønsker å spise mer bærekraftig, og mye av de plantebaserte matvarene tilgjengelig i Norge er basert på importerte råvarer, finnes det et marked for en økt og muligens innovativ bruk av norske grønnsaker og proteinvekster som ingredienser i plantebaserte produkter.

Målet med denne masteroppgaven var å bestemme hvilke effekter grønnsaksemulsjoner og norskdyrkede proteinvekster har kvalitetsegenskaper i plantebaserte matvarer, med fokus på vanntap og tekstur. Falafel, en tradisjonell plantebasert matvare, ble brukt som pilotprodukt. Grønnsaksemulsjoner med 10 % rapsolje ble produsert ved bruk av typiske overskuddsgrønnsaker (gulrot og løk) og restråstoff fra fryseindustri av grønnsaker (blomkål). Høytrykkshomogenisering (HPH) av emulsjonene ble utført for å bestemme mulige nye funksjonelle egenskaper hos grønnsaksemulsjon som ingrediens. Emulsjonene ble tilsatt falafeler basert på enten importerte kikerter, norskdyrkede åkerbønner eller norskdyrkede gule erter. Tekstur og vanntap ble målt instrumentelt, ettersom disse påvirker viktige kvalitetsegenskaper i falafel. I tillegg ble uformelle sensoriske analyser utført til sammenligning.

Resultatene viste at grønnsaksemulsjon tilsatt i falafel førte til mindre vanntap og noen forandringer i tekstur, men ingen klare ugunstige effekter. Grønnsakstype påvirket emulsjonsegenskapene, men hadde ingen signifikant effekt på falafeltekstur og vanntap. HPH-behandlede emulsjoner resulterte i falafeler med økt fasthet, men ingen endinger i vanntap. Falafeler basert på åkerbønner eller gule erter resulterte i større vanntap sammenlignet med kikerter. I tillegg førte bruk av åkerbønner til falafeler med ulik tekstur i noen tilfeller. For å konkludere, det er potensiale for å bruke grønnsaksemulsjoner basert på norsk overskudds-/restråmateriale, og muligens norskdyrkede proteinvekster, til å produsere mer næringsrike og bærekraftige plantebaserte matvarer.

Preface

This thesis is a part of a master’s degree program in Food Science at the Norwegian University of Life Sciences (NMBU), Faculty of Chemistry, Biotechnology and Food Science (KBM), Ås, Norway. The thesis was done in collaboration with Nofima AS, department Food and Health at Ås, January-May 2021. The main part of the practical work was performed at Nofima, while some initial work was performed at home due to Covid-19 restrictions. These restrictions also unfortunately limited the amount and type of practical work that was possible to carry out in this thesis.

I would like to thank my supervisors at Nofima, Grethe Iren Borge and Ann Katrin Holtekjølen, for all their help and guidance throughout the semester. I also want to thank Bente Kirkhus for acting as a third supervisor, with a lot of good help regarding experimental design and statistical analysis.

For advice and help with practical work in the laboratory and production hall, I would like to thank Cecilia Midtsund Kippe, Silje Johansen, Hanne Zobel, and Stefan Sahlstrøm.

I would also like to thank Trude Wicklund as my supervisor from NMBU.

Lastly, although we did not see each other often this semester, I want to thank my fellow classmates at Nofima for motivation and support.

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1. Introduction

1.1. Plant-based as a rising trend

Plant-based foods are derived from fruits, vegetables, grains, legumes, nuts, and/or seeds, and exclude all animal-based raw materials. Plant-based food products have increased in popularity the last few years. According to the report "Plant-based foods in Europe: How big is the market?", the sales value of plant-based food in Europe increased by 49 % from 2018 to 2020 (Smart Protein Project, 2021). These types of products do however not only appeal to vegans and vegetarians. According to a survey by Kantar (2018), 92 % of plant-based meals in the UK were consumed by non-vegans, indicating that the target group for plant-based food products is growing beyond those following a strict vegan or vegetarian diet. This is also supported by the report "The Rise of Vegan and Vegetarian Food" from Euromonitor International (2020), where one of the key findings state that the number of vegans and vegetarians still remained small, while 40 % of global consumers were aiming to reduce animal-based foods in 2020. The report additionally states that two key factors for these diets are health and animal rights. Furthermore, sustainability has also become an important reason for eating more plant-based in the last few years (Aschemann-Witzel et al., 2020). A study by González-García et al. (2018) concluded that northern and western European diets typically have a higher carbon footprint compared to other regions, and that substituting part of the animal protein consumed today with plant protein could reduce the negative environmental impact.

The Norwegian Directorate of Health recommends a mainly plant-based diet with a lot of vegetables, fruits and berries, whole grain products and fish, and less red and processed meat, sugar and salt (Helsedirektoratet, 2011). To follow these recommendations, most of the Norwegian population need to increase their consumption of vegetables and decrease their consumption of red and processed meat. Eating more plant-based is a solution to this problem. Today, a large amount of the plant-based foods available in Norway are based on imported raw materials and ingredients. At the same time, a growing number of Norwegian consumers wish to eat more sustainably, for example by buying more locally produced food. Thus, plant-based foods based on Norwegian raw materials could help this growing demand. This could result in an increased and possibly innovative use of Norwegian vegetables as ingredients in plant-based products.

High quality protein sources are also important in plant-based products. Many typical plant-based protein sources used today, such as soybeans and chickpeas, are not possible to produce in Norway due to climatic reasons. Instead, these raw materials must often be transported long distances, making them less sustainable. However, there are possible protein rich alternatives, such as faba beans (*Vicia faba*, also known as fava beans, broad beans, field beans and horse beans) and peas (*Pisum sativum*), that can be grown in Norway. According to an article by Abrahamsen et al. (2019) only ~1 % of the area used for production of grains and other seeds in Norway today are used to grow faba beans and peas. However, the article concludes that there is a potential increase that area by sevenfold, and that alternating grains with legumes might also result in a favourable effect on the soil quality.

Consumers sometimes view plant-based foods as highly processed and with high sodium contents, especially products designed to replace meat (Clark & Bogdan, 2019). Although there is still little research on the area, these products are often thought of as less healthy. This is related to the recent "clean label" trend. There is no official definition of "clean label", but it is associated with products being perceived by the consumers as natural, without artificial additives, and using minimally processed ingredients (Asioli et al., 2017). Some consumers then turn to more traditional plant-based products that are viewed as less processed. Falafel is a good example of this kind of product.

1.2. Falafel

Falafel (figure 1.1.a) is a traditional plant-based product originating from Egypt and the Middle East (Ismail & Kucukoner, 2017). The main ingredient is chickpeas or faba beans, or a combination of the two. The dried chickpeas/beans are soaked for a while in water, before being ground together with spices, garlic, and sometimes fresh herbs and onions. Common spices used in falafel include cumin and coriander. Baking soda is sometimes used to give the falafel a more airy texture. The falafel dough is shaped into balls or small patties before being deep-fried in vegetable oil. In certain regions it is also common to roll the falafels in sesame seeds before frying (figure 1.1.b).

Figure 1.1: a) Falafel (Vaitkevich, 2020). b) Shaped falafel dough with herbs and sesame seeds (Kozik, 2021).

1.3. Vegetable emulsions and fibre

Vegetables contain high levels of antioxidants, fibres, vitamins, and carotenoids. As previously mentioned, Norwegian dietary recommendations include increasing the consumption of vegetables. Incorporating puréed vegetables in various foods has previously been suggested as a good strategy to decrease energy density and increase vegetable intake, essentially making the products healthier (Blatt et al., 2011). When vegetables are incorporated as emulsions, the consumption of healthy unsaturated fatty acids will also increase.

An emulsion is a mixture of two normally immiscible liquids, such as oil and water (Fellows, 2009). One of the liquids (the dispersed phase) is then dispersed in the other (the continuous phase), creating either an oil-in-water or a water-in-oil emulsion. Surfactants, also known as emulsifying agents, stabilise the emulsion by reducing the surface tension of the liquid surface. Typical examples of emulsions are milk (oil-in-water) and butter (water-in-oil).

Fibres found in vegetables include pectin, cellulose, and hemicellulose, in varying amounts. Additionally, inulin can be found in onions (Kalyani Nair et al., 2010). When vegetables are used as a part of an oil-in-water emulsion, these fibres may be released during processing and influence the physical properties of the emulsion, such as the oil droplet size, structure, and viscosity.

Pectin is found in the middle lamella, which is the layer binding plant cells together (Lopez-Sanchez et al., 2011). It is a water-soluble polysaccharide consisting of poly α-D-galactopyranosyluronic acids (Fellows, 2009). Pectin can be divided into two main categories based on the amount of methyl ester groups along the chains. High methoxyl (HM) pectins have more than half of the carboxyl groups as methyl esters, while low methoxyl (LM) pectins have less than half. HM pectin forms gels in an environment with high sugar concentration and acid, while LM pectin forms gel in the presence of calcium ions. Pectin is one of the most important components of vegetable-based suspensions (of vegetables with a low starch content) concerning the effect on rheology (Moelants et al., 2014). Processing may affect pectin composition, and thus also the properties of the suspension or emulsion it is a part of. Due to the emulsifying, water binding, and gelling properties of pectin, it is often added as a stabiliser, increasing the viscosity of the continuous aqueous phase of an emulsion (Leroux et al., 2003; Schmidt et al., 2015).

Cellulose and hemicellulose are found in the cell walls of plant materials (Lopez-Sanchez et al., 2011). Cellulose is an insoluble polysaccharide structured in unbranched linear chains of D-glucose molecules (Fellows, 2009). It forms a crystalline structure of strong cellulose fibres, which are used by plants to support leaves and stems. Hemicellulose differs from cellulose by the structure, which is amorphously branched and can be composed of varying sugars (Fellows, 2009). These may form gels after becoming highly hydrated.

Inulin is a highly soluble polysaccharide (Ahmed & Rashid, 2019). It is a linear fructan consisting of fructosyl units. Inulin is non-digestible and often used as a fat replacer, due to its ability to form foams (Ahmed & Rashid, 2019; Kalyani Nair et al., 2010). The functional properties of inulin depend on the chemical structure and degree of polymerisation, which again depend on, among other things, plant source, growing conditions, and storage (Ahmed & Rashid, 2019).

Homogenisation is a process that, due to droplet size reduction, can be used to create more stable emulsions (Comuzzo & Calligaris, 2019; Molet-Rodríguez et al., 2018).

1.4. High pressure homogenisation

High pressure homogenisation (HPH) is defined as size reduction of particles in (liquid) foods by application of intense shearing forces, thus resulting in an increased number of solid or liquid particles in the dispersed phase (Fellows, 2009). Figure 1.2 shows a schematic overview of a homogenisation valve. The feed (liquid), driven by a high pressure pump, is pressed through the small opening between the valve and the valve seat. The high pressure then produces a high liquid velocity, followed by a pressure- and velocity drop as the liquid exits the valve. The turbulence induced by this sudden change creates high shearing forces. These forces, enhanced by the liquid hitting an impact ring, disrupt the droplets in the dispersed phase, resulting in a liquid with an increased number of smaller particles.

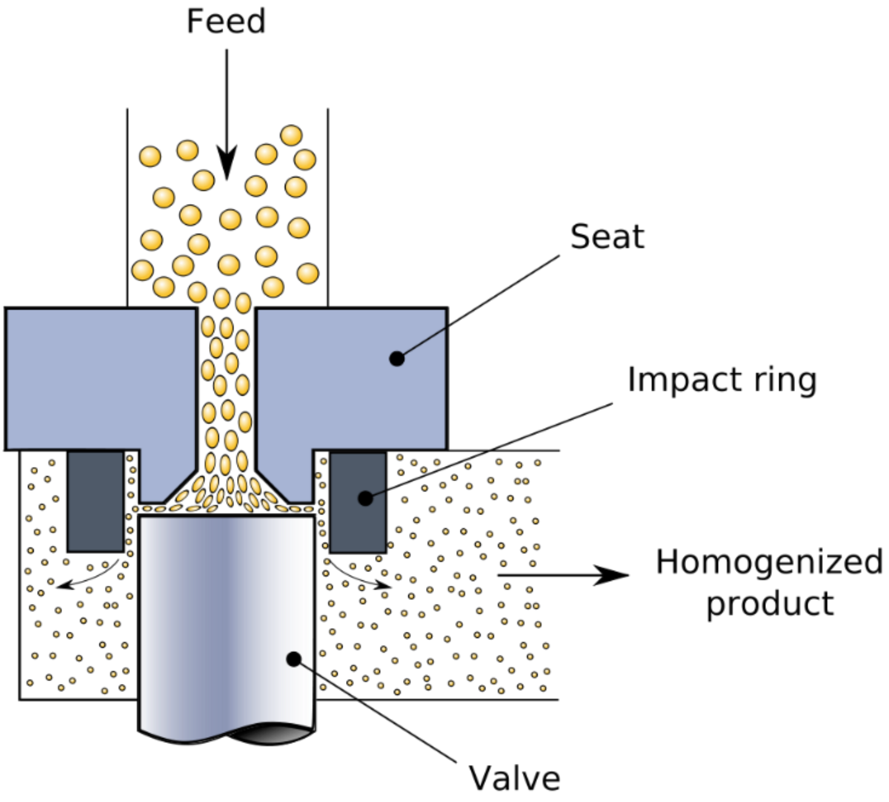

Figure 1.2: Schematic overview of a homogenisation valve (Pugliesi, 2010).

Homogenisation may change the functional properties or eating quality of the foods (Fellows, 2009). According to Aaby et al. (2020), HPH-treatment of sea buckthorn purees resulted in lighter and more yellow purees, due to reduced oil droplet size. Additionally, HPH-treatment did not affect the content of vitamin C, total carotenoids, or total phenolics. The results from a study by Kirkhus et al. (2019) at Nofima suggest that the release of carotenoids made available for intestinal absorption can be significantly improved by increasing the homogenization pressure and oil content. Furthermore, a review by Comuzzo and Calligaris (2019) stated that HPH-treatment can be used to inactivate spoilage microorganisms in grape juice and wine.

1.5. Texture and viscosity

Food texture is a quality attribute which is mostly determined by structural and mechanical properties (Fellows, 2009; Kilcast, 2004). Moisture and fat content, as well as types and amounts of structural carbohydrates and proteins, influence this. Texture is important for consumers' perception of food quality, and thus acceptability.

There are several different methods for measuring texture in foods, including tests using trained sensory panels and measurements using instruments (Fellows, 2009). The instrumental methods used for solid foods typically measure the forces needed to cut, compress, or penetrate a food product. For liquid foods it is common to measure viscosity, which can be defined as the liquid's resistance to deformation.

1.6. Objectives

Vegetable emulsions as ingredients in food products contribute to increased nutritional value, and the Norwegian health directorate recommend an increased intake of vegetables. The aim of this master's thesis was therefore to determine the effect vegetable emulsions as ingredients have on texture and water loss in plant-based products, using falafel as a model product. Differences due to type of vegetable, as well as different pre-treatments of the emulsions, were investigated. Finding new uses for surplus vegetables increases sustainability, which is why typical surplus vegetables grown in Norway such as carrot and onion were chosen. Additionally, cauliflower bouquets and a cauliflower fraction of stems and bouquets sorted out of production of frozen vegetables were included, as it is of interest for the industry to find new uses for these types of fractions. Lastly, to further investigate the possibility of using more locally produced raw materials, Norwegian-grown faba beans and yellow peas were compared with imported chickpeas as the main ingredient in the falafels. Thus, both health and sustainability are objectives related to this thesis.

2. Materials and methods

2.1. Experimental setup

Five falafel experiments were completed as a part of this study. Experiment 5 was a partial repeat of experiment 4. Table 1 shows an overview of the experimental setup. Initially, several informal experiments were performed to develop a basic falafel recipe with a decreased amount of spices and herbs, as these might cover up off-flavours from the vegetables or pulses used. The falafel recipes used in experiments 1-5 can be found in appendix A.

All vegetable emulsions consisted of 10 % water, 10 % oil, 0.1 % sodium benzoate, and boiled vegetable. The vegetable mash only consisted of 10 % water and boiled vegetable. An emulsion/mash content of 30 % was determined to be the upper limit that could be included while still having a dough that was possible to shape. Control falafels substituted the emulsion/mash with water.

Experiment setups were in part decided based on results from previous experiments (both preliminary and experiments 1-4), as well as on availability of raw materials. Additionally, when the HPH-emulsions had a shorter shelf life than expected, it was chosen to not do an entire repeat of experiment 3. Due to a technical issue, HPH-emulsion of carrot was not produced.

Flow diagrams of the emulsion and falafel production processes can be found in appendices B and C.

Table 1: Overview of all five falafel experiments, with varying type of pulse, vegetable, vegetable processing, and emulsion-, potato starch- and water content (%). Pre-emulsions were made by mixing boiled vegetable, 10 % water, 10 % oil, and 0.1 % sodium benzoate in a blender. High pressure homogenisation (HPH) was applied to sieved pre-emulsions to make HPH-emulsions. Controls (vegetable emulsion substituted with water) are marked with a “-“.

Experiment number	Pulse type	Vegetable type	Vegetable processing	Emulsion (%)	Potato starch (%)	Water (%)
1	Chickpea	-	-	0	5.6	40
	Chickpea	Carrot	Mash	30	5.6	10
	Chickpea	Carrot	Mash	30	12	3,6
	Chickpea	Carrot	Pre-emulsion	30	5.6	10
	Chickpea	Carrot	Pre-emulsion	30	12	3,6
2	Chickpea	-	-	0	5.6	40
	Chickpea	Carrot	Pre-emulsion	30	5.6	10
	Chickpea	Carrot	Sieved pre-emulsion	30	5.6	10
3	Chickpea	Onion	Pre-emulsion	30	5.6	10
	Chickpea	Onion	HPH-emulsion	30	5.6	10
	Chickpea	Cauliflower bouquet	Pre-emulsion	30	5.6	10
	Chickpea	Cauliflower bouquet	HPH-emulsion	30	5.6	10
	Chickpea	Cauliflower fraction	Pre-emulsion	30	5.6	10
	Chickpea	Cauliflower fraction	HPH-emulsion	30	5.6	10
4	Chickpea	-	-	0	5.6	40
	Chickpea	Cauliflower fraction	Pre-emulsion	30	5.6	10
	Faba bean	-	-	0	5.6	40
	Faba bean	Cauliflower fraction	Pre-emulsion	30	5.6	10
	Yellow pea	-	-	0	5.6	40
	Yellow pea	Cauliflower fraction	Pre-emulsion	30	5.6	10
5	Chickpea	-	-	0	5.6	40
	Chickpea	Cauliflower fraction	Pre-emulsion	30	5.6	10
	Faba bean	-	-	0	5.6	40
	Faba bean	Cauliflower fraction	Pre-emulsion	30	5.6	10

2.2. Raw materials

Norwegian carrots (*Daucus carota* subsp. *sativus*) and yellow onions (*Allium cepa* L.) were obtained fresh from a local grocery store. Two variants of Norwegian white cauliflower (*Brassica oleracea* var. *botrytis*) (ordinary bouquets and a fraction sorted out from the production; 0-8mm stems/small bouquets) were obtained from Norrek Dypfrys AS, Larvik, where they had been cut, blanched, and deep frozen.

