

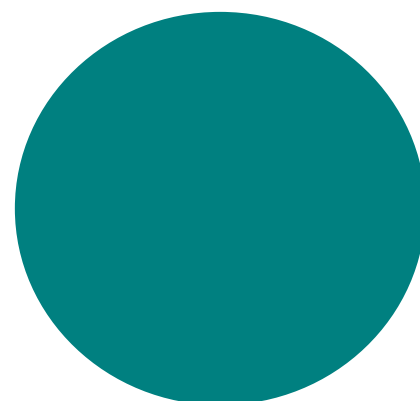
# Food Innovation & Product Design

## International talents in Food Innovation and Product Design

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## Congratulations to the FIPDes Cohort 9 !



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# PREFACE EXECUTIVE BOOK FOR THE 10<sup>th</sup> AGROPARISTECH FIPDeS PROMOTION

## INTRODUCTION

First, I would like to thank Barbara REGA and Marwen MOUS-SA for giving me the privilege and honor of writing the preface to the executive summaries of the MSc. FIPDeS theses.

It is also a real pleasure because, coming to the end of my agro-industrial career at Danone Fresh Products, my main objective is now to pass on to you - future owners of this industry and this research - to - I hope - enlighten you and perhaps, inspire you with my experience, my feelings, my convictions, my successes and failures.



You are lucky, because in the last 10 years, we have entered a real food revolution.

## MAJOR CONSUMER TRENDS

This means that instead of slightly improving what has been created and produced since the last war, when the food industry was really born, the consumer is leading us on very new paths, full of conscience, full of meaning, rejecting artificiality, seeking authenticity, transparency and true health through food.

## OUR DIET TO ENHANCE OUR BIRTH HEALTH POTENTIAL

We are all born with a genetic heritage, which has given us the possibility to live our lives in certain conditions : in addition to that, WE often have the choice to take care of and improve - or not - this potential thanks to many factors, living conditions, activities, etc...

Among these, our choices on food, water and air, the only 3 elements we ingest, can have a significant impact on the quality and potential of our health, positively or negatively; and among these 3 elements, food is perhaps, the factor we can play on the most, to improve or reduce this potential of life.

## 3 MISSIONS: FEED HUMANITY, PRESERVE HUMAN AND EARTH

Tomorrow, in 2050, there will be 9 billion of us on our planet (as a reminder, there were half a billion of us 300 years ago!!!).

As professionals in the food industry, we are faced with 3 main missions:

- TO FEED, (associated with a notion of quantity) these 9 billion people knowing that 2/3 of the demographic growth will come from Asia and Africa.
- PRESERVE THE HEALTH of these PEOPLE (associated with a notion of quality): HYPOCRATE, as well as many of his predecessors in "traditional Chinese medicine" or local medicine, understood very early that food was our first medicine,
- And to reach these two first objectives, we have no other choice than to PRESERVE OUR PLANET, so that it continues to NOURISH us in quantity and in quality.

Thus, we see here that to nourish the will of the human being, which is, since the dawn of time, to develop, to learn, to explore, to improve, we cannot dissociate it from the destinies of the food and the earth.

Taking care of people through food, taking care of their health potential and that of the earth, is inseparable if we want to create a virtuous future;

## LANDING ON THE LINK BETWEEN AGRICULTURE-FOOD-INDUSTRY and CONSUMERS

If we transpose these words closer to our daily life, we come to link Agriculture – food-industry and consumers.

Is one of these three more important than the others? I don't think so, we can think that they are deeply interdependent.

## MUST BE ADAPTED TO THE CONSUMER TO BE ADOPTED BY HIM

However, I would appreciate a focus on the consumer, as they have the ultimate power of choice and are, may be, the ones, subtly driving the equation.

The consumer will not eat what you invent because you invented it!

We have to be aware that in some cases, we mix what is new for the consumer and what is new for the company: many mistakes have been made to impress internally, to be more sophisticated than what was presented the previous time, when the real wealth is to correctly target the conscious and unconscious expectations of the consumer.

An innovation must make the consumer's life easier and more convenient, must give them meaning, build their identity (tell me what you eat, etc...), it must be ADAPTED to their expectations to be ADOPTED.

## EMPATHY TO BE ADAPTED

The real way to win this bet is to LISTEN, to OBSERVE, to UNDERSTAND the consumer before putting a single piece of project on the table: what are the criterias that count in his eyes, in his heart, the criteria in which you will invest the best of your professional skills?

What are, on the contrary, the criteria on which you should not invest, even if they seem great or technically brilliant: it doesn't matter, the consumer doesn't care about technical issues or about exceptional technical level of this product.

Get out from your research center, take your bicycle, go to his home, to his real life and listen to him, very carefully.

## WHAT IS AN INNOVATION?

As it was described by Chip HEATH in a very good book "Ces idées qui collent", an innovation to last must be "Simple, Credible, Concrete, slightly Unexpected, should tell a Story and reveal Emotion".

We must also consider that in any system, to change is to take a risk or to renounce the past: for a company but also for a consumer. I am convinced that if we exceed 50% of innovation in the field of consumer food, if the consumer is not able to find the reference points he knows in relation to other types of food, other types of consumption, he will be afraid and forget.

## PREFER PULLED THAN PUSHED BUSINESS MODELS

Therefore, many food (or non-food) companies have generally pushed their products and services across countries, sometimes experiencing successes, and other times, facing big failures.

There are many reasons for this.

Food remains an emotional behavior, we should not impose our models, our products, but look at the history of local food, of eating habits, of foods meanings, and draw inspiration from local sources.

We should use our knowledge to improve from this understanding, the quality, the perception, the taste, the use of a new food or bring new values (convenience, nutrition, food safety) to the ancestral local dishes they are used to.

This is what we could call a "pulled" model (based on consumer expectations), which is, in a way, opposed to the "pushed" (business) model, often practiced by companies.

## CURRENT CONSUMER VALUES ON FOOD

The equation to create a food in our countries does not seem generally so complex: globally the values of consumers tend towards "good taste, clean labels, naturalness, simplicity (of recipe, of understanding), sense, low transformation, recyclable / biodegradable packaging, why not organic, balance between animal and vegetal sources, local, fair trade and short channels".

It seems so simple, but it is sometimes so complex to get out of our own (business) habits.

## WITH TIME AND BUDGET TENSION

Two other important factors are becoming more prominent in consumer choice: time pressure (where, when to eat) and a shrinking budget for food, versus being connected, for example.

## BIODIVERSE FOODS FOR A HARMONIOUS DIET OF OUR EMOTIONS AND THE NEEDS OF OUR BODY

After talking about our emotion (preferences, values, convenience), we should talk about our body's needs through innovation, as emotion and body are inseparable and will impact each other.

If we look in the rearview mirror of our dietary transitions, over the last 250,000 years, our diet has of course gone through cycles of domination, but the pendulum has always swung back to central and balanced positions of coexistence between animal and plant foods, especially with the recent (10,000 years ago) entry of cereals in our diet.

Because we, HOMO SAPIANS, are bio-diverse, because of our history, our cultures, our religions, our diets, we are chemically bio-diverse (genetics, hormones, organ structure etc.).

We therefore need this biochemical diversity through food (amino acids, fats, minerals, vitamins, fibers, etc.).

But we are also very bio-diverse at the biological level, that of our own ecology, and I would take as an example only our microbiota.

Our microbiota, you know, those 3 kg or 100,000 billion bacteria, which inhabit our intestinal tract, are, as we have recently learned, nervously and hormonally linked to our brain.

Our microbiota has a major impact, on the metabolization of our food of course, but also on our immune system, our regulatory systems and even our emotions, this has been perfectly demonstrated recently.

In exchange for these services, our microbiota needs to be cajoled, and these "cajoleries" are simply the food biodiversity that we offer it to feed and develop.

Let's look at the blog that our grandmothers have been keeping for 100,000 years. They passed on these thoughtful gestures to us in the phrase "you need to have a balanced diet !!!" Seems simple, right??!!

What was implied, even if they were not familiar with the concept of microbiota was that “you need to have a balanced diet...to feed all your gut biodiversity, in a balanced way”.

So, feeding ourselves and bringing health through food to homo sapiens without taking advantage of this food biodiversity that is offered to us would be a nonsense that would slowly eat away at humanity.

These considerations may seem simple, but when we are asked to create an innovation, in a company that makes ice cream, or snacks, or sodas, how do we conceive this respect for the needs of the body in terms of biodiversity, how do we respect the initial and probably local chemical and biological diversity of these people?

What responsibility do we take when we propose foods that are, chemically (additives for example) or biologically, UFOs in their food history?

Be sure that we take, at that moment, a responsibility as a food industry. Every time we innovate, we vote to preserve, improve or erode the health potential of our consumers.

To link to another responsibility we have as a food industry, as Emmanuel FABER said, “every time we eat or drink, we vote for the world we want: tomorrow's world for our health, tomorrow's world for our earth.”

## CREATE VALUE FOR THE CONSUMER and FOR OUR EARTH AT THE SAME TIME

Every year, we ask our earth to produce 4 times the weight of our humanity in food + 30% for the wasted part. This is where the link that we must strengthen between the evolution of agriculture and the evolution of food, by asking ourselves some questions:

- Impact of animal and plant sources on the earth ? : impact not only on the consumption of CO<sup>2</sup> and water, but let's not forget the impact on the local economy installed, the food habits, the pleasure of food diversity.
- How can we orient our food towards the best return between what is taken from the earth (animal and vegetal) and what is returned to our body. In short, what is the best recipe, with 3 ingredients, between "organoleptic, nutritional and ecological impact"? A question of long term type of yield.

- Why don't we think about more efficient cultivation and breeding schemes, as practiced today in organic agriculture or permaculture, but on a larger scale, as the surface of arable land in the world is not very extensible?

- Food is the emotional expression of who we are; the tastes, colors, textures and commensality of our food are also part of our culture: how can we continue to build our human biodiversity by impoverishing the biodiversity of what we consume?

-And finally, how to recreate an indestructible link between agriculture and food, perceived as two independent worlds for many of our children?

## CONCLUSION

We are entering a new paradigm of a more responsible humanity: more responsible for how food and beverages will impact our life potential, more responsible for respecting the original choices of consumers, more responsible for how everything that is created, will impact the sustainability of our planet.

The materialism created from the 20th century onwards has led to individualism. Individualism has made us forget the stakes of humanity and the earth: the time is over now.

Humanity and the future of the earth are back on the front of the stage, on a interdependent between our way of life, the human beings and our home, the earth, which feeds us and gives us this necessary quality of water and air.

You were born with this issue, you will be the future leaders of companies, associations, maybe governments. Life on earth is a cycle: I am sure you will be sufficiently attentive, sufficiently open-minded to lead the future towards a virtuous life.

Be proud, be confident in yourselves and in your ability to be the leaders of the new paradigm, you will make it!

FIPDes is such a training platform, which gives you skills, a way to work together, to imagine together, by gathering all the issues we are facing.

FIPDes has given you the freedom to never forget to combine knowledge and scientific

rigor with your emotions, your intuitions, your vision of the future: keep this balance as the most beautiful gift given to you, because life is made of rational and irrational intertwined, inseparable ways to make humanity progress.

Very soon, you will enter the active life with an opportunity that others could not seize: I wish you all, sincerely, the best.

François COLOMBAN  
Food Design Director - Danone  
14th June 2021

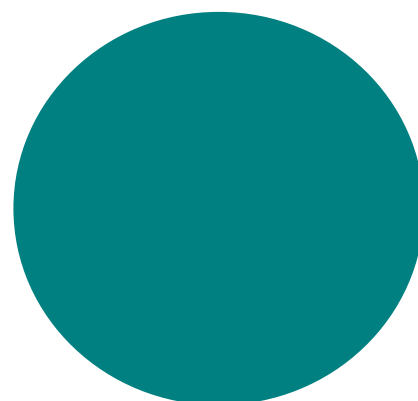


And never forget => :

*« Quoi que tu rêves d'entreprendre, commence-le. L'audace a du génie, du pouvoir, de la magie. »*

*“Whatever you dream of undertaking, start it. Boldness has genius, power and magic.”*

- Johann Wolfgang von Goethe





## Tomato Pomace Valorisation for the Development of Value-Added Tomato Ketchup

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Tomato pomace (TP), the waste stream generated by the tomato processing industry and consisting mostly of peels and seeds, is currently used primarily as animal feed and fertiliser. It shows great potential as a renewable ingredient and there is growing interest in its valorisation within the food industry due to its valuable macro-, micro-nutrient and bioactive content as well as its thickening capacity as a functional powder.

This project aimed to investigate the possibility of valorising TP from agro-industrial waste streams by developing value-added product formulations with varying tomato pomace powder (TPP) content. TP was transformed via mild drying and grinding to produce a functional and homogeneous ingredient that was incorporated into tomato ketchup. The new formulations underwent sensory, physico-chemical and nutritional analyses.

Two TK formulations were developed (1% peel and 1% whole valorised TPP below 0.200 mm) with sensory differences close to zero when compared with a TK reference. Off-flavour was the major limitation. TKs met target specifications such as viscosity, colour and pH and reduced production costs. However, they did not unlock health or nutrition claims, but contained 2.0-2.1 g fibre/100 g TK, which is 1.4-fold higher than the reference product, thereby improving the product's nutritional and tomato content.

The TPP-added TK developed is promising but its obtention process must be optimised to reduce bioactive content degradation for a more comparable, sensorily pleasing and nutritionally rich value-added TK.

**Confidential topic**



## Investigation of Cookies' Physico-chemical Characteristics and their relation with glycemic index.

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Dr. Olga DAVIDENKO  
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### Introduction

There are considerable reports on the prevalence of childhood obesity across many countries (Bae & Choi, 2021). Between 1976 and 2016, global obesity increased by three-fold (Abarca-Gómez *et al.*, 2017). The European Union project STOP (Science and Technology in Childhood Obesity Policy), is focused on curbing childhood obesity. One of the axis chosen to tackle this issue is to re-engineer cookies to improve their nutritional profile and glycemic indices, while considering other important factors such as its texture. This is because foods with lower glycemic indices have been reported to slow down postprandial glucose spike (Roberts, 2003). Sweet biscuits are important contributors of unhealthy diet composed of high calories, and subjected to ultra-processing (Costa *et al.*, 2018; Forde *et al.*, 2020; Hall *et al.*, 2019). Cookies in particular are energy dense and play an important role of added sugar intake among childrens' diet (Afeiche *et al.*, 2018; Denney *et al.*, 2017). In this frame, cookies were chosen as the target food in this study.

Jenkins *et al.* (1980) introduced the concept of *glycemic index (GI)*, to explain the effect of carbohydrates on postprandial blood glucose level. The higher the postprandial blood glucose levels after consuming a particular food, the greater the glycemic index of that food. Foods with GI of  $\geq 70$ ,  $\leq 55$ , and between 56 – 69 are classified as high, low and medium glycemic index foods respectively (Brouns *et al.*, 2005; Augustin *et al.*, 2015). Glycemic index can be determined by *in vivo* or *in vitro* methods. However, due to ethical issues and other inconveniences involved in using human subjects, *in vitro* methods are have been used more in literature (Lucas-González *et al.*, 2018). *In vitro* methods for

determining glycemic index can be dynamic or static (Minekus *et al.*, 2014). static models have been widely used in *in vitro* assays because of its simplicity and comparatively low associated cost (Wickham *et al.*, 2009). There are many protocols for determining carbohydrate hydrolysis and glycemic index of foods *in vitro*. However, most of the protocols used are those from Goñi *et al.* (1997), Englyst *et al.* (1992), and the INFOGEST protocol by Minekus *et al.* (2014). The type of food matrix influences the choice the appropriate multi-step enzyme hydrolysis.

Raw materials, processes and physicochemical state of macromolecules after processing, greatly influences the digestion and glycemic indices of foods (Singh *et al.*, 2010). Hence, it is important to use a reliable method to study the impact of these factors on glycemic index.

## Research objectives

This study was a subset of a PhD work, which was focused on improving nutritional quality of cookies while maintaining desirable physicochemical and sensorial properties. Twenty eight cookies were developed based on learnings from previous work. Then the carbohydrate digestibility indices and some physicochemical properties of these cookies, and their possible relations with the formulation levers were assessed. (figure 1).

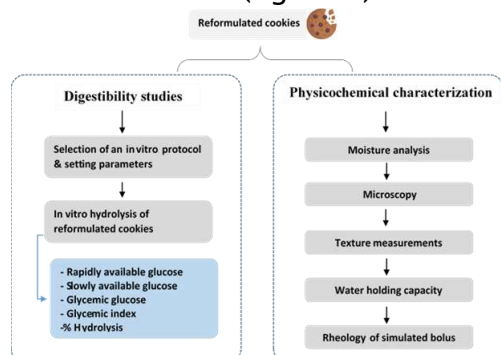


Figure 1: Study strategy

## Methodology

### Multi-step enzymatic in-vitro hydrolysis for estimation of carbohydrate digestibility (fig.2)

In vitro hydrolysis was adapted from Englyst *et al.* (1992), Englyst *et al.* (2018), Englyst *et*

*al.* (2000), Freitas & Le Feunteun, (2019) and Schuchardt *et al.* (2016).

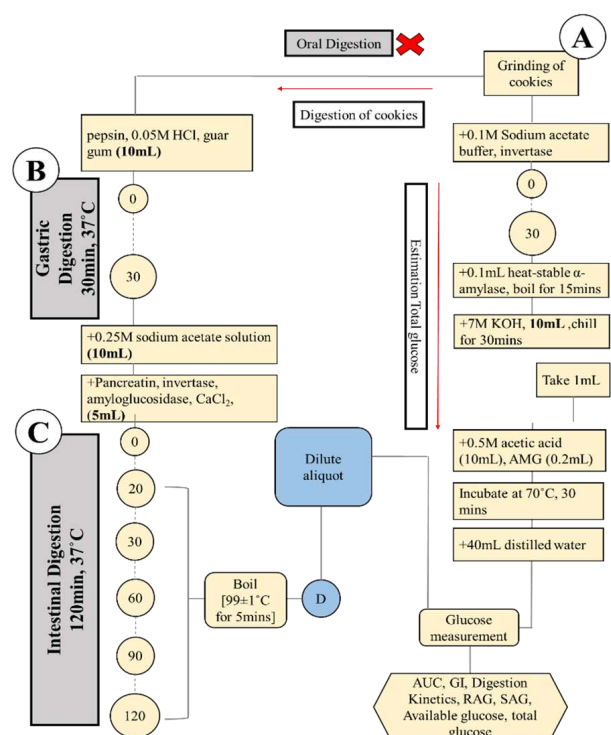


Figure 2 : Summary of hydrolysis protocol

## Estimation of parameters of hydrolysis

The predicted glycemic index (pGI) was calculated as using equations 1 (Alongi *et al.*, 2019; Jenkins *et al.*, 1981).

$$pGI = \frac{AUC(120 \text{ minutes}) \text{ of test food (ie cookies)}}{AUC(120 \text{ minutes}) \text{ of test food (ie bread)}} \times 100$$

Rapidly available glucose (RAG), slowly available glucose (SAG) and available glucose were estimated according to the method proposed by (Englyst & Hudson, 1996).

