Suitability of different pulses in falafel making

– A new application for Swedish foods

Lämplighet av olika baljväxter i falafeltillverkning – ett nytt användningsområde för svenska livsmedel

Johanna Janhager

Master thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
Department of Molecular Sciences
Agriculture programme – Food science
Molecular Sciences, 2020:05
Uppsala, 2020

Suitability of different pulses in falafel making – a new application for Swedish foods

Lämplighet av olika baljväxter i falafeltillverkning – ett nytt användningsområde för svenska livsmedel

Johanna Janhager

Supervisor:	**Jonas Ohlsson, SLU, Department of Molecular Sciences**
Assistant supervisor:	Daniel Johansson, SLU, Department of Molecular Sciences
Assistant supervisor:	Sanna Pyykönen, Sevan Hummus Factory AB
Examiner:	Sabine Sampels, SLU, Department of Molecular Sciences

Credits:	30 hp credits
Level:	Second cycle, A2E
Course title:	Master thesis in food science
Course code:	EX0877
Programme/education:	Agriculture programme – Food Science
Course coordinating dept:	Department of Molecular Sciences

Place of publication:	Uppsala
Year of publication:	2020
Cover pictures:	Johanna Janhager
Title of series:	Molecular Sciences
Part number:	2020:05

Keywords: pulses, grain legumes, Swedish agriculture, product development, falafel, Texture Profile Analysis, sensory analysis

Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Molecular Sciences

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visiable and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file.

If you are more than one author you all need to agree on a decision. You can find more information about publishing and archiving here: https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.

Abstract

There is potential for growing several types of pulses in Sweden. An increased domestic pulse cultivation and consumption could have many positive effects, such as reduced climate impacts, furthering of local societies, improved soils and increased resilience in food production. The present study aimed to evaluate the use of Nordic grown pulses in falafel, a deep-fried patty traditionally made from chickpeas or faba beans. The purpose was to create a new application for Swedish pulses in order to promote domestic pulse production. Falafels made from pea, bean, lentil and lupin were subjected to physicochemical analyses and a sensory acceptance test. The best liked falafel was then included in an optimisation to obtain a highly desirable texture. The falafels made from different pulses had significantly different physicochemical properties, with most of the variation due to differences in water absorption during soaking, water loss in deep-frying, the textural properties cohesiveness and hardness, and in colour measurements. The sensory evaluations indicated that all falafels were liked by consumers, with exception for yellow pea falafels. High liking of appearance correlated with large values of redness ($a*$) and contrast in lightness ($L*$) between falafel exterior and interior. High liking of texture correlated with large moisture content in falafel batter and weight increase in soaking, and with low hardness. An optimisation using response surface methodology was constructed for Gotland lentil falafels to investigate the effect of soaking time and $NaHCO_3$ concentration in the soaking water on the water uptake of lentils and textural hardness of falafels. Soaking time was the most important factor, where 10–13 hours was optimal for Gotland lentils to obtain both high water uptake and low hardness values. In conclusion, several Nordic grown pulses were suitable for falafel making, and soaking time had a significant effect on textural properties of Gotland lentil falafels.

Keywords: pulses, grain legumes, Swedish agriculture, product development, falafel, Texture Profile Analysis, sensory analysis

Sammanfattning

Det finns potential för att odla flera typer av baljväxter i Sverige. En ökad inhemsk odling och konsumtion av baljväxter kan leda till flera positiva effekter, såsom minskad klimatpåverkan, ökad motståndskraft i livsmedelsproduktionen, förbättrade jordar, och främjande av lokala samhällen. Denna studie syftade till att utvärdera användningen av Nordiskodlade baljväxter i falafel, en typ av friterad baljväxtbiff som traditionellt tillverkats av kikärtor eller åkerbönor i Mellanöstern. Målet med studien var att finna ett nytt användningsområde för svenska baljväxter för att på så sätt främja den inhemska produktionen av dessa grödor. Falaflarna utvärderades genom fysikokemiska analyser och ett sensoriskt acceptanstest. Den mest gillade falafeln inkluderades i en optimeringsprocess för att uppnå en maximalt önskvärd textur. Falaflar gjorda av baljväxter i de huvudsakliga baljväxtgrupperna ärtor, bönor, linser och lupiner kunde tas fram. De fysikokemiska egenskaperna skiljde sig signifikant åt mellan de olika falaflarna. Variationen mellan falaflarna förklarades framförallt av skillnader i vattenabsorption under blötläggning, vattenförlust vid fritering, texturegenskaperna sammanhållning och hårdhet, samt av skillnader i färgmätningar. De sensoriska bedömningarna antydde att alla falaflar gillades av konsumenterna, undantaget de som tillverkats av gula ärtor. Högt gillande av utseende korrelerade med färger mot rött i en grön-röd skala och höga värden för ljuskontrast mellan falaflars insida och utsida. Högt gillande av textur korrelerade med stort vattenupptag vid blötläggning och högt vatteninnehåll i falaflar före fritering, samt med låg hårdhet. En optimering konstruerades för falafel på Gotlandslins för att undersöka effekten av blötläggningstid och koncentration av $NaHCO_3$ i blötläggningsvattnet på linsernas vattenupptag och falaflarnas texturmässiga hårdhet. Blötläggningstid var den viktigaste faktorn för att uppnå stort vattenupptag och låg hårdhet, där 10–13 timmar var optimalt för Gotlandslins. Detta arbete visade att flera baljväxter odlade i Norden kunde användas i falafel, och att blötläggningstid hade signifikant effekt på texturmässiga egenskaper hos Gotlands lins-falafel.

Nyckelord: baljväxter, svenskt jordbruk, produktutveckling, falafel, texturanalys, sensorisk analys

Table of contents

List of tables

List of figures

Abbreviations

ANOVA	Analysis of variance
GHG	Greenhouse gases
HIP	Hexane-Isopropanol
PLS	Partial least squares
PCA	Principal components analysis
PC	Principal component
RCF	Relative centrifugal force
RSM	Response surface methodology
TPA	Texture profile analysis
VIP	Variable influence on projection

1. Introduction

Environmental health is largely impacted by food systems (Tilman & Clark, 2014). To be more sustainable, future diets should be high in plant-based foods, which have lower greenhouse gas (GHG) emissions than foods of animal origin. Pulses provide a protein source with low GHG emissions per gram of protein (*ibid.*), and pulse cultivation has several beneficial agricultural effects due to their nitrogen fixation (Foyer *et al.*, 2016).

The Swedish consumption of animal foods is decreasing (Swedish Board of Agriculture, 2019b), and Swedes are interested in consuming more domestically produced foods as a way of becoming more sustainable (Lööv *et al.*, 2015; Ekelund Axelson & Persson, 2012). In line with this is the increasing demand for domestic pulses (Östberg, 2019; Olsson, 2017; Sundén, 2014). Swedish farmers want to increase domestic pulse production to become more sustainable, resilient, and to increase self-sufficiency of Swedish food production (*ibid.*). The recently passed Swedish food strategy aims to increase domestic food production as a means of meeting climate goals, furthering a green economy, improving food security, and increasing employment and profitability of the agricultural sector (Government offices, 2017).

New areas of application are needed to enable the cultivation and consumption of Swedish pulses (Carlsson, 2012; Fogelberg, 2008). Product development brings forward new products, but the food market is highly competitive (Tuorila, 2007). It is important to understand consumer preference to ensure success of new products (van Kleef *et al.*, 2005). The sensory appeal of foods is vital, and information on consumer responses is valuable in predicting the acceptance and consumption of a food (Tuorila, 2007). Sensory analysis is thus a powerful tool in food product development.

In food research, analysis of several physicochemical properties, such as moisture content, lipids content and colour, is also of relevance (Nielsen, 2017). Texture is one of the most important food attributes (Liu *et al.*, 2019). Textural properties can be investigated through texture analysis to obtain a full description of product quality (*ibid.*).

New food products can be reformulations of an existing product (Fuller, 2011). Falafel is an example of an already existing pulse product. It is traditionally made in Middle Eastern countries from chickpeas or faba beans (Ismail *et al.*, 2018). In Sweden, chickpea falafel is produced on an industrial scale. It is of interest to investigate the possibilities of substituting Swedish grown pulses for chickpeas as a way of creating a new area of use for these domestic products.

1.1. Aim

The objective of this study was to evaluate the suitability of several Nordic-grown pulses in falafel making and to get insight into optimal processing conditions for a new falafel. In a longer perspective, the aim was also to enable a switch from chickpeas to Swedish pulses when making falafel on an industrial scale.

Specifically, the study aimed to find how physicochemical properties differ between falafels made from different pulses, what physicochemical properties in falafel create a high sensory acceptance among consumers, and how falafels can be optimised to gain highly liked properties.

1.2. Delimitations

The study was limited to include some chosen varieties of pulses that were, or had the potential to be, cultivated in Nordic/Swedish climate conditions. The focus was on finding a highly sensorially acceptable product, and other aspects were not included in the evaluation of pulse suitability in falafel making.

2. Background

The following sections give an insight into pulses, their cultivation in Nordic countries and how domestic pulse production aids in the work towards more sustainable food systems. An introduction to product development and methods to evaluate foods is also given.

2.1. Pulses

Pulses belong to the plant family *Fabaceae*, also called legumes, which includes 700 genera and more than 19 000 species (Fogelfors, 2015). Pulses are the legumes that are grown for their large, mature seeds. They are cultivated in different climates across the whole world (Allen, 2013).

In a global perspective, pulses give lower and more variable yields than cereals, and are grown on a much smaller acreage (Fogelfors, 2015). However, since legumes can form symbiosis with certain microbial species to fixate atmospheric nitrogen (Allen, 2013), soil fertility can be improved by their cultivation (Siddiq *et al.*, 2012). Other agronomic benefits from legume cultivation include reduced requirements for fertiliser, biocides and tillage, and increased yields of subsequent crops (Preissel *et al.*, 2015). Sustainability of cropping systems can be increased by including legumes (*ibid.*).

Some of the most important pulse species are pea (*Pisum sativum*), faba bean (*Vicia faba*), lentil (*Lens culinaris*), vetch (*V. sativa*), chickpea (*Cicer arietinum*), common bean (*Phaseolus vulgaris*), lupin (*Lupinus luteus, L. angustifolius, L. albus)* and soybean *(Glycine max)* (Fogelfors, 2015). More information on pulses included in the present study is given below.

Pea (*Pisum sativum*) is grown in temperate climates across the whole world, both for food and feed (Fogelfors, 2015). There are many different varieties of peas with different colours and ways of growing. Peas are harvested either as mature and dry seeds, as immature seeds, or as immature pods (Allen, 2013).

Faba bean (*Vicia faba*) is mainly cultivated in Asia, where China is the largest producer, and can be used both for food and feed (Fogelfors, 2015). In genetically susceptible persons, large intakes of faba beans can cause illness (favism).

Lentil (*Lens culinaris*) is used mainly in its dry, mature form (Allen, 2013). Lentils are adapted to cultivation in cooler climates, and are grown primarily in Canada, Turkey and India (*ibid.*). It is an important food crop especially in developing countries.

Chickpea (*Cicer arietinum*) is one of the most important pulses, grown in for example South and West Asia, North and East Africa, Southern Europe, North and South America and in Australia (Siddiq *et al.*, 2012).

Common bean (*Phaseolus vulgaris*) include many varieties, such as black bean and kidney beans that are harvested as mature seeds, and French beans that are harvested in their immature stage and used as vegetables (Allen, 2013). Common bean is grown in temperate regions and is important especially in Africa and Central and South America (*ibid.*).

Lupin (*Lupinus luteus, L. angustifolius, L. albus)* is successfully grown primarily in Australia, that has an important industry around this legume (Lucas *et al.*, 2015). Lupins are also grown to limited extent in Europe. Due to its high content of high-quality protein, lupin is a potential alternative to soybean (*ibid.*).

Pulses are versatile and are used both in traditional home-cooked foods and in processed foods (Siddiq *et al.*, 2012). They have received interest due to their potential use as protein enrichers in for example bread and pasta, and they have great potential of being processed into new food ingredients and applications (Sozer *et al.*, 2017).

The protein content of pulses is high, about 20–40 % of dry matter with a bioavailability of 32–78 % (Fogelfors, 2015). Pulses are the main protein sources for about 15% of the world population (*ibid.*). Since pulses are rich in lysine but deficient in sulphur-containing amino acids, they can be combined with cereals, which are lysine-deficient, to obtain diets with good protein quality for humans (Allen, 2013). Pulses are also important sources of starch, dietary fibre, essential minerals, and phytochemicals, especially in the developing world (*ibid.*). Most pulses, except soybean and peanuts, are low in lipids (Fogelfors, 2015). However, the lipids present are high in essential fatty acids (Allen, 2013). The consumption of pulses has been connected to health advantages such as regulation of body weight, improved glycaemic control, and improved bone mineral density (Derbyshire, 2011).

The use of pulses is somewhat limited due to antinutrients such as protease inhibitors, lectins, tannins, saponins, phytoestrogens, oligosaccharides and phytic acid (Siddiq *et al.*, 2012). The adverse effects of these include reduction of nutrient bioavailability and digestibility. Processing, for example dehulling, soaking, cooking, germination, and fermentation, reduces antinutrient levels (*ibid.*).

2.2. Pulses in Northern Europe, with focus on Sweden

The growing-seasons of northern Europe are cool with an average temperature that supports cultivation of crops such as pulses, cereals and rapeseed (Peltonen-Sainio *et al.*, 2013). The agricultural land use in northern Europe is dominated by grasslands and cereal crops. Political and financial factors have led to a decreased pulse production in Europe between the 1960s and 2013 (*ibid.*). Market values of legumes are low and unstable, and the many positive agronomic effects of legume cultivation are not translatable into financial benefits (Zander *et al.*, 2016). The competitive position of pulses has improved in the last years as there has been an increase in the prices paid for protein crops, and in the costs for fertiliser and imported soya (Poulsen & Solberg, 2015). There is potential to increase pulse production in Northern Europe, especially as growing seasons are expected to extend in the future as a result of climate changes (Peltonen-Sainio *et al.*, 2013).

Many different species of legumes have historically been cultivated in the Baltic sea region, for example Neolithic field pea (*Pisum sativum*), faba bean (*Vicia faba*), common vetch (*Vicia sativa*), several species of lupin (*Lupinus luteus, Lupinus augustifolius, Lupinus luteolus)*, common bean (*Phaseolus vulgaris*), lentil (*Lens culinaris)* and soybean (*Glycine max*) (Poulsen & Solberg, 2015). Beans and peas have a long history in the diets of Swedes, and pulses have been cultivated for a long time in Sweden (Institutet för språk och folkminnen, 2020). Expansive cultivation of peas and faba beans started during the medieval time, and the cultivation of *Phaseolus vulgaris* beans started at the end of the 1600s. Lentils were likely also cultivated to larger extent in earlier times (Institutet för språk och folkminnen, 2018).