Dried chickpeas (*Cicer arietinum*, figure 2.1.a) were bought in a local grocery store (TRS, United Kingdom). Dehulled Norwegian faba beans (*Vicia faba* L., mix of var. Konti and var. Louhi, figure 2.1.b) were obtained from Skjelfoss Korn, Hobøl. Norwegian yellow field peas (*Pisum sativum* L. var. Ingrid, figure 2.1.c) were obtained whole from the Norwegian University of Life Sciences (NMBU) and were dehulled by stone milling and air separation (figure 2.2). The chickpeas, faba beans and yellow peas were all hand sorted before use, to remove residual hulls and stones.

Figure 2.1: a) Chickpeas. b) Faba beans. c) Yellow peas.

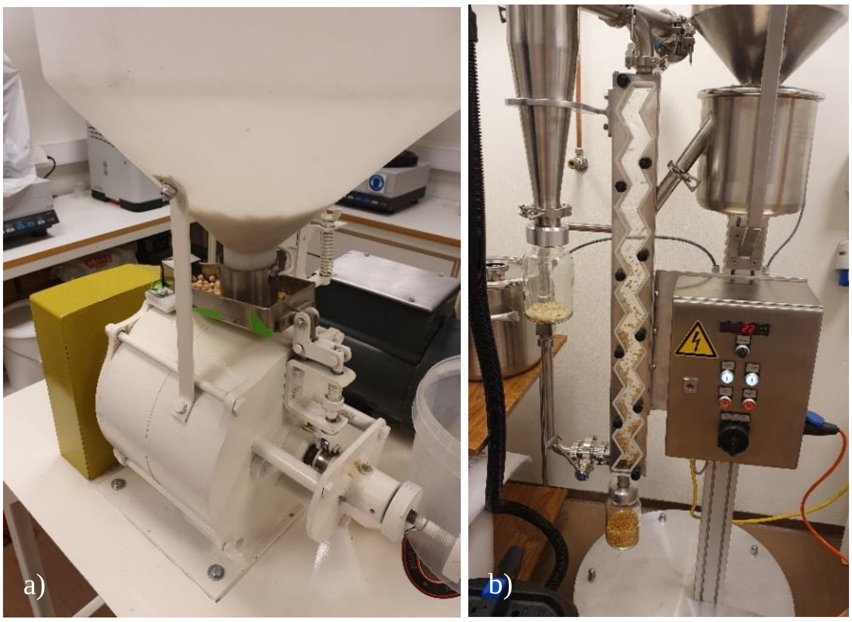

Figure 2.2: a) Splitting peas by stone milling. b) Air separation of hulls from pea kernels.

Potato starch (HOFF Potetmel, Norway), garlic, salt, ground cumin and ground coriander were obtained from a local grocery store. Oil to be used in the vegetable emulsions (Coop Rapsolje, 100 % rapeseed oil) and oil suited for frying (50 % sunflower oil and 50 % rapeseed oil) were bought in local grocery stores as well.

In experiment 5, a type of store bought falafel was used for comparison during texture analysis. Hälsans Kök Falafel (figure 2.3) was chosen because it is sold frozen, making it easier to control storage time after thawing, and thus more comparable to the falafels produced in this study. Ingredients of Hälsans Kök Falafels can be found in appendix D.

Figure 2.3: Hälsans Kök Falafel (Hälsans Kök, n.d.).

2.3. Preparation of vegetable mash, pre-emulsions, and HPH-emulsions

The fresh vegetables (carrot and onion) were peeled and cut in thin slices. The two cauliflower variants were used frozen, as obtained from NORREK. The mash used in experiment 1 was prepared by gently hand-mashing the boiled carrots and 10 % water with a potato masher. The mash did not contain any oil.

The pre-emulsions were prepared by boiling the vegetables for 20 minutes in 10 % water (based on total weight) in a saucepan covered with a lid (figure 2.4.a). They were then cooled to approximately 20°C and the amount of water evaporated during boiling was replenished, measured by weighing before and after boiling. The mixture was homogenised with 10 % rapeseed oil and 0.1 % sodium benzoate in a blender (Wilfa WBLB1400S, Norway) on speed level 1 for 2.5 minutes.

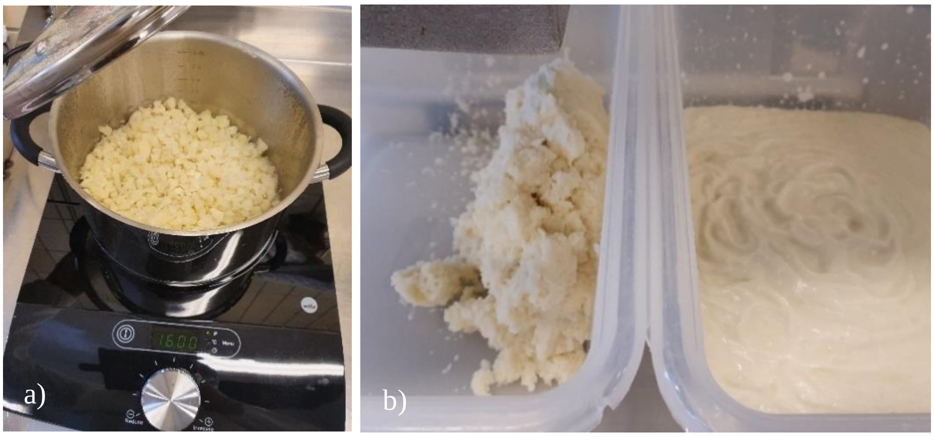

Figure 2.4: a) Boiling cauliflower. b) Sieved cauliflower pre-emulsion (right) and larger particles (left).

The pre-emulsions were further sieved in a Robot Coupe C80 automatic strainer with 0.5 mm pore size (Robot Coupe, USA), to remove possible large particles that might clog the high pressure homogenizer (figure 2.4.b). The fractions containing larger particles were sieved twice, as the pores were easily clogged when too much emulsion was fed into the strainer at once. HPH-emulsions were lastly produced by high pressure homogenisation of the sieved pre-emulsions at 1500 bar (figure 2.5), using a PandaPLUS 2000 (GEA Niro Soavi, Italy). Samples were taken after all three steps (pre-emulsion, sieved pre-emulsion, and HPH-emulsion) and stored in 100 ml plastic cups and larger plastic boxes, at 4°C. Emulsions were store maximum 10 days before use in falafel production.

Figure 2.5: a-c) High pressure homogenisation of cauliflower emulsion.

2.4. Preparation of falafels

The falafels were prepared by first soaking the chickpeas/faba beans/yellow peas overnight (*Exp. 1:* 18 hours. *Exp. 2, 4, 5:* 9 hours. *Exp. 3:* 14 hours). The peas/beans were weighed dried. These were then combined with garlic, ground cumin, ground coriander, salt, and possibly potato starch, and minced in a KitchenAid 2 food processor (KitchenAid, USA) for 4 minutes on speed level 2 (figure 2.6).

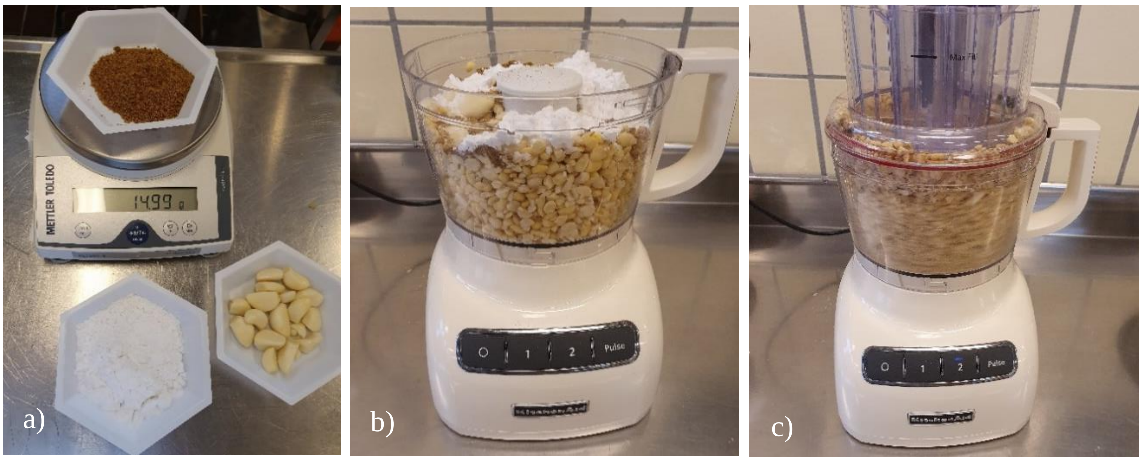

Figure 2.6: a) Measuring ingredients. b-c) Blending ingredients in a food processor.

The dough was further combined with water and, if applicable, vegetable emulsion in a Kenwood kitchen machine (Kenwood, UK) with a K-beater for 1 minute on speed level 1 (figure 2.7.a). The falafels were shaped by hand (figure 2.7.b), and deep fried in a fryer at 175-180°C for 4 minutes (figure 2.8). After cooling down in room temperature, the falafels were moved to storage. Some samples were only stored chilled (4°C), while others were first stored in a freezer (-24°C) for at least two days, before moving to a cold storage room (4°C).

Experiment 1 was performed at a different location, with slightly different equipment. Most importantly, the falafels were deep-fried in a saucepan without a working thermometer instead of a temperature controlled fryer as used in experiments 2-5.

Figure 2.7: a) Mixing the base dough with vegetable emulsion. b) Falafel dough.

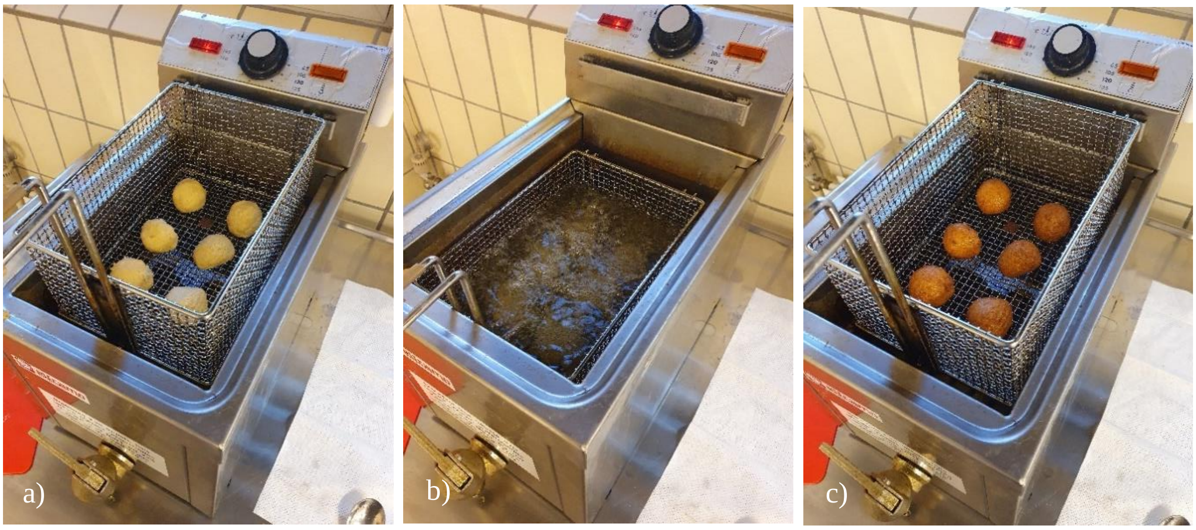

Figure 2.8: a-c) Frying falafels.

2.5. Analysis methods: Emulsions

2.5.1. pH

The pH of the emulsions was measured with a FiveGo™, FG2, portable pH meter (Mettler-Toledo AG, Switzerland) at 15.5-17.4°C.

2.5.2. Dry matter content

The dry matter content was determined by two methods: drying in a heating cabinet and in a rapid Moisture Analyser (Sartorius Thermo Control YTC 01 L, Germany). For the first method, approximately 5 g of emulsion in aluminium weighing dishes were placed in a heating cabinet at 105°C for 6.5 hours. For the second method, approximately 1.2-1.5 g of emulsion was dried using the Moisture Analyser at 160°C. The emulsions were analysed in duplicates for both methods.

2.5.3. Viscosity

Emulsion viscosity in centipoise (cP) was measured using a Rapid Visco Analyzer (RVA-Newport Scientific Pty, Australia). Emulsions (30 g) were analysed in triplicates at speed 160 rpm and temperature 25˚C.

2.5.4. Oil droplet size

Oil droplet size distribution was measured by laser diffraction using HELOS/KR-QUIXEL (Sympatec GmbH, Germany). Emulsions were sonicated for 120 seconds, with an optic concentration of 10-27 % (approximately 10 drops of sample in 250 mL distilled water), pump speed 100 %. The analysis was performed 3 times at room temperature (approximately 23˚C) for 30 seconds, pump speed 30 %.

2.5.5. Fluid release

Fluid release was measured by storing the emulsions in 15 ml tubes in duplicates at 4°C and visually registering water separation in the bottom of the tube. Additionally, after 4 weeks of storage, one tube from each duplicate was sentrifuged at either 2000 rpm or 4000 rpm for 5 min.

2.6. Analysis methods: Falafels

2.6.1. Water loss

Water loss in the falafels was measured by weighing before and after frying, as well after storing for 1 day, 3 days, and 1 week. Falafels previously frozen were used, and the days of storage were counted from the first day of chilled storage. The falafels were stored separately in 100 ml plastic cups with lids. In experiment 1 the falafels were stored in plastic bags closed with sealing clips.

2.6.2. Texture analysis

The texture of the falafels was measured using a TA.XT*plusC* Texture Analyser (Stable Micro Systems, UK), with the computer program Exponent connect v7.0.1.0. The main method used was with a knife attachment (Guillotine edge from the Standard Blade Set (HDP/BS)) (figure 2.9.a-b). A method using a cylinder probe attachment (36 mm radius) (figure 2.9.c), was used to compare with the knife-method in experiments 2 and 4. As some problems related to this method was discovered, some adjustments (such as increasing the strain from 40 % to 70 %) were made for experiment 4.

Firmness and toughness were the two properties measured. Firmness (expressed in g) is a textural property that in this case is defined as the maximum force required to cut the falafel in two (the force needed to penetrate the fried outer layer/surface) or compress the falafel (40 % or 70 % strain). Toughness (expressed in g.sec) relates to the entire accumulated force/work needed to cut or press the falafel. In a texture analysis graph, the firmness will be the peak of the curve, while the toughness is the total area under the curve. An example of a texture analysis graph can be found in appendix E.

The falafels were analysed either freshly made or after chilled storage. The stored falafels were left in room temperature for at least 40 min prior to analysis. In experiment 5 several samples were analysed after reheating. These were wrapped in aluminium foil and placed in a heating cabinet at 180˚C for 5 minutes before immediate analysis.

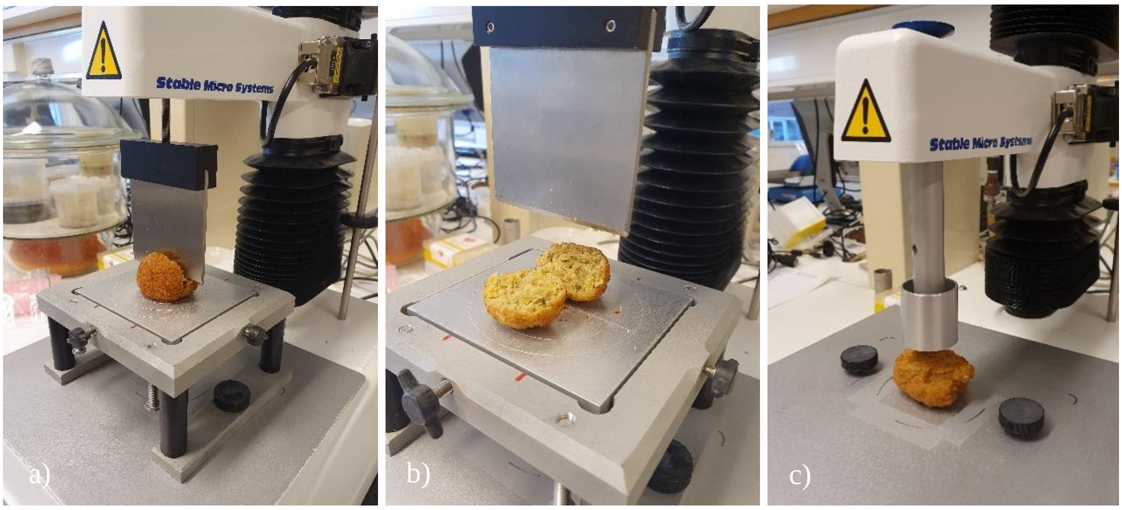

Figure 2.9: a-b) Texture analyser with knife attachment. c) Texture analyser with cylinder probe attachment.

2.6.3. Sensory analysis

An informal benchtop tasting of the falafels was performed before and after frying before the falafels had completely cooled. Texture of the dough and fried falafels was the main attribute assessed. Other attributes such as flavour, colour and odour were commented on when relevant. These analyses were aiming to be objective. However, as they were only performed by one person, the results can only be used as an indication.

In experiment 4, an informal sensory analysis with two additional people was performed in each participants' home, with falafels that had been frozen and then stored chilled for 2 days before heating and tasting. The test was not blinded, and the participants themselves chose which attributes to assess.