RAG = Glucose released after 20 minutes of digestion

Available glucose = Glucose released after 120 minutes of digestion

SAG = Available glucose – RAG

## Cookies' Physicochemical characterization

*Microscopy: state of starch in cookies*

The state of starch was studied using a light microscope. Starch granules were identified



by the presence of Maltese cross in the granules (Xiao *et al.*, 2020). Scaling and image analysis was done using the ImageJ software.

### Moisture content

About 0.5g of ground sample (cookies or bread) was dried for 18 hours at 103°C in an oven (EM10, Chopin, France). The sample was then placed in a desiccator for 1 hour before weighing (Upadhyay *et al.* 2017). The moisture content was determined as:

$$\% \text{ Moisture content} = \frac{MW - MD}{MW} \times 100$$

MW= mass (g) of the ground cookie before oven, MD= mass (g) of the dried cookie sample

### Texture analysis

The texture properties of the cookies were studied by a three point bending test using a Texture Analyser (Stable Microsystems, Surrey, UK). In order to compare products with each other, the stress ( $\sigma_r$ ) (equation 3) and strain ( $\epsilon_r$ ) (equation 4) were calculated, thus making it possible to avoid dimensional variations (Baltsavias *et al.*, 1997).

$$\sigma_r = \frac{3 \times F_r \times L}{2 \times l \times h^2} \quad (kN/m^2) \quad \text{equation 3}$$

$$\epsilon_r = \frac{6 \times h \times y_r}{L^2} \quad (\%) \quad \text{equation 4}$$

$L$  = the distance or the span length between the 2 fixed uprights of the plane on which the cookie rests (m);  $l$  = width of the cookie (m);  $h$  = height of the cookie (m);  $F$  = force (N);  $F_r$  = breaking force (N);  $Y$  = deviation (m) or distance;  $y_r$  = distance rupture (m)

### Measurement of glucose in samples

The glucose was measured using Megazyme D-Glucose Assay Kit (Product code K-GLUC), according to the instructions of the manufacturer. The glucose was expressed as percentage glucose per dry mass of sample.

### Statistical analysis

Statistical analysis was done using XLSTAT (version 2021.2.2). Error bars in graphs are standard division of the values. Comparison of means were done using one-way ANOVA followed by Tukey's honestly significance dif-

ferent (HSD) test, and student t-test.

Correlations between formulation parameters, digestibility indices and textural properties were done Principal Component Analysis (PCA). All analysis were done at significance level of  $\alpha = 0.05$ .

## Results and discussion

### Glycemic index of the reformulated cookies

The glycemic indices for the reformulated cookies which were analyzed in this study are shown in figure 9. The pGI of the reformulated cookies ranged from 53 to 45. Based on the classification of foods according to their GIs, all the reformulated cookies fall within the category of low glycemic index foods, which are foods having GIs of  $\leq 55$  (Brouns *et al.*, 2005a).

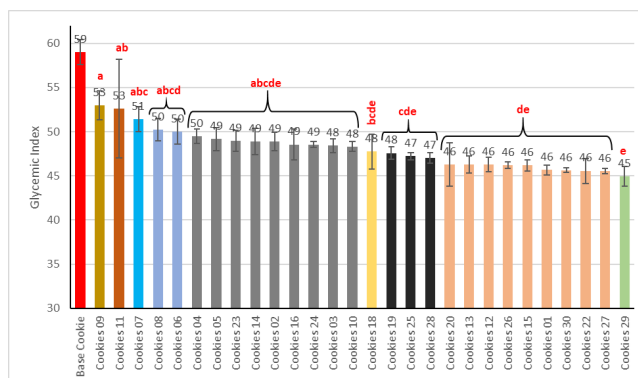


Figure 3: Glycemic indices of 28 reformulated cookies produced for the study (3 replication each)

Bars having different letters are statistically different ( $p < 0.0001$ ,  $\alpha = 0.005$ ).

Foster-Powell *et al.* (2002) published the glycemic indices of over 750 foods in the "international table of glycemic index and glycemic load values". With reference to the table, the majority of the cookies had medium to high glycemic indices (between 51 to 71). *In vivo* digestibility studies conducted by Garsetti *et al.* (2005) showed that, the mean GI of various plain white flour cookies was  $57 \pm 8$ , whereas Englyst *et al.* (2003) reported that GI of chocolate biscuits including cookies is between 51 to 65. Based on these values, it can be said that, the ingredients and process alterations was effective in ensuring a low GI of the reformulated cookies.

## Effect of formulation of various digestibility indices

The effect of formulation parameters on the various digestibility indices cookies was analyzed using PCA. Principal components F1 and F2 explains about 82% of the information (figure 4).

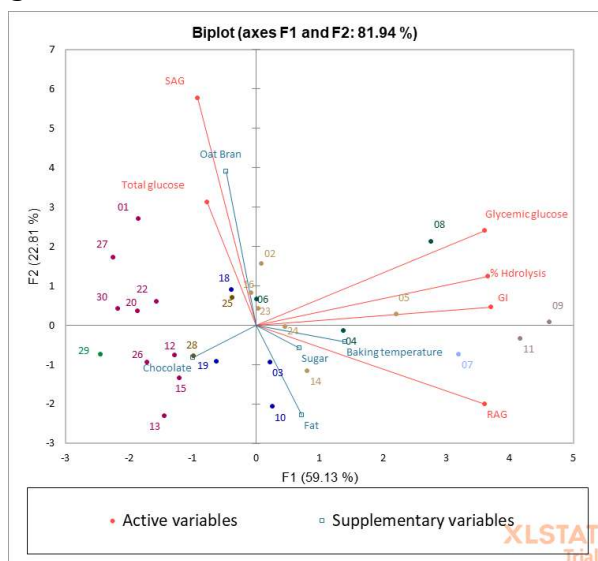


Figure 4: PCA biplot showing interaction between formulation parameters and hydrolysis indices

It can be observed that RAG and SAG are negatively correlated, implying that cookies that have a higher proportion of RAG would have a lower SAG. This observation has been seen earlier in figure 10. We can also tell from the plot that the glycemic index of cookies is not necessarily influenced by the total glucose in the cookies but rather the available glucose and the degree at which it is hydrolyzed. This is because not all the glucose that is present in a food matrix is released for absorption during digestion Englyst *et al.* (1992). For example, glucose form resistant starch may not be available during enzymatic hydrolysis (Englyst *et al.* 1996). Another interesting observation that was found is the correlation between oat bran and SAG ( $r=0.5$ ,  $p=0.003$ ). Thus, the SAG increases with the proportion of oat bran in the formulation, which is associated with reducing glycemic glucose and GI. The interaction between the influence of SAG and oat bran, and its positive effect in reducing the GI of cookies could be linked to the fiber present in oat bran. Numerous studies have shown that, the soluble fiber (1 → 3)(1 → 4)- $\beta$ -D-glucan in oat bran con-

tributes to reducing glycemic response of foods (Hallfrisch & Behall, 2000; Mäkeläinen *et al.*, 2007; Panahi *et al.*, 2007). An earlier study conducted by Dunaif & Schneeman (1981), reported that the presence of fiber reduces the activity of pancreatic  $\alpha$ -amylase.

## Conclusion

This study showed the possibility to reformulate healthier cookies with an improved nutritional profile and lower glycemic indices. The *in vitro* protocol adapted and used in this study to predict glycemic index is suitable for cookies (and any type of biscuit). This would be an interesting tool that could be utilized in the process of cookies innovation or reformulation to make healthier products, with positive impact on health and obesity relevant factors. Also, the impact of formulation on the digestibility of reformulated cookies has been established. With oat bran fiber positively influencing the release of glucose in cookies during *in vitro* digestion.

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## Dough Gas Retention (DGR) during fermentation: An exploratory study of the effect of different enzyme families.

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#### Master Thesis tutor :

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This research aims to validate a new measuring technique of Dough Gas Retention (DGR) called Gas Trap. The Gas Trap is designed to be adapted into a Risograph, which is a known methodology to measure Dough Gas Production (DGP) through pressure measurements. The performance evaluation of the Gas Trap was done by comparing the DGR results with a Dynamic Dough Volume (DDV) analysis. Additionally, an exploratory study considering different families of enzymes was carried out to evaluate the effect that they have on the DGR using the Gas Trap. Some fungal and bacterial enzymes tested had a positive effect on DGR. On the other hand, some bacterial enzymes can either be neutral or have a negative effect on the DGR depending on the dosage. The results of the enzymes apply to the raw materials, formulation, and process established for this study. To further validate, different types of flours should be considered, and more repetitions should be done using diverse batches of enzymes. By means of the exploratory enzymatic study, it was concluded that the Gas Trap allows the differentiation of DGR among samples.

*CONFIDENTIAL TOPIC*



## Potential bioaccessibility of N-Acylphosphatidylethanolamines, N-acylethanolamines and endocannabinoids in food: an *in vitro* digestion study

### Heather BROWNE

#### Profile in a nutshell

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Four years spent as a clinical UK dietitian working in various NHS hospitals

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**Masters thesis tutor:** Prof. Paola Vitaglione



**Introduction:** Endocannabinoids (ECs), N-acylethanolamines (NAEs) and their phosphorylated precursors (NAPEs) are part of the endocannabinoid system that is involved in metabolic homeostasis, food reward processing, energy balance and appetite regulation<sup>(1-4)</sup>. Dysregulation of the endocannabinoid system has revealed links to obesity, inflammation, and the metabolic syndrome<sup>(1-4)</sup>. Evidence indicates it may be mediated by diet. Recently, the content of ECs, NAEs and NAPEs in several foods have been assessed<sup>(5)</sup>, and although it is known that these compounds have been found in human biological samples<sup>(6-11)</sup> their bioaccessibility during digestion is unknown.

**Aim:** The aim of this study was to investigate the potential bioaccessibility of ECs, NAEs and NAPEs from foods *in vitro*.

#### Research objectives:

- To select seven commonly consumed and industrially produced foods;
- To subject those foods to a static model of *in vitro* digestion by adapting the protocol to the specific purposes of the study;

To assess the content of NAPEs, NAEs and ECs in foods before and upon digestion in order to evaluate the impact of a 'simulated' digestion across the gastrointestinal phases.

## Methods:

Seven industrially produced and commonly consumed foods were selected. These included walnuts, tomatoes, tuna, dark chocolate, chick-pea, wholegrain and refined wheat bread. Each food was subjected to a simulated human digestion *in vitro* using an internationally recognised protocol, INFOGEST. During digestion, gastric and intestinal samples were separated into the bioaccessible fraction and fraction resistant to digestion to understand their physiological role. Content of NAPEs, NAEs and ECs in the foods before and after salivary, gastric, and intestinal digestion was assessed by liquid chromatography-high resolution mass spectrometry (LC-HRMS) analysis.

## Results:

NAEs and ECs were found to be more bioaccessible across digestion, from salivary to small intestinal digestion. NAPEs were found to be more abundant than NAEs, consistent with the literature, but with largely opposing behaviour to NAEs.

As food is rarely consumed individually and, to translate this study's findings practically, average serving sizes were selected for each food sample to investigate the amount of NAPEs and NAEs which could be provided in a potential meal (**figure 1**). Simulated meal options provided 1570-1560 mg NAPEs, 750-770  $\mu$ g NAEs and 827 $\mu$ g ECs. These levels are much higher than those referenced in the literature for a chemically extracted, undigested simulated meal<sup>(4)</sup>.

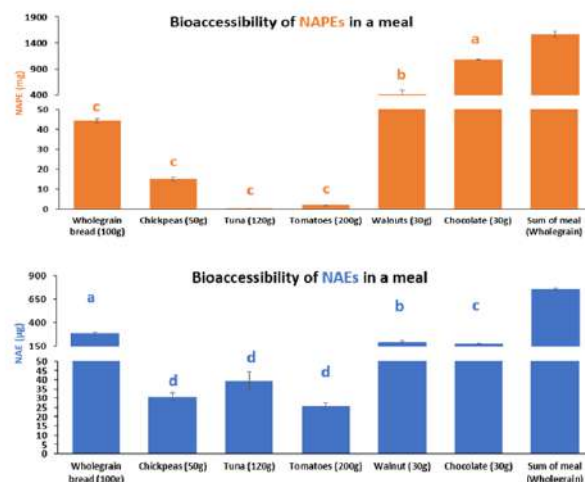


Figure 1: Content of NAPEs (mg/serving) and NAEs ( $\mu$ g/serving) in a meal and food serving size representing the bioaccessible fraction (A) bioaccessible NAEs, (B) bioaccessible NAEs. Data are expressed as means  $\pm$ SD  $\mu$ g with intestinal supernatants (bioaccessible portion) adjusted to fresh weight values and calculated per average serving size within a meal. Letters indicate differences across the foods for NAEs and NAPEs with  $p < 0.05$ . A one-way ANOVA with Tukey post hoc analysis was conducted across the foods to highlight significant differences between food servings.

Wholegrain bread contained the highest concentration of NAEs and NAEs reaching the colon in a standard meal serving, potentially implicating dietary fibre as an encapsulating agent, delaying release across digestion.

For individual NAEs, walnuts provided the highest concentrations across the foods of SEA (1.3 to 8-folds more) and PEA (4 to 18.6-folds more). Further, a serving of chocolate contained the highest bioaccessible NAEs (1.3 to 8-folds) and OEA (1.6 to 16.3-folds), at concentrations for OEA likely able to bind to GPR119 and PPAR- $\alpha$  receptors. LEA was the most abundant in refined wheat and wholegrain bread, and at levels potentially able to bind to GPR119 receptors and PPAR- $\alpha$  for OEA. The only endocannabinoid found was 2-arachidonoylglycerol in tuna and was bioaccessible in large quantities in a meal serving, while a significant amount was available to enter the colon.

## Conclusions:

The findings showed in general, ECs, NAEs and NAEs were present at levels much higher in processed foods than in fresh foods previously reported. Further, digestion increased the bio-accessibility of NAEs and ECs, largely in the small intestine where absorption takes place. Endocannabinoids were found in the only animal-based product consistent with previous research. While it is likely that nutrition and physio-chemical properties of food may affect concentration levels of these compounds within foods, other mechanisms such as compound inhibitors, enzymes and the digestive environment may impact their release across digestion. Finally, a simulated meal from this study may provide sufficient levels of these compounds for receptor activation, and thus allow for their physiological effects *in vivo*.

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## Development And Characterization Of A Plant-based Meat Analogue

### Using An Innovative Texturization Technology For Fiber Synthesis

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The technological hurdles of the current plant-based meat analogues processing techniques, mainly extrusion, have limited the development of whole cuts like chicken and fish fillets. This study highlighted the opportunity in using an alternative technology for the design of vegan fish fillets to respond to the rising environmental and consumers safety concerns associated with increased seafood consumption. Most currently marketed plant-based seafood products fail in mimicking the fibrous structure of fish muscles as they either consist of minced products or gel-based ones. The results of this study expanded the knowledge around a not-yet-commercialized technology for its ability in creating fish-like fibers and texture. Several formulation and process parameters in commercial soy and pea protein isolate slurries were tweaked to generate matrices with different structure and texture properties. Figure 1, provides an example of a soy-based slurry before and after texturization. Changes in protein interactions at a slurry level were tracked using viscoelastic measurements while finished products were characterized with a texture profile analysis, fibrous degree and moisture content determination. Steamed cod fish flakes were used as a reference for texture comparison.

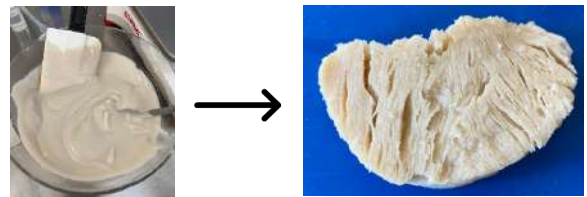


Figure 1. From a slurry to a meat-like fibrous matrix

Various blends showed potential for their application in designing fish analogues as matrices were found to be anisotropic. However,



further recipe and process improvements need to be made to get closer to the fish texture targets.

***Confidential topic***



## The discoloration of polyethylene obtained from chemical separation of laminates: Investigating additives and other potential causes

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**Master thesis host:**

Tetra Pak

**Master thesis supervisors:**

Mikael Hamskog (Tetra Pak)

Klas Hjort (LTH)



### Introduction & purpose

In Europe, 40% of plastic materials produced are used for packaging (Kaiser, Schmid and Schlummer, 2017), while the global replacement of virgin polymer feedstock with recycled plastics from both mechanical and chemical recycling is projected to double in ten years (Brooks, 2021). Polymer recycling is therefore not only a sustainable pathway, but also an economic choice for packaging companies.

Tetra Pak's aseptic cartons mainly consist of paperboard, aluminum (Al) foil, and polymer laminated together. The paper fiber is easily recovered during recycling, leaving behind the remainder mixed material of polymers and aluminum, known as PolyAl. In Europe, PolyAl from used beverage cartons (UBCs) is mostly incinerated for energy recovery or recycled as composite materials in a lesser extent.

The separation of PolyAl, through either chemical or mechanical recycling, is technically feasible as it further extends the circularity of the material. Interestingly, an undiagnosed green discoloration was observed in the PE fraction recovered from PolyAl after reprocessing (Figure 1). The phenomenon remains little known or studied in academia, typically attributed to residual ink when encountered (Diop, Lavoie and Huneault, 2016).



Figure 1 Plastic from the PE fraction of PolyAl delaminated with formic acid (Diop, Lavoie and Huneault, 2016)

As PolyAl separation is being commercialized in Europe in recent years, the green discoloration is receiving more attention due its potential impact on the end-product pricing. This study aims to explore the potential causes of the green discoloration in the context of mechanical recycling and discuss the impact of the phenomenon.

## Methodology

The study synthesizes the findings from a review of existing literature, stakeholder interviews, and laboratory analysis. The former two were conducted to identify potential causes of the discoloration throughout the base PE materials' lifetime, in stages of base materials, converting and packaging processes, and recycling processes.