Between the years 2014–2019, pulses were grown on approximately 1.5–2.2 % of the total agricultural land in Sweden (Swedish Board of Agriculture, 2019a). Out of this percentage, the crop-group “peas, faba beans, sweet lupin, vetch, chickpeas and other beans” composed 89%, canning peas 9% and brown beans 2%.

Field trials have shown a potential for growing more and new varieties of pulses, especially in the southern parts of Sweden and on the islands Öland and Gotland (Hushållningssällskapet, 2013; Fogelberg, 2008). Examples include kidney beans, black beans, soybeans and lentils. Field peas occur in several locally adapted varieties and can be grown also in the northern parts of Sweden (Hushållningssällskapet, 2013).

Breeding for cultivars adapted to the Nordic climate is needed in order to make pulse production more feasible (Poulsen & Solberg, 2015). Farmers have also reported that higher yields, and higher prices are necessary to enable cultivation of new pulses such as lentils (Östberg, 2019; Olsson, 2017;). Trading companies request more certainty in yields and larger volumes, and increased processing capacity is necessary (Olsson, 2017). Despite these challenges, actors in the Swedish food industry are positive towards increasing volumes and varieties in pulse production (*ibid.*). Farmers and other actors in the industry have experienced an increased demand for plant protein and for Swedish legumes (Östberg, 2019; Olsson, 2017; Sundén, 2014).

2.3. Swedish cultivation of pulses from a sustainability perspective

European crop rotations are dominated by cereals, and most other foods are imported (Stoddard, 2010). Imported foods can cause environmental issues in producing countries, and the import dependence leaves European countries vulnerable to fluctuations in prices.

In some cases, domestic food production could lead to reduced climate impacts (Röös, 2014). Greenhouse gas emissions from plant food production are generally low compared to animal foods (Knudsen, 2011). However, a large proportion of the environmental impacts from plant products, for example pulses imported from countries such as China or Brazil to European countries by sea or road, can be accounted to the transport (Knudsen, 2011; da Silva *et al.*, 2010). Virtual water import is also an issue, which could be reduced by switching to domestic production of pulses (Sandström *et al.*, 2018).

Most of the dried and canned pulses available in Swedish supermarkets originate from China, Canada or the USA (Ekqvist *et al.*, 2019). Pesticide residues have been found in pulses from China and Canada (*ibid.*). China has the world's largest pesticide use, with problems of low use efficiency and overuse resulting in environmental pollution. In Canada, the high glyphosate use is an issue. In contrast, Swedish food systems have lower environmental impacts regarding pesticide use, nutrient leakage and GHG emissions compared to the EU average (Kuylenstierna *et al.*, 2019). The incidence of pesticide residues in food produced in Sweden is low (*ibid.*).

Other advantages of domestic food production include possibilities to close nutrient loops, which lowers the needs for inputs and could in a longer perspective reduce eutrophication and GHG emissions (Röös, 2014). Domestic food production promotes local economies and activities and it increases control of food production. It also increases proximity between producers and consumers and creates a food production that is more resilient to climate change, economic crises and global energy crises (Karlsson *et al.*, 2017).

To achieve sustainable food systems with resilience, self-sufficiency and preparedness for climate changes, protein crops are important (Karlsson *et al.*, 2017; Bues *et al.*, 2013; Peltonen-Sainio *et al.*, 2013). Increased crop diversity with more legumes reduces use of fossil fuels and fertilisers, lowers GHG emissions and promotes biodiversity (Bues *et al.*, 2013).

2.4. Product development and sensory analysis

Product development is necessary for companies to remain successful and profitable (Fuller, 2011). As product development is often an expensive process, it is important to understand consumers' needs and wants (Gustafsson *et al.*, 2014). Instrumental measurements can be used to evaluate foods, but these cannot completely mimic or predict the human experiences connected to food consumption (Lawless & Heymann, 2010). Sensory tests, wherein food properties are evaluated by human subjects, are therefore useful tools in the evaluation of a food product during its development (*ibid.*). The sensory tests quantify the human experience of food products by evoking, measuring, analysing and interpreting responses. The responses are measured by the collection of numerical data that are analysed using statistical methods. Sensory analysis can provide important feedback on acceptance and attributes of the product (*ibid.*), that can be further developed accordingly (Gustafsson et al., 2014).

Sensory tests are divided into difference testing, descriptive analysis and affective testing. Difference tests include several setups and aim to analyse whether there are detectable sensory differences between samples, or how samples differ in certain attributes (Meilgaard, Civille & Carr, 2007). Descriptive analysis uses panels of trained subjects to obtain sensory profiles of products with information about qualitative characteristics and their intensities (*ibid.*). Affective (also called hedonic) tests assess the product appeal to consumers through preference and acceptance testing (Lawless & Heymann, 2010). The latter is used in the present study. Preference testing lets the consumer choose which product they like best in comparison to other products. In acceptance testing, consumers instead rate the sensory appeal of a product on a scale, commonly the 9-point hedonic scale, or the degree of liking-scale. The hedonic tests typically include 75–150 subjects that are untrained and users of the tested products.

2.5. Evaluation of foods using physicochemical analysis

Food analysis is needed for determination of food composition and is an important tool in product development (Nielsen, 2017). The below text describes analyses used in the present study.

2.5.1. Texture profile analysis (TPA)

TPA is used for texture measurements of various solid and semi-solid foods (Wee *et al.*, 2018). The analysis aims to mimic jaw action through a double compression. A texturometer is used for the analysis which results in information on several sample characteristics (Nishinari & Fang, 2018). For example, *hardness* is the force needed to reach a particular deformation, *cohesiveness* corresponds to strength of bonds within the product, and *springiness* describes at what rate a deformed material returns to its initial condition when the deforming force is removed (*ibid.*). This analysis is of interest since texture is important for the acceptability of foods (Bourne, 2002).

2.5.2. Moisture content

Analysis of moisture content (also called water content) in foods is fundamental as it is important for several quality and food safety factors (Mauer & Bradley, 2017). There are different methods for moisture content determination (*ibid.*). Direct methods remove water from the sample and determine moisture content by mass, volumetry or titration, while indirect methods analyse food properties related to the presence of water. Freeze drying has been used for moisture content determination but give lower moisture values compared to oven-drying methods (Samuelsson *et al.*, 2006).

2.5.3. Colour

Colour has an important influence on food acceptance, and objective colour measurements are of interest (Wrolstad & Smith, 2017). Colorimetry is the science of colour measurement, which includes several alternative systems (*ibid.*). These address the three-dimensionality of colour and include hue (e.g. green, red or blue), value (darkness or lightness) and saturation/chroma (intensity). The Hunter Lab system is widely used for colorimetry in the food industry. The parameters are $L*$ from black (0) to white (100), $a*$ for green (-) and red (+), and $b*$ for blue (-) and yellow (+). Limits for $a*$ and $b*$ are approximately between negative and positive 80. The system provides an efficient way of colour determination.

2.5.4. Lipids

Lipids are main components in foods, comprising various substances (Ellefson, 2017). Analysis is based on the lipid solubility in organic solvents, and insolubility in water, which enables separation of lipids from other food components such as proteins, water and carbohydrates (*ibid.*). Solvent extraction methods are therefore common and useful for lipid analysis. To aid lipid extraction, samples are often prepared by water removal, particle size reduction, and/or separation from other substances by hydrolysis.

2.6. Statistic analysis

The use of some statistical methods has been central in this study. These are briefly described below.

2.6.1. Analysis of Variance (ANOVA)

ANOVA is used to investigate differences between means when for example the effects of several product treatment factors are studied (Lawless & Heymann, 2010). The analysis can determine how much variance each treatment factor causes, and how much of the variation that is a result of error, i.e. other factors than the controlled variables. The ANOVA shows whether significant differences between several treatment means exist.

2.6.2. Principal Components Analysis (PCA)

PCA uses multivariate data from several types of observations (Eriksson *et al.*, 2013). The data variables are arranged in a multi-dimensional space, and are used to model a plane, whose axes are called principal components. The purpose of PCA is to provide an overview of data by showing outliers, trends and how observations group (*ibid.*). It can give information on relationships among variables, and between observations and variables. It can also uncover which variables that have influence over the patterns in observations.

2.6.3. Partial Least Squares Projections to Latent Structures (PLS)

PLS uses a linear multivariate model to relate two sets of data; factors and responses (Eriksson *et al.*, 2013). Data with many variables that may be noisy, collinear or incomplete can be analysed. The PLS model can be interpreted by several parameters (*ibid.*). The regression coefficients plot gives information on whether there is a significant influence of factors on responses, and how factors influence the responses. The coefficients plot is often interpreted in combination with the Variable Influence on Projection (VIP) plot, which shows the importance of the factor variables in the model, where large values are most influential.

2.6.4. Response Surface Methodology (RSM)

RSM is comprised of statistical and mathematical techniques that are used in process optimisation, improvement and development (Myers *et al.*, 2016). It investigates how different input variables affect performance measures, or responses. Statistical modelling is used to proximate the relationship between input variables and responses, which is displayed graphically in response surface plots or contour plots (*ibid.)*. The input variable values that give desirable response values can be identified and an optimum can be determined.

3. Experimental procedures

To investigate the suitability of the use of Swedish pulses in falafel, several analytical procedures were performed, divided into three major steps; a screening, sensory analysis and an optimisation. An overview of these is given in the flow chart below (Figure 1).

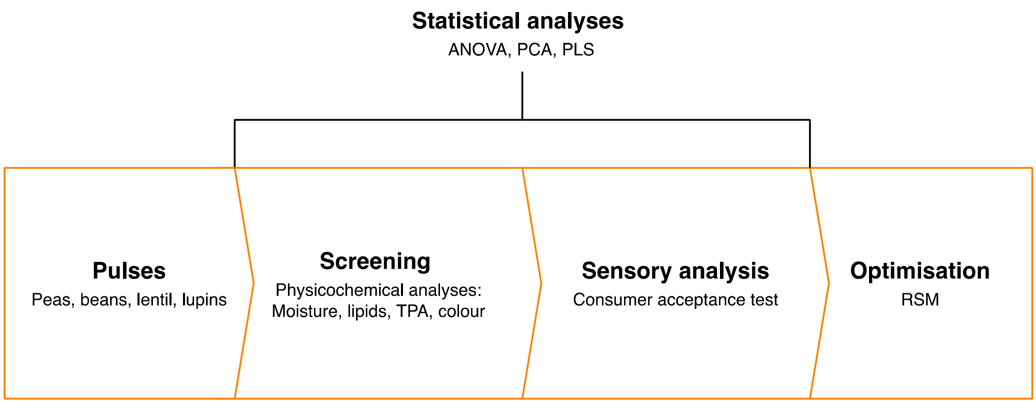


Figure 1. Flow chart of experimental procedures included in the study.

3.1. Preparation of falafels

3.1.1. Pulse samples

For the screening, nine pulses were chosen to obtain a set with a variation of species and varieties that could be cultivated in Swedish climate. A chickpea reference was also included. Pulses were obtained from Fredrik Fogelberg (RISE), Nordisk råvara and Kalmar Ölands Trädgårdsprodukter. Some brief information on the pulses can be found in Table 1.

Table 1. Information on the pulses used in the study

Pulse name and type	Species	Origin
Black bean	*Phaseolus vulgaris*	Sweden
Borlotti bean	*Phaseolus vulgaris*	Sweden
Bruno field pea	*Pisum sativum, var. arevense*	Sweden
Chickpea (reference)	*Cicer arietinum*	Canada/USA
Gloria fava bean	*Vicia faba*	Sweden
Gotland lentil	*Lens culinaris*	Sweden
Mirabor, blue lupin	*Lupinus angustifolius*	Germany
Mister, yellow lupin	*Lupinus luteus*	Poland
Samba, blue lupin	*Lupinus angustifolius*	Poland
Yellow pea	*Pisum sativum*	Sweden

3.1.2. Preparation procedure

The pulses were rinsed in cold water, and then soaked in cold water on a 1:3 w/v basis for approximately twelve hours. A simplified falafel recipe was used containing only pulse, sodium bicarbonate ($NaHCO_3$) and iodised table salt. After soaking, pulses were rinsed again with cold water and mixed in a food processor at medium speed until a moldable batter was observed. Table salt and $NaHCO_3$ was blended into the pulse mixtures that were then allowed to swell for ten minutes. Falafels were shaped using a Ø40 mm falafel tool and deep-fried in canola oil for two minutes at 180º C. After deep frying, excess oil was allowed to drip off for a few seconds and the falafels were then put on a non-fat-absorbing surface. After having completely cooled down at room temperature, falafels were kept refrigerated at approximately 4ºC. All analyses were performed within 24 hours after making falafels.

3.2. Screening – physicochemical analyses

One batch of falafels was made for the screening. Samples were analysed in triplicates in all physicochemical analyses, unless otherwise is stated. A chickpea reference falafel was used in all analyses.

3.2.1. Water absorption

Water absorption during soaking was determined gravimetrically and defined as the weight difference of samples before and after soaking. The water absorption was expressed as weight increase in percentage of dry weight.

3.2.2. Texture profile analysis

A Texture Analyser from Stable Microsystems was used for a Texture Profile Analysis (TPA). A 50 mm diameter aluminium cylinder probe was mounted on a 50 kg load cell. Samples were exposed to two compression cycles to 50 % of original height. The speed was 1.70 mm/second throughout the compression cycles. Room tempered samples were run in at least three replicates. Textural properties were calculated according to Bourne (2002):

Hardness = maximum force of first compression

Cohesiveness= the ratio of the positive force areas under the compressions

Springiness= recovered height of sample between end of first compression and start of second compression

3.2.3. Colour measurements

A portable Minolta CM-700d/600d was used to analyse colour both on the exterior and interior of falafels. The achieved values of L^*, a^* and b^* for each falafel replicate were averages of four measurements.

3.2.4. Moisture

Falafels and batter samples were freeze dried. Moisture content was determined gravimetrically by comparison of weights before and after freeze drying. Moisture loss during deep-frying was determined by comparison of moisture content in deep-fried samples to moisture content in batter.

3.2.5. Lipid content and oil uptake during deep-frying

Lipid content and oil uptake during deep-frying was determined by lipid extraction using a method proposed by Hara and Radin (1978) with some modifications. Briefly, freeze dried samples were ground, and 100 mg of sample was homogenised with 10 ml of hexane:isopropanol (HIP, 3:2 v/v). An amount of 6 ml of 6.67%

aqueous sodium sulphate (Na_2SO_4) was added to samples. Separation of organic and aqueous phase was achieved by centrifugation at 3041 RCF for 2 minutes. The lipid phase was transferred to separate tubes and organic solvents were evaporated using N_2 gas. A secondary extraction was performed in order to obtain as large amounts of lipids as possible from the samples. The lipids remaining after N_2 evaporation were weighed to determine lipid contents in samples, which was calculated as percentage of wet weight. Oil uptake during deep-frying was calculated by subtracting lipid content in falafel batter from lipid content in deep-fried falafels.