In experiment 5, a more comprehensive sensory analysis with three participants was performed. It was a blinded test performed at each participant's home. The samples were halved and placed in marked plastic bags, numbered by randomly generated three-digit codes, before being served in the same randomized order to each participant. The participants were asked to rate each falafel, both cold and reheated, according to firmness, toughness, and dryness, on a scale from 1-7. Questions and information from the questionnaire used can be found in appendix F. As there were only three participants, of which some knew which variants were being tested, the results can only be used as an indication of how the samples were perceived. Using an objective trained sensory panel would have been more ideal but was not possible due to time restraints and Covid-19 restrictions.

2.7. Statistics

Statistical analyses of designed experiments were performed with Unscrambler® v 10.3 (Camo Inc., Norway) to establish the effects of potato starch, vegetable emulsions, and storage conditions on texture and water loss in falafel. Significant ($p < 0.05$) main effects and interaction effects were analysed by classical Design of experiments (DOE) analysis using multiple linear regression (MLR) and Scheffé formulas. Multivariate analysis (Principal Component Analysis, PCA) was performed to find associations between variables. In some experiments significant differences between means were estimated by one-way analysis of variance (ANOVA) followed by the Tukey method using Minitab18 statistical software (Minitab Ltd., UK). P values < 0.05 denoted significance.

3. Results

The results are divided into three main sections presented below: vegetable emulsion analyses, falafel analyses, and PCA.

3.1. Vegetable emulsions

pH, dry matter content, viscosity, oil droplet size, and fluid release of the vegetable emulsions were analysed and is presented below.

3.1.1. pH

Figure 3.1 shows the pH of the vegetable emulsions. While processing appeared to have little to no effect on pH, there are some differences between vegetable types. Both variants of cauliflower had a pH value ranging from 6.3-6.4. Carrot had a pH value of 5.8-6.0. Onion had the lowest pH at 5.7.

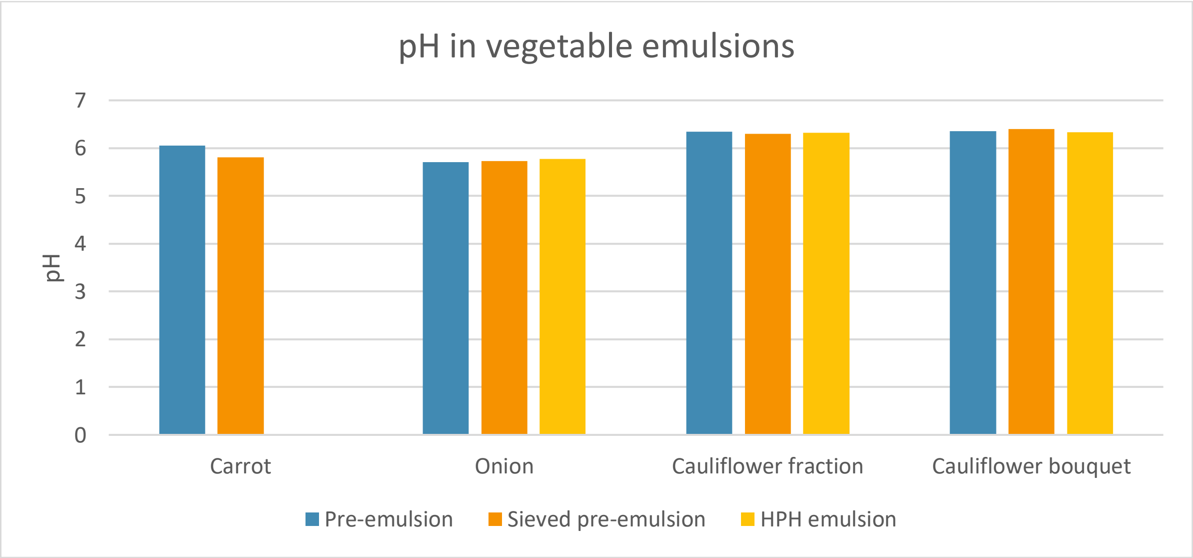

Figure 3.1: pH of carrot, onion, and cauliflower emulsions. The y-axis shows pH. The different emulsion processes are marked in different colours, explained in the bottom of the figure.

3.1.2. Dry matter content

The two methods used to determine dry matter content resulted in relatively similar results, with the emulsions having 0.4-1.1 % lower dry matter content using the rapid moisture analyser compared to the heating cabinet. As this indicates that the emulsions were dried better using the heating cabinet, these results are further commented on and illustrated in figure 3.2.

The dry matter content of the emulsions varied between vegetable types. Onion had the highest dry matter content (19-21 %), followed by carrot (18-19 %). The cauliflower variant had the lowest dry matter content, with cauliflower bouquet (15-16 %) slightly higher than cauliflower fraction (14 %).

Processing also had some effect on the dry matter content. Sieving the pre-emulsions resulted in a slightly higher dry matter content for carrot (+ 0.5 %) and cauliflower fraction (+ 0.4 %), while the dry matter content of onion decreased (- 0.3 %). HPH treatment of the sieved pre-emulsions resulted in a decreased dry matter content for onion (- 1.2 %), cauliflower bouquet (- 1.1 %) and cauliflower fraction (- 0.1 %).

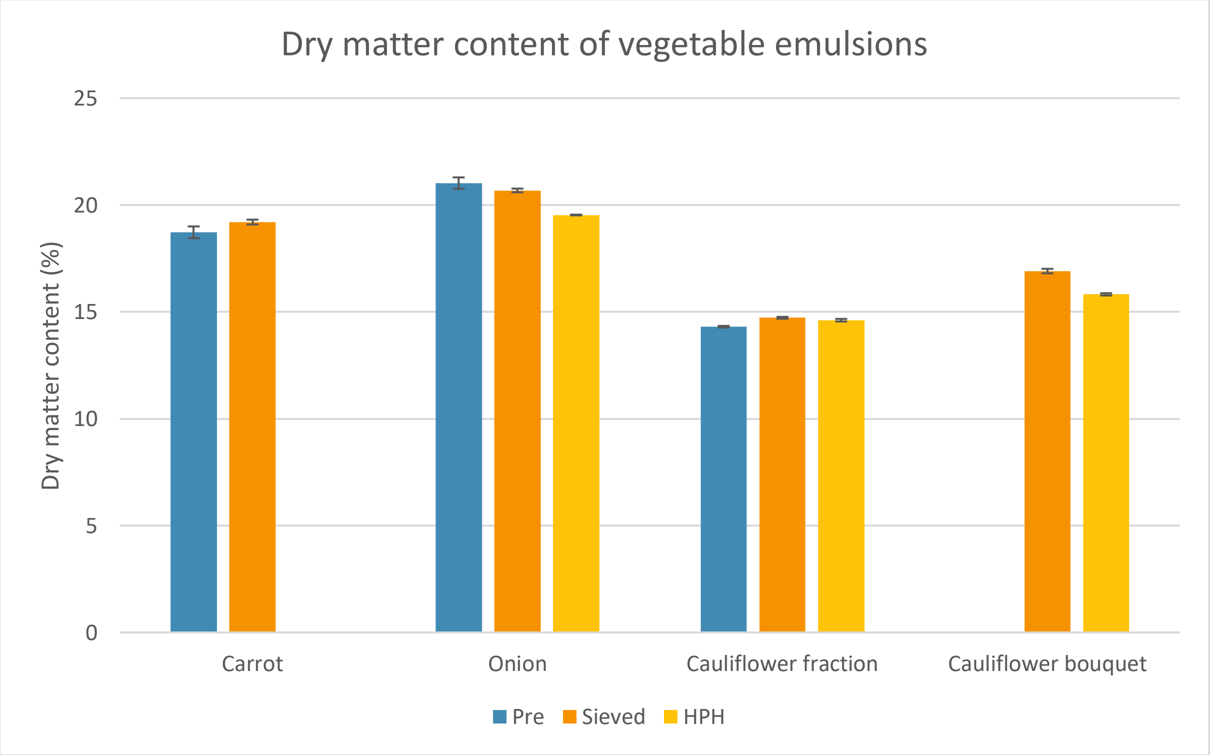

Figure 3.2: Dry matter content of carrot, onion, and cauliflower emulsions, measured using a heating cabinet. The y-axis shows dry matter content in %. The different emulsion processes are marked in different colours, explained in the bottom of the figure. Pre = pre-emulsion. Sieved = Sieved pre-emulsion. HPH = HPH-treated sieved pre-emulsion.

3.1.3. Viscosity

Appendix G shows the viscosity profiles of the vegetable emulsions. Pre-emulsion of carrot had the highest viscosity at 1246 cP, while onion had the lowest at 419 cP (figure 3.3). The cauliflower variants both decreased in viscosity from pre-emulsion to HPH-emulsion (842 cP to 273 cP for fraction and 1316 cP to 230 cP for bouquet), while onion increased (419 cP to 547 cP). As cauliflower bouquet pre-emulsion is only based on a single measurement, due to lack of emulsion material, it is an uncertain value. The true value is most likely closer to cauliflower fraction pre-emulsion. However, the conclusion that HPH-treatment results in decreased viscosity for cauliflower remains the same in either case.

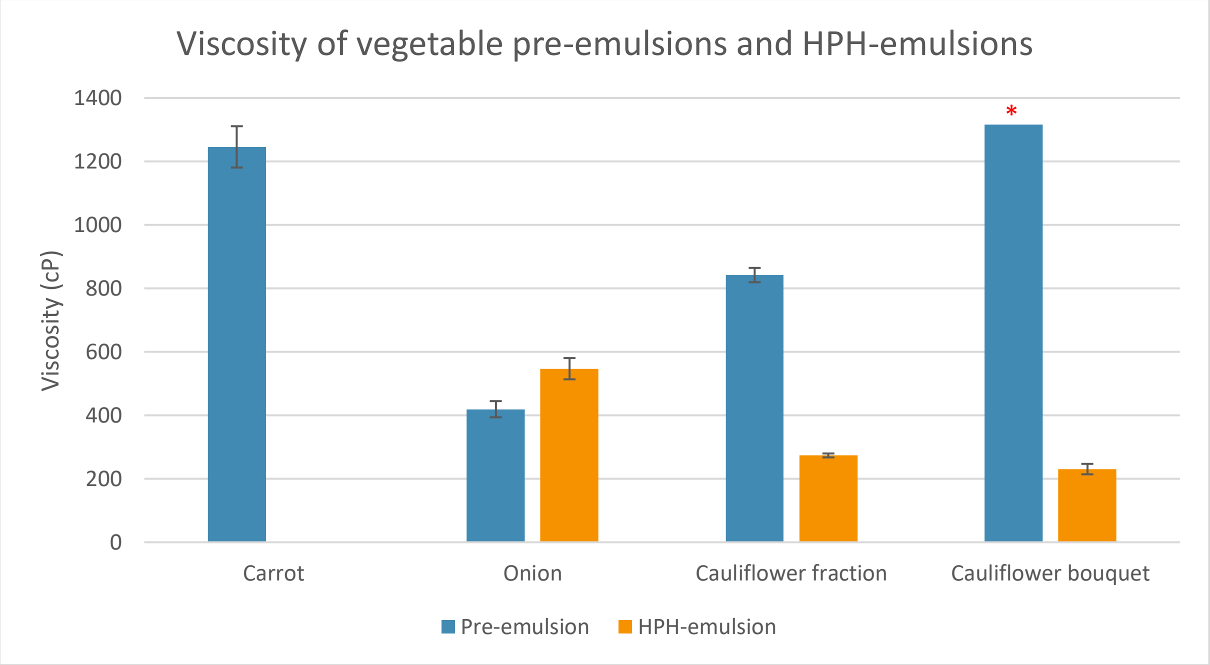

Figure 3.3: Viscosity of carrot, onion, and cauliflower pre-emulsions and HPH-emulsions. The y-axis shows viscosity measured in centipoise (cP). The different emulsion processes are marked in different colours, explained in the bottom of the figure. Cauliflower bouquet pre-emulsion (marked with a *) is only based on a single measurement.

3.1.4. Oil droplet size

Figure 3.4 shows mean values of oil droplet size in the vegetable emulsions. Onion had the largest oil droplet size, at 14.8-16.5 µm for the pre-emulsions. The two cauliflower variants were slightly smaller, with fraction at 11.2-12.1 µm and bouquet at 7.7-9.2 µm. Carrot had the smallest pre-emulsion oil droplet size, at 6.7 µm. Onion pre-emulsion increased (+ 2 µm) with sieving, while cauliflower fraction (- 0.8 µm) and bouquet (- 1.5 µm) decreased. HPH-treatment resulted in a large reduction in oil droplet size for all three vegetables that were used (onion 4.1 µm, cauliflower fraction 2.3 µm, and cauliflower bouquet 2.5 µm).

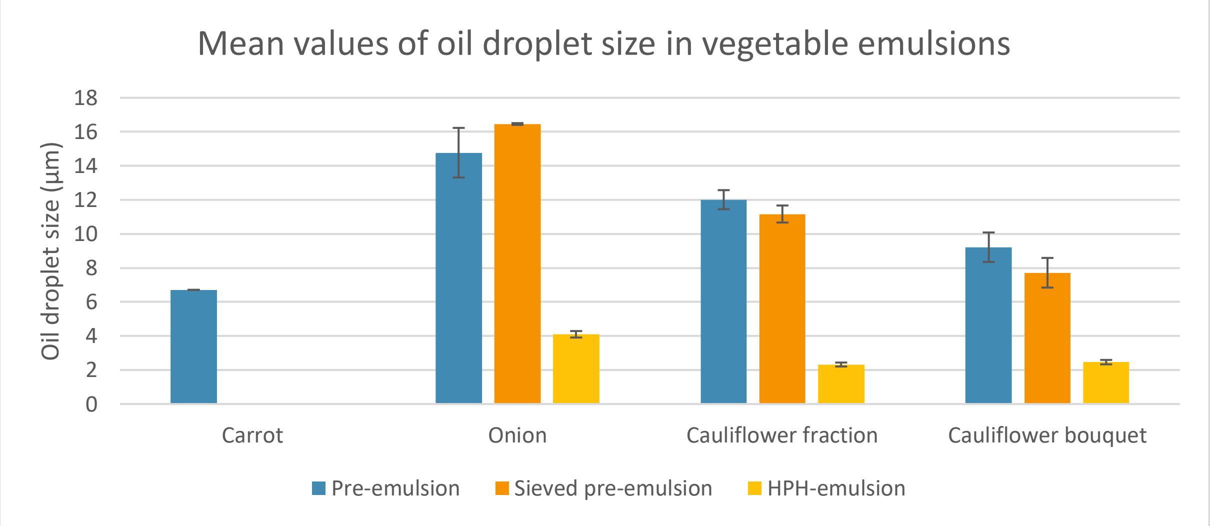

Figure 3.4: Mean values of oil droplet size in carrot, onion, and cauliflower emulsions, based on three measurements for each variant. The y-axis shows oil droplet size measured in micrometres (µm). The different emulsion processes are marked in different colours, explained in the bottom of the figure.

3.1.5. Fluid release

No fluid release was observed visually after four weeks of chilled storage in 15 ml tubes.

Results of fluid release accelerated by centrifugation can be found in appendix H. Overall, HPH-emulsions were less prone to fluid release, indicating that these emulsions were more stable. Regarding vegetable type, onion appeared to be most prone to fluid release, while cauliflower fraction was least prone to it.

3.2. Falafels

Five experiments with falafels were performed, where experiment 5 was a partial repeat of experiment 4 (see experimental setup in chapter 2.1, table 1). The results are divided into three parts; water loss, texture analysis, and sensory analysis.

3.2.1. Water loss

Results of the falafel water loss is presented below, in order of experiment. Most of the falafel control doughs had a loose texture that did not stick well together, resulting in some incorrect measurements before frying. In experiment 4 several of the control falafels also lost some dough during frying. These are marked in the figure text. Experiments 2-5 confirm that most of the water loss happened during frying, while little to no water loss happened during a week of chilled storage (using samples previously frozen). Depending on the variant, this water loss ranged between 10-20 %. Some variants in experiment 1 had an additional 2-4 % water loss during the first day of storage.

Figure 3.5 shows the water loss of experiment 1. There were significant effects of potato starch and carrot processing on water loss. Higher amount of potato starch added resulted in decreased water loss (p = 0.018). Falafel with carrot pre-emulsion also had decreased water loss (p = 0.030) compared to falafel with carrot mash. There were no interaction effects.

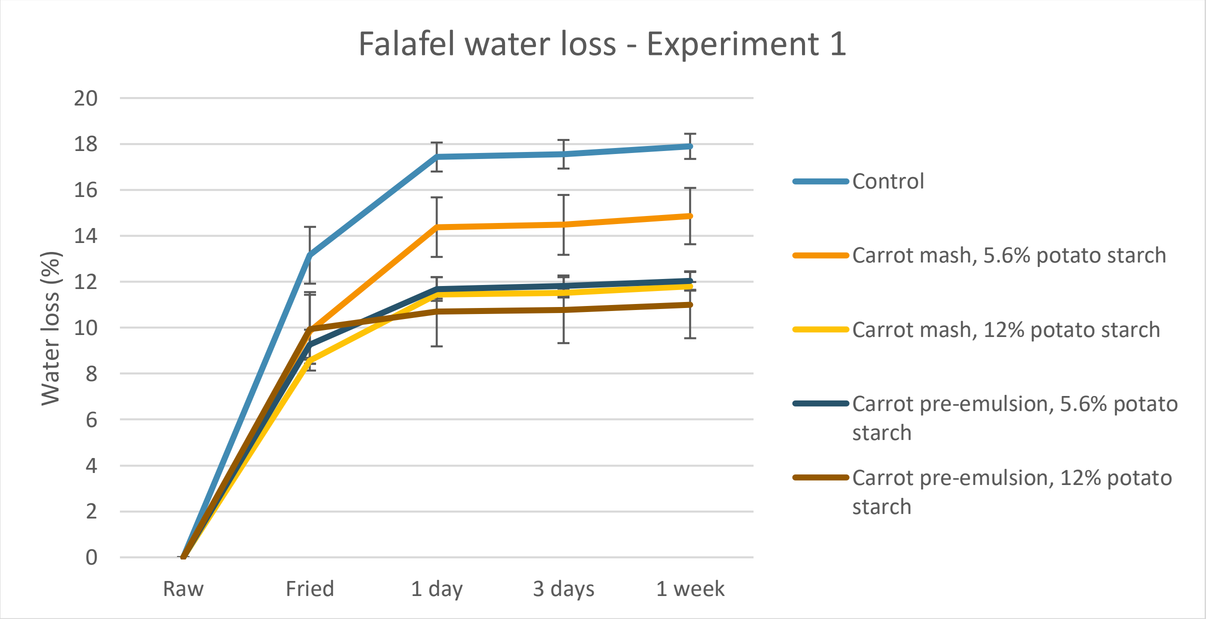

Figure 3.5: Water loss in experiment 1, effect of gentle mashing vs. emulsification of carrot, and potato starch amount, on water loss in falafel. The different falafel variants are marked in different colours, explained on the right side of the figure. The y-axis shows water loss measured in percentage (%) of total weight.