The experimental analysis involved two stages. In the first stage, an external laboratory (EL) analyzed separated films from the recycling stream manually sorted based on colors; their thermal-oxidative stabilities were evaluated using differential scanning calorimetry (DSC) and oxidation induction temperature (dynamic OIT), while color measurements were conducted for each color fraction compounded with virgin materials with colorimetry ( $L^*a^*b^*$ ,  $\Delta E$ , RGB). This established the hypothesis for the second stage of the experimental analysis, done by the author, to compare several polymer grades used by Tetra Pak (all metallocene PE, also known as mPE) with varying suppliers and additives. The base polymers were treated through an oven

aging process (250°C, 6 minutes), after which their respective discolorations were assessed through colorimetry ( $L^*a^*b^*$ ,  $\Delta E$ ).

## Results and discussion

### Potential causes and impacts

Through literature review and interviews, residues from the metallocene catalyst, phenolic antioxidants (AOs) and acid scavengers in additives, oxidation during extrusion melting, ozone treatment, peroxide bath, impurities, and oxidation during delamination were identified as the potential contributors to the discoloration.

Through the interview, a European recycler disclosed that discolored recycled PE experienced lower market prices than its colorless counterpart (Recycler E, 2021). The removal of the discoloration could therefore contribute to improving the value of the material, if out-balancing research and implementation costs.

### Analysis of recycled films

EL's experimental analysis suggested that the green discoloration was a combination of yellow and grey, and the thermo-oxidation of AOs producing yellow species may be the root cause for a yellow discoloration. The contribution of ink in the discoloration was likely small, given the close proximity of colors between the recycled PE granules (mixed colors) and the colorless separated films after oven treatment that imitated the re-processing conditions.

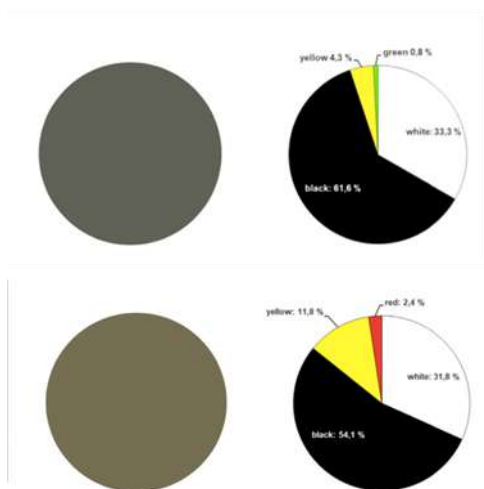


Figure 2. Left to right: human color feeling, and color composition by  $L^*a^*b^*$ ; top to bottom: recycled granules, colorless fraction of separated films after oven treatment

### Comparison of base polymers

The comparison of different PE grades further investigated the discoloration effects of different additives, mainly involving phenolic AOs and the acid scavenger calcium stearate. For each sample, the discoloration was calculated for the overall color difference before and after oven aging ( $\Delta E$ ), as well as differences of  $L^*$  (light vs. dark),  $a^*$  (red vs. green), and  $b^*$  (yellow vs. blue). The data is shown in Figure 3.

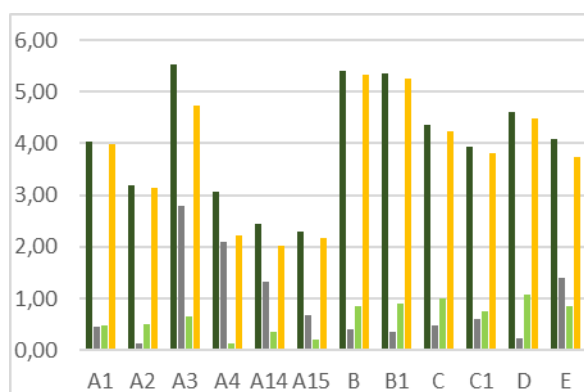


Figure 3. Discoloration ( $\Delta E$ ) of samples A1 to E. For each sample, the leftmost bar represents overall discoloration, followed by discolorations in the directions of darkening, greening, and yellowing from left to right.

The colorimetry demonstrated that the overall discoloration was led by yellowing. The samples without additives showed yellow discoloration, likely from the presence of residual metallocene catalysts (Epacher, Kröhnke and Pukánszky, 2000; Hoàng et al., 2006); the AOs were able to protect against this discoloration, although further treatment may result in aforementioned AO discoloration; calcium (Ca) stearate was linked to more advanced yellow discoloration when used with AOs, in line with existing research (Hoàng et al., 2004). Nevertheless, the use of phenolic AOs is necessary to protect the mPE from thermal-oxidative degradation (Internal Material Specialist, 2021).

### Conclusion

The green discoloration in recycled PE from chemical delamination of carton packages is a complex phenomenon. The study concludes that the choice of additives is a potential root cause amongst others, such as residues of impurities. While the study focused on the additives, future studies concerning other possible causes and the impact of different PolyAl recycling methods are recommended. In the search for resolution, alternative AOs with lower discoloring potentials and other PolyAl separation methods should be explored.

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## Eating the ‘inedible’. An extended theory of planned behaviour looking at consumption of the perceived inedible parts of fruits and vegetables in Ireland and Italy.

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Prof. Prof Francesco Caracciolo & Dr Maria Raimondo



### Introduction

1/3 of all food produced in the world is thrown away, with fruits and vegetables accounting for the most waste (FAO, 2017). Up to 55 % of fruits and vegetables produced are destined for the bin (Gustavsson et al., 2011). The United Nations sustainability goals aims to reduce food waste by a half by 2030, they also aim to reduce food poverty, promote healthy diets and ensure food security globally (UN, 2017). Given the predicted population growth there will simply not be enough food.

Food based dietary guidelines (FBDG) continuously recommended consumers to eat more fruits and vegetables despite them being the most wasted food group. Research has shown that adequate consumption of fruits and vegetables is protective against a number of chronic diseases, cancers and mental health disorders (Aune et al., 2017).

The perceived inedible parts (PIPs) of fruits and vegetables refers to the stalks, leaves, peels and seeds of fruits and vegetables. The PIPs of fruits and vegetables are therefore seldomly consumed, recommended or visible in validated nutritional databases. This research postulates that the PIPs of fruits and vegetables have the potential to reduce food waste, reduce dietary related disease and deaths and address the problem of food security. This proposed research aims to explore the factors that influence the consumption of the PIPs of fruits and vegetables in Ireland and Italy.

## Research objectives

- The primary aim was a quantitative analysis of consumer behaviour towards consuming the PIPs of fruits and vegetables using a conceptual model in Italy and Ireland.
- A secondary aim, was conducting a preliminary literary analysis on the PIPs of selected fruits and vegetables. This analysis considered the PIPs from (i) nutritional perspective (ii) food waste perspective.

## Methodology

The nutritional and food waste analysis was conducted based on information available from validated nutritional databases (where available) and previous literature. An estimated micronutrient analysis was conducted on the following fruits and vegetables: broccoli (stalk & leaf), cauliflower (stalk & leaf), carrot (green tops), mushroom (stalk), apple (peel) and kiwi (peel). From a food waste perspective, the composition of the PIPs of the selected fruits and vegetables was estimated. For example what % of broccoli is made up of stalk and leaf.

An online survey was conducted and divided into three sections. The first section comprised questions regarding the selected PIPs of fruits and vegetables. Consumer's were shown images of the PIPs of and asked if they (i) perceived them to be edible (ii) regularly consumed them.

The second part of the survey, contained a list of statements following a validated framework: The Theory of Planned Behaviour (TPB) in relation to the PIPs. These statements explored the classic TPB concepts: intention, attitudes, social norms and perceived behavioural control. Four additional constructs were also explored: edibility knowledge, 'stated' behaviour, perceived health benefits and sustainability benefits.

Statistical analysis was conducted on the TPB model using partial-least squares structural equation modelling (PLS- SEM).

## Results and discussions

Findings from the preliminary analysis found that the PIPs of the selected fruits and vegetables had a rich nutritional profile, in most cases superior than the commonly consumed parts. The leaves proved to be the most nutritious in terms of vitamin C, antioxidants, iron and other micronutrients. The stalks contained a rich source of fibre and the peel contained fibre, antioxidants and polyphenols. Their lack of visibility in nutritional databases showed how seldomly they are considered for their valuable nutritional content. The proportion of fruits and vegetables that were made up of a PIP ranged from 10 — 54%. In the case of broccoli, an estimated 54 % of the vegetable was made of PIPs (stalk & leaf). Highlighting the impact consuming all parts of this vegetable could have on food waste.

*Table 1. Summary of the preliminary research*

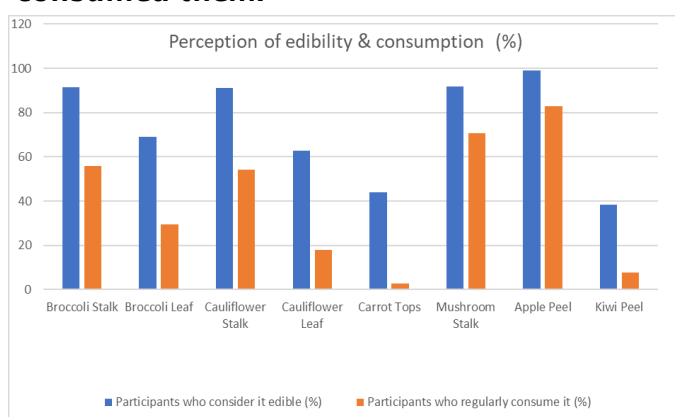
PIP of fruits & vegetables	Nutritional Attributes	Est. PIP composition
Broccoli stalk	Vitamin C, lutein (carotenoid), fibre, polyphenols	20-27 %
Broccoli leaf	Lutein, calcium, manganese, iron, vitamin E, K, $\beta$ carotene, polyphenols and antioxidants	20-47 % Total Est 54 %
Cauliflower stalk	Fibre (cellulose)	12 %
Cauliflower leaf	Protein, fibre, calcium, iron, $\beta$ carotene and vitamin C	24 % Total Est 34 %
Carrot tops	Protein, vitamin C, calcium, phosphorous, iron, polyphenol and antioxidants	Est 22 %
Mushroom stalk	Vitamin D and fibre ( $\beta$ glucans)	Est 25 – 33 %
Apple peel	Antioxidants, anthocyanins (polyphenols), flavonoids, fibre	Est 10 %
Kiwi peel	Fibre, vitamin E, folate and antioxidants	Est 25- 28 %

<sup>1</sup>Liu et al., 2019, <sup>2</sup>Inteli, 2014, <sup>3</sup>Goneim et al., 2011, <sup>4</sup>Cardwell et al., 2018, <sup>5</sup>Lata et al., 2009, <sup>6</sup>Richardson et al., 2019.

Findings from this preliminary research could be transferred to the PIPs of other fruits and vegetables such as beetroot

leaves, butternut squash peel and strawberry tops.

The consumption of the PIPs of fruits and vegetables was extremely varied. Perception of edibility did not positively correlate with consumption. Indicating that there are a number of barriers to consuming the PIPs of fruits and vegetables. in the case of carrot tops 44 % of respondents consider them to be edible but only 2.6 % regularly consumed them.



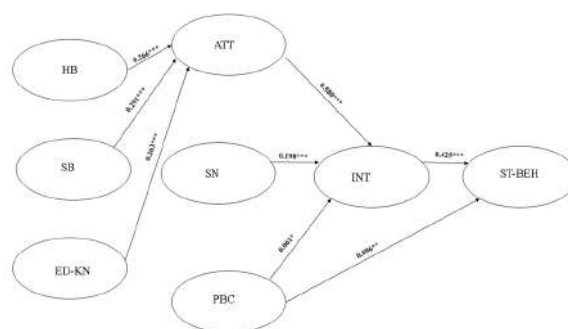
**Table 2. Perception of edibility & consumption of the PIPs of fruits and vegetables**

The total sample size was  $n = 659$  (Ireland = 405, Italy = 255). The main characteristics of the sample was mainly women (78%), young (50% are under 34 years), reside in Ireland (61%), have a high income (51 % earn > €2000 per month). Approximately half of the sample has an educational or professional background related to food or food production.

It was found that the consumption of the PIPs of fruits and vegetables was higher in women compared to men, those between the age 55 and 74 years and those with a food related background. This also reflects the literature whereby women are often found to waste less food and to be more sustainable in their mindset and actions when compared with men (Von Haartman et al., 2017). There was no difference noted between incomes and countries.

Results from the structural model, show that attitude, social norms and perceived behavioural control influence consumption of the PIPs of fruits and vegetables, with intention presenting as the strongest predictor of behaviour ( $\beta = 0.425$ ). Of all the constructs, attitude was found to have the strongest impact on intention to consume the PIPs of fruits and vegetables ( $\beta = 0.580$ ), followed by perceived behavioural control and subjective norms but to a lesser degree. The results also show that edibility knowledge, perceived sustainability and health benefits have a positive and significant impact on attitudes towards the PIPs of fruits and vegetables. There was no overall statistical difference noted between Ireland and Italy.

**Figure 1. Structural model output.**



*Notes: Significant relationships are marked by bold arrows, and non-significant relationships by dotted line arrows (\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ).*

The results from the structural model confirm all the proposed relationships are accepted. It proves to be a useful framework that has value in investigating consumer intentions and behaviours towards consuming the PIPs of fruits and vegetables. Based on the presented correlations it shows that in order to influence behaviour it is important to focus on people's attitudes considering the strongest correlation was found between attitudes and intentions.

## Recommendations

1. Revision of existing nutritional databases to include the PIPs of fruits and vegetables.
2. Food waste campaigns targeting younger people and males.
3. Information on the PIPs of fruits and vegetables (food labels, recipes, educational curriculum).
4. Creation of innovative products by the food industry using the PIPs of fruits and vegetables i.e. kiwi peel flour.

## Conclusion

This novel research has shown that an extended TPB model is an effective framework to explore the consumption of the PIPs of fruits and vegetables. The PIPs of fruits and vegetables are extremely nutritious commodities. Their consumption would have the potential to contribute towards preventing dietary related diseases and significantly reduce food waste.

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## Physicochemical stabilisation of emulsions formulated with camelina oil: Comparison of the efficiency of whey proteins, soy lecithin and camelina oil bodies as stabilising agents

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### Introduction

Camelina (*Camelina sativa* L.), is an ancient oil crop original from the Middle East and grown in European countries and Russia and belongs to the Cruciferae (Brassicaceae, mustard) (Zanetti et al., 2021). The main interest in camelina is related to the fact that it is a low-input crop that grows well in semiarid regions and in soils of low fertility, competing favourably with other plants and being tolerant to insects and weeds. Due to these features and high resistance to low temperatures, it is an attractive plant for sustainable agriculture (Ratusz et al., 2016).

Camelina seeds are rich in protein (40 wt%) and oil (35–40 wt%) (Belayneh et al., 2015). The oil extracted has high nutrition value as it contains high levels of polyunsaturated fatty acids (PUFA) (50–60 wt%), with omega-3 ( $\omega$ -3) accounting for 35–40 wt% of the total composition, being 10 times richer in these acids than many other vegetal oils, and omega-6 ( $\omega$ -6) for 15–20 wt% (Imbrea et al., 2011). In comparison with other vegetable oils, camelina oil is rich in natural antioxidant tocopherols (760 mg/kg oil) and phytosterols (up to 6500 mg/kg oil), which are health promoting minor lipid compounds (Belayneh et al., 2018) and could prevent PUFA oxidation and inactivate photooxidation as well as having radical scavenging activity.

Camelina oil has drawn the attention of the food industry, as it could give nutritional and therefore commercial advantages over the currently available alpha linolenic acid-rich plant oils (such as flaxseed and linseed oils), considering the consumer's demand for healthier foods (Goyal et al., 2015).

The incorporation of  $\omega$ -3, vitamin E and other fat-soluble ingredients into food matrices can be easier in the form of stable emulsions than in bulk oil, since they are dispersed throughout food products as droplet particles, avoiding physical separation from the aqueous phase during storage. The preparation of emulsions that are gravitationally and oxidatively stable over a time period (e.g., few days, weeks, months or years) requires the incorporation of substances known as stabilisers, which are of practical use in the food industry (Goyal et al., 2015).

Oleaginous seeds, store their lipids in the form of triacylglycerols in systems called oil bodies. The properties of oil bodies have generated a lot of industrial interest to incorporate them in oil-in-water emulsions, due to their significant stability against physical and chemical stresses, conferring gravitational stability through absorption at the oil-water interface, either individually or in combination with other stabilisers (Ishii et al., 2017; Nikiforidis, 2019; Abdullah, Weiss and Zhang, 2020). The singularity of the structure is based on their strong outer membrane made up of phospholipids and proteins (Ding et al., 2020).

The oil body system has been described as a natural emulsion that grants stability against coalescence and lipid oxidation (Nikiforidis, 2019).

### Research objectives

Formulate stable emulsions with camelina oil and oil bodies extracted from camelina seeds.

Evaluate the impact of common emulsifiers and camelina oil bodies when mixing with the ingredients of the formulation and provide a comparison on their performance.

Explore the emulsifying properties of oil bodies from camelina seeds.

Assess the influence of external conditions on these emulsions and stability over time of the obtained emulsions.

### Methodology

Oil-in-water (o/w) emulsions systems composed of camelina oil 30 (wt%), an aqueous phase supplemented with xanthan gum (0.3% (wt%) of the aqueous phase) and potassium sorbate 0.2% (wt%), and soy lecithin 0.55 (wt%), whey proteins 1 (wt%) or camelina oil bodies 0.55 (wt%) or 1 (wt%) as emulsifiers were developed. The emulsion systems were evaluated under an accelerated shelf-life study over 13 days at 45°C (steady conditions) to better understand the effect of pH (3.5, 5.5 and 7.5) on the stabilising mechanisms of the emulsifiers. The emulsions were characterised by measuring viscosity and particle size distribution and their gravitational stability was qualitatively assessed by visual observation and light backscattering profiles. The development of oxidation was tracked by monitoring the consumption of oxygen, the production of lipid hydroperoxides and aldehydes and the stability of tocopherols. A Multi-factor ANOVA (General Lineal Model) and Tukey pairwise comparison test (confidence interval 95%) were applied to determine significant differences between the samples for the all the markers.