3.2.6. Statistical analyses

Data from physicochemical analyses were subjected to one-way ANOVA using Minitab 18 to find if differences between falafels' physicochemical properties were significant. Data were also visualised in a Principal Components Analysis (PCA) using SIMCA 16.

3.3. Sensory analysis

For the sensory analysis, five falafels were chosen; those made from black beans, borlotti beans, Gotland lentils, Mirabor lupins, yellow peas, as well as a reference made from chickpeas. Falafels were chosen based on the screening, with the aim to cover different physicochemical properties. A consumer acceptance test was performed to achieve evaluations on liking of four important attributes; appearance, texture, flavour and overall liking. An incomplete randomised block design for 60 subjects was constructed using the package crossdes (Sailer, 2013), in R version 3.6.3 (R Core Team, 2020). The design was based on Wakeling and MacFie (1995) and balanced the six samples across the subjects resulting in a serving order of four samples for each subject. Each falafel type occurred 40 times in the design. The design also randomised the serving order to balance for presentation order and carry-over effects. The design is shown in Appendix 1. The falafel samples were randomly allocated to numbers 1–6. Random, three-digit codes were used for each sample for each subject, using the random codes table from Meilgaard, Civille and Carr (2007). Students and employees from the Swedish University of Agricultural Sciences in Uppsala evaluated the samples on a 9-point hedonic scale. To provide insight into whether the right target group was reached, subjects got to answer questions on age and eating frequency of falafel and similar products. To ensure that the right target group was reached, subjects got to answer questions on age and eating frequency of falafel and similar products. Falafels were cut in halves and served cold on non-fat-absorbing paper dishes. The test was carried out on several occasions during the day. A first group of consumers tested the falafels at 12 o'clock in a secluded conference room with minimal outside disturbance. A second and third group of consumers tested the falafels between 4–5 p.m. in an empty university lunch area. The evaluations were filled in on a form containing instructions on the procedure, see Appendix 2. Instructions were also given verbally before the test, where subjects were told to try one sample at a time in the order of presentation on the form. They were encouraged to take their time and to drink some water in between samples. Subjects were also informed about allergens. The test was performed in quiet during approximately 15 minutes.

The results from the consumer test were analysed statistically using Minitab 18 to achieve mean values and standard deviations of evaluations of all falafels across all subjects. The same analyses were performed on the different groups of subjects; age, sex, and eating frequency. Two-way ANOVA, with respondent and falafel as independent variables, was used to assess differences between falafels. PLS models correlating sensory evaluations to physicochemical analyses were constructed in SIMCA 16. The models used physicochemical analyses as x-variables and sensory evaluations as y-variables. Variable Importance in Projection (VIP) plots were used to find contributions of x-variables to the PLS-model, where values larger than one indicated significant contribution. Coefficients plot was used to visualise the relationship between x and y variables. For each property evaluated in the acceptance test (i.e. appearance, texture, flavour, overall), only those physicochemical measurements affecting evaluations were included in the models in order to avoid spurious correlations, e.g. colour measurements were excluded from the texture model.

3.4. Optimisation

The optimisation design was based on the findings from the previous analyses.

The falafels that achieved best overall liking in the sensory test (the Gotland lentil falafels) were chosen for the optimisation, which focused on texture. Since high sensory liking of texture was found to correlate with low hardness, high water absorption in soaking and high moisture content in falafel batter, these properties were studied in the optimisation. As moisture content in falafel batter is a result of the water uptake during soaking, water uptake was chosen as a response, as well as hardness.

In previous studies, $NaHCO_3$ soaking solutions have been used to soften the texture of pulses (Pirhayati *et al.*, 2011; Lu *et al.*, 1984), and soaking time has been found to affect pulse water absorption and thus texture (Maneesh Kumar *et al.*, 2018; Bhatty, 1995; Bhatty, 1990; Abou-Samaha *et al.*, 1985). Concentration of $NaHCO_3$ in soaking water, and soaking time was thus chosen as input variables. A factorial design was constructed using Modde from Umetrics, the design can be viewed in Table 2 below. The input variable levels were soaking for 6, 10 or 14 hours, and $NaHCO_3$ concentrations of 0, 0.75 or 1.5 % in the soaking water.

Table 2. Experimental design used in the optimisation aiming to achieve minimal hardness of falafels and maximal water absorption during soaking of pulses.

Experiment	**Soaking time (hours)**	**$NaHCO_3$ (%)**
N1	6	0
N2	14	0
N3	6	1.5
N4	14	1.5
N5	6	0.75
N6	14	0.75
N7	10	0
N8	10	1.5
N9	10	0.75
N10	10	0.75
N11	10	0.75

Falafels were prepared according to previously described procedures, see section 3.1. Each batter was run in the food processor for 1.5 minutes. The responses (weight increase in soaking and hardness from TPA analysis) were analysed according to the descriptions in Sections 3.2.1 and 3.2.2. Five replicates of each falafel were analysed by TPA within 24 hours of making falafels.

RSM calculations were performed in Modde to identify optimum levels of soaking time and $NaHCO_3$ concentration to achieve low hardness and large water absorption.

4. Results

4.1. Screening

The screening resulted in information on the physicochemical properties of the nine falafels made from different pulses. Results are depicted in Table 3.

Table 3. Physicochemical properties of the analysed falafels. Standard deviations are given in italic below each measurement. Where standard deviations were not available due to too few data, this is indicated by a star (*). The water uptake is expressed as weight increase in percentage of dry weight. All results from analyses on moisture and fat properties are expressed as percentage of falafel wet weight. The L value expresses lightness from black (0) to white (100), a* expresses colour from green (-) to red (+), and b* expresses colour from blue (-) to yellow (+). Dissimilar letters indicate statistically significant difference between means. Note: lipids were analysed only for falafels used in sensory analysis.*

	Borlotti bean	**Chickpea**	**Mirabor lupin**	**Black bean**	**Gotland lentil**	**Yellow pea**	**Bruno field pea**	**Gloria fava bean**	**Mister lupin**	**Samba lupin**
Weight increase (water uptake)	96.00 *5.66*	97.50 *3.54*	133.50 *3.54*	96.00 *5.66*	87.50 *0.71*	72.00 *1.41*	100.00 *	90.00 *	150.00 *	144.00 *
Moisture content batter	56.45^{D} *0.10*	54.80^{E} *0.14*	64.76^{A} *0.07*	56.86^{C} *0.13*	54.66^{EF} *0.09*	51.37^{G} *0.05*	54.76^{EF} *0.07*	54.51^{F} *0.08*	62.27^{B} *0.07*	61.97^{B} *0.11*
Water loss in frying	10.06^{C} *0.81*	12.60^{B} *0.41*	21.97^{A} *0.82*	14.05^{B} *0.94*	13.17^{B} *0.27*	12.30^{BC} *0.74*	13.02^{B} *0.30*	12.77^{B} *0.79*	21.79^{A} *0.92*	21.29^{A} *1.22*
Moisture content falafel	46.39^{A} *0.72*	42.21^{BC} *0.28*	42.79^{B} *0.79*	42.82^{B} *0.82*	41.50^{BC} *0.32*	39.06^{D} *0.79*	41.74^{BC} *0.30*	41.74^{BC} *0.76*	41.16^{BC} *0.34*	40.68^{CD} *1.21*
Hardness	138.72^{D} *15.48*	287.58^{BC} *29.16*	130.41^{D} *23.64*	291.56^{B} *12.58*	140.35^{D} *12.32*	434.49^{A} *7.14*	324.00^{B} *44.61*	239.10^{C} *35.21*	151.55^{D} *16.78*	157.48^{D} *8.09*
Cohesiveness	0.43^{C} *0.01*	0.46^{ABC} *0.01*	0.31^{D} *0.03*	0.50^{A} *0.01*	0.48^{AB} *0.01*	0.44^{BC} *0.01*	0.48^{AB} *0.01*	0.50^{A} *0.02*	0.33^{D} *0.03*	0.25^{E} *0.02*
Springiness	0.44^{E} *0.03*	0.56^{BCD} *0.02*	0.55^{CD} *0.01*	0.61^{AB} *0.02*	0.64^{A} *0.01*	0.50^{DE} *0.03*	0.57^{BC} *0.02*	0.58^{BC} *0.04*	0.53^{CD} *0.03*	0.54^{CD} *0.04*
Exterior *L**	57.69^{AB} *3.82*	59.43^{A} *1.79*	40.77^{E} *0.82*	31.40^{F} *1.56*	43.52^{DE} *0.87*	56.21^{AB} *0.42*	41.16^{E} *2.50*	52.38^{BC} *0.47*	48.96^{CD} *1.51*	57.58^{AB} *2.85*
Interior *L**	65.80^{BC} *1.84*	73.37^{A} *0.30*	59.06^{DE} *4.61*	45.58^{F} *0.55*	57.90^{E} *1.07*	72.40^{A} *0.87*	59.57^{CDE} *2.24*	65.63^{BCD} *1.14*	62.62^{BCDE} *1.72*	67.43^{AB} *3.98*
Contrast *L**	8.10^{B} *5.64*	13.94^{AB} *1.69*	18.30^{A} *4.76*	14.18^{AB} *1.96*	14.39^{AB} *1.41*	16.2^{AB} *1.11*	18.41^{A} *1.56*	13.25^{AB} *1.46*	13.66^{AB} *0.31*	9.85^{AB} *6.79*
Exterior *a**	5.20^{E} *0.58*	9.11^{D} *0.30*	19.98^{A} *0.19*	1.90^{F} *0.34*	6.52^{E} *0.42*	12.34^{C} *0.57*	6.49^{E} *0.40*	6.92^{E} *0.13*	12.07^{C} *0.64*	14.75^{B} *1.80*
Interior *a**	4.37^{AB} *0.82*	3.01^{ABC} *0.11*	4.93^{AB} *1.93*	0.16^{C} *0.09*	4.10^{ABC} *0.19*	3.75^{ABC} *0.27*	4.06^{ABC} *0.31*	5.98^{A} *3.47*	1.41^{BC} *0.49*	2.96^{ABC} *1.53*
Exterior *b**	19.95^{E} *0.47*	40.69^{B} *1.39*	31.34^{C} *1.22*	7.20^{F} *0.70*	24.40^{D} *1.53*	41.02^{B} *0.92*	18.95^{E} *2.21*	30.65^{C} *0.19*	37.83^{B} *1.62*	45.56^{A} *1.57*
Interior *b**	14.04^{AB} *0.25*	29.05^{A} *0.65*	23.38^{AB} *16.66*	5.04^{B} *0.41*	26.19^{AB} *0.49*	31.65 *0.85*	17.79^{AB} *1.78*	36.36^{A} *12.33*	33.28^{A} *1.48*	28.48^{A} *12.96*
Fat content batter	1.03^{B} *0.09*	4.57^{A} *0.77*	1.80^{B} *0.26*	0.99^{B} *0.14*	1.14^{B} *0.51*	0.89^{B} *0.12*				
Fat content falafel	5.30^{D} *1.42*	8.75^{B} *0.05*	13.67^{A} *0.31*	8.36^{BC} *0.96*	10.05^{B} *0.40*	6.53^{CD} *0.73*				
Fat absorption	4.27^{D} *1.35*	4.19^{D} *0.78*	11.87^{A} *0.48*	7.37^{BC} *1.07*	8.91^{B} *0.90*	5.64^{CD} *0.76*				

Tukey pairwise comparisons from the ANOVA divided falafels into statistically dissimilar groups at the significance level $\alpha = 0.05$. These groups are hereafter entitled groupings. Main results are given briefly below, while the table shows differences in detail.

Weight increase in lupin falafels was highest and significantly different from that in all other falafels. Moisture content in the falafel batter, which is directly linked to the water absorption, differed significantly from all others in Mirabor lupin and yellow pea falafels which had the highest and lowest batter moisture content, respectively.

Water loss divided samples into four separate groupings. Lupin falafels formed one group of the highest water loss and differed significantly from all other samples, while borlotti bean and yellow pea falafels were in the group with lowest values. The moisture content of deep-fried falafels was similar across all samples, where the high moisture content of borlotti bean falafels was the only one differing significantly from all others.

Colour measurements showed that in exterior and interior lightness, the low values of black bean falafels differed significantly from all others. Chickpea falafels had the lightest exterior, while chickpea and yellow pea falafels had the lightest interior. Bruno field pea and Mirabor lupin falafels had the highest lightness contrast between exterior and interior, whereas borlotti bean falafels had the lowest.

All falafels had positive values for both exterior and interior a^* and b^*, indicating that falafels were in the red-yellow part of the colour spectrum. For exterior a^*, Mirabor, Samba, chickpea and black bean falafels differed significantly from all other falafels, where Mirabor falafels had the highest value and black bean falafels the lowest. For exterior b^*, Samba lupin, Gotland lentil and black bean falafels differed significantly from all other falafels, where Samba had the highest value and black bean the lowest. For interior a^*, Gloria faba bean falafels had significantly higher values than all other falafels. Black bean falafels had the lowest value of both interior a^* and b^* and differed significantly from all other falafels in this aspect.

The TPA showed that yellow pea falafels had the significantly highest hardness. Remaining falafels had hardness values similar to at least one other falafel. In cohesiveness, Samba lupin falafels differed from all other samples with their significantly lower values. The other falafels shared grouping with at least one other falafel, where Gloria and black bean falafels had the highest cohesiveness. Gotland lentil falafels had the highest springiness values while borlotti bean falafels had the lowest. Lupin falafels shared similar hardness and springiness values.

The fat content of falafel batter was similar across all samples, except chickpea falafels which had significantly higher fat content. Fat absorption differed between falafels, where Mirabor lupin falafels had significantly higher values compared to all others. Mirabor falafels also had significantly higher fat content, but were not significantly different from yellow pea falafels in this aspect.

The PCA showed how falafels and analysed properties related to each other. The PCA is depicted in Figure 2. Principal component one (PC1) and principal component 2 (PC2) in the model explained 36.9 and 24.5% of the variation, respectively, thus, a total of 61.4% of the variation could be explained by the first two components.