Figure 3.6 shows the water loss of experiment 2. Sieving of carrot pre-emulsion resulted in no significant effects on water loss in falafel. However, sieved pre-emulsion tended to result in less water loss compared to the control (p = 0.064), while sieving of pre-emulsions may result in a decreased water loss compared to not sieving (p = 0.106).

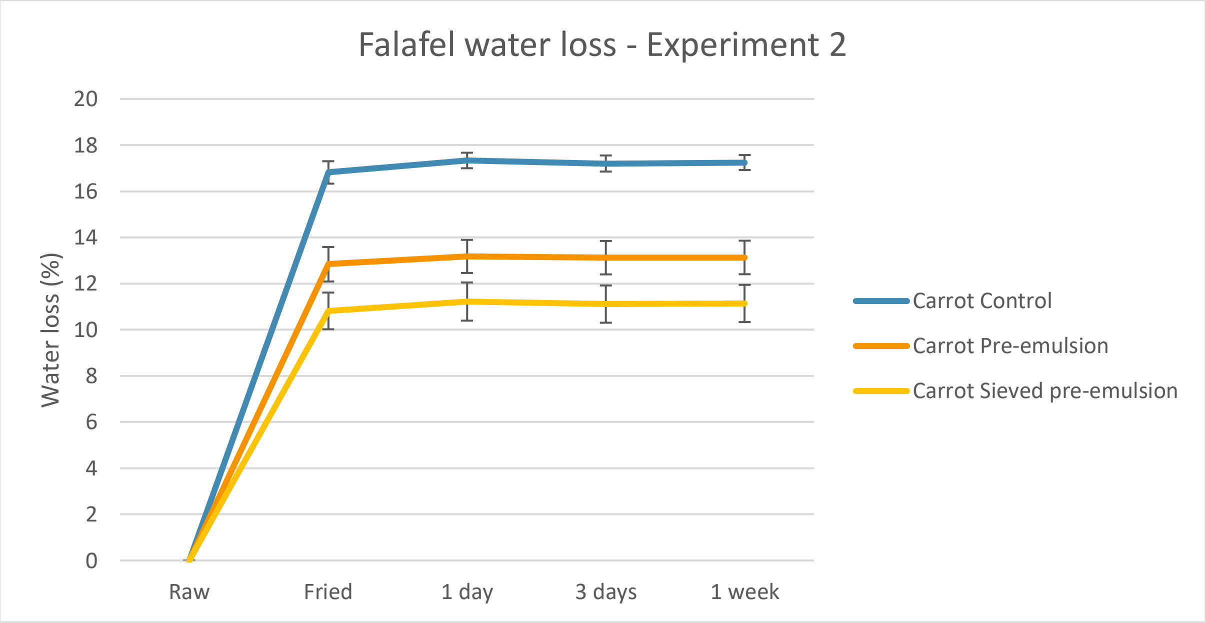

Figure 3.6: Water loss in experiment 2, effect of sieving of carrot pre-emulsions on water loss in falafel. The different falafel variants are marked in different colours, explained on the right side of the figure. The y-axis shows water loss measured in percentage (%) of total weight.

Figure 3.7 shows the water loss of experiment 3. There were no significant effects due to different vegetable types or emulsion processing (pre-emulsion compared to HPH-emulsion) on water loss.

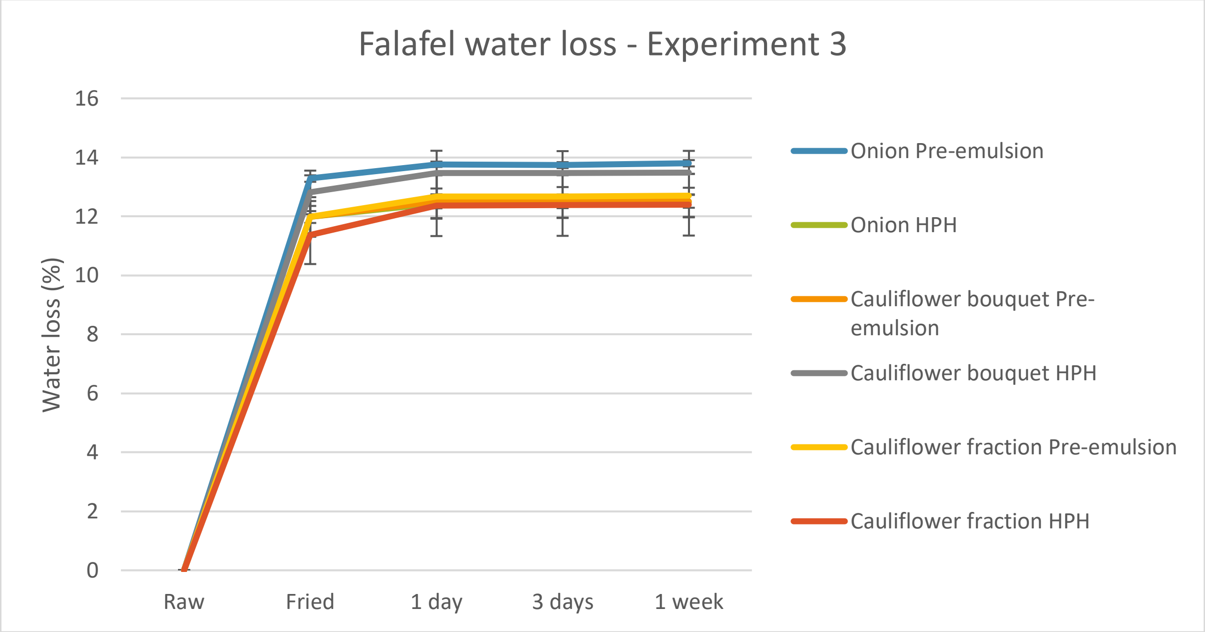

Figure 3.7: Water loss in experiment 3, effect vegetable type and high pressure homogenisation (HPH) of vegetable emulsions on water loss in falafel. The different falafel variants are marked in different colours, explained on the right side of the figure. The y-axis shows water loss measured in percentage (%) of total weight.

Figure 3.8 shows the water loss of experiment 4. Both faba beans and yellow peas resulted in a higher water loss than chickpeas (p = 0.004). There were no significant differences between faba beans and yellow peas. Additionally, falafel containing emulsion had a lower water loss than the control containing only water (p = 0.0002). There was a significant interaction effect showing that added pre-emulsion in falafel made of yellow peas resulted in a larger decrease in water loss compared to chickpea and faba bean (p = 0.0508).

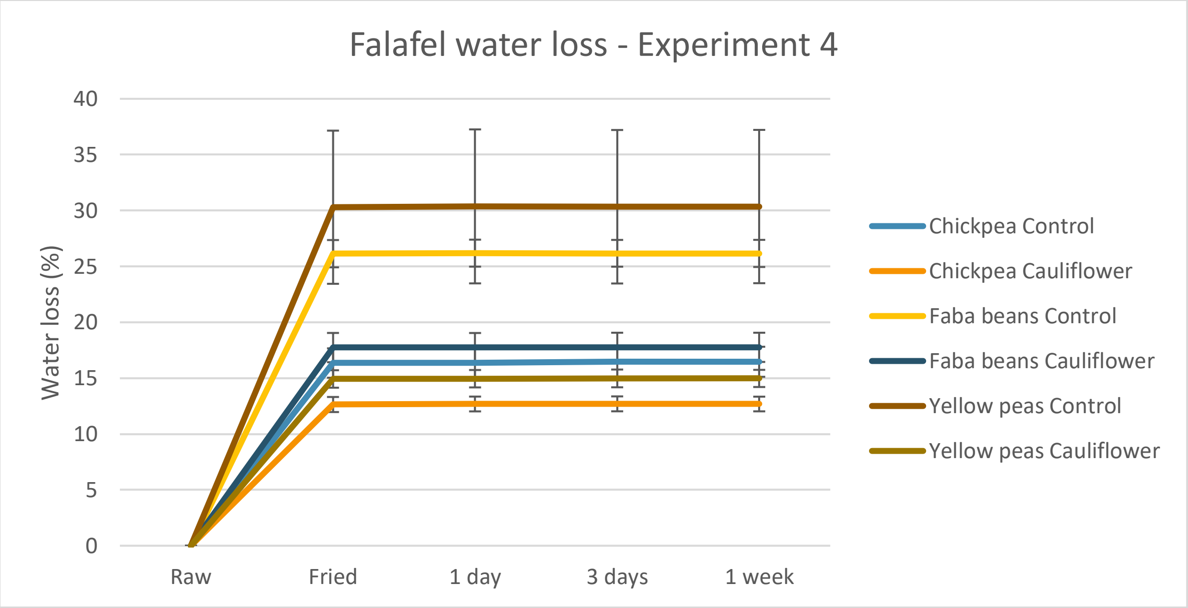

Figure 3.8: Water loss in experiment 4, effect of faba beans, yellow peas, and cauliflower fraction on water loss in falafel. The different falafel variants are marked in different colours, explained on the right side of the figure. The y-axis shows water loss measured in percentage (%) of total weight. Falafels from all three control variants lost varying amounts of dough during frying.

Figure 3.9 shows the water loss of experiment 5. Faba beans resulted in a higher water loss compared to chickpeas, as in experiment 4. However, this time the difference is smaller, and therefore not significant (p = 0.104). The effect of pre-emulsion compared to the control is still significant, though also with a smaller difference (p = 0.0239).

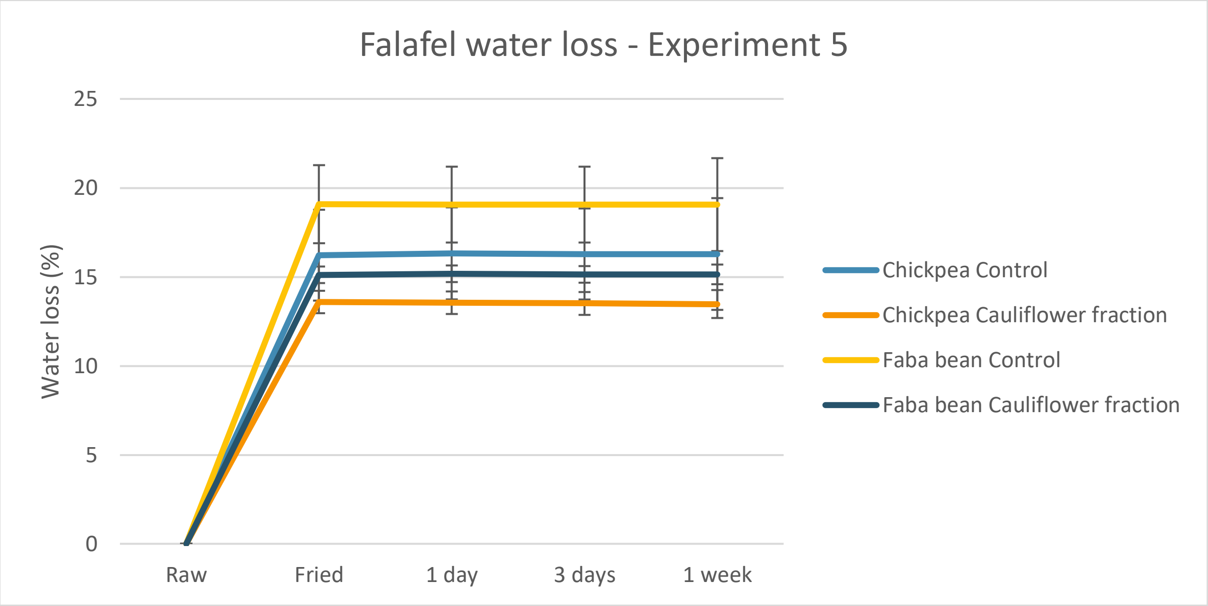

Figure 3.9: Water loss in experiment 5, effect of faba beans and cauliflower fraction on water loss in falafel. The different falafel variants are marked in different colours, explained on the right side of the figure. The y-axis shows water loss measured in percentage (%) of total weight.

3.2.2. Texture analysis

Results of the texture analyses are presented below, in order of experiments. Some outliers were removed during statistical analysis. These are marked in the figure texts.

Figure 3.10 shows the texture analysis results from experiment 1. Chilled samples were stored for seven days at 4°C, while frozen samples were stored for at least two days at -24°C, followed by eight days at 4°C. There were significant effects of potato starch and carrot processing on firmness of the frozen samples. Both higher amount of potato starch added and using pre-emulsion instead of carrot mash resulted in increased firmness (both p = 0.000). There were no significant effects on toughness and no interaction effects. The chilled samples only had significant effect of potato starch on firmness (p = 0.002). The falafels that were frozen before storage appear to have a decreased firmness and possibly a slightly decreased toughness.

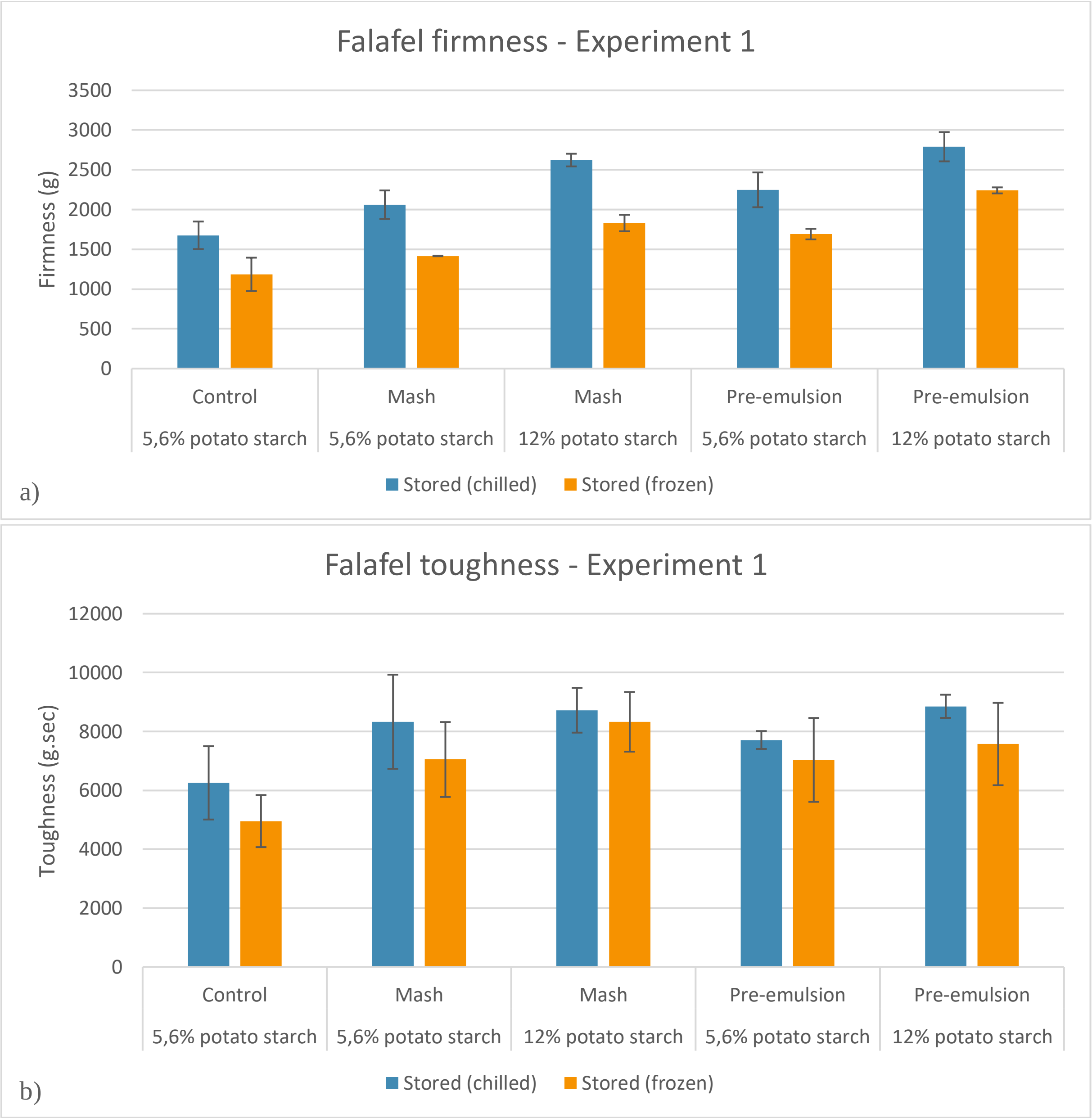

Figure 3.10: Texture analysis of experiment 1, effect of gentle mashing vs. emulsification of carrot, and potato starch amount, on texture in falafel. Two storage variations, seven days chilled storage and frozen prior to eight days chilled storage, are marked in different colours, explained in the bottom of the figures. a) Firmness. The y-axis shows firmness measured in g. One outlier of mash, 5.6 % potato starch was removed. b) Toughness. The y-axis shows toughness measured in g.sec.

Figure 3.11 shows the texture analysis results from experiment 2. The samples had been stored for at least two days at -24°C, followed by seven days at 4°C. Falafels with pre-emulsion (sieved or not sieved) had significantly increased firmness ($p = 0.002$) and toughness ($p = 0.045$) compared to the control samples containing water instead of emulsion. There were however no significant differences in firmness and toughness between falafels with pre-emulsion and sieved pre-emulsion.