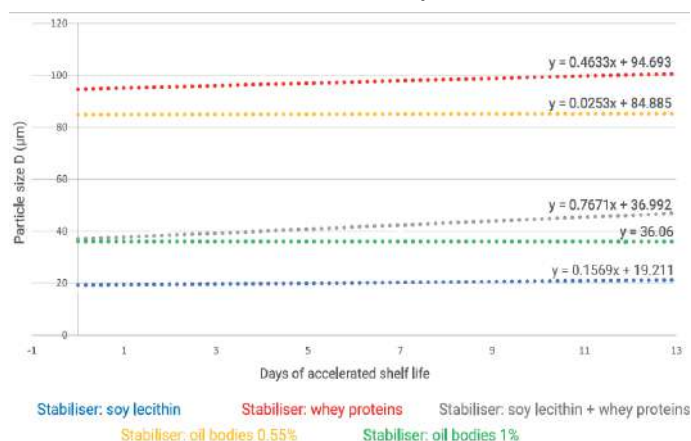
### Results and discussions

#### Physicochemical Stability Assessment

In many emulsions, the stability against droplet aggregation is due to the presence of a charged interface that generates a strong electrostatic repulsion (McClements & Jafari, 2017). Then, most emulsions stabilised with proteins are very sensitive to high temperatures and changes in the pH, which influence these electrostatic interactions against droplet aggregation (ultimately leading to coalescence). The stability of these emulsions against aggregation and coalescence in a micro-ordered scale was evaluated depending on a relative particle size change over time.

Figure 1 displays the average diameter in volume of the droplets was calculated as the

maximum value of the highest peak for the particle size distribution and plotted as a function of time for each emulsion at pH 3.5.



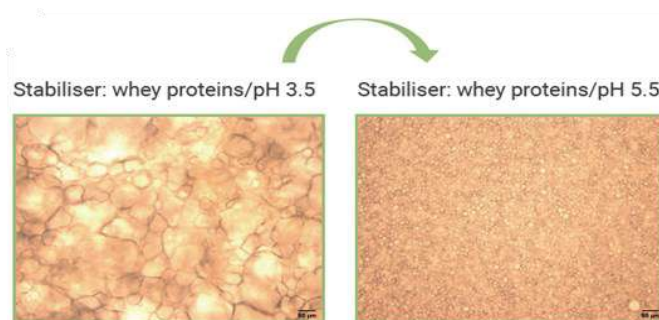
**Figure 1. Average particle size of camelina (o/w) emulsions at pH 3.5 over thirteen days of the accelerated shelf-life study, linear trend from values expressed as the mean value  $\pm$  standard deviation calculated based on three repetitions.**

No change of particle size happened during the accelerated shelf-life study for any sample, with a trend line slope of almost zero. Then, there is a good resistance to coalescence for all emulsions, since the diameter of the main population of oil droplets can be considered as constant over time regardless the emulsifier ( $p > 0.05$ ).

Having the same oil fraction and emulsification process, lecithin-stabilised emulsions were expected to have the smallest particle size, followed by native whey proteins and denatured proteins and then, oil bodies. This hypothesis was confirmed by the particle size of the emulsions obtained, in which whey proteins and oil bodies at low concentration were larger than with lecithins and oil bodies at high concentration.

In the emulsification process of the samples, the adjustment of the pH was done adding a solution of hydrochloric acid (1 mol/L) on the aqueous phases containing whey proteins, and during this process, a precipitation of proteins was observed, perhaps, as a result of the decrease of the pH, passing throughout the isoelectric point, in which they can denature and exhibit larger size (McClements & Jafari, 2017). Unlike pH 3.5, at pH 5.5 no denatured protein

structures were observed in the micrograph for whey protein-stabilised emulsion in Figure 2. At this pH there is a much more homogeneous size distribution between the three emulsions stabilised by lecithin and whey protein, with no significant difference for average oil droplet diameters ( $p = 1$ ).



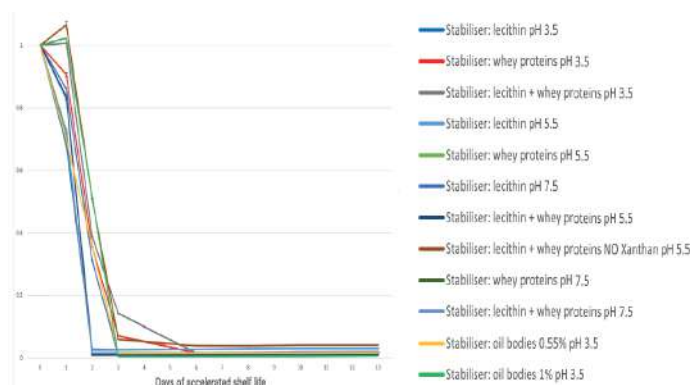
**Figure 2. Micrographs for emulsions stabilised with whey proteins at pH 3.5 (left) and pH 5.5 (right) with scale bars = 50  $\mu$ m.**

What is interesting about the oil bodies is that when they are dispersed in an aqueous media, they represent a natural emulsion system themselves. At that point, an electrostatic connection already exists between charged phospholipids and the basic amino acids of the oleosin protein, keeping its hydrophilic part in a flat arrangement towards the oil body, covering the surface instead of being extended into the aqueous phase. This arrangement is likely to persist over a wide range of acidic pH values due to the low pKa value of the phosphate group on the phospholipids (White et al., 2008).

### Oxidation Stability Assessment

Emulsions containing unsaturated lipids, such as camelina oil, can be susceptible to oxidation reactions when exposed to heat, light or metal ions (such as iron and copper) (Ahmed et al., 2016).

The percentage of oxygen in the bulk of the emulsions was tracked from day zero until day thirteen and is shown in Figure 3. The oxygen percentage in all samples decreased from about 21% to values close to 0%, after two to six days.



**Figure 3. Oxygen partial pressure (normalized values) in the bulk of camelina (o/w) emulsions over thirteen days of the accelerated shelf-life study.**

The immediate consumption of oxygen that could be via unsaturated fatty acids present in the lipid phase, is in line with the increase in hydroperoxides for all samples. As discussed by Berton-Carabin et al., (2014), some studies have shown that the creation of oil-water interface could favour the contact between unsaturated lipids and prooxidant compounds dissolved in the aqueous phase. Besides, the emulsification process itself could promote oxidation through incorporation of oxygen or overheating when high shear stress is applied.

All emulsions showed similar behaviour in that their peroxide and *p*-anisidine value significantly increased on time (after 13 days) ( $p < 0.05$ ), showing that primary and secondary oxidation reactions took place from the production time and over their shelf-life. However, the oxidation stage relatively low. The presence of antioxidant compounds naturally present in non-refined camelina oil and camelina oil bodies, such as tocopherols, carotenoids and phenolic compounds could block the generation of hydroperoxides and aldehydes through various chemical mechanisms, including quenching of free radicals by electron transfer or hydrogen donation, and metal chelation (Berton-Carabin et al., 2014).

Some of the possible explanations for oxidation phenomena are exposed below:

At pH 3.5, the denaturation of proteins mentioned above (Figure 2) could interfere in their

organization at the interface and therefore to the exchanges with the aqueous phase, possibly exposing the lipid phase to pro-oxidant compounds, triggering oxidation reactions that could continue during aging. Also, the proteins have a very high net positive charge and their antioxidant activity might be reduced or inhibited, by affecting mechanisms such as the chelation of metallic ions or the free radical scavenging by negatively charged residues as cysteic, methionyl, tryptophanyl, and tyrosyl (Pernin et al., 2019).

At pH 5.5, the neutral charge can limit the antioxidant activity of whey proteins explained before. However, in combination with a surfactant like soy lecithin, they might compete for the interface, leaving part of the unadsorbed proteic emulsifier in the aqueous phase, in which it is more soluble and, where it can strongly interact with water-soluble reagents such as free radicals and metal ions, exhibiting in a better way its antioxidant properties, preventing or delaying primary oxidation reactions (Berton-Carabin et al., 2014).

At pH 7.5, the negatively charged droplets could attract positively charged transition metals onto the surface, which are known to accelerate lipid oxidation reactions by hydrogen abstraction and peroxide decomposition, resulting in the formation of free radicals (Osborn-Barnes and Akoh, 2003).

## Conclusions

The results indicated that pH has a strong influence on the stability mechanisms of protein-stabilised emulsions. Emulsions stabilized only with oil bodies remained gravitationally stable over time at a pH of 3.5 compared to emulsions including whey protein, which was attributed to the presence of a strongly pre-stabilised phospholipid/protein interface.

All camelina oil-in-water emulsions exhibited excellent stability against coalescence and presented an extended resistance to oxidation regardless pH condition or emulsifier.

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## Development and examination of liquid plant-based young child formulae; from prototyping to product concepts

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### Introduction

Young children show rapid growth and development as their height and weight are increased by approximately 25 and 50 percent, respectively (WHO, 2009).

Young child formulae (YCF) had been developed as an alternative to breast milk for ensuring adequate nutrient intake to young children during the transition period from breastfeeding to weaning. Such formulae are commonly made of dairy ingredients, such as milk proteins, and lactose, fortified with essential nutrients (Eussen et al., 2015, Zhang et al., 2020).

Today's nutrition trends are to a great extent shifting towards the consumption of plant-based (PB) foods. Vegan, vegetarian and flexitarian populations are showing a constant growth over the years (Wunsch, 2020).

By default, parents following plant-sourced diets are interested in introducing these diets to their children. Despite that, PB products intended to young children are hardly available on the market. Products like PB milks intended to adults do not satisfy the nutritional criteria for a young child, and can set a child's health in risk (R. Mangels & Driggers, 2012).

### Research objectives

- Development of liquid PB YCF by following a prototyping method.
- Examination of consumer behaviour, and nutritional, functional, physico-chemical, and sensorial properties.
- Creation of product concepts, and suggestion of packaging and labelling solutions.

## Methodology

### Selection of raw materials

Each category of raw materials; proteins, carbohydrates, lipids, and flavours were initially selected based on the ingredients' commercial availability.

Further evaluation was done on safety and quality by following the company's criteria for ingredients of the specific age group.

Moreover, nutritional quality and techno-functional suitability for YCF were ensured by obtaining information from the supplier and previous internal studies.

Lastly, the raw materials were examined by consumers on their perception for facilitating their final selection.

### Recipe design and development

Recipes were designed using the company's internal software for ensuring nutritional compliance for the target consumer group.

Three pilot-scale trials, and one kitchen-scale trial were performed as explained in the following sections.

#### *Proteins - Trial 1*

Trial 1 had as scope the examination of different protein blends and the selection of the most desired ones.

Seven samples were prepared using 11 different protein blends, as demonstrated in Table 1. All samples contained a standard carbohydrate, a standard oil blend, and a complex of minerals.

**Table 1** Samples' number and protein composition

Sample	Protein composition
1.0	Legume 1, Cereal 1, Cereal 2
1.2	Legume 1, Legume 2
1.4	Legume 1, Seed 1, Cereal 2
1.5	Legume 3, Legume 4, Cereal 2
1.6	Legume 5, Seed 2
1.7	Legume 2, Pseudocereal 1
2.0	Legume 1, Cereal 3

#### *Carbohydrates - Trial 2*

The purpose of Trial 2 was the examination of different carbohydrates, aiming to the identification of raw materials with improved nutritional and sensorial properties, and with higher consumer acceptance compared to the current raw material used.

Five samples were prepared with different carbohydrate sources, as it can be seen in Table 2. All of the samples contained a standard protein and oil blend, and a complex of minerals.

**Table 2** Samples' number and carbohydrate composition

Sample	Carbohydrate composition
2.0	Control carbohydrate
2.1	Liquid cereal carbohydrate
2.2	Whole cereal carbohydrate
2.3	Root carbohydrate
2.4	Legume carbohydrate

#### *Lipids - Trial 3*

Trial 3 was carried out to evaluate different lipids, aiming to the identification of raw materials with improved nutritional and sensorial properties, and with higher consumer acceptance compared to the current raw material used.

Three samples with different lipid sources were prepared, as shown in Table 3. All samples contained a standard protein blend, a standard carbohydrate, and a complex of minerals.

**Table 3** Samples' number and lipid composition

Sample	Lipid composition
2.0	Seed oil 1
2.5	Nut oil
3.0	Seed oil 2

### Flavours - Trial 4

Trial 4 had as purpose the evaluation of flavours' sensorial attributes when infused in the samples of Trial 1. Trial 4 was performed in a form of a workshop at the company's Design Kitchen.

**Table 4** Samples' number, and their protein and flavour composition

Sam- ple	Protein composi- tion	Flavour composition
4.1	Legume 1, Seed 1, Cereal 2	Flavour 1
4.2	Legume 1, Cereal 1, Cereal 2	Flavour 2
4.3	Legume 5, Seed 2	Flavour 3 & Flavour 4
4.4	Legume 1, Legume 2	Flavour 5, Flavour 6 & Flavour 7
4.5	Legume 1, Legume 2	Flavour 8
4.6	Legume 1, Cereal 1	Flavour 9
4.7	Legume 1, Cereal 1	Flavour 10
4.8	Legume 3, Legume 4, Cereal 2	Flavour 11 & Flavour 12

### Analyses

Examination on physicochemical and functional properties included visual assessment, heat stability, pH, calcium ion activity, viscosity, particle size distribution, and optical microstructure.

Sensorial attributes, consumer perception, and nutritional properties; protein digestibility-corrected amino acid score (PDCAAS), and dextrose equivalent (DE) were also evaluated.

The physicochemical analyses were done after homogenization, after heat treatment, and after four weeks of storage at 25 °C, and 37 °C, as accelerated shelf-life.

Trial 4 was not examined for physicochemical properties as the samples were produced at a kitchen scale.

### Product concepts, packaging and labelling

Simultaneous activities were involved in the project for obtaining information and assist in the creation of different product concepts, as well as packaging and labelling solutions.

Following from the results of the four trials, a brainstorming session took place, in which the selected raw materials were assigned to a product concept.

### Results and discussion

#### Proteins - Trial 1

All samples showed similar physicochemical results, therefore, the selection of the samples was done based on the PDCAAS value, the consumer perception, and the sensory analysis. The samples can be seen in Figure 1.



**Figure 1** Visual appearance of Trial 1 samples.

The selected samples were 1.4 and 2.0. Sample 1.4 was selected as it had received the most acceptable sensorial characteristics, as well as a high PDCAAS value (0.95).

Sample 2.0 had shown acceptable physicochemical and sensorial characteristics, as well as the highest PDCAAS value (1). The latter sample's ingredients familiarity and perception added an advantage to the sample, which facilitated its selection.

#### Carbohydrates - Trial 2

Sample 2.1 exhibited the lowest sedimentation along with the control sample and had shown decreased aggregation under the microscope, due to the carbohydrate's liquid nature. The sample was therefore selected for further examination.

Sample 2.4 showed somewhat increased aggregation compared to some of the other

samples. Despite that, the rest of the results were considered acceptable, which lead to the sample's further examination.

In addition to the above, both of the samples showed good organoleptic properties. Moreover, the coherent origin of the ingredients was considered as beneficial in terms of labelling and consumer acceptance.

Despite this, considerations on the two samples' labelling should be taken into account, as concerns may arise from the consumers due to the unfamiliarity of the ingredient's form or controversial perception.

#### *Lipids - Trial 3*

The samples showed similar physicochemical and sensorial results. Additionally, as all three oils were positively perceived by the consumers, it was concluded that all samples may be used for further examination.

#### *Flavours - Trial 4*

The organoleptic properties of Samples 4.2, 4.3, 4.4, 4.5, 4.7, and 4.8 received a positive feedback, thus the botanicals included in the samples were selected for further examination.

Overall, the addition flavours increased the viscosity of the samples, which contributed to the improvement of watery attributes identified in some of the samples of the previous trials. Additionally, the flavours masked certain undesired attributes observed in some samples of the previous trials.

#### **Product concepts, packaging and labelling**

Through the insights obtained from the different activities, and based on the results of the four trials, different product concepts were formulated.

Each concept was aligned with the selected raw materials of the four trials. The different concepts and their composition can be seen in Table 5.

Furthermore, packaging and labelling suggestions were designed, as it can be seen at the examples in Figure 2.

**Table 5** Product concepts and their composition.

Product concept	Protein	Carbohydrate	Lipid	Flavours
Concept 1 - A	Legume 1, Cereal 3	Liquid Cereal carbohydrate	Nut oil	-
Concept 1 - B	Legume 1, Cereal 3	Liquid Cereal carbohydrate	Nut oil	Flavour 1 Flavour 2 Flavour 3
Concept 2 - A	Legume 1, Seeds 1, Cereal 2	Legume carbohydrate	Seed 2 oil	Flavour 4 Flavour 5 Flavour 3
Concept 2 - B	Legume 1, Seeds 1, Cereal 2	Legume carbohydrate	Seed 1 oil	Flavour 6 Flavour 7 Flavour 8
Concept 2 - C	Legume 1, Seeds 1, Cereal 2	Legume carbohydrate	Seed 1 oil	Flavour 9 Flavour 10 Flavour 11 Flavour 2



**Figure 2** Example of the products' packaging and labelling.

#### **Conclusion**

This study aimed to the prototyping development of liquid plant-based young child formulae at a pilot scale, by examining various macronutrients and ingredients, including proteins, carbohydrates, lipids, and flavours.

The samples were examined for their sensorial, functional and physicochemical properties, nutritional compliance, and consumer perception. Based on the results, the ingredients with the most promising results were determined.

Different product concepts were then formulated, and packaging and labelling solutions for each concept were suggested.

This study suggests the development and examination of the final recipes as they were designed for each product concept, and upon complete nutritional composition. In this way, the products' final composition can be adjusted and optimized, for the products to proceed to factory scale development.

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## Retardation of oxidation during the deep-frying of potato crisps :

### replacing TBHQ with natural antioxidants

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- MSc in Food Innovation and Product Design (Erasmus Mundus), specialising in Food Engineering from AgroParis-Tech (Université Paris-Saclay), France.
- BSc with Honours in Food and Nutrition from Coventry University, United Kingdom.
- Experiences include flavour profiling, bakery product development, and application of flavours and food ingredients in sweet and savoury categories for European and South East Asian markets.

##### Interests:

Innovation in bakery and flavours, world's traditional cuisine and culture, sociopreneurship, photography and game sports.