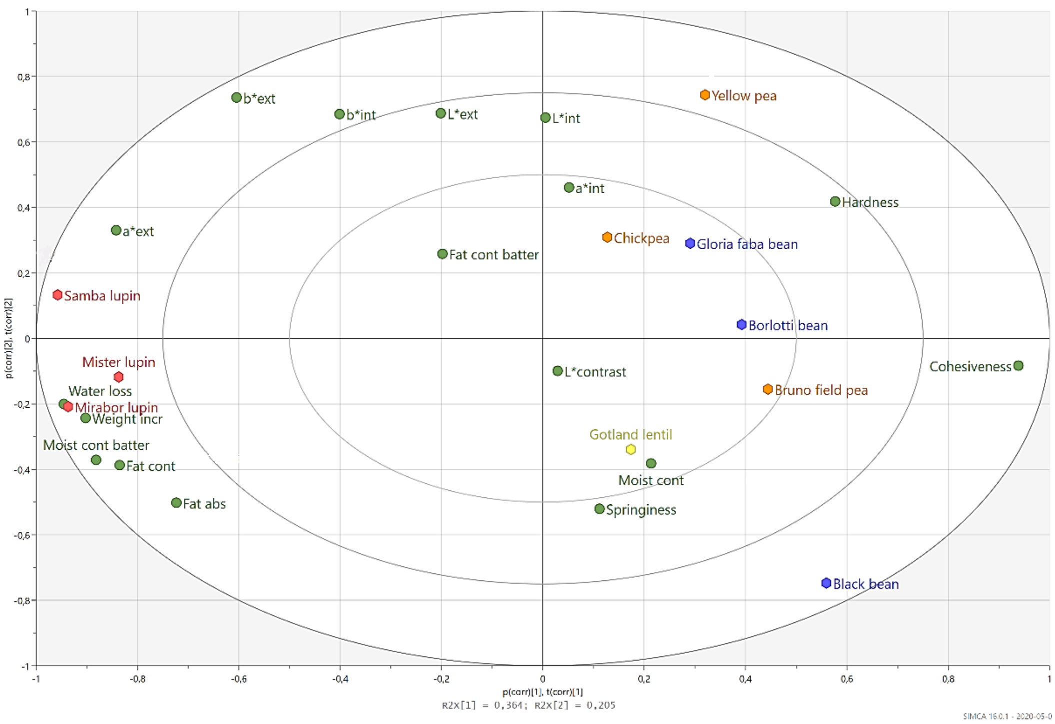


Figure 2. PCA of physicochemical analyses in green, and falafels coloured depending on type of legume where lupins are red, peas orange, beans blue and lentil yellow. In colour measurements L, a* and b*, "ext" is used for measures taken on exterior of falafel, and "int" is used for measures on the interior. Note: lipid analyses were only performed on Mirabor lupin, Gotland lentil, black bean, borlotti bean, chickpea and yellow pea falafels.*

The variation in PC1 seemed to be primarily due to differences between samples in *cohesiveness* and in the group of properties *water loss, batter moisture content* and *weight increase,* of which the last three were strongly intercorrelated. Fat content and fat absorption also seemed to be correlated to these three properties, although fat properties were only evaluated in a subset of falafels. There seemed to also be a negative correlation between this group of properties and hardness, as well as between moisture content and water loss. In PC1, the samples formed two major clusters; one containing the lupins, and one containing the other samples. In PC2, the variation between samples seemed to primarily be due to differences in colour measurements, since these represented the most extreme points. In PC2, the lupins were still diverging from the other samples.

The screening resulted in five falafels with different properties in the PCA being chosen for sensory evaluation. By choosing falafels with different properties, it could be investigated which of them that were highly accepted by consumers. An informal sensory evaluation of the falafels also affected this choice and resulted in the exclusion of falafels made from Mister and Samba lupins due to a prominent bitter taste, of falafels made from Gloria faba bean due to an unpleasant flavour and of falafels made from Bruno field peas due to high dryness. The chosen falafels were those made from black beans, Gotland lentil, Mirabor lupin, Borlotti bean and yellow pea. A chickpea reference was also used.

4.2. Sensory analysis

Results from the sensory evaluation are presented in Table 4. More detailed information on the evaluations from each subgroup of subjects are given in Appendix 3.

Table 4. Mean of sensory evaluations across all subjects, for each falafel and attribute. Means with dissimilar letters are significantly different

	Black bean	**Borlotti bean**	**Chickpea**	**Gotland lentil**	**Mirabor lupin**	**Yellow pea**
Appearance	5.4^{C}	5.9^{BC}	6.0^{BC}	6.2^{BC}	7.8^{A}	6.6^{B}
Texture	5.1^{BC}	5.9^{AB}	5.8^{AB}	6.0^{AB}	6.7^{A}	4.6^{C}
Flavour	6.2^{AB}	5.6^{AB}	6.2^{AB}	6.7^{A}	5.3^{B}	5.3^{B}
Overall	5.8^{AB}	5.8^{AB}	6.0^{AB}	6.6^{A}	5.7^{AB}	5.4^{B}

There were 54 subjects out of the expected 60 that performed the acceptance test. This resulted in each falafel being evaluated 33–38 times. Most respondents were women (n=35), in the age group 20–29 (n=39), and ate falafels less often than once per month (n=16). Only 5 of the respondents never ate falafel or similar products.

Across all judges, Mirabor lupin falafels obtained the highest liking of appearance and texture, whereas Gotland lentil falafels obtained the highest liking of flavour and overall liking. The appearance evaluation on Mirabor falafels was significantly higher compared to all other falafels. In evaluations of texture, significant difference was only observed between Mirabor falafels, and yellow pea and black bean falafels. The latter were the least liked. In evaluations of flavour, Gotland lentil falafels were significantly better liked than Mirabor and yellow pea falafels. Significant difference in overall liking was only observed between Gotland lentil falafels and yellow pea falafels which were the least liked.

Comments left by subjects during the evaluation indicated that falafels were dry, regardless of what pulse they were made from. Otherwise, comments ranged from positive to negative for all falafels. Borlotti bean falafels had several negative comments on appearance, but both negative and positive comments on texture and flavour. Comments on chickpea falafels were mixed. Several commented that Mirabor falafels had a bitter aftertaste, while these received positive comments regarding colour and texture. Black bean falafels were both liked and disliked for their colour. Gotland lentil falafels had both negative and positive comments regarding appearance, and mostly positive comments on flavour. Some subjects identified an additional flavour in these falafels, described as reminding them of fish. Yellow pea falafels had especially many comments regarding them being too dry. Comments on appearance were positive.

PLS models were constructed to find how physicochemical properties correlated with sensory evaluations. These are depicted in Figures 3 and 4. Models could be made for sensory evaluations on appearance and texture. Models handling physicochemical properties in combination with sensory evaluations on flavour or overall liking were not statistically significant, these models were therefore excluded.

For sensory evaluations on appearance, the variables exterior and interior $a*$ and contrast in $L*$ had VIP values above one and thus had significant effect on the liking of appearance. These variables all correlated positively with liking of appearance. Hardness, weight increase and moisture content of falafel batter had VIP values above one in the model for liking of texture. The liking of texture correlated positively with weight increase and moisture content of the batter, and negatively with hardness.

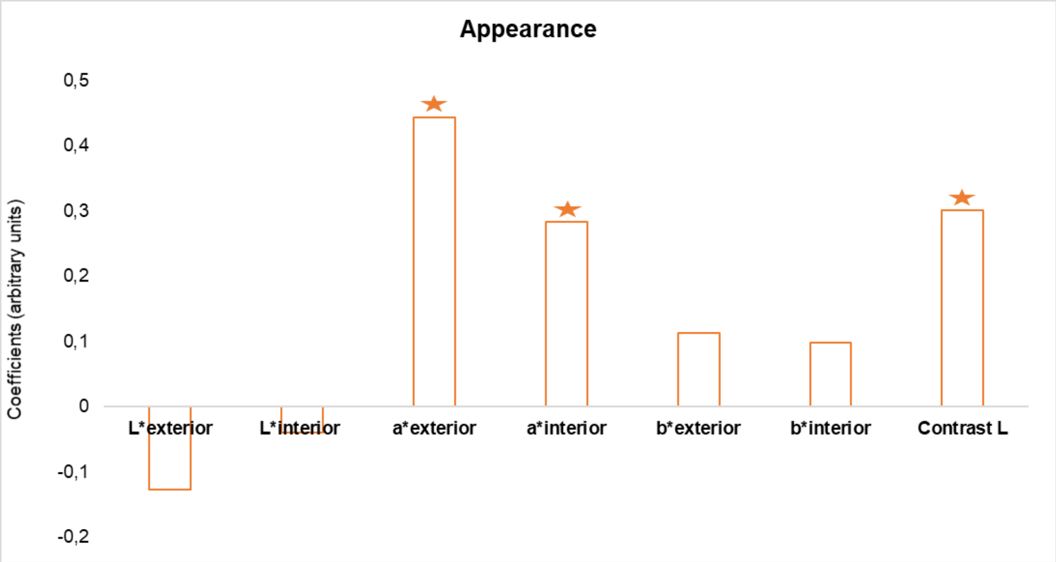


Figure 3. Coefficients from PLS model showing the effect of colour measurements on sensory evaluations of appearance. Measurements with VIP-values above 1 are indicated by a star and signify properties with significant effect on sensory evaluations. The direction of the bar indicates whether the impact of the analysed property on the sensory evaluation was positive (upward direction) or negative (downward direction).

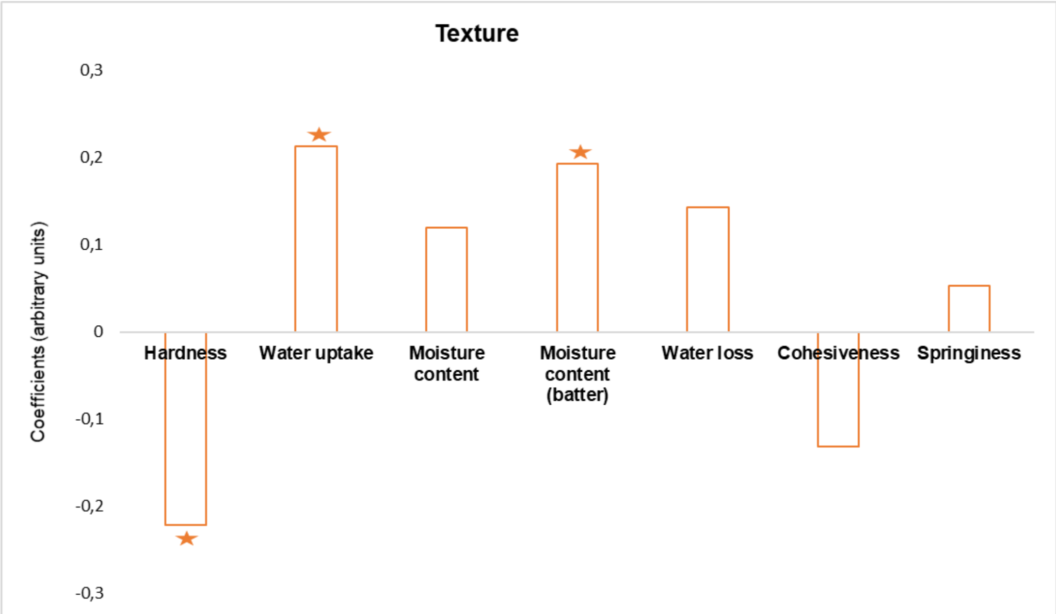


Figure 4. Coefficients from PLS model showing the effect of physicochemical properties on sensory evaluations of texture. Measurements with VIP-values above 1 are indicated by a star and signify properties with significant effect on sensory evaluations. The direction of the bar indicates whether the impact of the analysed property on sensory evaluation was positive (upward direction) or negative (downward direction).

4.3. Optimisation

Falafels were made according to the study design, and the responses were analysed. Validation metrics (R^2 and Q^2) showed that valid models could be fit to the data. Contour plots with system centres showing optimum levels of soaking time and $NaHCO_3$ concentration for maximal water uptake and minimal hardness are depicted in Figures 5 and 6. Contour plots for cohesiveness and springiness can be found in Appendix 4.

No interaction was found between the variables. Maximum water uptake was observed at soaking times between approximately 11.5–13 hours and at $NaHCO_3$ concentrations of between 0–0.8 %. Minimum hardness was observed at soaking times between just over 10 hours to just over 13 hours and $NaHCO_3$ concentrations of 0 to 1.4 %.

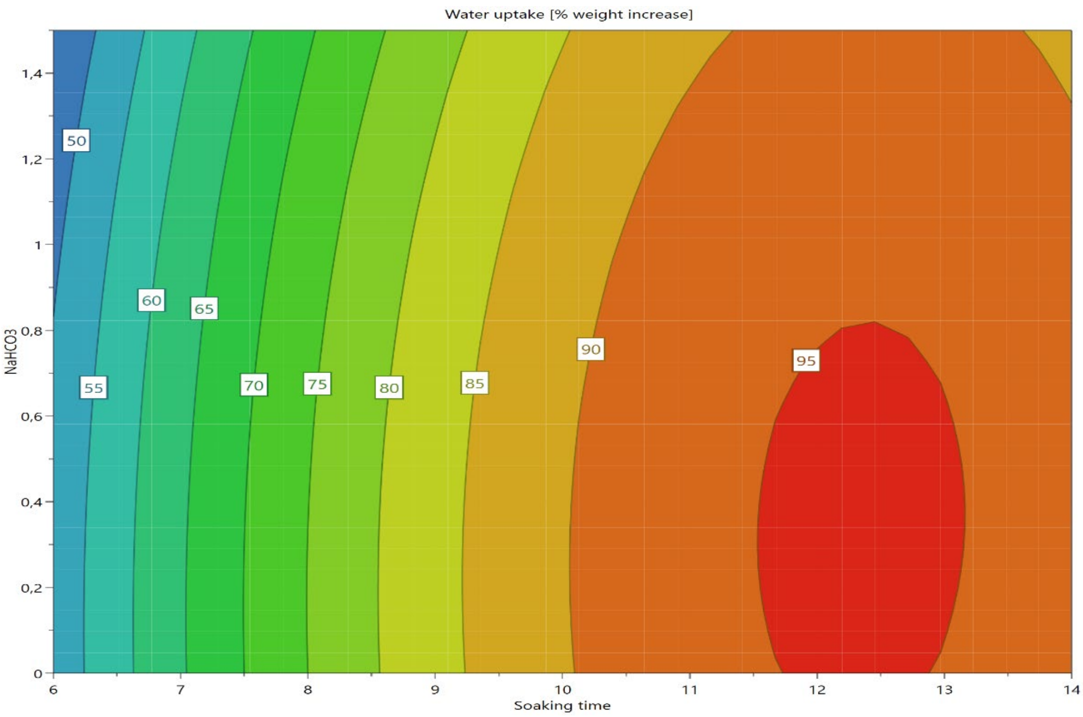


Figure 5. Contour plot showing the effect of $NaHCO_3$ concentration and soaking time on pulse water uptake.