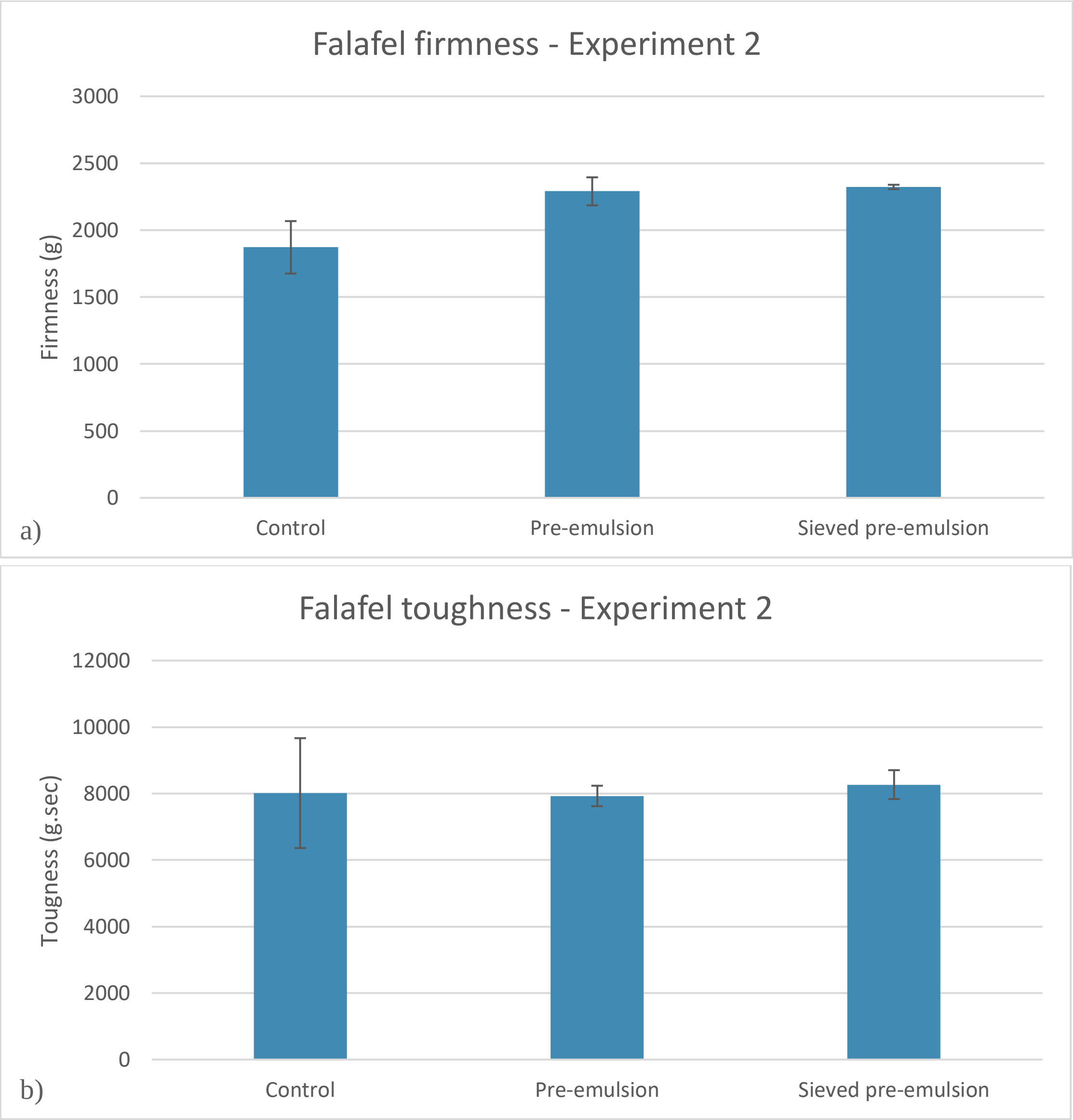

Figure 3.11: Texture analysis of experiment 2, effect of sieving of carrot pre-emulsions on texture in falafel. All falafels analysed were frozen prior to seven days chilled storage. a) Firmness. The y-axis shows firmness measured in g. b) Toughness. The y-axis shows toughness measured in g.sec.

Figure 3.12 shows the texture analysis results from experiment 3. As for experiment 2, the samples had been stored for at least two days at -24°C, followed by seven days at 4°C. HPH-treated emulsions in falafel resulted in significantly increased firmness compared to pre-emulsions (p = 0.008). The effect was larger for cauliflower compared to onion. However, type of vegetable did not show any significant effects on firmness, and there were no interaction effects. There were no significant effects on toughness.

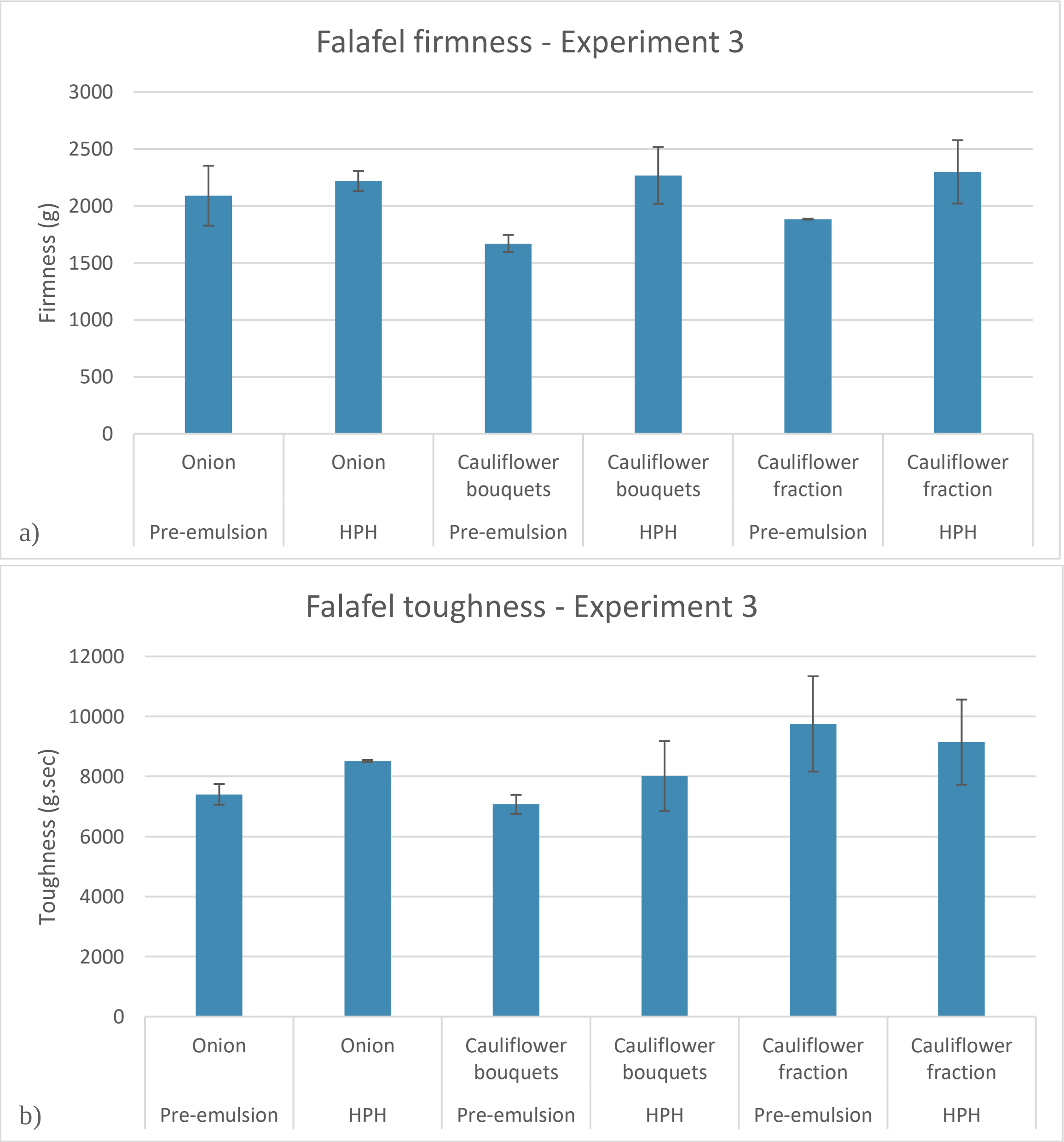

Figure 3.12: Texture analysis of experiment 3, effect vegetable type and high pressure homogenisation (HPH) of vegetable emulsions on texture in falafel. All falafels analysed were frozen prior to seven days chilled storage. a) Firmness. The y-axis shows firmness measured in g. One outlier of cauliflower fraction pre-emulsion was removed. b) Toughness. The y-axis shows toughness measured in g.sec. One outlier of onion pre-emulsion and one outlier of cauliflower bouquet pre-emulsion were removed.

Figure 3.13 shows the texture analysis results from experiment 4. Fresh falafels were analysed on production day, while stored falafels were treated as in experiment 2 and 3. Significant effect of pulse type was found in fresh falafels regarding both firmness ($p = 0.0057$) and toughness ($p = 0.051$), showing that faba beans resulted in the highest firmness and toughness, while chickpeas resulted in the lowest firmness and toughness. The stored falafel variants did however not result in any significant effects regarding firmness and toughness. There were no significant differences between falafels containing cauliflower fraction pre-emulsion and control falafels.

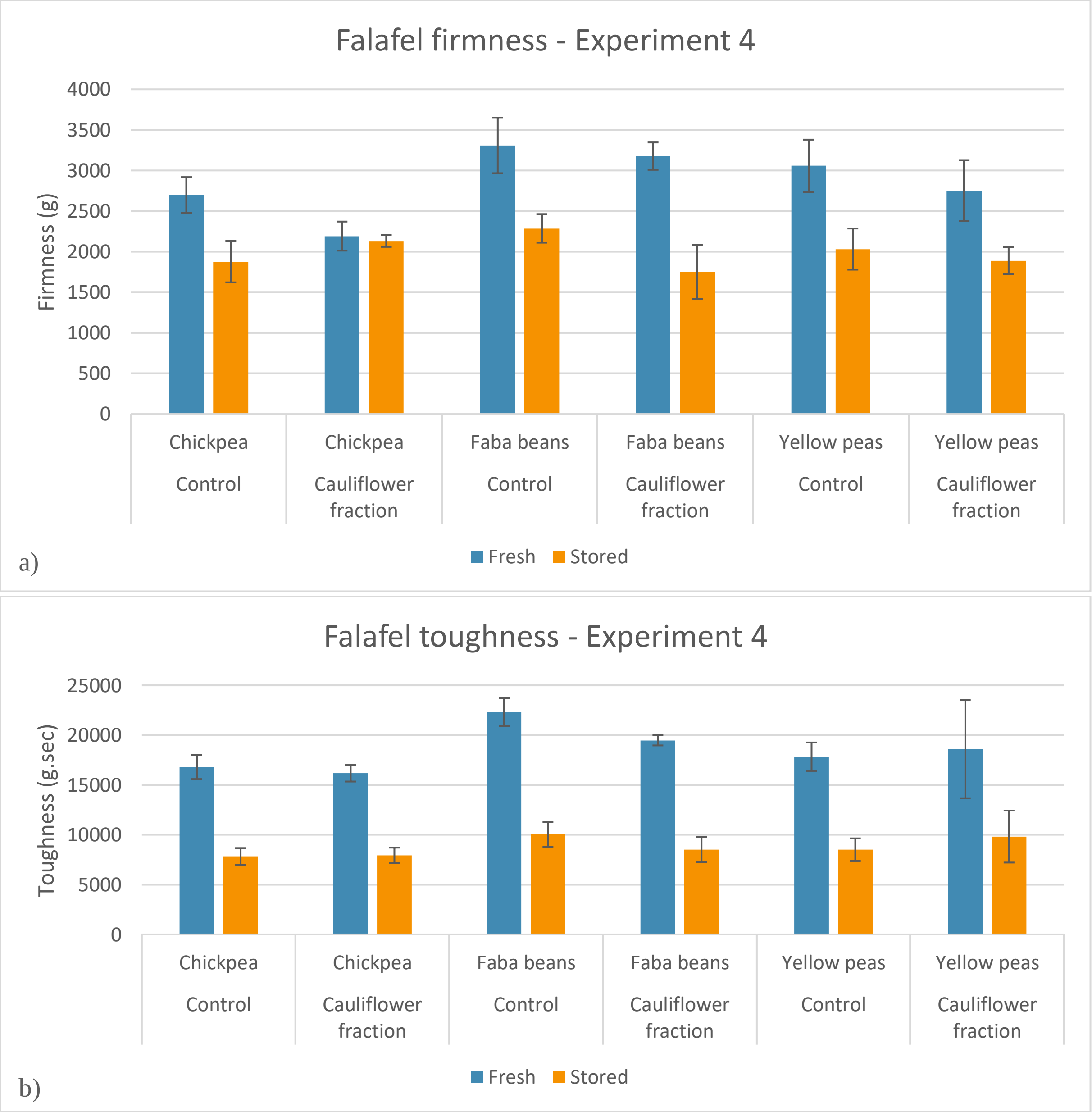

Figure 3.13: Texture analysis of experiment 4, effect of faba beans, yellow peas, and cauliflower fraction on texture in falafel. Two storage variations, fresh and frozen prior to seven days chilled storage, are marked in different colours explained in the bottom of the figures. a) Firmness. The y-axis shows firmness measured in g. b) Toughness. The y-axis shows toughness measured in g.sec.

Figure 3.14 shows the texture analysis results from experiment 5. This experiment had a larger number of storage variations. Fresh and stored falafels were treated in the same way as in experiment 4. The three remaining variants were all stored one day chilled after being frozen and were either analysed at room temperature, reheated, or at room temperature cut in halves. The fresh falafels showed no significant effects, but the stored falafels showed that faba beans resulted in significantly increased firmness (p = 0.0331) and toughness (p = 0.0482) compared to chickpeas.

Of the falafels stored one day, room temperature falafels also confirmed that faba beans resulted in significantly increased toughness compared to chickpeas (p = 0.0419). This effect was however not observed when the falafels were reheated, and the opposite effect (faba beans resulting in decreased toughness compared to chickpeas) was shown when falafel halves were analysed (p = 0.0314). Lastly, only falafel halves showed a significant effect of adding pre-emulsion in experiment 5, where pre-emulsion resulted in significantly decreased toughness compared to the control (p = 0.0041). This was an interaction effect, as it was more clearly observed with chickpea falafels compared to faba bean falafels. No significant effects on firmness were shown analysing falafel halves.

The texture analysis results of the store bought falafels were not analysed using statistical software. However, as can be seen in figure 3.14, the store bought falafels clearly had a decreased firmness and toughness compared to the falafels produced in this study.

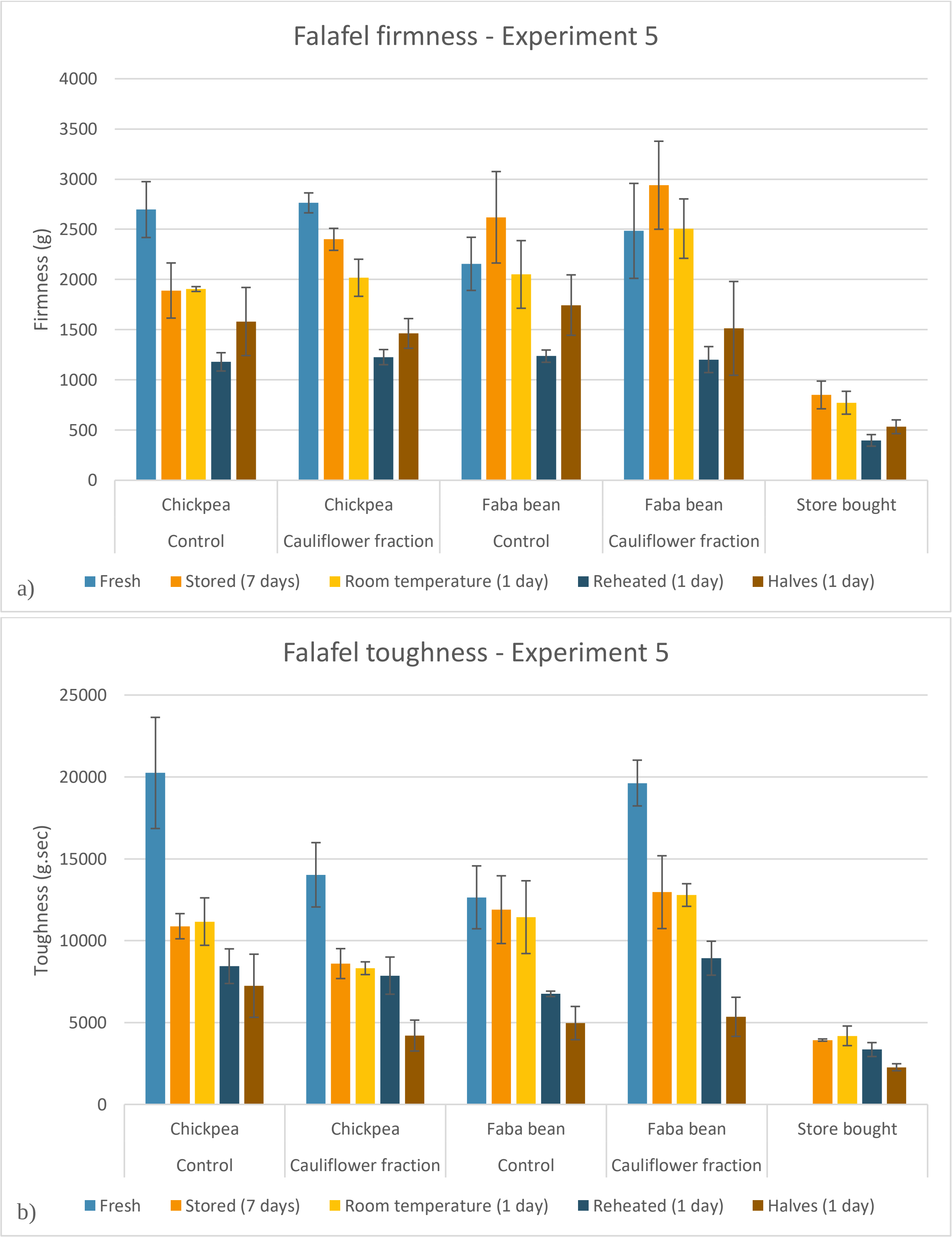

Figure 3.14: Texture analysis of experiment 5, effect of faba beans and cauliflower fraction on texture in falafel. Three storage variations, fresh and frozen prior to seven days chilled storage, as well as one day chilled storage after freezing analysed at room temperature, reheated, and cut in half, are marked in different colours explained in the bottom of the figures. a) Firmness. The y-axis shows firmness measured in g. b) Toughness. The y-axis shows toughness measured in g.sec.