##### Master thesis hosting lab:

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##### Academic master thesis tutors:

Dr Marie-Noëlle MAILLARD  
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The frying industry constantly looks for ways to increase the number of frying cycles of their frying oils before having to replace them with the fresh ones for economic reasons. *Tert*-butylhydroquinone (TBHQ) has been used for this purpose, especially by potato crisp manufacturers, due to its efficiency, stability, wide availability and low cost. However, with the increasing demand from end consumers of healthier and more natural food products, the industry is trying to shift to more natural solutions. The current study aimed to replace TBHQ with a natural plant extract (NPE) alone, or blended with another NPE or synthetic antioxidants during the deep-frying of potato crisps. The analyses included are physical, chemical and organoleptic. Results showed that blends of NPEs and NPE-synthetic antioxidants outperformed the NPE alone. The two best performing blends could increase the number of frying cycles by 33% and 9% respectively when compared to TBHQ. Slight foaming and discolouration of the oil were observed in these two formulations, however, the physical nor organoleptic qualities of the fried products remained unaffected. Finding natural sources of these complementary synthetic antioxidants would allow a better consumer acceptance. Carry-over rule applies (Reg (EU) 1333/2008 Article 18 (1)), so no declaration on the final fried products is required.

*Confidential topic*



## Exploring the opportunities of reducing the environmental impact of ready meal trays

*Exploratory research on the opportunities and challenges in a food packaging company*

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#### Interests:

- Sustainable social project related to the reduction of food waste
- Reduction of the negative environmental impact in food chains
- Passionate dancer

**Master Thesis hosting lab/ company:** Micvac AB.



#### Master Thesis tutor :

Academic Supervisor: Henrik Pålsson (Lund University)  
Company Supervisor: Malin Broden (Micvac AB)



### Introduction

The changing lifestyle of consumers has driven them to increase the importance of the convenience factor when shopping for meals (Chen, 2013). According to Euromonitor International (2021), an increase of 8.6% in this category sales was observed in 2020 compared to the previous year. In Sweden, this sector is forecasted to grow 9% in the following years, of which chilled ready meals are projected to have the strongest growth (Euromonitor International, 2020). Nevertheless, the latter will also increase the environmental impact and the greenhouse gases (GHG) generation, as chilled ready meals have been found to generate more GHG than home-prepared meals (Schmidt Rivera, Espinoza Orias and Azapagic, 2014). At the moment, 26% of the global GHG emissions are accounted to the food sector, from which 18% correspond to the supply chain (Ritchie and Roser, 2020). In order to achieve Europe's 2030 climate ambitions of reducing 55% GHG emissions (European Commission, 2020), the negative environmental impact of these products should be addressed and reduced.

In this context, strategies have been previously presented to address this issue. Considering the role of food packaging and the product's supply chain has been identified to be crucial to craft a holistic solution. It is well known that including logistic requirements in the packaging design process brings benefits to the food companies (García-Arca, Prado-Prado and Gonzalez-Portela Garrido, 2014; Molina-Besch and Pålsson, 2020), and it has been studied to some extent. However, fewer insights on the opportunities and challenges

for food packaging companies in applying this principle are currently available.

### Research objectives

The purpose of the thesis is to explore the opportunities and challenges of including logistic requirements in the packaging development process at a packaging company to reduce the indirect environmental impact of chilled ready meals' packaging.

To accomplish the aim, the following research questions (RQs) must be addressed:

1. How does Micvac's packaging design affects the environmental impact along the supply chain?
2. What requirements are currently considered during the tray design process at Micvac?
3. How can logistic requirements be included in the packaging development process to improve transport efficiency?

### Methodology

The research was framed as an exploratory case study with qualitative and quantitative data gathering. The study has three main components, each of which addressed a research question and used defined tools:

1. Environmental impact in the supply chain
  - Supply chain mapping for a selected product
  - Carbon footprint estimation of packaging material, transport, waste handling, and material handling
  - Evaluation of the impact of the tray design
2. Packaging development process and portfolio evaluation
  - Packaging design process mapping
  - Identifications of requirements currently used
  - Volume fill rate calculations of trays in crates
3. Logistic requirements to improve transport efficiency
  - Analysis of requirement to be implemented
  - Identification of opportunities and challenges

A literature review and a database search were used for secondary research. Interviews with key actors, questionnaires, observation during visits and experiments (CAD modelling and Physical samples) were conducted as part of primary research.

### Results and discussions

#### Environmental impact in the supply chain

A simplified scheme of Micvac's supply chain can be observed in Figure 1.

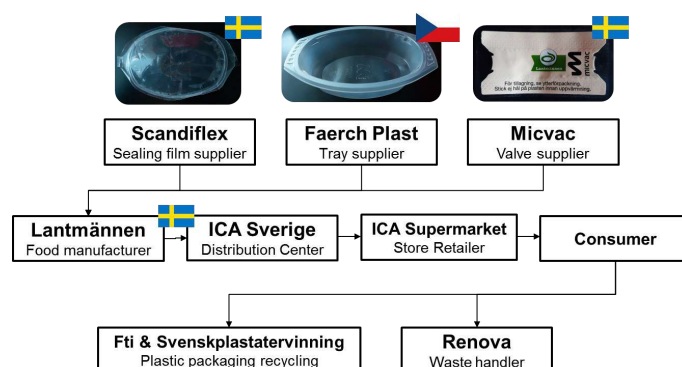


Figure 1. Simplified scheme of Micvac's supply chain.

The primary packages are manually packed to reusable crates and piled up in pallets at the food manufacturer stage. The tray dimensions determine the maximum number of trays that can fit. Nevertheless, the retail's distribution centre has requirements on the amount the crates should contain based on the smallest store format. The latter limits the control the food manufacturer has on increasing the fill rate of the secondary packages. The packaging system configurations used can be observed in Figure 2.

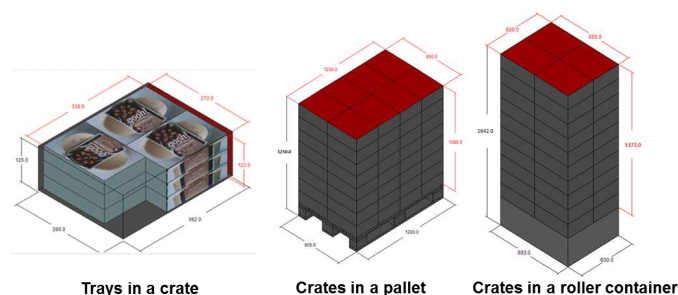
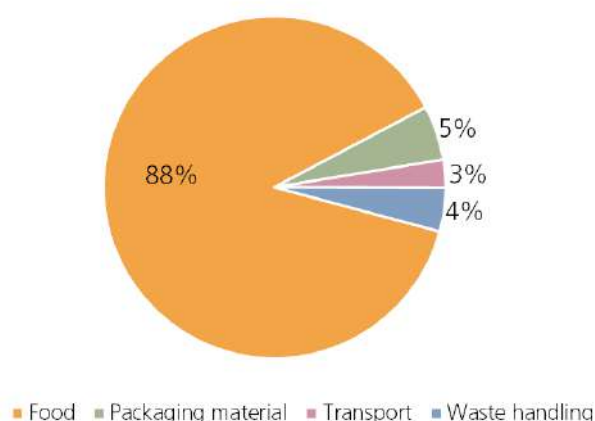


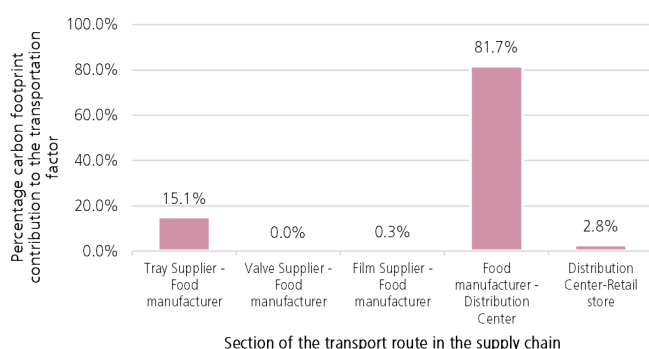
Figure 2. Packaging system used for transporting ready meal trays produced with Micvac technology

The carbon footprint of the food product, packaging material, transportation, material handling, and waste handling were estimated. The CO<sub>2</sub>e emissions from material handling was considered to be very low compared to the other factors due to Sweden's energy Matrix. The results can be observed in Figure 3.



**Figure 3. Carbon footprint of different factors for a 400 g ready meal**

From a food packaging company perspective, there is no control on the carbon footprint of the ingredients used for producing the ready meal. Packaging material and waste handling are related, as they are co-dependent. As the main focus of the study was to include logistic requirements in the design process, the transport aspect was analysed in more detail. The results of the distribution of the emissions along the supply chain can be observed in Figure 4.



**Figure 4. Carbon footprint percentage contribution at different transport routes along the supply chain**

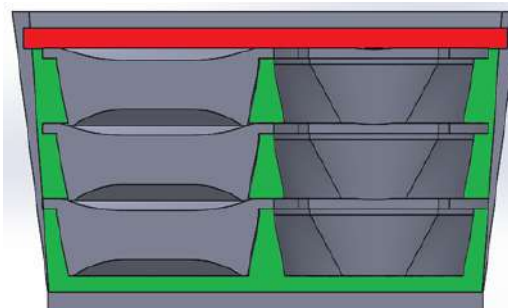
Transport companies oversee choosing the transport mode based on the customer's need

and internal availability, limiting the actor's control for the service. However, this could have a positive effect as transport companies can help avoid air being transported by planning and allocating co-distribution when needed.

### The packaging development process and portfolio evaluation

Micvac currently uses a funnel model for innovation and technological project. The requirements that Micvac currently considers during the tray design process include production, product, and customer requirements. There is an intention to include environmental requirements due to consumers' requests, a consequence of the increasing awareness. The main constraints on getting new trays models into the market are financial, as small customers cannot invest in new moulds. However, there is a potential for designing based on consumer needs.

The current fill rates of the Micvac portfolio vary from 25-38%. There are opportunities for increasing the fill rate of the current Micvac trays. As an example, it was shown that for the Oval 300 g tray there is a 44% of the void space that could be avoided if changes in the handles are made. This is depicted in Figure 5 and 6. Figure 5 shows the current situation and evidenced the void space inside the crate, while Figure 6 shows the potential improvements in changes in the tray handles are made.



**Figure 5. Cross section cut (middle of the crate) of tray Sample B in a crate Sample Y where the green area shows the void space, and the red line shows the maximum height to allow stacking.**



Volume Fill rate:	33%	47%
Trays per pallet:	576	876
Carbon footprint per tray:	15.17 gCO <sub>2</sub> e	10.25 gCO <sub>2</sub> e

Figure 6. a) Before and b) After tray design if logistic requirements are included in the design process

Increasing the volume fill rate shows that lower GHG emission per kilogram of meal transported can be achieved. Even small increases have an overall impact. There is an opportunity of reducing the environmental impact if the fill rates of the current packages are increased.

#### Logistic requirements to improve transport efficiency

Within logistic requirements, transport, storage, and material handling requirements were taken into consideration for the evaluation. The study resolved that transport requirements are the most relevant to consider as part of logistic requirements during the packaging design, and that they should be included to increase volume fill rate and reduce the negative environmental impact.

The main opportunities and challenges of including the requirements in the design process at Micvac are presented in Table 1.

Table 1. Summary of opportunities and challenges identified.

Opportunities	Challenges
<ul style="list-style-type: none"> <li>·Reduce the carbon footprint caused by transportation by increasing the fill rate</li> <li>·Increase the fill rate by reducing the empty volumes caused by the handles</li> <li>·Improve relationships with actors in the supply chain, such as retailers, to optimize for apportionment and increase fill rate</li> </ul>	<ul style="list-style-type: none"> <li>·Obtain information related to the order size and projection from the retailer in Sweden and in other markets</li> <li>·Test the new design to be sure that the new model does not reduce functionality for the consumers</li> </ul>

## Conclusion

The carbon footprint of transporting the ready meal from the food manufacturer to the retailer has the highest percentage contribution to the overall transportation impact. At the moment, the company only considers production, product, and customer requirements.

There is an opportunity for reducing the environmental impact by including transport requirements in the design process.

Considering the best apportionment for the retailer is key to achieve a high fill rate in practice, which involves collaboration between actors in the supply chain.

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## New Product Development for Plant Based Beverage from Baobab Fruit

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#### Interests:

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### Introduction

Baobab tree is primarily found in South Africa and known as the upside-down tree. Baobab fruit pulp, seeds, leaves, flowers, roots, and barks are edible and have numerous biological properties including antimicrobial, anti-malarial, diarrhoea, anaemia, asthma, antiviral, anti-oxidant and anti-inflammatory activities amongst others (Rahul et al., 2015). Baobab dried fruit pulp is very rich in dietary fiber ( $\approx 50\text{g}/100\text{g}$ ), pectin ( $\approx 25\text{g}/100\text{g}$ ), and low in fat and calorie. Moreover, it is also rich in vitamin C ( $\approx 100\text{mg}/100\text{g}$ ). Additionally, It is a good source of calcium ( $\approx 317\text{mg}/100\text{g}$ ), iron ( $\approx 5.9\text{mg}/100\text{g}$ ) and magnesium ( $\approx 148\text{mg}/100\text{g}$ ) as compared to other fruits (PhytoTrade Africa, 2009).

### Research objectives

- To develop the liquid baobab base from baobab fruit, which is suitable for beverage application.
- To reduce the viscosity of liquid baobab base by enzyme treatment.
- To formulate the recipes for plant-based beverages (Baobab-Oat beverages).

- To carry out the sensory evaluation for Baobab-Oat beverages.

## Methodology

### Development of Liquid Baobab Base

Three formulations of liquid baobab base (30-32%, 35-37%, 40-42% by weight of baobab fruit) were developed. The Baobab fruit (pulp + seed) was weighed, the boiling water was added and stirred with the agitator at temperature 75 – 90 °C in the water bath, at speed 200 rpm for 45 minutes. Then, the mixture was brought to filtration and the liquid baobab base was obtained.

### Enzyme Treatment on Liquid Baobab Base

The base with the highest dry matter and better nutritional composition was subjected to pectinase enzyme treatment (0.05%, 0.07%, 0.1%) to reduce its viscosity. The base was heated to 50 – 60 °C in the water bath, then the pectinase enzyme was slowly dropped into the base and stirred with the agitator at speed 200 rpm for 2 hours. After the enzyme treatment, the base was immediately removed from the hot water bath into ice bath at 5 °C for 30 minutes to deactivate the enzyme activity and the liquid baobab base with the pectinase enzyme treatment was obtained.

### Formulation of Plant-Based Beverage (Baobab-Oat Beverages)

The enzyme-treated liquid baobab base showing the best viscosity and pH was selected as a base to mix with other ingredients to produce three plant-based beverages: Blueberry, Mango, and Apple Cinnamon. All the ingredients were weighed and stirred well with the agitator at ambient temperature 20-25 °C, at 200rpm, for 10 minutes. Then, the mixtures were homogenized with the hand Bamix for 1 minute. After that, the mixtures were further carried out the pasteurization at 78-95 °C for 2 minutes using the microwave heater. The Baobab-Oat beverages were obtained. The

three beverages underwent physicochemical and nutritional analysis as well as a sensory test with thirty-seven panellists using ANOVA analysis by SPSS programme.

## Results and discussion

### Liquid Baobab Base (LBB)

Table 1. the pH of LBB (3.3, 3.3, 3.2) was slightly decreased with the increasing amount of baobab fruit (30-32%, 35-37%, 40-42%) ( $p \leq 0.05$ ). On the other hand, the highest dry matter was seen in LBB produced from baobab fruit 40-42% (16.3%) ( $p \leq 0.05$ ). Meanwhile, the viscosity of LBB was dramatically increased (53.83 mPa, 10863 mPa, 54430 mPa) when the amount of baobab fruit was increased (30-32%, 35-37%, 40-42%) ( $p \leq 0.05$ ). This can be explained that, when the amount of baobab fruit was increased, the dry matter in the suspension was higher and the baobab fruit fibre absorbed and bonded with all the free water in the system that resulted in increasing the viscosity in the system.

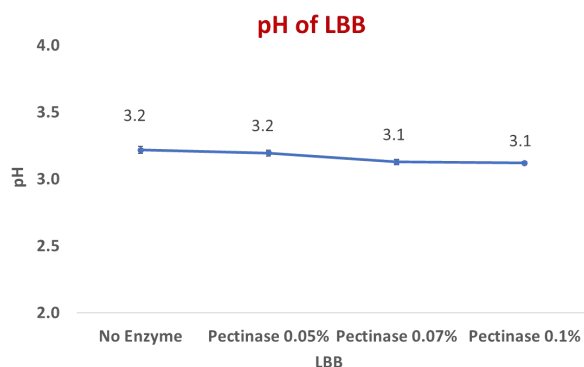
**Table 1.** pH, dry matter, and viscosity of the three liquid baobab bases (LBB) produced from different percentages of baobab fruit (30-32%, 35-37%, 40-42%).

LBB	LBB 30-32%	LBB 35-37%	LBB 40-42%
pH	3.3 ± 0.01	3.3 ± 0.01	3.2 ± 0.03
Dry Matter (%)	12.3 ± 0.1	13.8 ± 0.3	16.3 ± 0.1
Viscosity (mPa)	5383 ± 28.9	10863 ± 15.3	54430 ± 69.3

### Enzyme Treatment on Liquid Baobab Base

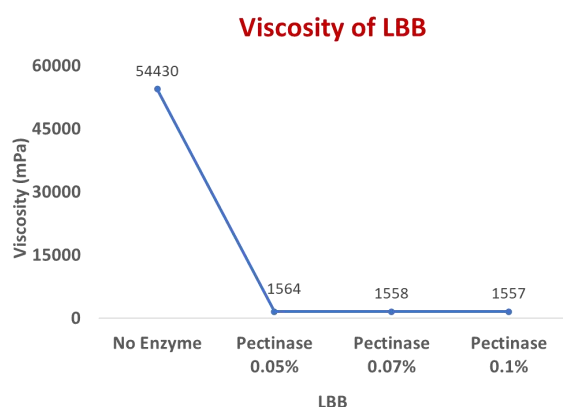
Figure 1. the data indicates that the pH of liquid baobab base (3.2, 3.1, 3.1) was slightly decreased after increasing the amount of pectinase 0.05%, 0.07%, 0.1% ( $p \leq 0.05$ ). The pectinase enzyme treatment decreased the pH value of the LBB and made the LBB become more acidic due to the increasing amount of galacturonic acid content result-

ing from the pectin polymer hydrolysis into monomer form named galacturonic acid by the pectinase (Berutu et al., 2017).



**Figure 1.** pH of liquid baobab base with the different amounts of pectinase enzyme treatment (0%, 0.05%, 0.07%, 0.1%).