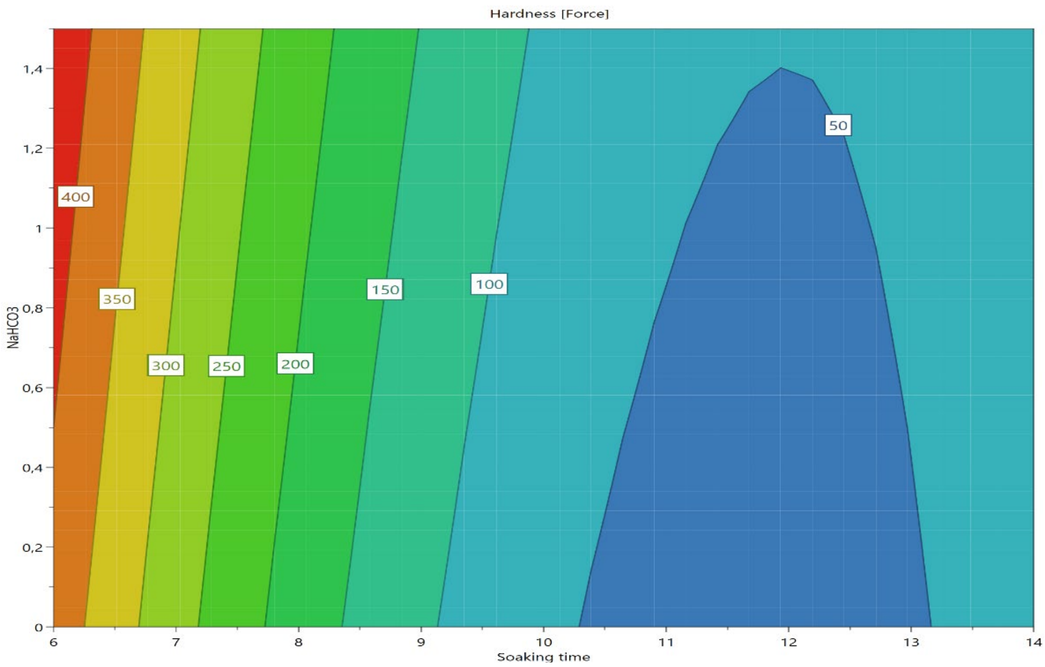


Figure 6. Contour plot showing the effect of $NaHCO_3$ concentration and soaking time on textural hardness of falafels.

Each line in the contour plot represents a set of points that all have the same response value, given by the number on the line. For example, the line with response 75 in the water uptake plot indicates that this response is achieved across all $NaHCO_3$ concentrations, but in a soaking time only ranging between 8–8.5 hours. The same pattern could be observed for almost all other contours in both plots. The plots thus suggest that most of the variation in water uptake and hardness is a result of soaking time, and that $NaHCO_3$ concentration did not have much impact. This is also apparent from the low spread of response values across the y-axis. The short spacing of the lines to the left in the plots suggests that the fastest increase in water uptake and decrease in hardness occurred at the beginning of soaking.

5. Discussion

5.1. Screening

5.1.1. Physicochemical analyses

The physicochemical analyses showed that falafels made from different pulses had significantly different properties. This suggests that different pulses could be used depending on what falafel properties are wanted.

Water loss, moisture content before deep frying and hardness, as well as exterior a^* and b^* had no or almost no overlapping groupings in the ANOVA. This could be an indication that these properties are what primarily made the falafels different from each other. This is consistent with the observations in the PCA, which are further discussed below.

The results of the present study are in line with previous findings. Water uptake in pulses has been found to be in the range 79–131 % (Gupta *et al.*, 2018; Bhatty, 1995; Abou-Samaha *et al.*, 1985; Deshpande *et al.*, 1984), whereas moisture content of falafels varies between 33–83 % (Al-Asmar *et al.*, 2019; Ismail *et al.*, 2018; Abu-Alruz, 2015; Pinthus *et al.*, 1993) and has been found to be around 54% in falafels prior to deep-frying (Pinthus *et al.*, 1993). Fat content in deep-fried falafels have been found to be approximately 14–58 % of dry matter (Al-Asmar *et al.*, 2019; Ismail *et al.*, 2018). It should be noted that water and fat contents is an effect also of cooking conditions and other ingredients in the falafels. There might also be differences in the raw material affecting the analysed compositions, and different methods used to analyse components might affect results. However, since the results in the present study are consistent with what has previously been found, the generalisability is strengthened. If the analyses were to be repeated, it could be expected that results in a similar range would be obtained.

Previous studies have found lipid contents in pulses ranging between approximately 0.79–4 % for peas, beans and lentils (Hall *et al.*, 2017; Derbyshire, 2011; Boye *et al.*, 2010a; Wang & Daun, 2006; Koehler *et al.*, 1987) and 4.5–12.6 % for lupins (Martínez-Villaluenga *et al.*, 2006; Sujak *et al.*, 2006) on dry matter basis. The findings of the present study are in accordance with this (the results on lipid contents on wet weight basis reported in the results correspond to 2.4, 10.1, 5.1, 2.3, 2.5 and 1.8 % lipids per dry weight for falafels made from borlotti beans, chickpeas, Mirabor lupins, black beans, Gotland lentils and yellow peas, respectively). The lipid content in falafel batter was somewhat higher than in previous studies on chickpea falafel (Hall *et al.*, 2017; Derbyshire, 2011; Boye *et al.*, 2010a).

Some of the lipid content data had large standard deviations, lowering the reliability. The variation between replicates could be a result of variation in the raw material, but is likely due to incomplete extraction of lipids.

Another limitation of the study was the relatively large standard deviations in TPA and colour measurements. This could be a result of presence of unevenly sized pieces of pulses or undispersed seed coat pieces in some of the falafels. However, other authors have also observed large variations in colour measurements (Arvanitoyannis *et al.*, 2007). To gain stronger results, more replicates could be used for the analyses to balance out differences in the raw material and obtain lower standard deviations.

In future studies, it would be interesting to perform additional physicochemical analyses, for example on carbohydrates or protein content in the falafels, in order to obtain better understanding of interactions between pulse composition and resulting falafel properties and sensory appeals.

5.1.2. PCA

Several of the observations from the PCA have a logic ground. The two clusters formed in PC1 indicate that lupin falafels differed from the others. Lupin falafels correlated positively with water uptake, batter moisture content, water loss and negatively with cohesiveness, which was consistent with observations; lupins absorbed a lot of water during soaking, the falafels had high water loss and a soft texture which fell apart easily (i.e. had low cohesiveness). The negative correlation between hardness and water uptake/water loss/batter moisture content was also observed during physicochemical analyses. It has been observed earlier that lower moisture content results in higher hardness (Oztop *et al.*, 2007). The negative correlation between moisture content and water loss is also logical; as more water is lost during deep-frying, the moisture content decreases.

The PCA in the present study showed a correlation between water absorption during soaking and water loss upon deep-frying. This might be because there is more free, unbound water in the pulses with higher water uptake, that can easily be evaporated during deep-frying. The correlation between water loss and oil absorption has been observed in previous studies, and can be explained by the mass transfer that happens during deep-frying, where oil moves into falafels in place of water that moves out (Abu-Alruz, 2015; Oztop *et al.*, 2007).

The PCA only contains information on fat content for falafels made from chickpea, yellow pea, Mirabor lupin, borlotti bean, black bean and Gotland lentil. It is therefore not known how falafels made from the other pulses in the screening correlates with lipid properties, and it cannot be excluded that such correlations exist.

5.2. Sensory analysis

Most of the falafels received liking scores above 5 for all attributes and were thus liked rather than disliked. In overall liking, there were no significant differences between the best liked falafel and the other falafels except for those made from yellow peas. This suggests that all studied pulses, apart from yellow peas, could readily be used in falafels and receive similarly high overall liking scores, and that chickpeas could be replaced by other pulses without significantly affecting the results of liking.

The sensory analysis was possibly limited by the relatively low number of evaluations. However, the study was carefully designed following recommended procedures, and most of the subjects participating were in an age range and had an eating frequency of falafel-like products that represented the assumed target population of early adapters. The test standard deviations were consistent with what can be expected in acceptance testing according to Lawless & Heymann (2010), and the resulting PLS model shows logical relations between sensory liking and other physicochemical analyses (see discussions below). Although the general recommendation is to have 75-100 subjects, smaller consumer groups have been used for acceptance testing in earlier studies where it was concluded that at least trends of liking could be determined (Stone *et al.*, 2012; Gacula Jr & Rutenbeck, 2006). The results of the present study can therefore be viewed as at least providing information on trends of liking.

The purpose of the sensory evaluation was merely to correlate physicochemical properties to degree of liking in order to be able to create an optimised product. The instrumental textural measurements can therefore not be directly correlated to perceived experience of texture.

5.2.1. PLS

In the construction of the PLS models, some of the variables from physicochemical analyses were excluded to achieve a better model. Although this practice is discouraged by some (Umetrics, no date), it was considered necessary to avoid spurious correlations which could result in a misleading model. When using all variables, it was for example observed that liking of texture correlated with high values of some colour measurements. This could lead to the conclusion that a specific colour correlates with a highly liked texture, which is an unlikely correlation. The strong regression coefficients for liking of texture and colour measurements could be a result of data being "pulled" since the Mirabor lupin falafels, which achieved the highest liking of texture, also had high values in certain colour measurements. Thus, the PLS models obtained when excluding data were considered more reasonable. A result of this exclusion of variables is however that the PLS models should not be used for predictive purposes, but are only suitable for the interpretation of the particular data set used in this study.

The PLS models showed that in order to obtain high sensory liking of appearance and texture, falafels should have a colour towards red in a green-red spectrum (a^* in colour measurements), high contrast between exterior and interior lightness, low hardness and large water absorption in soaking, high moisture content in falafel batter and high water loss.

5.3. Optimisation

The optimisation results indicated that to obtain large water uptake and low hardness of falafels, soaking time was the most important factor, which should be around 10–13 hours for Gotland lentils. Earlier studies have also found soaking time to be important for lentil water uptake and texture, with similar hydration patterns of high initial absorption (Maneesh Kumar *et al.*, 2018; Oroian, 2017; Joshi *et al.*, 2010; Bhatty, 1995; Abou-Samaha *et al.*, 1985). Hardness of lentils has been observed to decrease as soaking time increased (Joshi *et al.*, 2010; Sefa-Dedeh *et al.*, 1979), which is consistent with findings in the present study.

Addition of $NaHCO_3$ to the soaking water did not seem to impact hardness, and water uptake was largest at low or no addition of $NaHCO_3$. Although some authors have found that addition of $NaHCO_3$ did not have large impact on water absorption in pulses (Haladjian *et al.*, 2003; Perry *et al.*, 1976), the results of the present study were opposite to what was expected, since other studies have found that soaking in bicarbonate salts lead to larger water absorption and improved textural qualities of pulses (Siddiq *et al.*, 2012; Pirhayati *et al.*, 2011; Wanjekeche *et al.*, 2003; de León *et al.*, 1992; Lu *et al.*, 1984). This effect is a result of the pH change that the addition of $NaHCO_3$ causes, which softens the seed coat and increases the osmotic pressure in the solution (Siddiq *et al.*, 2012). The pH-change also affects the solubility and water binding capacity of pulse proteins, which increases outside the isoelectric point at pH 4–6 (Boye *et al.*, 2010a; Boye *et al.*, 2010b; Garcia-Vela & Stanley, 1989). As the softening process is pH-dependent, the absent effect of $NaHCO_3$ addition in the current study could be an effect of insufficient pH change. Future studies should focus on controlling pH rather than $NaHCO_3$ concentrations.

It can be added that previous studies have found differences in water absorption processes among different pulse varieties and between cultivars of the same pulse (Miano *et al.*, 2018; Joshi *et al.*, 2010; Abou-Samaha *et al.*, 1985). Several seed properties and agronomic factors affect the water absorption (Miano *et al.*, 2018; Siddiq *et al.*, 2012). Thus, the findings of the present study are likely due to the specific properties of Gotland lentils. Hydration mechanisms, especially upon $NaHCO_3$ addition into soaking water, should be further studied to improve understanding of Gotland lentil properties.

To obtain a full evaluation of the optimisation, the falafels should be analysed sensorially by consumers. The optimisation in this study has presumed that as large water uptake and low hardness as possible is desirable. This must not necessarily be the case, as consumers might request some degree of hardness to find the texture pleasing. By evaluating the Gotland lentil falafels from the optimisation sensorially, optimum hardness and water absorption values could be pinpointed. A repeated optimisation could find which soaking times and $NaHCO_3$ concentrations that give the optimum values. A sensory evaluation of the falafels is also important to determine whether the different processing conditions causes a detectable difference between the falafels.

5.4. Implications of the findings

This study has used a few chosen pulse varieties. As there might be differences between varieties of the same pulse species, the results of the current study are not generalisable to all varieties of the studied pulses. For example, the faba bean falafels were excluded after the screening due to an unpleasant flavour. This does not imply that all faba beans are unsuitable for falafel making.

The focus of the study has been to develop a sensorially desirable product from Swedish pulses, and in that aspect, it seemed like Gotland lentils were best suited in falafel making. However, other factors, such as pricing, nutritional value and availability, might be important for the choice of pulse in an industrial context, not only sensory acceptance. It is neither only the sensory evaluation that determines whether a food product will be successful or not on the market, where factors such as label and positioning are of importance (Lawless & Heymann, 2010). A sensory appeal is however a fundamental factor for the food to be successful (*ibid.*). The insights given in this study are therefore valuable for further development of a new falafel product, and perhaps also other pulse-based foods.

The study has also provided some insight into the properties of pulses that could be of use for future product development. Knowledge on hydration properties of pulses is especially valuable, since soaking of pulses is important regardless of subsequent use. As simplified recipes have been used, containing only pulse, table salt and $NaHCO_3$, the results on physical properties of patties could be useful in further studies, and the sensory analysis provided insight into what attributes and properties of pulses that are desirable among consumers. Thus, the study has found a new use for Swedish pulses, and simultaneously provided information that can be useful for future product development, which has been stated to be of importance to increase the interest for Swedish pulses (Carlsson, 2012; Fogelberg, 2008).

6. Conclusion

The study aimed to evaluate suitability of using Swedish pulses in falafel making by analysing physicochemical and sensory properties, and optimising the texture for a new falafel. It was found that falafels could be made from all the pulses included in the study. However, due to variation in physicochemical properties and sensory evaluations on liking, some pulses were more suitable to use in falafel than others. Most of the variation between falafels could be attributed to properties relating to moisture content, texture and colour. These properties were also important for sensory liking, which correlated with large values of $a*$, contrast in $L*$, moisture content and weight increase, and low hardness. Sensory evaluations indicated that all the included pulses except yellow peas were suitable to use in falafel to obtain high overall liking, suggesting that chickpeas could be replaced by most of the studied pulses. To obtain falafels with maximum liking of appearance and texture, Mirabor lupins were most suitable out of the studied pulses. To obtain maximum liking of flavour and overall liking, Gotland lentils were the most suitable. The texture of Gotland lentil falafels could be optimised for both large water uptake and low hardness by applying soaking times of 10–13 hours.

7. References

Abou-Samaha, O.R., El-Mahdy, A.R. & Moharram, Y.G. (1985). Effect of soaking on the quality of lentil seeds. *Zeitschrift für Lebensmittel-Untersuchung und Forschung,* 180(6), pp. 485-490.

Abu-Alruz, K. (2015). Effect of frying time and falafel balls size on fat uptake during deep fat frying. *American-Eurasian JAgri Environ Sci,* 15, pp. 648-1654.