An alternative texture analysis method using a cylinder probe was performed to compare with the knife-method in experiment 2 and 4. In experiment 2, a method with 40 % strain was used. Due to some problems related to this method, such as lack of toughness-values, the method was adjusted (amongst other things increasing from 40 % to 70 % strain) in experiment 4.

In experiment 2 (figure 3.15), as previously mentioned, falafels containing vegetable emulsions had significantly increased firmness compared to control falafels (p = 0.002), when measured using the knife method. When the cylinder method was used however, no significant differences in firmness were observed.

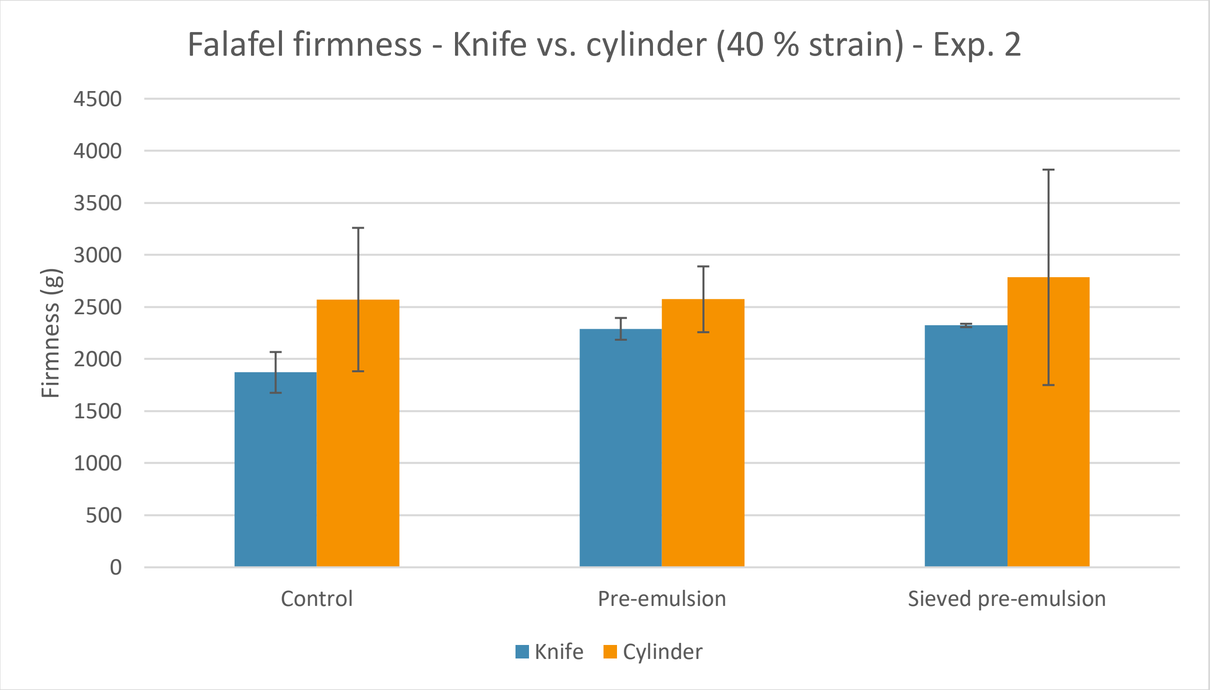

Figure 3.15: Texture analysis of experiment 2, comparison of knife and cylinder probe method (40 % strain). The methods are marked in different colours explained in the bottom of the figures. Chickpea falafels frozen prior to seven days chilled storage were used. The y-axis shows firmness measured in g.

In experiment 4 (figure 3.16), using the chickpea variants, both the knife method and the cylinder probe method showed no significant differences between the falafel variants.

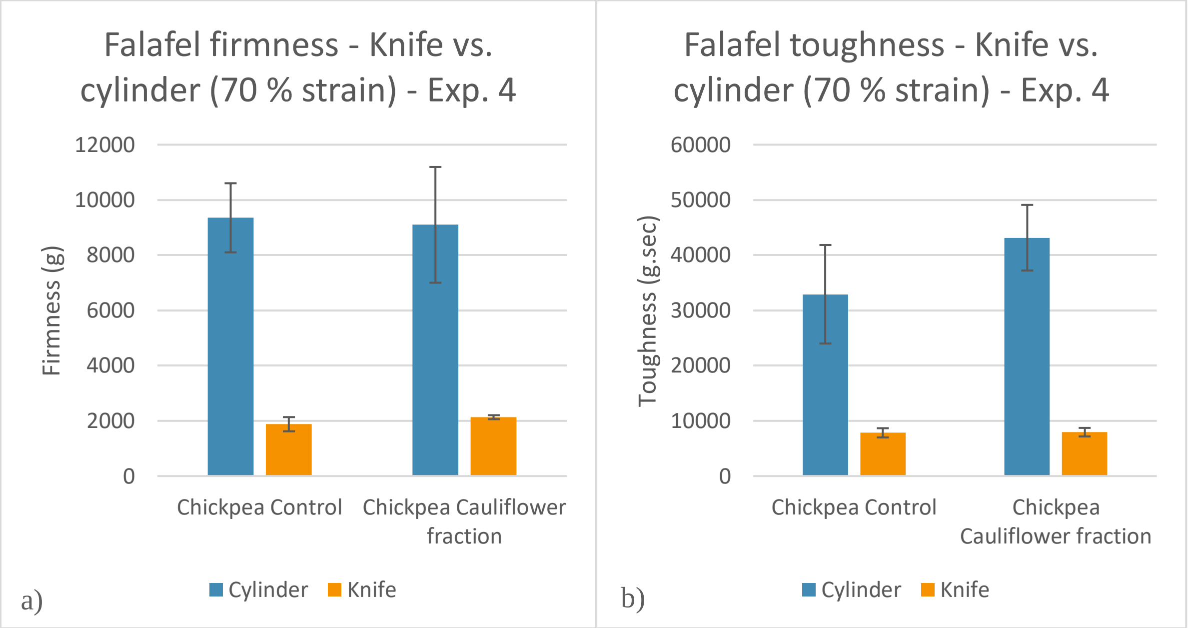

Figure 3.16: Texture analysis of experiment 4, comparison of knife and cylinder probe method (70 % strain). The methods are marked in different colours explained in the bottom of the figures. Chickpea falafels frozen prior to seven days chilled storage were used. a) Firmness. The y-axis shows firmness measured in g. b) Toughness. The y-axis shows toughness measured in g.sec.

3.2.3. Sensory analysis

A brief summary of the informal benchtop tastings of experiment 1-4, as well as the more comprehensive analysis from experiment 5, is presented below.

Overall, the control falafel doughs had a looser texture compared to the doughs containing vegetable emulsions. Additionally, the control doughs, especially faba bean and yellow pea, expelled some water between shaping and frying. The doughs containing emulsions were described as stickier.

Regarding texture, falafels with higher potato starch level were perceived as more compact in experiment 1. In experiment 3 some variants containing HPH-emulsions are described as more compact compared to pre-emulsions. Most of the participants in experiment 4 perceived the controls as drier than the falafels containing emulsions, while chickpea and yellow pea were regarded as drier than faba bean. Lastly, the controls are described as less firm compared to the falafels containing cauliflower fraction pre-emulsion in experiment 5.

In experiment 1 and 2 the carrot flavour was described as more intense with pre-emulsion instead of mash, and after sieving compared to no sieving. Additionally, in experiment 3, the cauliflower taste was possibly stronger with HPH-treated emulsions compared to pre-emulsions. In experiment 4 however, which had two additional sensory participants, most participants tasted no clear cauliflower flavour and no apparent faba bean or pea flavour. Falafels containing vegetable emulsion had a darker surface after frying compared to control falafels.

Figure 3.17 shows the numerical results of the sensory analysis from experiment 5. For most of the variants, reheating appears to increase firmness and decrease dryness. There is no clear variant that stands out, but faba bean cauliflower appears to be less firm and tough. The participants disagreed most on evaluation of toughness. Additionally, several participants commented that it was difficult to differentiate the samples.

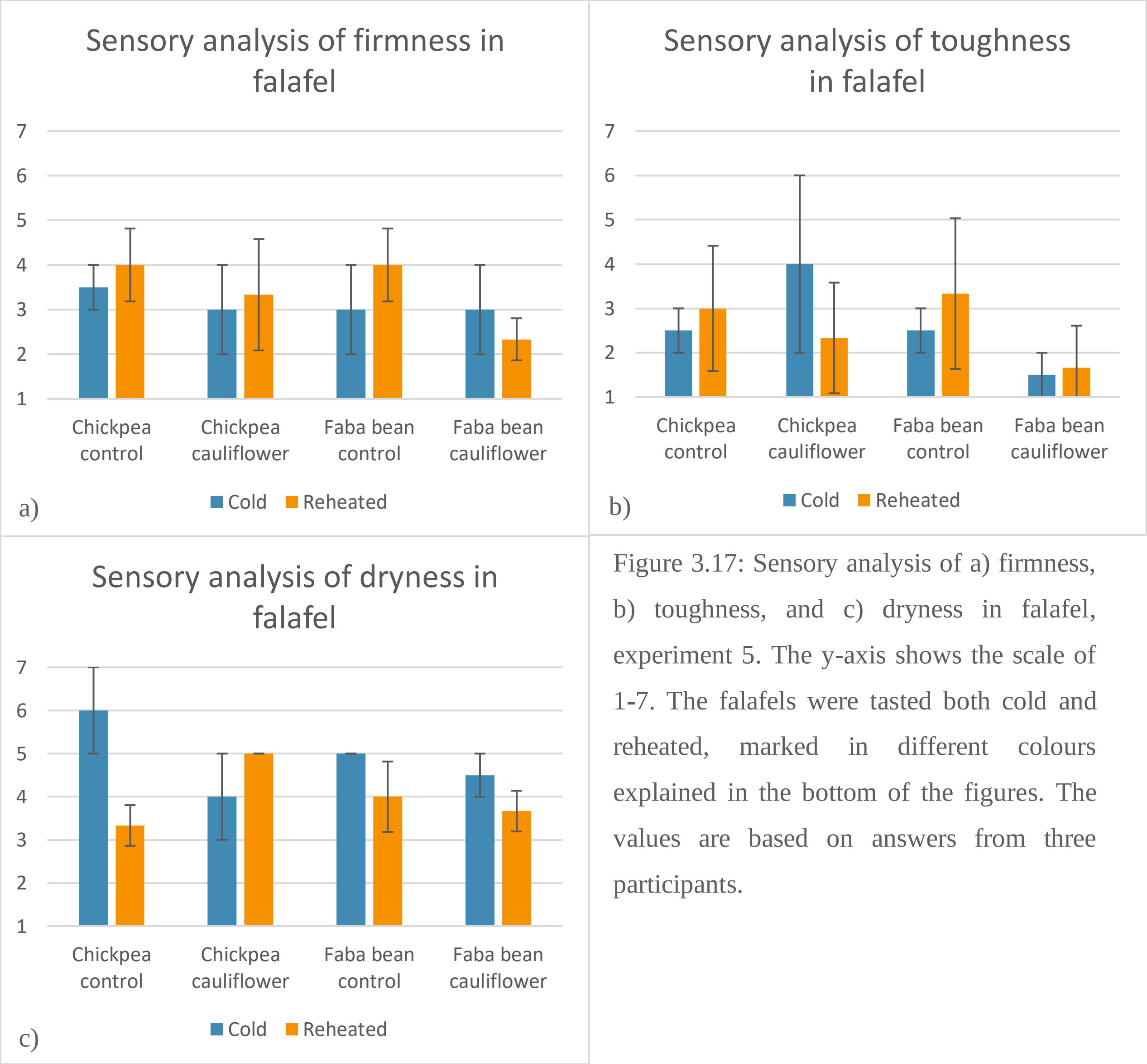

Figure 3.17: Sensory analysis of a) firmness, b) toughness, and c) dryness in falafel, experiment 5. The y-axis shows the scale of 1-7. The falafels were tasted both cold and reheated, marked in different colours explained in the bottom of the figures. The values are based on answers from three participants.

3.3. Principal Component Analysis (PCA)

The PCA-plot (figure 3.18) shows how the results of the emulsion analyses (pH, oil droplet size, viscosity, and dry matter content) and falafel attributes (water loss, firmness, and toughness) relate to the falafel variants. As the data related to the store bought falafel was limited, it was not included in the PCA.

Principal component 1 (PC-1) and principal component 2 (PC-2) in the model explains, respectively, 41 % and 33 % of the variation. Thus, 74 % of the variation is explained by the first two components.

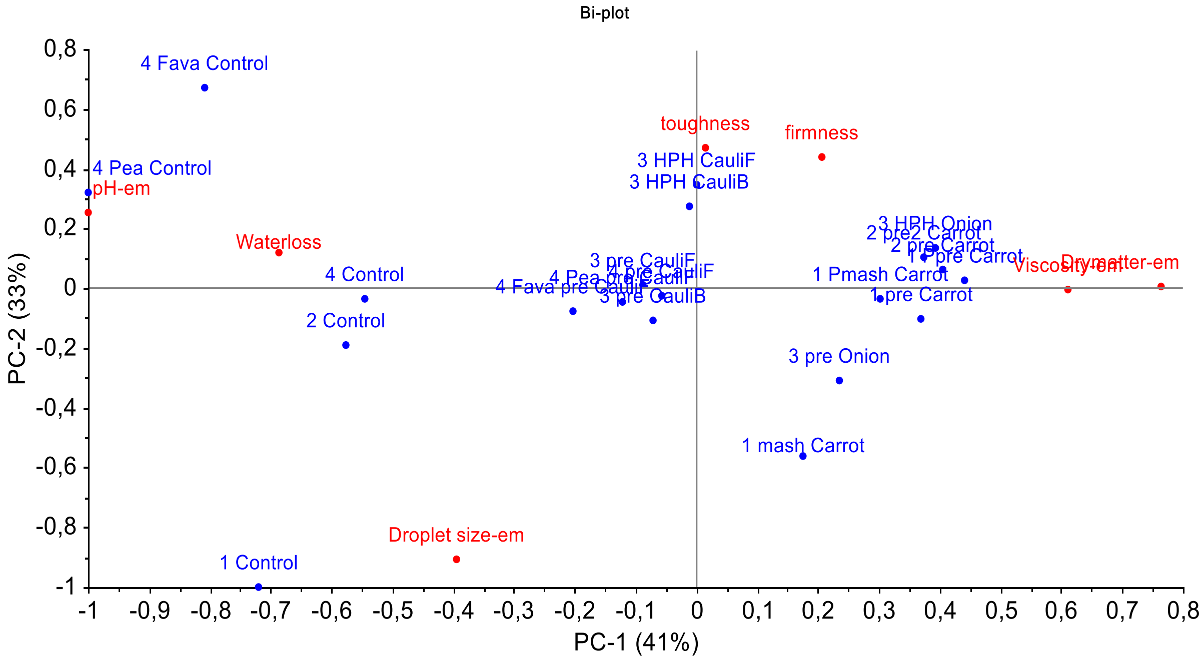

Figure 3.18: PCA-plot of emulsion analyses (in red, marked with "-em"), falafel attributes (in red), and falafel variants (in blue, first digit signifies experiment number). Data from falafels frozen and stored chilled from all experiments was used in this plot. P = High level of potato starch. Fava = Faba beans. Pea = Yellow peas. Absence of fava/pea = Chickpeas.

Differences in falafel water loss, as well as emulsion viscosity and dry matter content explain most of the variation in PC1. Emulsion viscosity and dry matter content appear to be positively correlated to each other, while being negatively correlated to falafel water loss. There is a clear difference between the control falafels and the falafels containing emulsions, where the controls are more likely to have a higher water loss.

Most of the variation in PC2 is due to toughness and firmness, which appear to be positively correlated, and oil droplet size, which appears to be negatively correlated to the two other attributes. The chickpea control of experiment 1 differentiates itself from the two chickpea controls of experiment 2 and 4, and is more likely to have a decreased toughness and firmness. Faba bean and yellow pea controls more likely have an increased toughness and firmness compared to the chickpea controls. Falafels with HPH-emulsions appear to be less associated with increased oil droplet size, and more associated with increased firmness and toughness, compared to falafels with pre-emulsions or carrot mash. Additionally, falafels with a higher level of potato starch are more associated with increased firmness and toughness compared to a lower potato starch level. Overall, toughness and firmness did not appear to be correlated to falafel water loss.

4. Discussion

The results related to the vegetable emulsions are discussed first, followed by the falafel results and how these can be viewed in context with each other. Limitations related to this study, and how these could have been improved, are further reflected upon. Lastly, outcome of the results and suggestions for further research are considered.

4.1. Vegetable emulsions

The viscosity of the emulsions varied depending on vegetable and processing. Dry matter content of the emulsions appeared to be positively correlated with viscosity in the PCA-plot. However, this was not apparent solely based on the emulsion analysis results. Thus, it is possible that the dry matter content itself (of which fibre is a main component), not the amount of it, is more important regarding emulsion viscosity.

As expected, HPH-treatment decreased the oil droplet size in the emulsions. According to Rød (2015) decreased particle size in tomato emulsions, as a result of increased homogenisation pressure, was correlated to increased viscosity. The results of this study show that this seems to be true regarding onion, as the HPH-treated onion emulsion had a higher viscosity compared to the pre-emulsion. The cauliflower variants, on the other hand, showed a reduction in emulsion viscosity when treated with HPH.