Figure 2. the data shows that the viscosity of the LBB was dramatically dropped down after the pectinase enzyme treatment ( $p \leq 0.05$ ). The enzyme-treated LBB with pectinase 0.05% showed very low viscosity (1564 mPa) compared to the untreated LBB (54430 mPa), which is 97.1% of viscosity reduction. This can be explained that upon the enzyme treatment, degradation of pectin leads to a reduction of water holding capacity and consequently free water was released to the system thus reducing the viscosity of the liquid baobab base (Anurag Singh, 2012). However, in this study the viscosity of the liquid baobab base was not reduced much more after increasing the Pectinase to 0.07% and 0.1%.

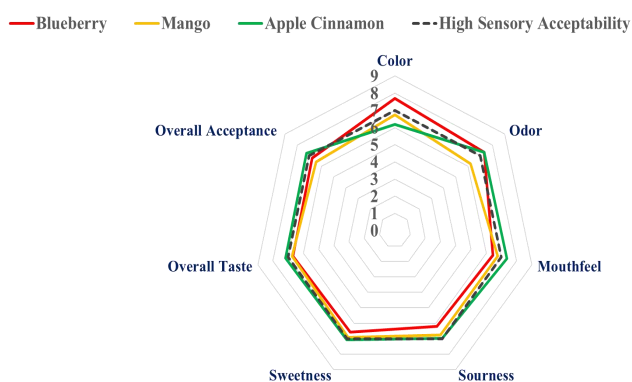


**Figure 2.** Viscosity of liquid baobab base with the different amounts of pectinase enzyme treatment (0%, 0.05%, 0.07%, 0.1%).

### Plant-Based Beverages (Baobab-Oat Beverages)

Figure 3. for the Color of the products ( $p \leq 0.05$ ), Blueberry flavor obtained the highest degree of liking, followed by the Mango and Apple Cinnamon Flavor. For the Odor of the products ( $p \leq 0.05$ ), Mango flavor obtained the lowest degree of liking. For the Mouthfeel ( $p \leq 0.05$ ), Sourness ( $p \geq 0.05$ ), and Sweetness ( $p \geq 0.05$ ) of the products, Apple Cinnamon Flavor obtained the highest degree of liking, followed by the Mango Flavor and Blueberry Flavor. For the Overall Taste ( $p \geq 0.05$ ) and Overall Acceptance ( $p \geq 0.05$ ), Apple Cinnamon Flavor obtained the highest degree of liking among all.

#### **Sensory Evaluation of Baobab-Oat Beverages**



**Figure 3.** Sensory evaluation of Baobab-Oat beverages with the three different formulations. Data indicate the score on a 9-point hedonic scale.

**Table 2.** P-value from the means of the assessment from 37 panellists on sensory of the three Baobab-Oat beverages using One-way ANOVA analysis.

Baobab Oat Beverages	P-value
Color	$\leq 0.05$
Odor	$\leq 0.05$
Mouthfeel	$\leq 0.05$
Sourness	$\geq 0.05$
Sweetness	$\geq 0.05$
Overall Taste	$\geq 0.05$
Overall Acceptance	$\geq 0.05$

## Product Nutritional Analysis

Table 3. all the three Baobab-Oat beverages are claimed "Source in Fiber" in accordance with Regulation (EC) No 1924/2006.

**Table 3.** presents the nutritional values in 100 ml of Blueberry, Mango, and Apple Cinnamon Baobab-Oat beverages.

Nutritional Value (Per 100ml)	Blueberry	Mango	Apple Cinnamon
Energy (kcal)	49.1	50.4	49.8
Fat (g)	0.1	0.1	0.1
Carbohydrate (g)	10.0	10.5	10.2
Fiber (g)	3.6	3.7	3.7
Protein (g)	0.4	0.4	0.3
Iron (mg)	1.1	1.1	1.2

## Conclusion

In conclusion, the liquid baobab base produced from Baobab fruit 40-42% (LBB 40-42%) showed the best properties for the beverage application due to it obtained the highest dry matter content and nutritional values. However, its viscosity was a bit high, but it could be reduced by the enzyme treatment. Furthermore, the liquid baobab base with 0.05% pectinase enzyme treatment provided the optimal pH value considering the balance sour taste of the finished products, and the optimal viscosity considering the texture of finished products. On the other hand, among all the three formulated Baobab-Oat Beverages, the Apple Cinnamon Baobab-Oat beverage obtained the highest degree of liking or sensory acceptability for the overall taste and overall acceptance. Additionally, all the three Baobab-Oat beverages are claimed "Source in Fiber" in accordance with Regulation (EC) No 1924/2006.

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## Evaluation of post-consumer recycled materials for folding cartons: A sustainable packaging study

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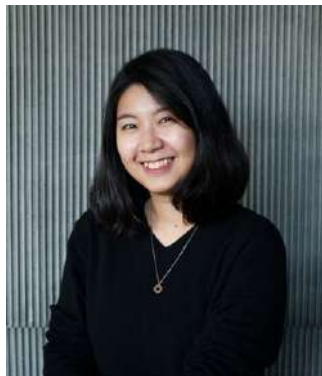
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#### Master Thesis tutors:

Company supervisor: Manon Vacher

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### Introduction and Background

Reducing the environmental impact from packaging has become a highlight in both consumers and industrial interest. The paperboard from virgin fibres is commonly used in the folding carton packaging across various type of products, including health care products (Robertson, 2012). The smoking cessation product in the European market was selected in this study where the standard secondary packaging is virgin fibre. It provides the premium perception to the product value yet less circulates the fibre economy. Paper packaging is well-known for its recyclability and seen as one of the most environmentally friendly materials. After the paperboard folding carton serves the end-consumer purpose, it becomes post-consumer wastes (Yardley, 2019). To reduce the environmental impact from using virgin fibre paperboard and escalate the paper circular economy, using post-consumer recycled (PCR) materials becomes more popular. As part of the development process, new materials need to be evaluated by different stakeholders to see their potential before implementation. The initiative started as a sustainability project (Ellen MacArthur Foundation, 2020); however, the other aspects of desirability, viability and feasibility, need to be considered. Therefore, to study PCR materials, this master's thesis aims to investigate the suitable PCR material for folding cartons.

### Research objectives

The focus of this study is divided into the following objectives

1. Explore consumer's perception towards the post-consumer recycled paper material in folding cartons.
2. Assess the post-consumer recycled paper material properties compared with current folding carton requirements.

## Methodology

### *Qualitative consumer research*

The aim is to explore respondents' underlying motivations, attitudes, and feelings on the PCR folding cartons. As it is a one-on-one interview, the method is semi-structured, which would enhance the opportunity to probe more topics and get more insight from fewer respondents. Ten respondents of smoking cessation products of mixed genders, and sustainability attitudes participated in the interview. Two PCR folding carton samples, which differ in colour (grey and brown), were involved in the interview. They were compared with the current packaging to test perception and acceptance.

### *Material evaluation*

A comprehensive assessment of PCR materials was conducted based on the four aspects: Desirability, Viability, Feasibility and Sustainability. Each element involved a specific subject related to PCR materials. Information was provided by suppliers and experts in the company. The result was analysed by using all four aspects together to have a holistic view.

## Result and discussion

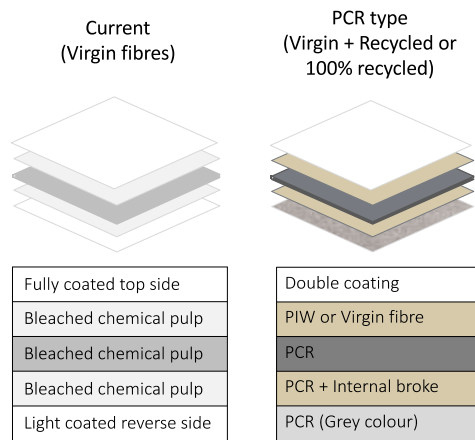
The consumer research compared two post-consumer recycled packaging to the current virgin fibre packaging where the results showed that respondents expected the brand to use sustainable packaging and were willing to sacrifice their usual aesthetic preferences for more sustainable options. However, the sustainability is less of a key purchase driver than the product efficacy in the smoking cessation product. The same trend also shows in the per-

sonal care products (O'Rourke and Ringer, 2015). Consumers perceived the colours of two PCR materials differently. Whilst the brown sample was preferred as associated with a natural and sustainable product, the grey sample received a range of perceptions from a cheap material to similar to the current packaging. It can be assumed that the PCR brown pack is unlikely to have an adverse impact on the brand image. The result suggested to use sustainability claims and messaging about PCR materials on a package to prevent misunderstanding and boost brand image.



**Figure 1: Samples for the consumer research**

Feasibility plays an important role in the near future implementation. The evaluation and comparison of six PCR materials to the current packaging suggested that potential PCR paperboards should have the higher grammage and thickness to maintain packaging integrity due to the inferior qualities of recycled fibres (Iggesund, 2019). At the point of writing, there is no clear regulation of recycled paperboard as secondary packaging material in the EU. The most concern issue regarding safety is the mineral oil migration from recycled materials (Biedermann, Uematsu and Grob, 2011). Therefore, a combination of standards and certifications were used to evaluate the product safety. The demand of PCR material is rising, material availability hinders the progress which could affect the business viability. Finally, two post-consumer recycled materials were suggested for future testing in the actual production based on the four dimensions evaluation.



**Figure 2: Structure comparison of the current and PCR type paperboards**

**Conclusions**

The outcome of this study can be used in the smoking cessation and other similar products to better develop sustainable packaging. Also, evaluation criteria provide more information on how to compare packaging materials in a holistic view. With the uncertainty of regulations, the use of PCR materials as secondary packaging should be closely monitored. On this basis, the balances between each dimension and stakeholder requirements should be taken into account when developing sustainable packaging. Trade-offs between each option should be considered accordingly.

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## Development, Chemical Composition and Microbiological Assessment of Smoothie and Grissini based on Agri-food By-products

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Erasmus+ Traineeship at Food Design and Consumer Behaviour Department, University of Copenhagen, Denmark on vegetables' acceptance by children

Nutrition educator in different settings and age groups

Recipe developer and editor-in-chief of health- and wellness-related websites

#### Interests

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#### Master Thesis tutors

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#### Introduction

The land and water used to produce raw ingredients and for the processing plants are the major contributors to greenhouse gas emissions, making for about 20-30% of the total environmental footprint of private consumption [1]. When food is not consumed but wasted, the footprint of food production and consumption is magnified. According to Food and Agriculture Organization of the United Nations (FAO), only two thirds of the food that is produced for humans is in the end consumed, at a global level [2]. It is estimated that  $88 \pm 14$  Mt of food loss or waste are produced within the European Union annually [3], which carry the environmental impacts of the up-stream stages of the supply chain but also the emissions from food disposal. Food loss and waste have a social impact as well, taking into consideration the estimated increase of the population by 2050 and the high prevalence of hunger and hidden hunger globally. The concept of upcycling seems like a promising solution to this challenge, as it defines a process in which materials that are already used or otherwise wasted are converted into new products with an added value, following the values of circular economy.

Four different ingredients that were discarded by the producers were used in this project. Apple (*Malus domestica*) can be found in the market all year long and it was the third most consumed fruit in 2019 [4]. The fruit has a high nutritional value, with dietary fibre, polyphenols and vitamins to be the main major classes of the potentially beneficial compounds that it contains [5-7]. Cellulose and part of the hemicelluloses comprise the main insoluble fibre in apples,

while pectic polysaccharides and water-soluble hemicelluloses account for the main part of the soluble fibre. Pectic polysaccharides have been correlated with numerous protective effects on human health, such as increasing satiety, maintaining normal cholesterol levels and glycaemia, as well as impacting the composition of the gut microbiota [8–11]. Apples also exert antioxidant activity due to its content in chlorogenic acids, quercetin, epicatechin and anthocyanins [12,13]. Sadly, 300 g of apple are discarded along the food chain for every kg consumed [14].

Yacon (*Smallanthus sonchifolius*) is a plant originating from Andes but also cultivated in Europe. The distinctive characteristic of yacon compared to other edible roots is that its carbohydrates are stored in the form of inulin and fructooligosaccharides (FOS) instead of starch [15,16]. Inulin has been shown to affect lipid metabolism, while FOS can regulate the production of gastrointestinal peptides that are related to the homeostasis of glucagon and gastric emptying and exert a prebiotic effect [17–19].

The third ingredient used in this thesis was egg white, which is known for its exceptional essential amino acid profile and the high digestibility of its proteins. The main protein present in egg white is ovalbumin, the gold standard protein in terms of biological value [20–22]. The consumption of protein has generally been correlated with muscle mass growth and maintenance. The egg white as an ingredient has also many functional properties, such as gelling, foaming and emulsifying [23]. In the community of Aveiro, Portugal, more than 200 tonnes of *Ovos Moles de Aveiro*, a dessert with Protected Geographical Indication (PGI) status are produced, yielding to more than 3 tonnes of egg white discarded per year.

The final ingredient were “herbal distillates”, otherwise called “herbal waters” or “hydrosols”, a liquid by-product from herb stems that were discarded by the producers and were used to

make essential oils, Hydrosols can be safely used in the food industry and they exert antimicrobial, antioxidant and flavouring properties. The particular herbs used in this study were winter savory (*Satureja montana*) and lemongrass (*Cymbopogon citratus*) [24,25].

### Aim of the Thesis

The aim of this work was to valorise these different otherwise wasted ingredients, while investigating the optimum combinations or, in other words, the synergisms from a formulation perspective. The new products developed aimed to be palatable, nutritious and safe for consumption, following the trend of minimally processed foods and “clean label” products.

### Materials and Methods

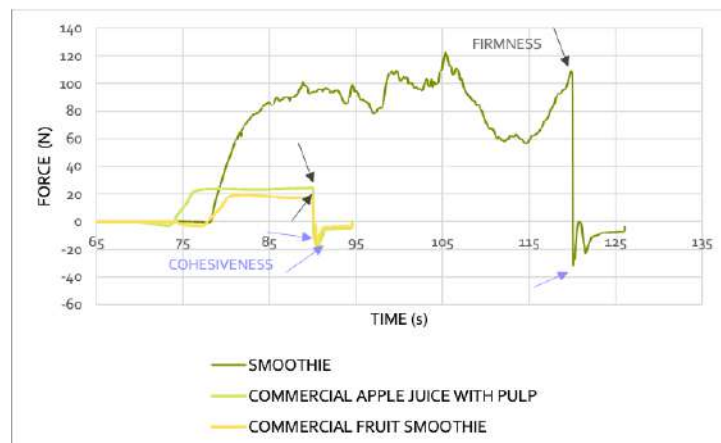
The first stage of this thesis comprised of idea brainstorming, which along with a market research and an extended literature review yielded the final concepts. Apples, yacon, egg white and herb stems were sourced from local producers towards making a smoothie-like beverage as well as a bakery product that resembles the Italian grissini. After numerous kitchen-scale trials, the final optimised prototypes in terms of formulation and texture were characterised following three main pillars: the chemical composition, the microbiological quality as well as some sensory parameters. In the frame of the chemical composition ash, moisture, total and free carbohydrates as well as proteins were determined, while mesophilic bacteria, yeasts and moulds, total coliforms, *E. coli*, *Salmonella* spp. and *Shigella* spp. were counted in terms of microbiological quality. The pH was also measured, as well as the colour, the texture profile and the volatiles in the headspace of the samples. Statistical analyses (non-parametric tests) were performed to investigate the significant differences among key comparisons.

## Results and Discussion

### Smoothie

The smoothie prototype contained 40% egg white, as well as apple puree, yacon and lemongrass water. The production process was quite complex due to the many ingredients of the matrix. The heat treatment consisted of two steps: one first step pasteurisation of the plant ingredients at 95 °C for 30 seconds, followed by the addition of the egg white and a second pasteurisation at 60 °C for 3.5 minutes. The final product has a high nutritional value, providing more energy than fruit-only and dairy beverages, while it was found to contain more non-digestible polysaccharides. The smoothie contains around 27 g of protein, almost reaching the 30 g optimum protein intake threshold per meal for muscle anabolism [26]. The prototype was in general hard to benchmark due to its unique nutritional profile, while a 100 g serving size is highly recommended. The 2-step pasteurised prototype was stable for at least 7 days stored at 4 °C. The heat treatment did not affect the pH. The heat treatment affected the colour of the smoothie, with the pasteurised one to be less brown, more clear and greener, indicating the deactivation of the polyphenol oxidase enzymes that are responsible for enzymatic browning. The texture profile of the smoothie was evaluated by a backwards extrusion analysis, and it was compared with two fruit-only beverages. The prototype was quite heterogeneous, while it differed significantly in terms of firmness and in a lower extent in terms of cohesiveness (Figure 1). The differences in the texture compared to the fruit beverages could be attributed to the higher fibre and protein content, as well as to the pectin-ovalbumin coacervates that might be present in this matrix [27]. A headspace volatile analysis was performed in unpasteurised and pasteurised samples, served at 6 and 25 °C. This experiment showed that the egg volatiles were not present in the headspace of none of the samples, as most of the compounds (such as neral and geranial) originate from the lemongrass water. There was observed an effect of the serving temperature and the heat treatment of the intensity of the volatiles, with it being higher when the beverage was un-

pasteurised and served in room temperature.

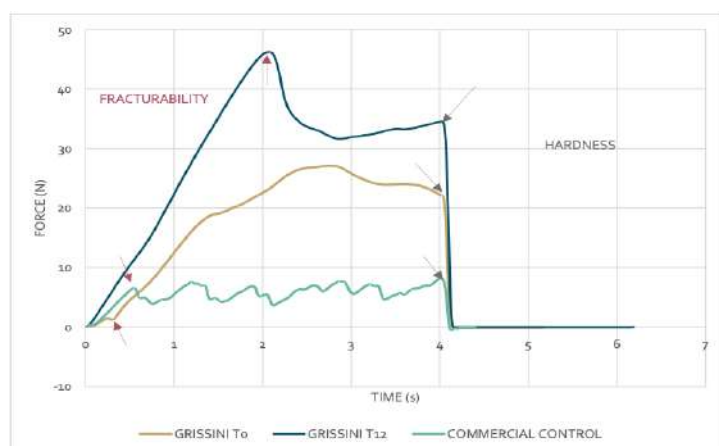


**Figure 1: Texture profile analysis for the developed smoothie, as well as a commercial fruit smoothie and a commercial apple juice with pulp**

### Grissini

The final grissini prototype contained 25% of egg white, as well as equal amounts of yacon and apple flour and winter savory water. The leavening agent used was sourdough, which was left to ferment the dough for 12 hours in total. The nutritional value of the developed grissini was found to be quite comparable to the commercial control, as well as to grissini found in the literature, especially in terms of energy [28]. The grissini was higher in total carbohydrates, which included the non-digestible polysaccharides. The free sugars content was expected to be higher, due to the yacon and apple enrichment. In terms of protein, the grissini provided with around 11 g per 100 g, which was similar to the other two products. However, the protein quality in the prototype is expected to be higher, due to the egg white content. The grissini were found to be stable for at least 12 days stored in ambient temperature. The texture profile analysis was performed via compression testing on the developed grissini at the day of production, the grissini 12 days after production, as well as a commercial grissini product. The results showed that the grissini get significantly harder to break along their shelf-life, while they differed in terms of hardness to the commercial control.