Al-Asmar, A., Giosafatto, C.V.L., Panzella, L. & Mariniello, L. (2019). The Effect of Transglutaminase to Improve the Quality of Either Traditional or Pectin-Coated Falafel (Fried Middle Eastern Food). *Coatings,* 9(5), p. 331.

Allen, L.H. (2013). Legumes. In: Caballero, B. (ed. *Encyclopedia of Human Nutrition (Third Edition)*. Waltham: Academic Press, pp. 74-79. Available from: http://www.sciencedirect.com/science/article/pii/B9780123750839001707

Arvanitoyannis, I.S., Mavromatis, A., Rodiatis, A. & Goulas, C. (2007). Physicochemical and sensory analysis of dry bean landraces in conjunction with multivariate analysis: an exploratory approach. *International Journal of Food Science & Technology,* 42(7), pp. 819-826.

Bhatty, R.S. (1990). Cooking quality of lentils: the role of structure and composition of cell walls. *Journal of Agricultural and Food Chemistry,* 38(2), pp. 376-383.

Bhatty, R.S. (1995). Comparisons of good- and poor-cooking lentils. *Journal of the Science of Food and Agriculture,* 68(4), pp. 489-496.

Bourne, M.C. (2002). *Food Texture and Viscosity : Concept and Measurement*. San Diego, United States: Elsevier Science & Technology. Available from: http://ebookcentral.proquest.com/lib/slub-ebooks/detail.action?docID=294600.

Boye, J., Zare, F. & Pletch, A. (2010a). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International,* 43(2), pp. 414-431.

Boye, J.I., Aksay, S., Roufik, S., Ribéreau, S., Mondor, M., Farnworth, E. & Rajamohamed, S.H. (2010b). Comparison of the functional properties of pea, chickpea and lentil protein concentrates processed using ultrafiltration and isoelectric precipitation techniques. *Food Research International,* 43(2), pp. 537-546.

Bues, A., Preissel, S., Reckling, M., Zander, P., Kuhlman, T., Topp, K., Watson, C., Lindström, K., Stoddard, F. & Murphy-Bokern, D. (2013). *The environmental role of protein crops in the new common agricultural policy.* Brussels: European Parliament.

Carlsson, C. (2012). *Baljväxter på bordet: En undersökning av svensk ekologisk yrkesodling av baljväxter för humankonsumtion och potentialen för en utökad odling.* University of Gävle. Department of Electrical Engineering, Mathematics and Science/Gardening programme.

da Silva, V.P., van der Werf, H.M.G., Spies, A. & Soares, S.R. (2010). Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios. *Journal of Environmental Management,* 91(9), pp. 1831-1839.

de León, L.F., Elías, L.G. & Bressani, R. (1992). Effect of salt solutions on the cooking time, nutritional and sensory characteristics of common beans (Phaseolus vulgaris). *Food Research International,* 25(2), pp. 131-136.

Derbyshire, E. (2011). The nutritional value of whole pulses and pulse fractions. In: Tiwari, B.K., Gowen, A. & McKenna, B. (eds) *Pulse Foods*. San Diego: Academic Press, pp. 363-383. Available from: http://www.sciencedirect.com/science/article/pii/B9780123820181000137.

Deshpande, S.S., Sathe, S.K. & Salunkhe, D.K. (1984). Interrelationships between certain physical and chemical properties of dry bean (Phaseolus vulgaris L.). *Plant Foods for Human Nutrition,* 34(1), pp. 53-65.

Ekelund Axelson, L. & Persson, K. (2012). *Konsumenter om klimat, mat och klimatmärkning*: LTJ-faculty, Swedish University of Agricultural Sciences. Available from: https://pub.epsilon.slu.se/9377/7/ekelund_et_al_%20130111.pdf.

Ekqvist, I., Röös, E. & Tidåker, P. (2019). *Grain legumes on the Swedish market: origin and pesticide use in the production*.

Ellefson, W.C. (2017). Fat Analysis. In: Nielsen, S.S. (ed. *Food Analysis*. 5. ed Springer International Publish, pp. 299-314.

Eriksson, L., Byrne, T., Johansson, E., Trygg, J. & Vikström, C. (2013). *Multi- and Megavariate Data Analysis. Basic Principles and Applications*. 3rd ed. Malmö: MKS Umetrics AB.

Fogelberg, F. (2008). *Svenska bönor inte bara bruna : klimat och jordmån passar även exotiska bönor*. Uppsala: JTI - Institutet för jordbruks- och miljöteknik.

Fogelfors, H. (2015). *Vår mat : odling av åker- och trädgårdsgrödor : biologi, förutsättningar och historia*. 1 ed. Lund: Studentlitteratur.

Foyer, C.H., Lam, H.-M., Nguyen, H.T., Siddique, K.H.M., Varshney, R.K., Colmer, T.D., Cowling, W., Bramley, H., Mori, T.A., Hodgson, J.M., Cooper, J.W., Miller, A.J., Kunert, K., Vorster, J., Cullis, C., Ozga, J.A., Wahlqvist, M.L., Liang, Y., Shou, H., Shi, K., Yu, J., Fodor, N., Kaiser, B.N., Wong, F.-L., Valliyodan, B. & Considine, M.J. (2016). Neglecting legumes has compromised human health and sustainable food production. *Nature Plants,* 2(8), p. 16112.

Fuller, G.W. (2011). *New Food Product Development : From Concept to Marketplace, Third Edition*. Baton Rouge, United States: CRC Press LLC. Available from: http://ebookcentral.proquest.com/lib/slub-ebooks/detail.action?docID=688509.

Gacula Jr, M. & Rutenbeck, S. (2006). Sample size in consumer test and descriptive analysis. *Journal of Sensory Studies,* 21(2), pp. 129-145.

Garcia-Vela, L.A. & Stanley, D.W. (1989). Water-Holding Capacity in Hard-to-Cook Beans (Phaseolus vulgaris): Effect of pH and Ionic Strength. *Journal of Food Science,* 54(4), pp. 1080-1081.

Government offices (2017). *En livsmedelsstrategi för Sverige – fler jobb och hållbar tillväxt i hela landet*.

Gupta, S., Chhabra, G.S., Liu, C., Bakshi, J.S. & Sathe, S.K. (2018). Functional Properties of Select Dry Bean Seeds and Flours. *Journal of Food Science,* 83(8), pp. 2052-2061.

Gustafsson, I.-B., Jonsäll, A., Mossberg, L., Swahn, J. & Öström, Å. (2014). *Sensorik och marknadsföring.* Lund: Studentlitteratur AB.

Haladjian, N., Fayad, R., Toufeili, I., Shadarevian, S., Sidahmed, M., Baydoun, E. & Karwe, M. (2003). pH, temperature and hydration kinetics of faba beans (Vicia faba L.). *Journal of Food Processing and Preservation,* 27(1), pp. 9-20.

Hall, C., Hillen, C. & Garden Robinson, J. (2017). Composition, Nutritional Value, and Health Benefits of Pulses. *Cereal Chemistry,* 94(1), pp. 11-31.

Hara, A. & Radin, N.S. (1978). Lipid extraction of tissues with a low-toxicity solvent. *Analytical Biochemistry,* 90(1), pp. 420-426.

Hushållningssällskapet (2013). *Alternativa livsmedelsgrödor*. Available from: http://hushallningssallskapet.se/wp-content/uploads/2014/09/alternativa-livsmedelsgrodor-for-hemsidan.pdf.

Institutet för språk och folkminnen (2018). *Linser*. Available at: https://www.isof.se/matkult/baljvaxter/linser.html [2020-03-26].

Institutet för språk och folkminnen (2020). *Om baljväxter i kosthållet*. Available at: https://www.isof.se/matkult/baljvaxter/om-baljvaxter-i-kosthallet.html [2020-03-26].

Ismail, M.M., Turgut, S.S., Karacabey, E. & Kucukoner, E. (2018). Determination of Physical Properties of Falafel (Fried Chickpea Balls) under the Effect of Different Cooking Techniques. *International Journal of Food Engineering,* 4(3).

Joshi, M., Adhikari, B., Panozzo, J. & Aldred, P. (2010). Water uptake and its impact on the texture of lentils (Lens culinaris). *Journal of Food Engineering,* 100(1), pp. 61-69.

Karlsson, J., Röös, E., Sjunnestrand, T., Pira, K., Larsson, M., Andersen, B.H., Sørensen, J., Veistola, T., Rantakokko, J., Manninen, S. & Brubæk, S. (2017). *Future Nordic Diets: Exploring ways for sustainably feeding the Nordics*. Copenhagen: Nordisk Ministerråd.

Knudsen, M.T. (2011). *Environmental assessment of imported organic products-focusing on orange juice from Brazil and soybeans from China*. Diss: University of Copenhagen, Faculty of Life Sciences.

Koehler, H.H., Chang, C.i.-H., Scheier, G. & Burke, D.W. (1987). Nutrient Composition, Protein Quality, and Sensory Properties of Thirty-Six Cultivars of Dry Beans (Phaseolus vulgaris L.). *Journal of Food Science,* 52(5), pp. 1335-1340.

Kuylenstierna, J., Barraza, H.J., Benton, T., Larsen, A.F., Kurppa, S., Lipper, L. & Virgin, I. (2019). *Food Security and Sustainable Food Systems - Research to support a sustainable, competitive and innovative Swedish food system by 2030*. Stockholm: Mistra

Lawless, H.T. & Heymann, H. (2010). *Sensory evaluation of food : principles and practices*. 2nd ed. New York: Springer.

Liu, Y.-X., Cao, M.-J. & Liu, G.-M. (2019). 17 - Texture analyzers for food quality evaluation. In: Zhong, J. & Wang, X. (eds) *Evaluation Technologies for Food Quality* Woodhead Publishing, pp. 441-463. Available from: http://www.sciencedirect.com/science/article/pii/B9780128142172000172.

Lu, C.L., Hsu, K.H. & Wilson, L.A. (1984). Quality Attributes and Retention of Selected B-Vitamins of Canned Faba Bean as Affected by Soaking Treatments. *Journal of Food Science,* 49(4), pp. 1053-1056.

Lucas, M.M., Stoddard, F., Annicchiarico, P., Frias, J., Martinez-Villaluenga, C., Sussmann, D., Duranti, M., Seger, A., Zander, P. & Pueyo, J. (2015). The future of lupin as a protein crop in Europe. *Frontiers in Plant Science,* 6(705).

Lööv, H., Widell, M.L. & Sköld, O. (2015). *Livsmedelskonsumtionen i siffror - Hur har konsumtionen utvecklats de senaste femtio åren och varför?* Swedish Board of Agriculture. (Report 2015:15).

Maneesh Kumar, M., Prasad, K., Sarat Chandra, T. & Debnath, S. (2018). Evaluation of physical properties and hydration kinetics of red lentil (Lens culinaris) at different processed levels and soaking temperatures. *Journal of the Saudi Society of Agricultural Sciences,* 17(3), pp. 330-338.

Martínez-Villaluenga, C., Frías, J. & Vidal-Valverde, C. (2006). Functional lupin seeds (Lupinus albus L. and Lupinus luteus L.) after extraction of α-galactosides. *Food Chemistry,* 98(2), pp. 291-299.

Mauer, L.J. & Bradley, R.L.J. (2017). Moisture and Total Solids Analysis. In: Nielsen, S.S. (ed.) *Food analysis* 5. ed. Springer International Publish, pp. 257-286.

Meilgaard, M.C., Civille, G. M. & Carr, B. T. (2007). *Sensory evaluation techniques*. 4. ed. ed. Boca Raton, Fla: CRC.

Miano, A.C., Sabadoti, V.D., Pereira, J.d.C. & Augusto, P.E.D. (2018). Hydration kinetics of cereal and pulses: New data and hypothesis evaluation. *Journal of Food Process Engineering,* 41(1), p. n/a

Myers, R.H., Montgomery, D.C. & Anderson-Cook, C.M. (2016). *Response Surface Methodology : Process and Product Optimization Using Designed*

Experiments. New York, United States: John Wiley & Sons, Incorporated. Available from: http://ebookcentral.proquest.com/lib/slub-ebooks/detail.action?docID=4312599.

Naturhistoriska riksmuseet (2008-07-10). *Den virtuella floran: Fabaceae - Leguminosae - Ärtväxter*. Available at: http://linnaeus.nrm.se/flora/di/faba/welcome.html [2020-03-25].

Nielsen, S.S. (2017). Introduction to Food Analysis. In: Nielsen, S.S. (ed. *Food analysis*. 5. ed. (Food Science Text Series Springer International Publish, pp. 3-16.

Nishinari, K. & Fang, Y. (2018). Perception and measurement of food texture: Solid foods. *Journal of Texture Studies,* 49(2), pp. 160-201.

Olsson, C. (2017). *Expanding the grain legume food production in Southern Sweden.* Alnarp: Swedish University of Agricultural Sciences.

Oroian, M. (2017). The temperature hydration kinetics of Lens culinaris. *Journal of the Saudi Society of Agricultural Sciences,* 16(3), pp. 250-256.

Oztop, M.H., Sahin, S. & Sumnu, G. (2007). Optimization of microwave frying of osmotically dehydrated potato slices by using response surface methodology. *European Food Research and Technology,* 224(6), pp. 707-713.

Peltonen-Sainio, P., Hannukkala, A., Huusela-Veistola, E., Voutila, L., Niemi, J., Valaja, J., Jauhiainen, L. & Hakala, K. (2013). Potential and realities of enhancing rapeseed- and grain legume-based protein production in a northern climate. *The Journal of Agricultural Science,* 151(3), pp. 303-321.

Perry, A.K., Peters, C.R. & Van Duyne, F.O. (1976). Effect of variety and cooking method on cooking times, thiamine content and palatability of soybeans. *Journal of Food Science,* 41(6), pp. 1330-1334.

Pinthus, E.J., Weinberg, P. & Saguy, I.S. (1993). Criterion for Oil Uptake during Deep-fat Frying. *Journal of Food Science,* 58(1), pp. 204-205.

Pirhayati, M., Soltanizadeh, N. & Kadivar, M. (2011). Chemical and microstructural evaluation of ‘hard-to-cook’ phenomenon in legumes (pinto bean and small-type lentil). *International Journal of Food Science & Technology,* 46(9), pp. 1884-1890.

Poulsen, G. & Solberg, S.Ø. (2015). *Baltic Sea region: Mapping of regional potentials in protein supply from agriculture*. NordGen. Available: https://www.nordgen.org/wp-content/uploads/2018/01/20150626_Sustainable_protein_production.pdf

Preissel, S., Reckling, M., Schläfke, N. & Zander, P. (2015). Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: A review. *Field Crops Research,* 175, pp. 64-79.

R Core Team (2020). *R: A language and environment for statistical computing.* . [Computer Program]. Vienna, Austria: R Foundation for Statistical Computing. Available from: https://www.R-project.org/.