It has previously been shown that HPH-treatment can affect the pectin structure in vegetable suspensions/emulsions, and thus the viscosity. HPH-treatment was shown by Van Buggenhout et al. (2015) to increase the water holding and swelling capacity of orange pulp, due to changes in pectin structure. Additionally, Santiago et al. (2017) has shown that intense HPH-treatment may restore and improve the viscosity of tomato purées with consistency loss following enzymatic degradation of pectin. HPH-treatment of carrot was shown to provoke mechanical solubilization of pectin, which affects serum viscosity (Moelants et al., 2013). In the same experiment, tomato suspensions were shown to be less sensitive to the same process. Rød (2015) discovered a correlation between viscosity and pectin content of tomatoes, with increasing pectin content resulting in increased viscosity of tomato emulsions. Thus, it was expected that HPH-treatment might solubilise the pectin of the vegetable emulsions, resulting in increased viscosity. However, as onion had an increased viscosity while cauliflower viscosity decreased, it is possible that the pectin is not as easily solubilised in all vegetable types.

A study by Lopez-Sanchez et al. (2011) confirmed that HPH-treatment increased the viscosity of tomato dispersions. However, the same process decreased the viscosity of broccoli and carrot dispersions, indicating that the changes are dependent on vegetable type. The authors argue that this may be due to different microstructures, as a result of particle size distribution, morphology, and phase volume. Different cellulose/pectin ratios and crosslinking between the polysaccharides of the different vegetables were highlighted. While the carrot and broccoli cell wall structures remained compact, tomato cell walls were more affected by HPH-treatment and thus significantly swollen, resulting in a higher phase volume. The cauliflower variants in this study may therefore, as the broccoli and carrot in the mentioned study, result in different microstructures after HPH-treatment compared to onion, and thus also different viscosities. Differences between cauliflower fraction and cauliflower bouquet emulsions could be due to cauliflower fraction containing more stem tissue, which might have different fibre content ratios compared to the bouquets. This has previously been observed with broccoli (Lopez-Sanchez et al., 2011).

As HPH-emulsions of carrot were not produced in this study, no conclusions can be made regarding this vegetable. Comparing with the study by Lopez-Sanchez et al. (2011) however, it was expected that the viscosity should decrease with HPH-treatment.

The fluid release results indicated that the HPH-emulsions were more stable compared to the pre-emulsions. This was as expected, since the increased processing may have solubilised more fibre, which can bind water.

4.2. Falafels

This study mainly focused on texture in falafel. A study by Ismail et al. (2018) argue that higher moisture and oil contents of falafels results in lower firmness and hardness. Thus, it was expected that higher water loss should result in firmer falafels in this study. However, firmness (and toughness) appeared to be neither positively nor negatively associated with water loss, according to the PCA-plot. A possible reason for this is that the water loss was not large enough to influence the texture with the types of analyses used in this study. Another explanation could be that firmness and toughness are measurements that are more dependent on surface/crust texture compared to the texture inside the falafel. This is further discussed in chapter 4.2.5. The sensory analyses do not appear to give a clear answer to this when used for comparison. Further research, preferably including a trained sensory panel, is needed to determine this.

4.2.1. Effect of potato starch level

Higher level of potato starch (12 % compared to 5.6 %) resulted in increased firmness and was perceived as more compact in the informal sensory analysis. As expected, it also decreased water loss. This is because potato starch has a good water binding capacity (Wootton & Bamunuarachchi, 1978).

4.2.2. Effect of vegetable emulsion

Comparing the falafels containing vegetable emulsions with control falafels, addition of emulsion overall resulted in decreased water loss in falafel. Emulsions appeared to increase firmness in experiments 1-2, while any emulsion effects were less apparent in experiments 4-5. As the first experiments used carrot emulsions, while the last used cauliflower fraction emulsions, this difference could be due to vegetable type. However, although vegetable type was shown to affect viscosity in the emulsions, it did not significantly affect water loss and texture in falafel in experiment 3. No correlations were found between falafel firmness/toughness and emulsion viscosity/dry matter content in the PCA-plot either. Additionally, the sensory analyses indicated that the falafels containing vegetables in many cases did not have a strong vegetable flavour. This could indicate that several types of vegetables may be used without large changes in quality, making possible producers less dependent on certain vegetable types. However, as flavour was not the focus of this study, this should be further investigated. This is especially relevant since flavour can develop over a longer storage time than investigated in this study. Furthermore, the sensory analysis of experiment 4 indicated that falafels containing vegetable emulsions were less dry compared to the controls. This is positive, as dryness is a common problem related to these types of products.

Although texture was the main focus in this study, the informal sensory analyses also included some comments on falafel colour. The falafels containing vegetable emulsions had a darker fried outer layer compared to the controls. This is most likely due to the higher amount of sugars, which take part in the Maillard reaction (non-enzymatic browning) (Fellows, 2009).

4.2.3. Effect of vegetable processing

As previously discussed, processing type may affect fibres in vegetables, such as pectin and cellulose, which may affect texture in falafel when those processed vegetables are added as an ingredient.

It was expected that more pectin and other fibres would be released by homogenisation in a blender compared to gentle hand mashing. Falafels containing carrot pre-emulsion had a decreased water loss and increased firmness, compared to falafels containing carrot mash. The emulsification might have resulted in the decreased water loss, while it is possible that more solubilised fibre resulted in firmer falafels.

As sieving the vegetable pre-emulsions may remove fibres, it was expected that it might affect water loss and texture in falafel. However, there were no significant differences discovered related to firmness and toughness, and only a possible tendency of decreased water loss.

Falafels containing HPH-emulsions did not have a significantly different water loss or toughness compared to falafels containing pre-emulsions. However, HPH-treatment of the vegetable emulsions appeared to increase firmness in falafels, which may be due to the increased amount of solubilised fibre, as already suggested. On the other hand, as the effect was larger for cauliflower compared to onion, and HPH-treated onion was shown to have a higher viscosity compared to HPH-treated cauliflower, this contradicts the theory. However, as there were no significant effects of vegetable type, the difference in effect may have another reason. This experiment should be repeated for increased validity of the results.

4.2.4. Effect of pulse type

There were few differences found between falafels based on faba beans/yellow peas and chickpeas. Falafels based on faba beans were significantly firmer than yellow pea falafels and chickpea falafels for several storage variations. Additionally, both falafel types based on alternative pulses had a significantly increased water loss in experiment 4, but the difference was not significant when repeated for faba beans in experiment 5. No clear variant stood out from the sensory analysis of experiment 5.

A master’s thesis by Janhager (2020) regarding use of Nordic grown pulses in falafel, concluded that many types of pulses can be used to make falafel, including faba beans and yellow peas. Some pulses, such as lupins and lentils, were however more suited than others, based on sensory evaluations on liking and variation in physicochemical properties. Both of these conclusions are thus in line with the results of this study, as there were few differences using the three pulse types, but yellow peas might be a more suitable alternative to chickpeas than faba beans.

The sensory analysis of experiment 4 showed that, overall, there was no obvious faba bean or pea flavour. This is positive, as unwanted “beany” flavours are a common problem when peas are used as a protein-rich food ingredient (Lan et al., 2019). However, although a falafel recipe with a decreased spice and herb amount was used, there was still some garlic, cumin, and coriander included. This mask such flavours, and thus, this problem may arise for pulse-based products using less spices.

4.2.5. Effect of storage conditions and reheating

The effects on falafel discussed in chapters 4.2.1-4.2.4 were shown to be dependent on both storage conditions and reheating, as some effects were significant in fresh falafels but not stored, and vice versa. Overall, stored falafels had a decreased firmness and toughness compared to fresh falafels. As the stored falafels had been frozen (stored at -24°C) for at least two days, followed by chilled thawing and storage (4°C), it is possible that moisture has migrated from the inside of the falafel to the crust, which is expected to decrease crust firmness. Fat migration during storage could also result in this.

Texture analysis of falafel halves was performed in experiment 5 to further investigate how the crust influences the measurements. Values for both firmness and toughness were decreased compared to whole falafels, confirming that the crust contributes to both firmness and toughness in falafel. Additionally, while whole falafels stored one day showed that faba beans resulted in significantly increased toughness compared to chickpeas, falafel halves stored one day showed the opposite significant effect (faba beans resulting in decreased toughness compared to chickpeas). Falafel halves also showed significant effects of incorporating pre-emulsion, which were not found in whole falafels. This indicates that the variations in the falafel recipes may affect the surface and the inside of the falafels differently.

Regarding falafel temperature, texture analysis showed that reheating the falafels decreased firmness and toughness. The sensory analysis however indicated that reheated falafels had an increased firmness and decreased dryness. This contradiction could also be due to differences in how falafel crust and inside texture are determined by measurement type. Furthermore, comparing the texture analysis results of the room temperature and reheated falafel samples of experiment 5, the significant effects shown in room temperature falafels was not found in reheated falafels. This also indicates that the texture changes after cooling down and/or reheating.

4.2.6. Comparison with store bought falafels

The store bought falafel appeared to be a lot softer compared to the variants produced in this study, also after heating. This could be due to different ingredients used and/or the different ingredient ratios. The store bought falafels contained less chickpeas and possibly more flour/starch. Since the fat content of the falafels made in this study was not known after frying, it is also possible that the store bought falafels contained more fat, which could result in a softer texture.

It is however worth noting that the store bought falafels would normally be heated 15 minutes, as stated on the packaging, not 5 minutes, which was used in this study for better comparison. Thus, the texture of a properly prepared store bought falafel might be firmer and tougher than measured in this study. In further research, it is therefore suggested to also compare with falafels prepared according to the packaging instructions.

4.2.7. Validity of the results

According to both PCA-plots and by comparing the firmness and toughness values, the control of experiment 1 appeared to differentiate itself from the controls of the other experiments by having a decreased firmness and toughness. As experiment 1 was performed in a different location and with more uncertainty associated with the frying temperature, the variants of experiment 1 might be less comparable to the variants of the other experiments.

The controls of experiment 2 and 4 were closer associated in the PCA-plot, and chickpea controls of experiments 2, 4, and 5 had similar values related to water loss, firmness, and toughness. This improves the validity of these experiments' results. Additionally, the partial repeat of experiment 4 resulted in the same conclusions, further improving the results' validity. However, surprisingly, the same significant effects only discovered in the fresh falafels of experiment 4 were only discovered in the stored falafels of experiment 5.

A control falafel was unfortunately not included in experiment 3. However, experiments 3-5 all include the "chickpea cauliflower fraction pre-emulsion" variant, which can be used for comparison between experiments. The firmness and toughness values of the experiment 3 variant differentiates itself more from the other two experiments' values, compared to the previously mentioned controls. However, the difference is not as large as between experiment 1 compared to the other experiments.

4.2.8. Choice of texture analysis method

The choice of texture analysis method used is also important for the validity of the results. The method needs to be chosen based on the type of food product, as well as on what kind of information about the product is desired. Using additional alternative methods may indicate how accurate the measurements of the main method are. The assumption that the results of the main method are correct can be strengthened if the results of the additional alternative methods result in the same conclusion.

In this study, it was decided that an alternative method using a cylinder probe should be used. The first cylinder probe method used (experiment 2) was deemed as unsuitable, mainly due to two reasons. Firstly, 40 % strain might have been too low to determine differences between the variants. Secondly, values related to toughness were not measured, which made the method less comparable with the knife method. Therefore, the cylinder results from experiment 2, which contradicted the results using the knife-method, are viewed as uncertain. This shows the importance of correct equipment settings, as well as correct type of method, on the validity of the results.

The method was adjusted in experiment 4, using 70 % strain and recording values related to toughness as well as firmness. The results of this experiment showed that both methods, knife and 70 % strain cylinder, resulted in the same conclusion regarding both firmness and toughness. Thus, this strengthens the assumption that the results using the knife method in the remaining experiments are valid.

4.3. Limitations

The limitations related to this study are discussed below. Overall, using more replicates for the analyses and repeating more of the experiments could have decreased the variation and increased the validity of the results. However, in this study it was chosen to focus on testing a larger amount of falafel varieties, rather than repeating all experiments.

4.3.1. Water content in falafel

As the chickpeas, faba beans, and yellow peas were measured by dry weight, the water content of the falafel dough was dependent on water absorption during soaking. Three of the experiments (2, 4, and 5) had a soaking time of 9 hours, while experiment 3 had a soaking time of 14 hours and experiment 1 had 18 hours. Thus, the water absorption might have varied between experiments. This makes the experiments less comparable. Additionally, the different pulses do not necessarily have the same rate of water absorption, as shown by Janhager (2020). Therefore, the falafel dough water content might also vary within the last two experiments. Additionally, as the control falafels clearly expelled water before weighing and frying, this could also result in varying water contents between the variants.

4.3.2. Water loss in falafel

The falafel water loss results are likely not entirely correct. The variants that had a looser dough texture (mainly the controls with 40 % water instead of 10 % water and 30 % vegetable emulsion) tended to have a higher water loss. However, this apparent water loss might also be due to the loose dough texture, as some of these falafel variants tended to lose dough before and/or during frying.

4.3.3. Texture analysis

Most of the texture analysis measurements turned out to have a large variation. There are several possible reasons for this. Firstly, and perhaps most importantly, falafel dough is not a completely homogenous mass. Mixing the dough in a food processor does not necessarily eliminate all large particles. The texture analyser is a very sensitive instrument, which can result in higher values when the probe hits larger pieces. As most of the obvious outliers in this study had higher values than the two related parallels, this seems to be a likely cause. Secondly, the falafels were shaped by hand, without weighing a specific amount of dough for each falafel. Even though all the falafels were shaped by the same person, this is still a source of increased variation. An improvement could be to use a tool to create the shapes, which would decrease the variation. Additionally, some of the variants, especially the controls, were based on a dough that had a very loose texture. This resulted in irregularly shaped falafels during frying, which again may increase the variation. Lastly, as already mentioned, the frying-oil used in experiment 1 was not temperature-controlled.

4.3.4. Sensory analysis

The large variation of the sensory analysis results from experiment 5 regarding firmness, toughness, and dryness indicates that the participants did not always agree and possibly used the scale differently. This makes it less valid to use the mean values for comparison. Additionally, the number of assessors was a bit low. Another source of variation, which may result in participants experiencing the falafels differently, is that the tests were performed individually at home. Using a trained sensory panel in a common neutral location would have improved the validity of these results. The panel would then first agree on which attributes to assess and be trained and calibrated on these. This means that all assessors agree on what each attribute means and how to use the scale (e.g., using a reference product or the two variants expected to be most different to determine what is a low or high value on the scale for each attribute). The panel could also be used to determine attributes related to flavour, such as bean/pea flavour or vegetable flavour. This was however outside the scope of this study.

4.4. Outcome and further research

These results are relevant for the food industry, as they show that it is possible to use vegetable emulsions in this type of product without unfavourable effects on texture and water loss. It is also indicated that different types of Norwegian-grown pulses may be used. This should however be further investigated, as some pulses are likely more suitable than others, and further processing and combinations with other ingredients will affect the quality characteristics.

HPH-treatment of the emulsions did not appear to have a large effect on water loss, and only some effect on texture in falafel. However, as HPH-treatment results in increased stability of the emulsions, HPH-emulsions are better suited for commercial production compared to pre-emulsions, which either need be used fresh or contain added stabilisers due to the relatively short shelf life. As it is still not common for many companies to have HPH-equipment, further research is needed to determine possible additional benefits regarding HPH-treatment of vegetable emulsions used in pulse-based products.

Additionally, it is suggested that further research in this field can focus on using mixes of different vegetables as a part of emulsions used in pulse-based products. Mixing different vegetables could make it possible to tailor functionality depending on what is required for each product. More knowledge regarding effects on oxidation, shelf life, and flavour development is also needed.

5. Conclusion

This study aimed to determine the effects vegetable emulsions and Norwegian-grown pulses have on water loss and textural properties in plant-based products, using falafel as a model. The results of the study showed that incorporating vegetable emulsions resulted in decreased water loss in falafel, and in some cases led to an increased firmness and toughness. Although differences between emulsions based on different vegetable regarding viscosity and oil droplet size were found, there were no significant differences found in falafel when different vegetable types were used. HPH-treatment of the emulsions resulted in increased falafel firmness, but no changes in toughness and water loss. Regarding pulse type, there were few differences between the imported and Norwegian-grown varieties. Faba beans and yellow peas resulted in increased water loss in falafel. Additionally, using faba beans appeared to result in increased firmness in some cases.

Thus, this study indicates that vegetable emulsions can be included to create more nutritious pulse-based products, without clear unfavourable effects on texture and water loss. As typical surplus vegetables, in addition to residual raw material from production of frozen vegetables, were chosen, this study suggests a sustainable and innovative use of these Norwegian-grown raw materials. Additionally, the results indicate that there may be potential for increased use of Norwegian-grown pulses, as opposed to using imported raw materials.

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Appendix A – Falafel recipes

Tables A.1-A.3 show the recipes used in the falafel experiments. All ingredient amounts are shown in percentages (%).

Table A.1: Recipe of control falafels.