The analysis of the volatile compounds in the headspace of the grissini showed that most of the aroma, like furfural, is coming from the Maillard reaction which takes place during the baking of the product. The second most abundant volatile was carvacrol, the main compound of winter savory water. Acetic acid (from the sourdough), but also benzaldehyde (from egg white) were detected.



**Figure 2: Texture profile analysis for the developed grissini at the day of production and 12 days after production, as well as to a commercial grissini**

## Conclusions

The main conclusion of this study was about the feasibility of developing such products that combine all these different otherwise wasted materials. Both prototypes developed were safe for consumption, had a satisfactory shelf-life as well as a good nutritional profile. The texture profile for both cases was quite different than the commercial products, but a sensory testing should be performed in the future to conclude whether these different textures would be accepted or not by the consumers. Finally, the herbal waters seemed to contribute remarkably to the flavour of both beverage and baked product.

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## *In-situ* Functionalization of Fruit-Based Beverages by Mechanical Treatment

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### **Introduction**

A juice is defined as a heterogeneous suspension of disintegrated insoluble pulp particles in a continuous serum solution that is rich in soluble compounds like sugars, salts, acids and minerals (Dahdouh et al., 2016). The perception of quality of fruit-based beverages varies, but a sediment or phase separation is viewed as a product defect (Beveridge, 2002). Reducing pulp sedimentation through mechanical treatment could improve consumer acceptability and eliminate the need for adding hydrocolloids in juice matrices, which has several logistic and economic implications (Rojas et al., 2016). High Pressure Homogenization (HPH) can rupture plant tissue into particles with different morphological properties and microstructures, giving them particular rheological and functional properties (Moelants et al., 2014), which in turn make possible the generation of a wide range of textures in aqueous systems (Redgwell et al., 2008). This highlights the potential of using plant cells as structuring elements to texturize foods in a more natural way (Lopez-Sanchez et al., 2011).

### **Research objectives**

This study has the objective of gaining a more thorough understanding of the process-related structuring mechanisms that govern the physical properties of apricot juices, in a more global attempt to texturize and stabilize juices in a natural way. In other terms, it is to answer the following global question: is it possible to stabilize a fruit juice without additives?

## Methodology

### Juice formulation & processing

11.5 ±0.23 °Brix apricot juices were obtained by diluting a 20.4 ±0.2 °Brix commercial puree in distilled water and adding sucrose under gentle magnetic stirring (**Table 1**). The average pH of the juices was 3.485 ±0.06. The aliquots of apricot juice were introduced into the equipment at 20°C and cooled after treatment at 4°C until analyses were carried out. Three pressure levels were applied: 0, 35 and 70 MPa.

Puree (w%)	Sucrose (w%)	Distilled Water (w%)
20	8.5	71.5
40	4	56
60	0	40

Table 1. Juice formulation

### Physicochemical characterization

**Pulp content** The amount of pulp was obtained by centrifuging 30g of juice at 5000g for 2 hours at 20°C. The serum was collected for dry matter and rheological analyses. %Pulp=Weight pulp / Weight juice ×100.

**Dry matter** 3g of juice or serum were weighed on an aluminum cup and dried in an oven at 105°C for 8 hours until a constant weight was reached. %DM = Weight dry matter/Weight initial juice× 100.

**Particle size & shape** The particle size distribution of the samples was acquired via laser diffraction (granulometry) and microstructures observations were made with a 10X objective lens in phase contrast.

### Rheological characterization

**Flow curve** a logarithmic shear rate ramp was applied from 1 to 250 s<sup>-1</sup> for a duration of 6.5 minutes. The data were fitted to the Ostwald-de-Waele model  $\sigma=k \cdot (\dot{\gamma})^n$ , allowing to obtain the consistency and flow behavior indices.

**Strain sweep** a strain ranging from 0.01 to 150% was applied at constant frequency (10 rad/s), measuring 22 points, after 5 minutes of resting time. Average values for the storage (G') and loss (G'') moduli were taken in the linear viscoelastic region (LVR).

## Physical stability

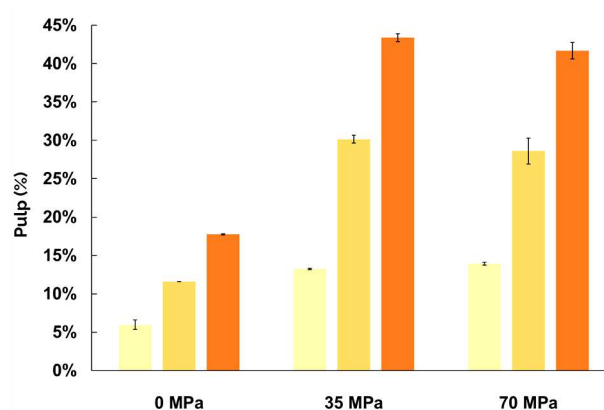
**Sedimentation** Pulp sedimentation was evaluated via image analysis (ImageJ software), by comparing sample tubes stored at 4 and 20°C at day 0 and day 7. SI= sediment height at D<sub>7</sub>/ total liquid height at D<sub>0</sub>.

### Experimental design & statistical analysis

In order to evaluate the effect of homogenization pressure (factor 1) and puree content (factor 2) on the behavior of the beverages, a 3<sup>2</sup> full factorial design was set-up. A total of 11 samples were produced, including the center point which was repeated an additional two times. Significance was determined at 95% confidence level (p-value <0.05) and the quadratic model was postulated.

## Results and discussion

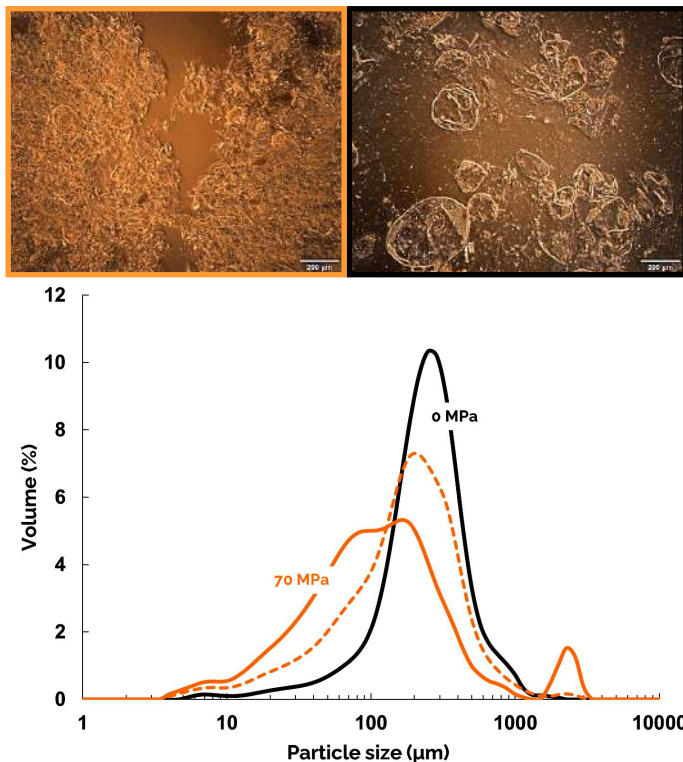
### The effect of pressure on composition



**Figure 1.** The evolution of pulp content with pressure. Different letters indicate significant differences (p<0.05).

The pulp content more than doubled for all samples, with no significant difference discernable between 35 and 70 MPa. The pulp content typically varies with the shape, size and amount of particles in the sample (Espinosa-Muñoz et al., 2013) and the increase in the pulp content with pressure across all samples confirms the effect of pressure on particle morphology and hence the packing or volume occupied by the particles post-centrifugation (Leverrier et al., 2016).

## The effect of pressure on structure

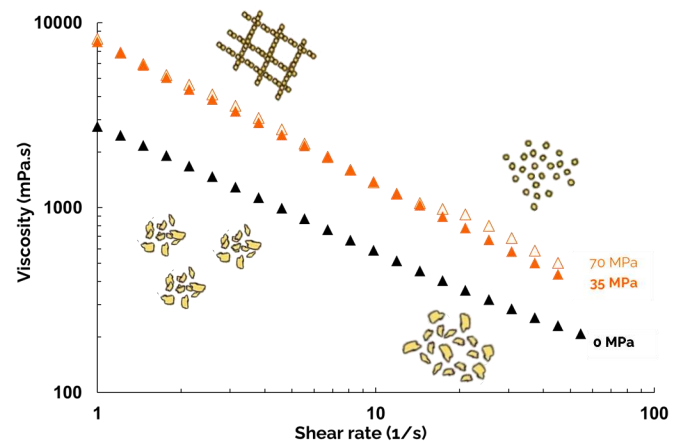


**Figure 2.** The effect of pressure on the particle size distribution (PSD) and microstructure of a 60% puree apricot juice.

The mean particle size of the juice made with 60% puree is halved, decreasing significantly from  $165 \pm 0.52 \mu\text{m}$  at 0 MPa to  $73 \pm 0.91 \mu\text{m}$  at 70 MPa ( $p=0.00$ ). The PSD curves shifted to the left (**Figure 2**), indicating the generation of smaller particles at the expense of mechanically disrupted larger ones. The reduction in  $d(0.1)$  particle diameter was more pronounced between 0 and 35 MPa than between 35 and 70 MPa, which may support the hypothesis related to the asymptotic behavior of HPH caused by the physical limitation of the equipment in providing the higher shear required to disrupt smaller particles (Leite et al., 2014). In the control samples, individual or clusters of large intact cells are discernable, along with some cell fragments. Homogenization breaks cell fragments and releases cell content into the dispersed phase (Salehi, 2020) resulting in smaller cell clusters and a larger number of cell fragments (Augusto, Ibarz, et al., 2012; Day et al., 2010; Lopez-Sanchez, Svelander, et al., 2011).

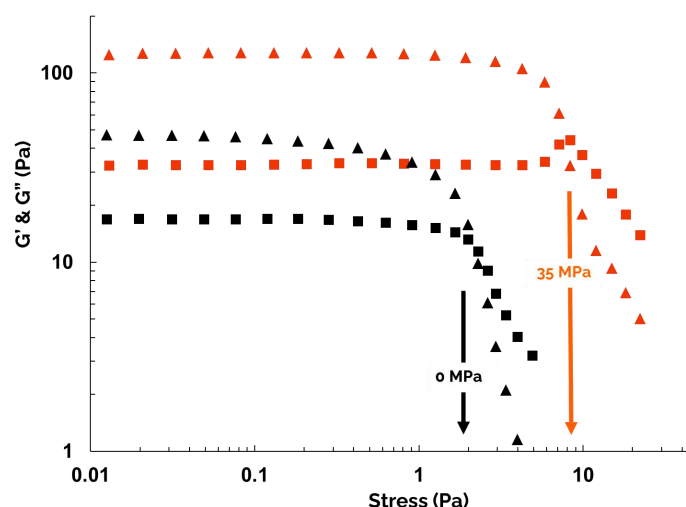
After homogenization, a few smaller individual cells as well as cell ghosts are still visible but the sample mainly consists of a continuum of dispersed ruptured cell wall materials and membranes that are interconnected with some voids in between. Particle aggregation into a network is suggested to be brought by an increased surface area of the suspended particles which is implicated in enhancing particle-particle interactions and driving more pronounced rheological properties like viscosity (P. E. D. Augusto, Ibarz, et al., 2012).

## The effect of pressure on rheology



**Figure 3.** The effect of pressure on the viscosity of a 60% puree apricot juice

Compared to the non-homogenized samples (0 MPa), all the treated apricot juices presented higher viscosities over the entire range of shear rates (**Figure 3**), highlighting the viscosity-enhancing effect of HPH. The apricot juice's flow behavior was well-described using the Ostwald de Waele or power law model ( $R^2 > 0.98$ ), and pressure was demonstrated to improve the consistency ( $K$ ) and reduce the flow-behavior index ( $n$ ). The smaller particles post-HPH mean a larger surface area (for the same volume fraction), a lower mean distance between the particles (Rao, 2010) and consequently higher particle-particle interactions (Yoo & Rao, 1994), which explains the higher viscosities (Augusto et al., 2013).

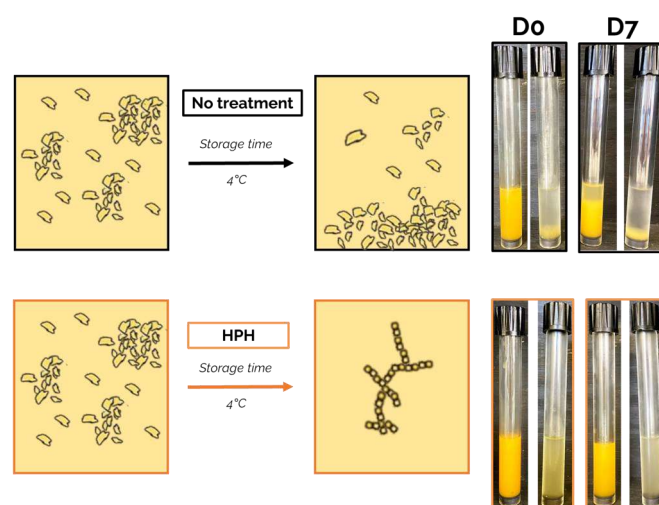


**Figure 4.** Yield stress values for a 60% puree apricot juice at 0 and 35 MPa.

The sample exhibited the typical behavior of a weak gel at constant frequency and at low strain (<10%), with  $G'$  consistently higher than  $G''$ . Applying a 35 MPa pressure led to 183% escalation in  $G'$  for the 60% puree juice, again with a less pronounced increase occurring between 35 and 70 MPa. The increase in the  $G'$  value after a single HPH pass is attributed to enhanced suspended solid interactions induced by particle size reduction (Augusto et al., 2013), and particle shape changes (Dahdouh et al., 2015), whereby irregular broken cells have a higher tendency to build structure in rest conditions (Moelants, Cardinaels, et al., 2013). When the strain is increased,  $G'$  decreases while  $G''$  starts to increase, going beyond a cross-over point where  $G''$  is higher than  $G'$  and the dispersion flows. This yield stress suggests that the sample possesses a network structure that requires a given stress for flow to occur (Moelants et al., 2014), and the values for yield stress increase with pressure (**Figure 4**). The network structure is a result of small particles aggregating, dictated by electrostatic and van der Waals forces at low shear rates (Genovese et al., 2007).

The weak gel structure is not only directly implicated in physical stability, but is also a sought-after juice property because it allows the product to remain pourable.

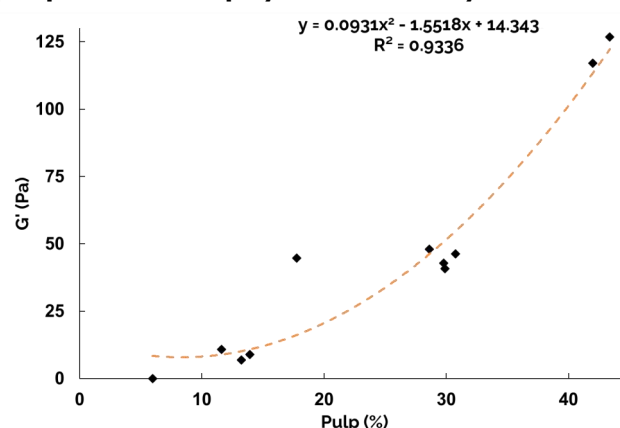
### The effect of pressure on physical stability



**Figure 5.** Schematic representation of pulp particle behavior with time before (top) and after (bottom) HPH treatment.

None of the homogenized samples showed any pulp sedimentation after 7 days of storage at 4°C. This not only confirms the ability of apricot cell wall network structures to withstand sedimentation during storage but also validates HPH as a promising tool in juice stabilization (Kubo et al., 2013; Redgwell et al., 2008), linking its particle size reduction capacity to greater stability.

### The effect of pulp content on rheological properties and physical stability



**Figure 6.**  $G'$  as a function of pulp content

The pulp content represents the interaction of the two factors (pressure and puree content) and is shown to significantly influence the  $G'$ , yield stress, consistency index and viscosity.

It was possible to model those rheological parameters as a quadratic function of the pulp percentage, with  $R^2$  regression values always higher than 0.92 (Figure 6). The elastic modulus, yield stress, viscosity and consistency index increased when the pulp content increased, consistent with the results elaborated so far revolving around network formation post-HPH and its role in driving the rheological behavior. The set of rheological parameters that were modeled is closely linked to product texture and physical stability over time. Higher juice viscosity and viscoelastic moduli brought by smaller particle sizes have been suggested to govern physical stability (Augusto, Falguera, et al., 2012; Salehi, 2020).

## Conclusion

Irrespective of the puree content, the pressure-induced physicochemical and structural changes intensified particle interactions, allowing them to reorganize into a network structure. This structure confers the characteristic weak gel behavior to the juices, which consists of an elevated elastic modulus and a yield stress, essential to ensure physical stability over time. In that way, processing can be considered as a method to control, predict and tailor the texture and stability of plant particle-based matrices (Espinosa et al., 2011). The findings underlined pin down the two fundamental levers for the formulation of innovative clean-label products with a broad spectrum of textures: HPH as a tool to bring desirable structural changes to pulpy juice systems, and plant cell walls as structuring materials (Christiaens et al., 2016). Their versatility could lead to innovative applications.

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## Dynamically predicted shelf-life label in minced meat product: A consumer-driven design & analysis

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### Introduction

Minced meat was considered as one of top ten waste in the supermarkets' meat department in Sweden (Erikson, 2015). For five years, Swedish minced meat contributed to 8.6 tonnes in-store waste, whilst imported minced meat contributed to 2.7 tonnes in-store waste. The facts imply that the solution to curb meat loss and waste is needed, as a pathway towards sustainability development.