Röös, E. (2014). *Mat-klimat-listan*. Uppsala: Department of Energy and Technology, Swedish University of Agricultural Sciences. (Report: 077)

Sailer, O.M. (2013). *Crossdes: Construction of Crossover Designs. R package version 1.1-1*. [Computer Program]. Available from: https://CRAN.R-project.org/package=crossdes.

Samuelsson, R., Burvall, J. & Jirjis, R. (2006). Comparison of different methods for the determination of moisture content in biomass. *Biomass and Bioenergy,* 30(11), pp. 929-934.

Sandström, V., Lehikoinen, E. & Peltonen-Sainio, P. (2018). Replacing Imports of Crop Based Commodities by Domestic Production in Finland: Potential to Reduce Virtual Water Imports. *Frontiers in Sustainable Food Systems,* 2(67).

Sefa-Dedeh, S., Stanley, D.W. & Voisey, P.W. (1979). Effect of storage time and conditions on the hard-to-cook defect in cowpeas (Vigna unguiculata). *Journal of Food Science,* 44(3), pp. 790-795.

Siddiq, M., Uebersax, M.A. & Uebersax, M.A. (2012). *Dry Beans and Pulses : Production, Processing and Nutrition*. Hoboken, United States: John Wiley & Sons, Incorporated. Available from: http://ebookcentral.proquest.com/lib/uu/detail.action?docID=947721.

Sozer, N., Holopainen-Mantila, U. & Poutanen, K. (2017). Traditional and New Food Uses of Pulses. *Cereal Chemistry,* 94(1), pp. 66-73.

Stoddard, F. (2010). Improving food and feed security in the Nordic and Baltic region by using appropriate crop rotations. *Agronomy Research,* 8 (Special Issue II), pp. 311-316.

Stone, H., Bleibaum, R.N. & Thomas, H.A. (2012). Chapter 7 - Affective Testing. In: Stone, H., Bleibaum, R.N. & Thomas, H.A. (eds) *Sensory Evaluation Practices (Fourth Edition)*. San Diego: Academic Press, pp. 291-325. Available from: http://www.sciencedirect.com/science/article/pii/B9780123820860000078.

Sujak, A., Kotlarz, A. & Strobel, W. (2006). Compositional and nutritional evaluation of several lupin seeds. *Food Chemistry,* 98(4), pp. 711-719.

Sundén, V. (2014). *Framgångsfaktorer för ökad svensk odling av baljväxter till livsmedel.* Alnarp: Swedish University of Agricultural Sciences. Department of Biosystems and Technology/Horticultural management, Bachelor's programme

Swedish Board of Agriculture (2019-05-15). *Jordbruksmarkens användning 2019 - JO 10 SM 1901*. Available from: http://www.jordbruksverket.se/webdav/files/SJV/Amnesomraden/Statistik,%20fakta/Arealer/JO10/JO10SM1901/JO10SM1901_infoSM.htm [March 25].

Swedish Board of Agriculture (2019b). *Livsmedelskonsumtion och näringsinnehåll - uppgifter till och med 2018*. Available: https://www.scb.se/contentassets/8af9fcac17634fc197825dfec6e2b0ce/jo1301_2018a01_sm_jo44sm1901.pdf

Tilman, D. & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature,* 515(7528), pp. 518-522.

Tuorila, H. (2007). 2 - Sensory perception as a basis of food acceptance and consumption. In: MacFie, H. (ed.) *Consumer-Led Food Product Development* Woodhead Publishing, pp. 34-65. Available from: http://www.sciencedirect.com/science/article/pii/B978184569072450002X

Umetrics (no date). *SIMCA -P and Multivariate Analysis - Frequently Asked Questions*. Available from: https://umetrics.com/sites/default/files/kb/multivariate_faq.pdf.

Wakeling, I.N. & MacFie, H.J. (1995). Designing consumer trials balanced for first and higher orders of carry-over effect when only a subset of k samples from t may be tested. *Food Quality and Preference,* 6(4), pp. 299-308.

van Kleef, E., van Trijp, H.C.M. & Luning, P. (2005). Consumer research in the early stages of new product development: a critical review of methods and techniques. *Food Quality and Preference,* 16(3), pp. 181-201.

Wang, N. & Daun, J.K. (2006). Effects of variety and crude protein content on nutrients and anti-nutrients in lentils (Lens culinaris). *Food Chemistry,* 95(3), pp. 493-502.

Wanjekeche, E., Wakasa, V. & Mureithi, J. (2003). Effect of germination, alkaline and acid soaking and boiling on the nutritional value of mature and immature Mucuna (Mucuna pruriens) beans. *Tropical and Subtropical Agroecosystems,* 1(2-3), pp. 183-192.

Wee, M.S.M., Goh, A.T., Stieger, M. & Forde, C.G. (2018). Correlation of instrumental texture properties from textural profile analysis (TPA) with eating behaviours and macronutrient composition for a wide range of solid foods. *Food & function,* 9(10), pp. 5301-5312.

Wrolstad, R.E. & Smith, D.E. (2017). Color Analysis. In: Nielsen, S.S. (ed. *Food analysis*. 5. ed Springer International Publish, pp. 545-556.

Zander, P., Amjath-Babu, T.S., Preissel, S., Reckling, M., Bues, A., Schläfke, N., Kuhlman, T., Bachinger, J., Uthes, S., Stoddard, F., Murphy-Bokern, D. & Watson, C. (2016). Grain legume decline and potential recovery in European agriculture: a review. *Agronomy for Sustainable Development,* 36(2), p. 26.

Östberg, J. (2019). *Managing uncertainties and development of grain legumes in Sweden.* Alnarp: Swedish University of Agricultural Sciences, Department of Biosystems and Technology/Horticulturalist programme.

Acknowledgements

I would like to give special thanks to my supervisor Jonas Ohlsson for all the help and support during my work with this thesis. Thanks also to my assistant supervisor Daniel Johansson for insights into texture analysis. Thanks to Sevan Hummus Factory for initiating this project, and especially to Sanna Pyykönen. I am grateful to Fredrik Fogelberg who kindly provided pulse materials for the project. I also want to give thanks to Mikolaj Chmielarz for being so helpful in the lab.

Appendix 1 – Serving order design for sensory acceptance test

Judge	*Code*	*Falafel*	*Code*	*Falafel*	*Code*	*Falafel*	*Code*	*Falafel*
1	*967*	2	*259*	3	*532*	6	*618*	4
2	*624*	3	*396*	4	*562*	2	*134*	6
3	*563*	4	*932*	6	*441*	3	*834*	2
4	*787*	6	*231*	2	*958*	4	*352*	3
5	*537*	3	*439*	4	*956*	6	*531*	5
6	*345*	4	*232*	5	*918*	3	*481*	6
7	*797*	5	*621*	6	*743*	4	*827*	3
8	*377*	6	*916*	3	*966*	5	*429*	4
9	*657*	1	*246*	2	*423*	4	*277*	3
10	*685*	2	*533*	3	*937*	1	*223*	4
11	*582*	3	*946*	4	*323*	2	*626*	1
12	*116*	4	*573*	1	*464*	3	*191*	2
13	*132*	2	*218*	3	*786*	6	*258*	5
14	*296*	3	*471*	5	*372*	2	*935*	6
15	*353*	5	*747*	6	*123*	3	*863*	2
16	*644*	6	*161*	2	*793*	5	*196*	3
17	*223*	1	*398*	2	*183*	6	*795*	4
18	*138*	2	*369*	4	*163*	1	*743*	6
19	*593*	4	*252*	6	*581*	2	*355*	1
20	*542*	6	*691*	1	*537*	4	*222*	2
21	*746*	1	*636*	2	*478*	5	*368*	4
22	*949*	2	*651*	4	*295*	1	*199*	5
23	*113*	4	*478*	5	*933*	2	*375*	1
24	*979*	5	*414*	1	*891*	4	*129*	2
25	*938*	1	*862*	2	*572*	6	*698*	5
26	*128*	2	*363*	5	*941*	1	*214*	6
27	*841*	5	*314*	6	*437*	2	*792*	1
28	*874*	6	*926*	1	*477*	5	*776*	2
29	*339*	1	*818*	3	*251*	6	*916*	5
30	*581*	3	*232*	5	*372*	1	*374*	6
31	*799*	5	*461*	6	*276*	3	*486*	1
32	*274*	6	*791*	1	*369*	5	*774*	3

1 Borlotti bean
2 Chickpea
3 Mirabor lupin
4 Black bean
5 Gotland lentil
6 Yellow pea

33	*795*	1	*681*	2	*458*	5	*938*	3
34	*505*	2	*829*	3	*614*	1	*547*	5
35	*869*	3	*742*	5	*822*	2	*554*	1
36	*448*	5	*813*	1	*976*	3	*688*	2
37	*959*	2	*714*	3	*912*	5	*646*	4
38	*873*	3	*397*	4	*159*	2	*155*	5
39	*136*	4	*463*	5	*363*	3	*335*	2
40	*662*	5	*875*	2	*282*	4	*617*	3
41	*274*	1	*635*	3	*379*	6	*287*	4
42	*791*	3	*334*	4	*139*	1	*117*	6
43	*963*	4	*448*	6	*957*	3	*451*	1
44	*585*	6	*821*	1	*829*	4	*267*	3
45	*512*	1	*638*	4	*477*	6	*776*	5
46	*581*	4	*818*	5	*251*	1	*232*	6
47	*383*	5	*349*	6	*468*	4	*122*	1
48	*771*	6	*481*	1	*723*	5	*335*	4
49	*511*	2	*889*	4	*896*	6	*338*	5
50	*937*	4	*313*	5	*594*	2	*158*	6
51	*987*	5	*932*	6	*889*	4	*918*	2
52	*768*	6	*857*	2	*694*	5	*591*	4
53	*214*	1	*851*	3	*669*	5	*394*	4
54	*349*	3	*299*	4	*192*	1	*179*	5
55	*264*	4	*332*	5	*294*	3	*896*	1
56	*782*	5	*397*	1	*791*	4	*659*	3
57	*921*	1	*569*	2	*811*	6	*683*	3
58	*762*	2	*681*	3	*829*	1	*614*	6
59	*547*	3	*869*	6	*742*	2	*822*	1
60	*554*	6	*448*	1	*813*	3	*976*	2

Appendix 2 – Form used in sensory acceptance test

Acceptance test - Legume patties (falafels)

Date:

Tester number:

Welcome to a sensory evaluation of a new falafel product. Before you start tasting the samples, please fill in the following information.

Are you:

☐ Woman ☐ Man ☐ Other

Age:

☐ Under 20 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ Over 60

How often have you eaten legume patties, falafel or similar products in the last 3 months?

☐ Never

☐ Less often than once per month

☐ Once per month

☐ More often than once per month but less often than once per week

☐ Once per week or more

Test instructions

You are presented with 4 samples of falafels. Your task is to try each of the samples in the order they are presented, from left to right. Make sure that the 3-digit code on the plate matches the code on the answering form. You are encouraged to rinse your mouth with some water in between the samples. Take your time, and do not rush. The objective is to get your individual evaluation of the product, so please do not talk to your neighbour during the test. Circle the sentence that best matches your evaluation of the samples regarding your liking of the products' appearance, texture, flavour as well as your general liking of the product. If you want to leave comments, you can do so at the end of each page. Observe that there are questions for you to answer on both sides of the paper.

Thank you for your participation!

Sample code: _________

Circle one phrase to indicate your opinion on the **appearance** of the sample.

Like extremely

Like very much

Like moderately

Like slightly

Neither like nor dislike

Dislike slightly

Dislike moderately

Dislike very much

Dislike extremely

Circle one phrase to indicate your opinion on the **texture** of the sample.

Like extremely

Like very much

Like moderately

Like slightly

Neither like nor dislike

Dislike slightly

Dislike moderately

Dislike very much

Dislike extremely

Circle one phrase to indicate your opinion on the **flavour** of the sample.

Like extremely

Like very much

Like moderately

Like slightly

Neither like nor dislike

Dislike slightly

Dislike moderately

Dislike very much

Dislike extremely

Circle one phrase to indicate your **overall liking** of the sample.

Like extremely

Like very much

Like moderately

Like slightly

Neither like nor dislike

Dislike slightly

Dislike moderately

Dislike very much

Dislike extremely

Comments:

Appendix 3 – Complete table of sensory evaluations

The table depicts sensory evaluations on appearance, texture, flavour and overall liking of falafels made from six different pulses. Average evaluations per sex, age and eating frequency are presented together with standard deviations (StDev) in italic. Where evaluations were too few to obtain standard deviations, this is indicated by a hyphen. Empty cells signify absence of evaluation for that particular sample. Scores go from 1 (dislike extremely) to 9 (like extremely). Note: the means in the below table differs from those presented in Table 4 since a two-way ANOVA was used to obtain the latter, while the below data is a result of simple descriptive statistics.