Ingredients	%
Chickpeas/faba beans/yellow peas (dried)	46.9
Garlic	5.1
Cumin	1.1
Ground coriander	0.4
Salt	0.9
Water	40.0
Potato starch	5.6
Vegetable emulsion	0.0
Frying oil	
Total	100.0

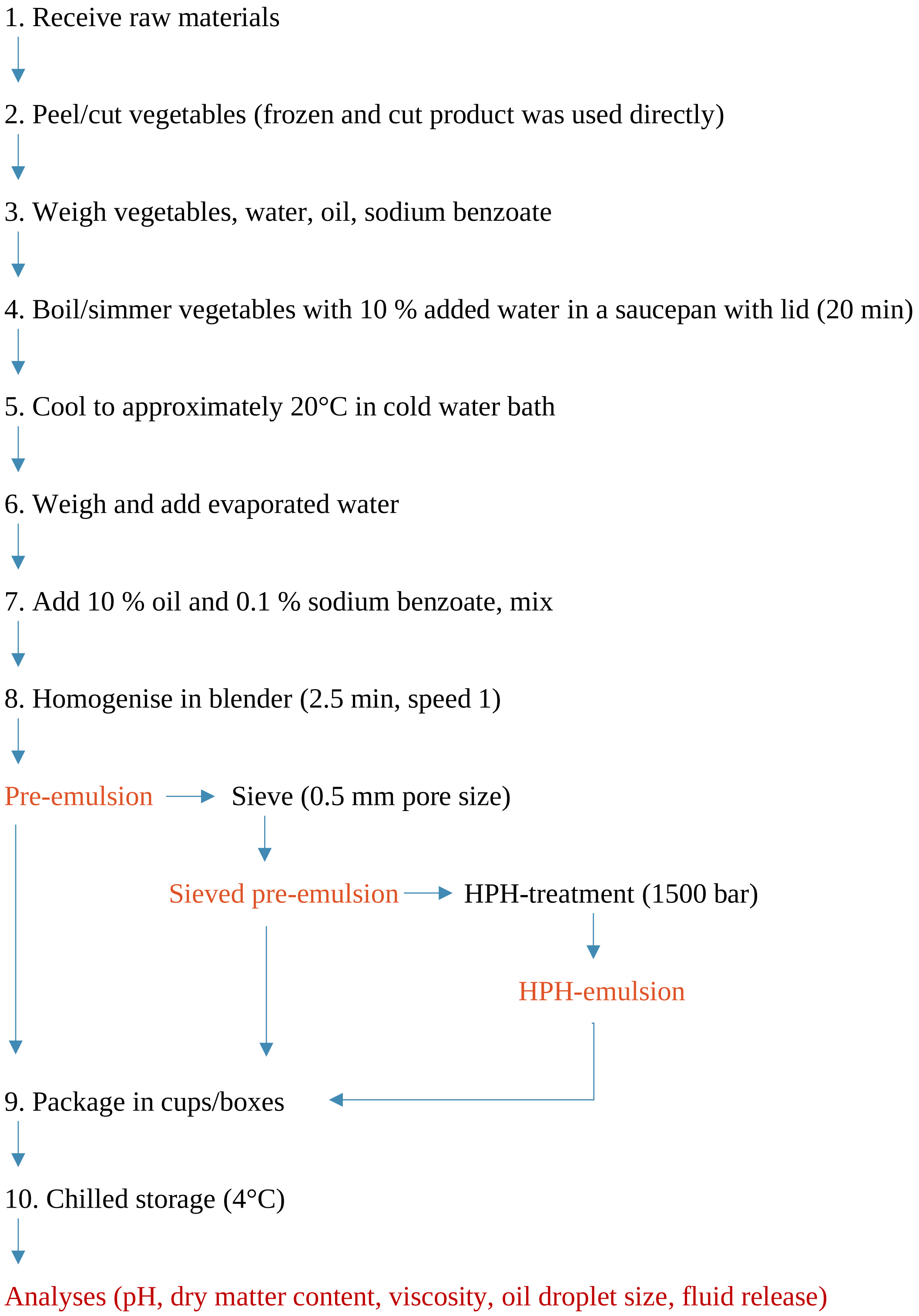
Table A.2: Recipe of falafels containing vegetable emulsion.

Ingredients	%
Chickpeas/faba beans/yellow peas (dried)	46.9
Garlic	5.1
Cumin	1.1
Ground coriander	0.4
Salt	0.9
Water	10.0
Potato starch	5.6
Vegetable emulsion	30.0
Frying oil	
Total	100.0

Table A.3: Recipe of falafels containing vegetable emulsion and high level of potato starch.

Ingredients	%
Chickpeas (dried)	46.9
Garlic	5.1
Cumin	1.1
Ground coriander	0.4
Salt	0.9
Water	3.6
Potato starch	12.0
Vegetable emulsion	30.0
Frying oil	
Total	100.0

Appendix B – Flow diagram of vegetable emulsion production



Appendix C – Flow diagram of falafel production

1. Receive raw materials

↓

2. Soak beans/peas overnight in water (approximately 9 timer, 4°C)

↓

3. Weigh remaining ingredients

↓

4. Make dough in food processor (chickpeas/faba beans/yellow peas, garlic, cumin, coriander, salt, potato starch) (4 min, speed 2)

↓

5. Distribute dough

↓

6. Mix dough with water and, if applicable, vegetable emulsion in kitchen machine (1 min, speed 1)

↓

7. Shape falafels (by hand)

↓

8. Fry falafels (4 min, 175-180°C)

↓

9. Cool → Analyses (texture analysis, sensory analysis)

↓

10. Package in cups/boxes

↓

11. Freeze/Chilled storage (-24°C / 4°C)

↓

Analyses (weighing, texture analysis, sensory analysis)

Appendix D – Hälsans Kök Falafel ingredients and nutritional info

Ingredients:

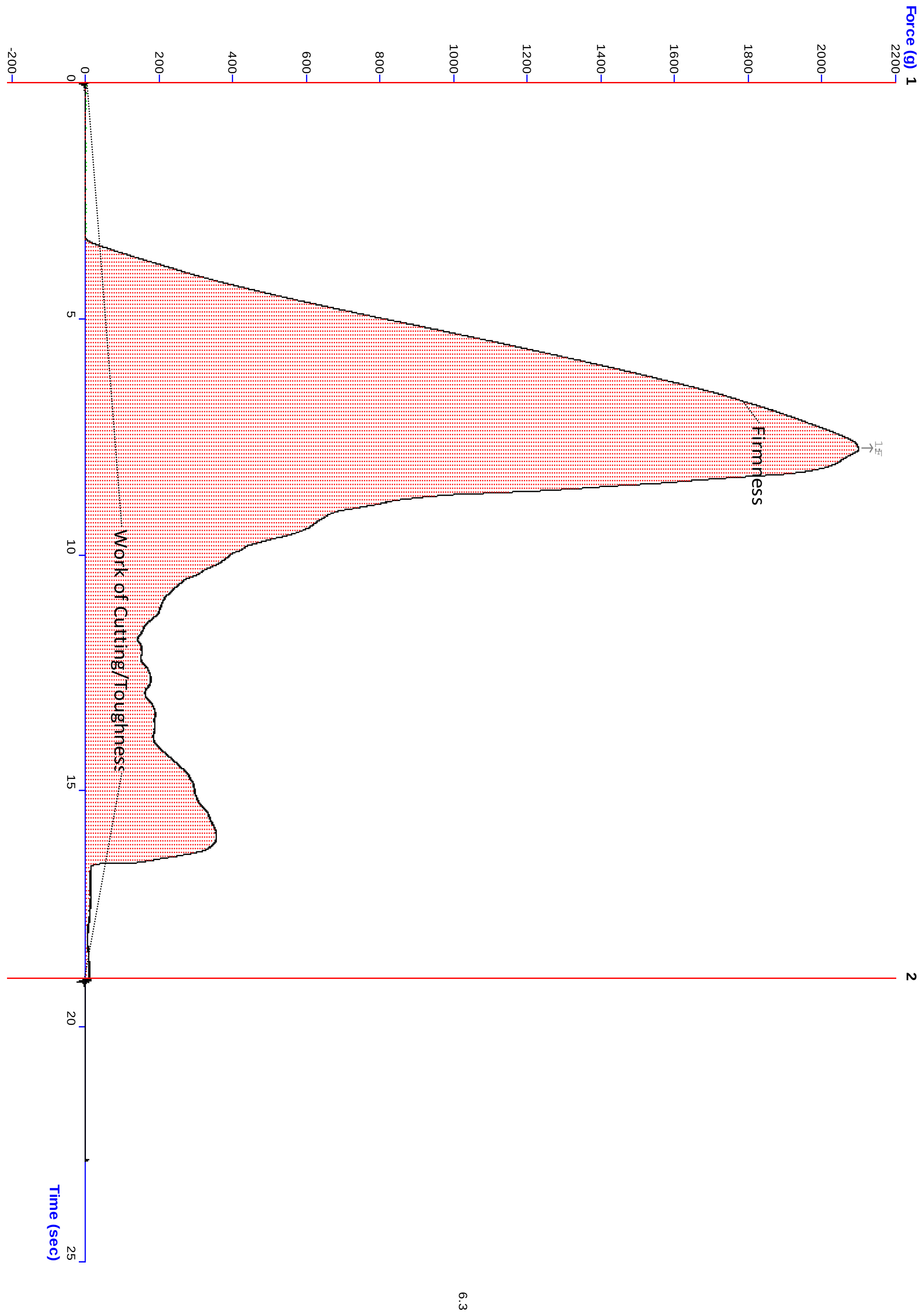
Water, chickpeas (24 %), zucchini, onion, vegetable oils (rapeseed, sunflower), wheat flour, apple puree, spices (coriander, cumin, garlic, black pepper), vinegar, parsley, salt, corn starch, yeast extract, spice extract (paprika).

May contain: egg, soy, sesame seeds, celery, and mustard.

Nutritional info	Per 100 grams
Energy	851 kJ / 204 kcal
Fat of which saturates	9.5 g 0.9 g
Carbohydrate of which sugars	19 g 2.8 g
Fibre	7.8 g
Protein	6.7 g
Salt	1.2 g

Appendix E – Texture analysis graph

The figure shows an example of a graph generated during texture analysis. The peak of the curve illustrates the maximum force needed to cut/press the falafel, which is related to firmness (expressed in g). The total area under the curve illustrates the entire accumulated force/work needed to cut or press the falafel, which is related to toughness (expressed in g.sec).



Appendix F – Sensory analysis questionnaire

Information and questions used in the sensory analysis questionnaire for experiment 5, translated from Norwegian to English.

Information part 1:

> This taste test consists of two parts. In part 1 you will taste all samples without heating them. Use one half of each sample and save the other half for part 2.

Information part 2:

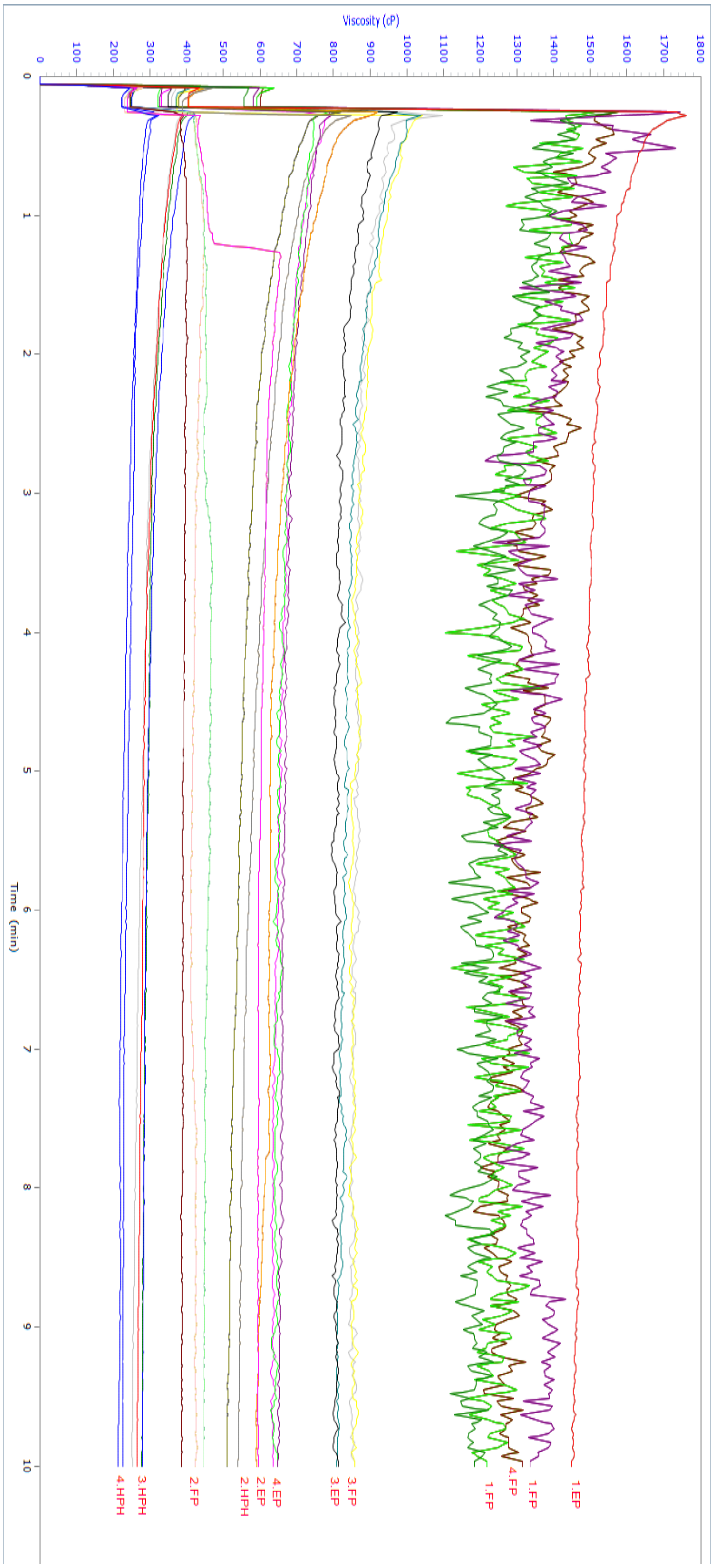
> In part 2 you will heat the second half left of each sample and taste again. The falafels can be heated in an oven at 180 degrees, approximately 5 minutes (until they are heated through).

Questions used for all variants in both parts:

1. On a scale of 1-7, how firm/hard is sample ###? Firmness is defined as a mechanical textural property related to force needed to bite through the sample. Judged by the molars at 1st bite. 1 = No intensity = no firmness. 7 = Clear intensity = clear firmness.
2. On a scale from 1-7, how tough/chewy is sample ###? Toughness is defined as a mechanical textural property related to cohesion in a tender product. In the mouth it is related to the effort needed to finely distribute the product to a state ready for ingestion. 1 = No toughness = short. 7 = clear toughness = rubbery.
3. On a scale from 1-7, how dry is sample ###? Dryness is defined as a surface textual property that describes liquid absorbed or released from a product. Mouthfeel of dryness, judged after 4-5 chews. 1 = No intensity = no dryness (juicy). 7 = Clear intensity = clear dryness (shortbread).

Appendix G – Viscosity profiles of vegetable emulsions

The figure shows the curves of the viscosity measurements of all vegetable emulsions, over 10 min. The y-axis shows viscosity measured in centipoise (cP), while the x-axis shows time measured in minutes.



1 = Carrot

2 = Onion

3 = Cauliflower fraction

4 = Cauliflower bouquet

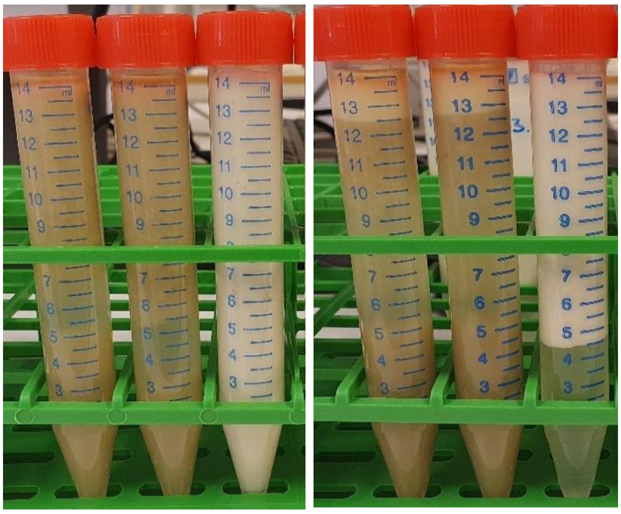
FP = Pre-emulsion

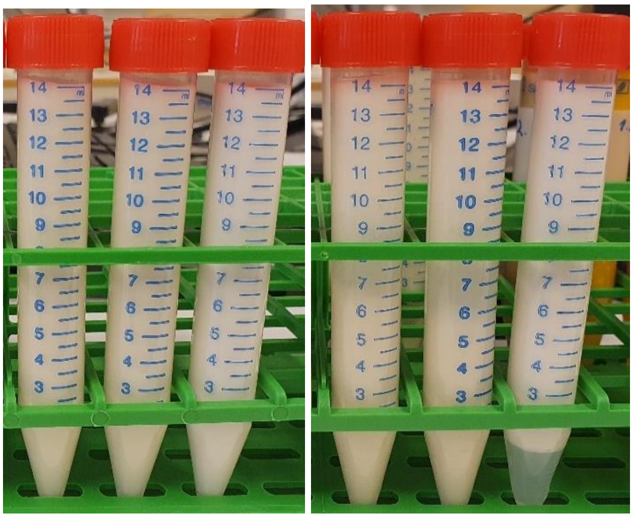
EP = Sieved pre-emulsion

HPH = HPH-treated sieved pre-emulsion

Appendix H – Results of emulsion fluid release

The table shows the results of centrifugation on fluid release in vegetable emulsions, after 4 weeks of storage at 4°C. 14 ml of emulsion was centrifuged for 5 minutes at either 2000 rpm or 4000 rpm. rpm = revolutions per minute.

Emulsion type	Visual evaluation of fluid release
Carrot. Left: Pre-emulsion Right: Sieved pre-emulsion  2000 rpm 4000 rpm	**2000 rpm:** Pre-emulsion no change. Watery bottom layer of sieved pre-emulsion. **4000 rpm:** Watery bottom layer for both variants. Most for sieved pre-emulsion.
Onion. Left: Pre-emulsion Middle: Sieved pre-emulsion Right: HPH-emulsion  2000 rpm 4000 rpm	**2000 rpm:** Approximately 1.5 ml watery middle layer and thin top oil layer for both pre-emulsion variants. No change for the HPH-emulsion. **4000 rpm:** 4-5 ml watery middle layer for both pre-emulsions (most for sieved). 1.5 ml white top layer and thin top oil layer for both pre-emulsions. 4.5 ml clear bottom layer for HPH-emulsion.

Cauliflower fraction. Left: Pre-emulsion Middle: Sieved pre-emulsion Right: HPH-emulsion  2000 rpm 4000 rpm	**2000 rpm:** No change **4000 rpm:** 3.5-4.5 ml watery middle layer for both pre-emulsions (most for sieved). Approximately 1 ml clear bottom layer for HPH-emulsion.
Cauliflower bouquet. Left: Sieved pre-emulsion Right: HPH-emulsion  2000 rpm 4000 rpm	**2000 rpm:** Watery bottom layer for sieved pre-emulsion. Small clear bottom layer from HPH-emulsion. **4000 rpm:** 3 ml watery middle layer for sieved pre-emulsion. 4.5 ml clear bottom layer for HPH-emulsion.

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