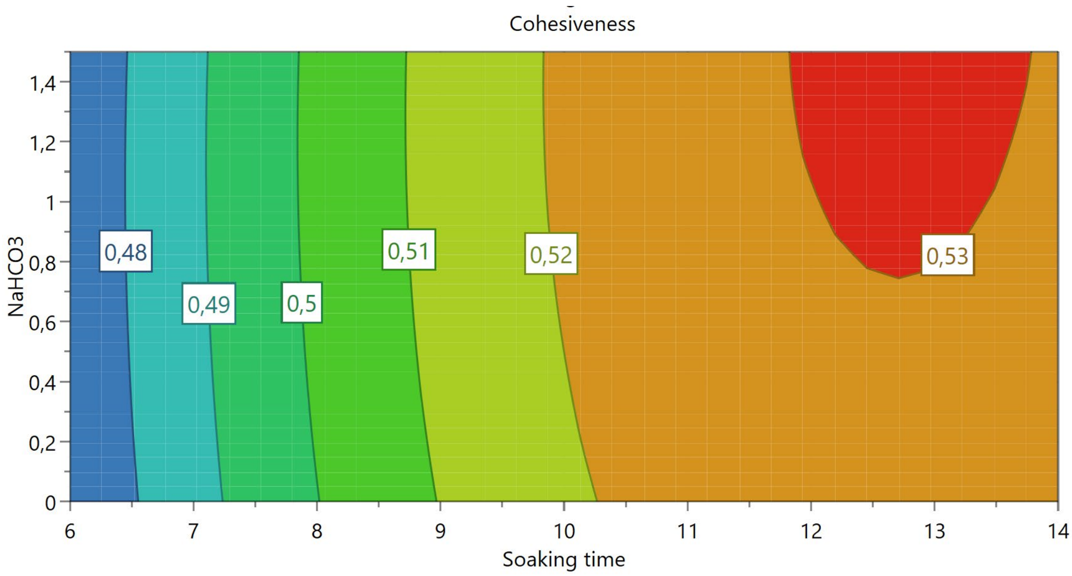
	Group of judges (n)	**Borlotti bean** ***Stdev***	**Chickpea** ***Stdev***	**Mirabor lupin** ***Stdev***	**Black bean** ***Stdev***	**Gotland lentil** ***Stdev***	**Yellow pea** ***Stdev***
Total no of evaluations		35	35	33	38	38	36
			APPEARANCE				
Mean score	All	5.9	6.3	7.7	5.3	6.2	6.6
	(54)	*1.8*	*1.9*	*1.1*	*1.8*	*1.6*	*1.6*
Mean score per sex	Woman (35)	5.6	6.2	7.7	5.2	6.5	6.3
		1.9	*2.1*	*1.3*	*1.8*	*1.4*	*1.6*
	Man	6.6	6.3	7.7	5.6	5.7	7.0
	(18)	*1.5*	*1.5*	*0.9*	*1.9*	*1.9*	*1.4*
	Other	7.0	7.0	8.0		6.0	
	(1)	-	-	-		-	
Mean score per age	20–29	5.5	5.9	7.6	5.4	6.4	6.3
	(39)	*2.0*	*2.0*	*1.2*	*1.8*	*1.6*	*1.6*
	30–39	7.0	7.4	7.9	3.8	5.6	7.8
	(10)	*0.6*	*1.1*	*0.8*	*0.8*	*1.5*	*0.8*
	40–49	6.0	5.0	8.5	6.5	8.0	7.0
	(2)	-	-	*0.7*	*2.1*	-	-
	50–59			8.0	6.0	4.0	7.0
	(1)			-	-	-	-
	Over 60 (1)		7.0	8.0	8.0		7.0
			-	-	-		-
	Missing (1)	7.0		6.0	5.0		5.0
		-		-	-		-
Mean score per eat frequency	Never	6.5	6.6	7.3	5.0 *2.0*	5.7	6.5
	(5)	*0.7*	*0.9*	*0.6*		*2.1*	*0.7*
	< once/	6.2	6.6	8.1	5.0	5.7	6.9
	month (16)	*1.8*	*2.2*	*0.8*	*1.8*	*2.0*	*1.2*
	Once	5.7	5.4	7.4	5.8	6.6	6.1
	/month (14)	*1.9*	*1.3*	*1.7*	*1.8*	*1.3*	*1.7*
	Monthly–	6.0	6.4	7.7	4.7	7.4	7.0
	weekly (11)	*2.1*	*2.6*	*1.3*	*1.9*	*0.7*	*1.80*
	≥ Once	5.3	6.8	7.5	6.5	5.8	6.0
	/week (8)	*2.1*	*1.6*	*0.8*	*1.3*	*1.3*	*1.7*
			TEXTURE				
Mean score	All	5.7	6.0	6.5	5.2	6.0	4.6
	(54)	*1.8*	*1.7*	*1.7*	*1.6*	*1.6*	*2.1*
Mean score per sex	Woman (35)	5.6	5.6	6.7	5.1	5.9	4.1
		1.9	*1.7*	*1.8*	*1.8*	*1.7*	*2.0*
	Man	5.9	6.8	6.3	5.5	6.1	5.6

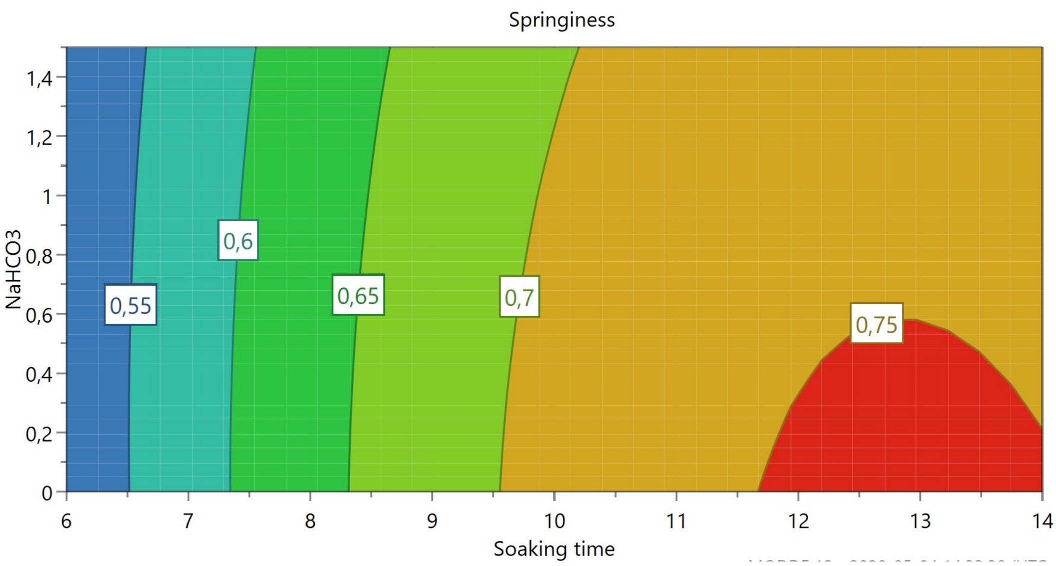
	(18)	*1.5*	*1.4*	*1.7*	*1.2*	*1.5*	*2.2*
	Other	7.0	7.0	7.0		7.0	
	(1)	-	-	-		-	
Mean score per age	20–29	5.7	5.8	6.6	5.1	5.7	4.4
	(39)	*1.8*	*1.6*	*1.8*	*1.8*	*1.5*	*2.1*
	30–39	6.4	7.0	6.6	5.2	7.1	5.4
	(10)	*1.3*	*1.7*	*1.3*	*0.8*	*1.4*	*2.5*
	40–49	6.0	6.0	7.5	6.5	8.0	7.0
	(2)	-	-	*0.7*	*0.7*	-	-
	50–59			4.0	5.0	5.0	3.0
	(1)			-	-	-	-
	Over 60 (1)		4.0	7.0	7.0		7.0
			-	-	-		-
	Missing (1)	2.0		4.0	5.0		2.0
		-		-	-		-
Mean score per eat frequency	Never	5.5	6.2	6.7	4.8	6.0	6.0
	(5)	*2.1*	*0.8*	*1.5*	*1.5*	*1.7*	*2.8*
	< once/	6.0	6.8	6.8	5.4	6.6	4.6
	month (16)	*1.3*	*2.1*	*1.8*	*1.4*	*1.6*	*2.8*
	Once	6.0	5.2	6.9	5.7	5.3	4.6
	/month (14)	*1.8*	*1.6*	*1.9*	*1.6*	*1.8*	*2.1*
	Monthly–	5.0	6.3	6.3	5.0	6.5	4.6
	weekly (11)	*2.4*	*1.8*	*1.5*	*2.0*	*1.3*	*1.9*
	≥ Once	6.0	5.6	5.7	4.5	5.3	4.0
	/week	*1.8*	*1.3*	*1.5*	*1.9*	*1.4*	*1.0*
	(8)						
			FLAVOUR				
Mean score	All	5.6	6.3	5.3	6.1	6.8	5.3
	(54)	*2.0*	*1.8*	*2.1*	*1.6*	*1.5*	*1.8*
Mean score per sex	Woman (35)	5.3	6.2	5.5	6.0	6.7	5.0
		2.1	*2.1*	*2.1*	*1.5*	*1.6*	*1.6*
	Man	6.1	6.5	5.3	6.3	6.7	5.8
	(18)	*1.5*	*1.3*	*2.3*	*1.8*	*1.4*	*1.9*
	Other	8.0	7.0	4.0		8.0	
	(1)	-	-	-		-	
Mean score per age	20–29	5.5	6.2	5.4	5.9	6.6	5.3
	(39)	*1.9*	*1.8*	*2.1*	*1.7*	*1.5*	*1.7*
	30–39	5.9	6.9	4.6	7.0	7.7	5.8
	(10)	*2.7*	*2.2*	*2.2*	*1.6*	*1.5*	*0.5*
	40–49	6.0	6.0	8.0	6.0	5.0	7.0
	(2)	-	-	0.0	*1.4*	-	
	50–59			3.0	5.0	6.0	2.0
	(1)			-	-	-	-
	Over 60 (1)		6.0	7.0	7.0		7.0
			-	-	-		-
	Missing (1)	5.0		6.0	7.0		2.0
		-		-	-		-
Mean score per eat frequency	Never	4.0	6.0	4.7	5.8	5.7	6.5
	(5)	*4.2*	*2.5*	*2.3*	*2.2*	*2.1*	*2.1*
	< once/	6.3	6.8	5.1	6.6	7.0	4.8
	month (16)	*1.3*	*1.6*	*2.0*	*1.6*	*1.3*	*2.2*
	Once	5.6	5.0	5.4	6.1	6.4	5.3
	/month (14)	*1.7*	*1.8*	*2.7*	*1.3*	*1.4*	*1.8*
	Monthly–	4.6	7.0	6.3	5.1	7.1	5.0
	weekly (11)	*2.5*	*1.5*	*1.5*	*1.6*	*1.6*	*1.4*
	≥ Once	6.2	7.4	5.5	7.3	6.6	6.3
	/week	*1.8*	*0.6*	*2.1*	*0.5*	*1.9*	*0.6*
	(8)						
			OVERALL				
Mean score	All	5.8	6.1	5.7	5.8	6.6	5.4
	(54)	*1.7*	*1.7*	*1.9*	*1.4*	*1.3*	*1.7*
Mean score per sex	Woman (35)	5.6	6.1	5.7	5.5	6.6	*5.0*
		1.7	*1.8*	*2.0*	*1.3*	*1.1*	*1.6*
	Man (18)	6.1	6.3	5.9	6.3	6.4	6.2
		1.6	*1.5*	*1.6*	*1.5*	*1.6*	*1.5*
	Other (1)	8.0	7.0	4.0		8.0	

Mean score per age	20–29 (39)	5.7 *1.5*	6.0 *1.6*	5.6 *1.8*	5.6 *1.4*	6.5 *1.2*	5.3 *1.6*
	30–39 (10)	6.4 *2.5*	7.0 *1.6*	5.6 *2.3*	5.8 *1.8*	7.7 *1.0*	6.2 *1.3*
	40–49 (2)	6.0 -	4.0	8.0 0.0	6.0 *1.4*	5.0 -	7.0 -
	50–59 (1)			4.0 -	6.0 -	4.0 -	3.0 -
	Over 60 (1)		5.0 -	7.0 -	8.0 -		6.0 -
	Missing (1)	4.0 -		5.0 -	6.0 -		2.0 -
Mean score per eat frequency	Never (5)	4.0 *4.2*	6.4 *1.5*	5.3 *2.9*	5.8 *2.0*	6.3 *1.5*	6.5 *2.1*
	< once/ month (16)	6.4 *1.2*	6.8 *1.6*	5.9 *1.8*	5.8 *1.3*	6.4 *1.6*	5.4 *1.9*
	Once /month (14)	5.6 *1.7*	4.7 *1.4*	5.6 *2.3*	6.0 *1.2*	6.6 *0.5*	5.3 *1.7*
	Monthly–weekly (11)	5.8 *1.8*	6.6 *1.5*	5.5 *1.3*	5.1 *1.4*	6.9 *1.4*	5.0 *1.7*
	≥ Once /week (8)	5.8 *1.5*	6.8 *1.3*	5.7 *1.9*	6.3 *1.5*	6.7 *1.4*	6.0 *1.0*

Appendix 4 – Additional contour plots from optimisation

The contour plots below show the effect of $NaHCO_3$ concentration and soaking time on the textural cohesiveness and springiness.





Appendix 5 – Popular scientific summary

Most of us know that eating meat is not very good for the climate, and that our diets must become more plant based. Many of us are also aware of how important the domestic food production is. We want to support our farmers and reduce the consumption of imported foods to become more sustainable. There are a lot of vegetarian products out there, but you might, like me, have noticed that these are rarely of Swedish origin. This may put us in a dilemma – what should we choose when we want a protein rich vegetarian food, but at the same time we want to support the Swedish farmers?

When looking at plant-based protein sources, beans, peas, lentils and lupins are the stars. These belong to the group of plants called pulses. Apart from their high protein contents, pulses contain dietary fibre and essential minerals, and can have health promoting effects. There is a long history of growing and eating pulses in Sweden. These plant foods do not only provide nutritional benefits, but also have positive agricultural effects since they can improve soils and reduce the need for resource demanding inputs. By growing more pulses domestically in Sweden, the climate impact of pulse products could be reduced as a result of less import and of the good environmental performance of Swedish food systems. Increased pulse production would also lead to increased self-sufficiency and preparedness for climate changes.

Despite all these benefits, Sweden does not produce a lot of pulses today. There is great potential in growing more varieties and larger volumes of pulses in Sweden, and there is interest to do so from the food industry. One way of enabling an increased Swedish pulse production and consumption is to develop new uses for the Swedish pulses.

A popular Middle Eastern food is falafel. Falafel is a type of deep-fried patties, traditionally made from faba beans or chickpeas. In Sweden, there is chickpea falafel production on industrial level. Therefore, I wanted to look into the possibilities to switch from imported chickpeas to Swedish grown pulses in falafel making, and thereby find a new application of Swedish pulses.

To understand if chickpeas can be replaced in falafel, I analysed and evaluated falafels made from different pulses. The study was divided into three main parts – a screening, a sensory evaluation, and an optimisation.

For the screening, I chose to make falafels from nine different types of Swedish or Nordic grown pulses; borlotti beans, black beans, faba beans, Gotland lentils, yellow peas, field peas and three lupin varieties. I analysed moisture content, fat content, colour and texture and found that the properties differed between the falafels, especially regarding texture, moisture content and colour.

In the development of new food products, the opinions of consumers are of course very important – there is no use in developing a product that no one will like once it hits the market. Therefore, an important part of this study was to perform a sensory evaluation of the falafels. In sensory evaluations, foods are tasted by human subjects and evaluated based on their sensory attributes, such as appearance, texture and flavour. Five different falafels from the screening were chosen for a sensory evaluation – those made from black beans, borlotti beans, Gotland lentils, one type of lupin and yellow peas. The falafels were evaluated by consumers on a scale, and received scores indicating that they were all liked. The lupin falafels obtained highest liking for appearance and texture, while Gotland lentil falafels obtained the highest scores for flavour and overall liking.

By using statistical analysis, it was possible to find out that colour of falafels was most important to achieve high liking of appearance, and a soft texture and high moisture content in the falafel batter was most important for a high liking of texture.

Gotland lentil falafels were chosen for an optimisation of texture with the goal to obtain a high water absorption during soaking of the lentils and a low hardness value of falafels. Different soaking times and soaking solutions containing sodium bicarbonate were analysed to find the best conditions. It was found that the most important factor was the soaking time, which should be 10–13 hours for Gotland lentils. Sodium bicarbonate addition to the soaking water did not have significant effect.

All in all, the study showed that it is possible to switch chickpeas for several other pulses and obtain falafels that will be liked by consumers. So, in the future, we might very well see new uses for Swedish pulses, such as falafel, letting you be plant based and at the same time support Swedish farmers!