Packaging contributes to curb meat waste, as it is designed with 'fit-for-purpose' across the supply chain. It also becomes a communication medium to assist consumers who want to make better-informed choices (European Commission, 2011). However, studies found that the consumers' lack of understanding of the date label caused the unnecessary wasted food. Meat product was discarded in the consumers' hands, and more than 50% of them reasoned because it had passed the printed shelf-life date (Hanssen and Møller, 2013). Therefore, dynamically predicted shelf-life (DPSL) label is developed to give more accurate food shelf-life than printed static shelf-life, thus curbing meat waste can be achieved. Studies related to DPSL label have been established for more than twenty years (Kerry and Butler, 2008; Lydekaityte and Tambo, 2020), nonetheless studies related to the DPSL label and perceptible information obtained by the consumers are scarce.

### Research objectives

According to the problem, this research

aims to identify the critical factors to design a DPSL label for minced meat consumers, as well as to design and assess the label with the consumers. Therefore, two research questions (RQs) are defined:

*RQ 1. What are the critical factors to design a DPSL label in minced meat product for consumers?*

*RQ 2. How do consumers perceive the information from a DPSL label in minced meat product?*

## Methodology

The research used a qualitative approach comprised by three stages, which were insight mining, DPSL label development, and usability test. In the stage 1, the insight mining was conducted by exploring the critical factors from two different perspectives: (1) minced meat consumers, and (2) experts, which are design expert, food safety expert, and supply chain expert. In-depth interviews were conducted online through Zoom software, recorded, and transcribed in a modified verbatim with Office365 transcription and manual editing shortly after. The most insightful quotations were highlighted manually, then the content was then summarised into insights to design the personas according to Cooper et al. (2014) and the critical factors.

In the stage 2, DPSL label designs were developed according to the personas and the critical factors from the stage 1. Three designs were chosen for the first usability test. The label designs were modified according to the consumers' feedback, then three new design prototypes were presented for the second usability test.

In the stage 3, the first usability test simulated first moment of truth (FMOT) and second moment of truth (SMOT) scenarios to the consumers (Stephens, 2016). The second usability test was conducted to assess the response of the participants towards the improvement of the prototype. In-depth follow-up interviews were

conducted at the usability laboratory, recorded, and transcribed in a modified verbatim. Notes were also taken during the usability test to highlight the insights and attitudes from the consumers regarding the labelled packaging. Those insights were compiled about how the consumers perceived the information from a DPSL label in minced meat product.

## Results and discussions

From the interview with consumers and experts in stage 1, three personas were developed, which were autopilot consumer, steadfast consumer, and cautious explorative consumer. The autopilot consumers tended to feel satisfied with the current status quo of the label design, and they did the shopping decision by habitual activities unconsciously. The steadfast consumers showed the tendency to believe in their personal perspective, thus they set an established pattern and is less open to a new change in the label. The cautious explorative consumer showed a deeper interaction to the minced meat label, they invested more time to understand the information provided in the label.

The finding of three personas led to four critical factors, which are (1) sustainability communication; (2) detailed information; (3) size and dimension; and (4) quick decision-making support. The sustainability communication is related to cautious explorative consumers, who are more aware of sustainability issues. Detailed information is related to the steadfast and cautious explorative consumers, who demand for more information to trust the DPSL label. Size and dimension, as well as quick decision-making support are related to autopilot consumers, who demand the label to be not intrusive to their current habits. The three personas and four critical factors were considered in the development of DPSL label design. Later the perceptible information gained by the personas was ex-

explored in the FMOT and SMOT scenarios of the usability test.

In the usability test, the personas perceived the information from a DPSL label in minced meat product by two different approaches, which were sustainability and meat freshness. The sustainability impression is related more to cautious explorative consumers, while the meat freshness is related more to steadfast and autopilot consumers. The sustainability impression was perceived by the 'too good to waste' title and the green-blue border line colour. However, the meat freshness impression was perceived by the 'check the meat freshness here' title and the orange-red-blue border line colour.

Furthermore, the DPSL label size of 7cm x 4 cm was perceived just right and proportional to different sizes of the minced meat package. The circle symbol was perceived as a clear and scientific symbol for the consumers, hence it did not lead to confusion. The explanatory text 'meat freshness changes the colour inside the circle' was perceived short, and it mentioned the two elements, which were the location of the colour, and the change of the colour. These two elements were fundamental and should be kept along the language modification.

The indicator text of 'fresh-still good-spoiled' was perceived short and positive by the consumers. The QR code benefited for the cautious explorative consumers to get an access for more information about the DPSL label. Hence, the final DPSL label designs are depicted below.



Figure 1. Final DPSL label designs

## Conclusion

There are four critical factors identified to answer RQ 1, which are (1) sustainability communication; (2) size and dimension; (3) detailed information; and (4) quick decision-making support. Consumers perceive the information from a DPSL label in minced meat product differently in FMOT and SMOT scenarios. In FMOT scenario, three critical factors which are sustainability communication, size and dimension, and quick decision-making support are more related to the grocery behaviour of the consumers. The DPSL label should be self-explanatory thus the consumers can understand the information within a limited time when shopping. In SMOT scenario, the critical factor of detailed information is more related to the storing, use, and disposal behaviour of the consumers. Therefore, DPSL label should not confuse the consumers by providing appropriate information about the meat freshness, thus they could take a correct action as a response from it.

## Recommendation for company

The consumers perceive the information from a DPSL label in minced meat product by two different approaches, which are sustainability and meat freshness. Different design attributes support each approach separately. Having a sustainability impression may be ineffective if the consumers will not understand how the DPSL label works, due to the unclear message from the DPSL label. Therefore, focusing on the meat freshness impression may be better to introduce a new DPSL technology in the market to the consumers, rather than sustainability.

Furthermore, a DPSL label size of 7cm x 4 cm is recommended to be the size for further design development from this research, and to place the DPSL label on the top left of the minced meat packaging. It is essential to not modify two elements in the explanatory text, which are the location of the colour, and the change of the colour.

One recommended explanatory text from this research is 'the colour inside the circle will change according to the meat freshness'. The indicator text of 'fresh-still good-spoiled' was perceived short by the consumers, and it added a positive impression rather than 'fresh-alright-spoiled' text.

### Recommendation for further research

Further qualitative research with more participants is recommended to be conducted. An on-site grocery and home observation could be conducted to reduce social desirability bias, and the study using eye tracking could be conducted to confirm the consumers' perceptible information gained from this research with quantitative data. Lastly, further study related to the consumer behaviour to discard edible food product that has passed the 'best before' date of minimum durability can be conducted for a better understanding related to this issue.

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## Optimisation of starch functionality through post-fermentation addition during yoghurt manufacturing

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Yoghurt is a nutritionally dense and highly consumed food commodity. Several studies have been made concerning the optimisation of ingredients and the condition of processes involved to produce good quality yoghurt. However, the production process also contains shear, high pressure, and temperature which are known to impact starch functionality negatively. Therefore, it was hypothesised that starch addition separately in the form of a slurry into the yoghurt white mass could allow better starch functionalisation.

In the current study, modified and clean label starch functionality was optimised by studying the impact of starch concentration, homogenisation pressure, pasteurisation temperature, and holding time on the viscosity of the starch slurry. The response surface modelling showed that starch concentration, homogenisation pressure, their interaction and exponential effects had a significant impact on the viscosity of the modified starch slurry, but pasteurisation temperature and holding time did not produce a significant effect. On the other hand, Clean label starch slurry was significantly impacted by starch concentration, homogenisation pressure, their exponential effects and interactions like starch concentration with homogenisation pressure and homogenisation pressure with pasteurisation temperature. This knowledge of slurry characteristics was then implemented in stirred yoghurt production, which allowed a 10% reduction of starch without significant impact on rheology, visible syneresis and sensory characteristics of the stirred yoghurt.

**Confidential Topic**



## Electrical Resistance Oven (ERO): Yeast Performance and Viability during Baking

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The Electrical Resistance Oven (ERO) is a device that works on the principle of ohmic heating to perform proofing and baking of a dough. This technology allows to maintain a gradientless temperature profile across the dough/bread and to exclude the impact of the crust on volume expansion. These characteristics allow a deeper study of the yeast activity in the dough/crumb matrix. In this framework, Yeast Performance Indicators (YPIs) were developed to assess objectively the performance of the seventeen different yeasts during proofing and baking. To complement the analysis, the activity of the yeast was studied by evaluating cell viability and yeast-derived metabolites during baking. The YPIs revealed that some non-breadmaking strains behaved as good as the breadmaking-designed yeasts during both proofing and baking. Strong correlations were detected between proofing YPIs and baking YPIs. This enabled to predict the baking performance of the yeast based on its activity during proofing. The assessment of yeast viability during baking (HPLC and flow cytometry) revealed that yeast is still alive at high temperatures within the baking phase. The results of this study open the door for further research with specific yeast strains.

***Confidential topic***



## Thermal Validation of Alternative Preservation Technologies

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The increase in consumer's awareness of the health benefits and risks associated with food consumption has challenged the food industry to reinvent itself and investigate new processes and ingredients to tailor better products. Nowadays, heat is widely used to increase the shelf-life of products at the expense of its freshness. However, freshness plays a fundamental role in consumer's perception wherein less heat-processed products are perceived to be healthier. Hence, alternatives to traditional heat treatment technologies are gaining more and more space. These technologies take advantage of different heating mechanisms to maintain the sensory and nutritional characteristics of food products at higher levels. However, one of the main challenges when implementing such technologies is their thermal validation to assure that the microbial lethality is achieved, and the product can be considered safe. In this light, the present master's thesis aimed to evaluate the effectiveness of a protocol put in place to validate an alternative preservation technology in comparison to traditional heat treatment.

Three different methodologies were tested using food models that mimic the physicochemical characteristics of real food particles undergoing heat treatment. Results showed a potential application of the established protocol to thermally validate the new preservation technology. The insights obtained during this master's thesis provided one more solid block for paving the journey to successfully implement the alternative preservation technology.

*Confidential topic*



## Packaging and E-commerce:

### *An exploration of needs and potential innovations*

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*Katrin Molina-Besch (Lund University), Jan Wahlberg (Tetra Pak), Nils Toft (Tetra Pak)*



#### **Introduction**

E-commerce has been growing in the past decade. Globally, the value is predicted to rise from \$2.3 trillion in 2017 to \$4.9 trillion in 2021 (Sabanoglu, 2020). Although increase the consumer's convenience, compared to the traditional in-store shopping, E-commerce produces 70-85% more CO<sub>2</sub> emission (Escursell, et.al., 2020). The adverse environmental impacts of E-commerce are mainly due to the extra packaging use and the last-mile delivery service (Manerba, et al., 2018).

#### **Research objectives**

This thesis project was initiated to respond to the emerging trend of E-commerce, along with the potential environmental impacts from its packaging. As a collaboration project between Lund University and Tetra Pak, this thesis project addressed three research questions:

1. What are the factors that trigger specific packaging requisites in E-commerce which are different from the current packaging solutions?
2. How should the packaging for liquid products be designed to fulfil the product, the logistics, and the consumer requirements in E-commerce channels?
3. For Tetra Pak, what should be considered to fulfil the gaps between the current portfolio and the expected packaging requirements in E-commerce?

As delimitations; 1) only three categories of products were evaluated for the product requirements analysis (fruit juices, dairy milk, and plant-based dairy alternatives (PBDA)),

and 2) although the basic packaging requirements in E-commerce summarised in this thesis might potentially be generally applicable, it is worth to note that the information sources were mainly from the European Union (EU), America, and Asia Pacific (APAC), with majority from Sweden and Indonesia.

## Methodology

In order to answer the research questions, literature review and semi-structured interviews were conducted; followed by data analysis using open coding, axial coding, and selective coding.

The sixteen interviewees were divided into three categories; 1) Tetra Pak's employees, 2) E-commerce players, and 3) producer which owns its internal E-commerce. Tetra Pak's employees were interviewed to understand the current state of E-commerce packaging development, the customers' expectations of the packaging performance, and how this research could contribute to the on-going development projects. E-commerce players both from Indonesia and Sweden were interviewed to understand their supply chain models, the challenges within food and beverage products, the current packaging specification, and how packaging could further support their online businesses. Finally, the interviews with a food and beverage manufacturer in Indonesia, which also owns its internal E-commerce, were aimed to understand the supply chain, the challenges, the current packaging specification, and the products differentiation in different channels. The interviewees were also asked how they foresee the possibility of having different packaging types for online and offline channels.

## Results and discussions

From the studies, factors that trigger specific packaging requisites in E-commerce are 1) the higher number of handling and touch points in the online channels compared to brick and mortar (B&M), 2) the package breakdown that could happen in the intermediate point of the supply chain, leaving the products free from

the original transport packaging, thus transported as individual packs, 3) unstandardized packaging configuration during transport (e.g. horizontal, diagonal, etc.).

Currently, most packaging is developed for B&M and therefore might not be strong enough to endure the rough distribution scheme of E-commerce. Nevertheless, these needs are predicted to be only applicable for the pure players with centralised fulfilment centres, not for the E-grocers or omnichannel players with micro-fulfilment centres which have almost similar supply chain with B&M.

Combining the results of the literature reviews and the interviews, the summary of packaging requirements in E-commerce is depicted in Figure 1.

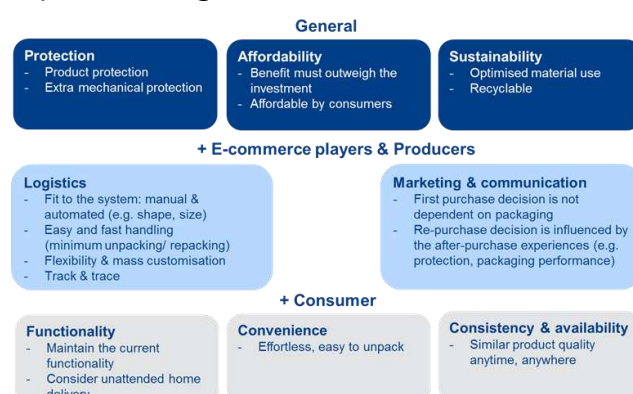


Figure 1. Summary of packaging requirements in E-commerce

Tetra Pak has already had strong building blocks to fulfil the packaging requirements in E-commerce, particularly 1) the brick shape which supports logistics efficiency, 2) the wide range of portfolio that supports both ambient and cold distribution, and 3) the use of sustainable materials. Nevertheless, the protruding features, such as caps, may reduce the mechanical properties of packaging, and thus might be a challenge to survive in E-commerce distribution scheme.

There are several packaging innovation ideas that might be interesting to explore. The first idea is designing sustainable packaging for E-commerce by replacing the aluminium

foil layer and removing the promotional attributes from the packaging. The second idea is to modify the mechanical properties of either primary or secondary packaging to promote packaging survival in the rough distribution scheme. The third idea is to redefine the group packs in E-commerce. For instance, instead of having a bulky box with 24 portion packs inside, it might be interesting to have 4-6 portion packs per box, excluding the needs of unpacking and repacking in the fulfilment centres.

When designing the packaging for E-commerce, it is essential to take into account the system in the E-commerce players as well as the geographical insights. This is due to the fact that different players and different regions might apply different ways of packing and handling goods. The success of defining just the right packaging solution for E-commerce might contribute to the actualisation of the 12th United Nations-Sustainable Development Goal, Responsible Consumption and Production.

## Conclusion

1. The need for more robust packaging is identified in E-commerce, especially in the pure players, due to the higher number of touch points, the early package breakdown, and the unstandardized package configuration throughout the supply chain. However, this need might not be applicable to the omni-channel players which have almost similar supply chains with brick and mortar.
2. The new solution should maintain the product protection feature, while being low cost and sustainable. The package no longer needs the promotional attributes to enhance the first purchase decision, but it may promote the repurchase decision through great after-purchase experiences.
3. Tetra Pak has already had some potential building blocks, including the brick packaging shape, the paper-based packaging materials, the aseptic packaging, the packages for chilled products, as well as the technology of track and trace and digital printing in

its packing solution. For the future innovation, it would be interesting to evaluate the pros and cons of innovating the primary or secondary packages, redefining the concept of group packs, as well as including the geographical insights.

## Recommendations and Future Research

In order to develop an effective packaging solution for E-commerce, there are several recommendations that might be worth to consider. Firstly, since there is no one solution that fits for all, it is important to focus on a potential target market by analysing the consumer's choice of purchasing channels. Offering a breakthrough innovation to a new market area, such as meal subscription model, could also be a point of interest. Secondly, it is also important to consider the geographical insights to understand the drivers of purchase and re-purchase. Thirdly, understanding the needs is mandatory to define the right solution. In this case, the packaging manufacturer shall carefully select what properties shall be kept and which properties must be changed. The decision shall take into account not only the current system in the E-commerce players, but also the future development strategy, especially related to the last-mile logistics.

For further research, more literature reviews, and interviews are highly suggested to capture different needs among actors and project the suitable solution. It is recommended to include more actors in the supply chain, for instance the end consumers, the packaging suppliers, and the transport providers.

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## Study of an integrated fermentation/membrane-based solvent extraction process for the production of 2-phenylethanol

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**Master Thesis tutor:** Dr Marwen MOUSSA



**Introduction:** 2-Phenylethanol (2-PE), a higher aromatic alcohol having a rose-like odour, is the second most industrially used aroma compound (Rodríguez-Romero et al., 2020). 2-PE can be produced by microbial fermentation via the Ehrlich pathway, which uses the amino acid L-phenylalanine (L-phe) as the precursor. This process is considered natural, it is also selective and environmentally friendly (Chreptowicz & Mierzejewska, 2018). This biotechnological process suffers growth inhibition of microorganisms due to 2-PE accumulation in the medium (Etschmann et al., 2005). To overcome this, the use of the *In-Situ* Product Recovery (ISPR) technique of membrane-based liquid-liquid extraction using an organic solvent can be used to extract the 2-PE periodically, before it reaches its limit of inhibition (Qian et al., 2019). This strategy involves the coupling of the fermentation and the extraction system using a membrane contactor, leading to an increase in the efficiency of 2-PE production. However, in this extraction process, the organic solvents used are known to cause toxicity to the microorganisms (Marinova & Yankov, 2009). In the fermentation part, it has been identified that the presence of other nitrogen sources apart from the amino acid precursor leads to competition with the Ehrlich pathway (Etschmann et al., 2005). Taking the above into account, this study focuses on improving the integrated process for 2-PE production and extraction, mainly focusing on membrane-based solvent extraction. The main objectives of the study were as follows:

- To understand the effect of different solvents' toxicity and shear stress caused by the extraction system.
- To improve the fermentation media by

decreasing other sources of nitrogen for increasing the productivity of 2-PE.

- To evaluate the selected conditions for membrane-based solvent extraction coupled to fermentation system.

### Methodology:

**Solvent toxicity studies:** Solvent saturated aqueous phases were prepared using selected solvents, comprising of esters of different chain lengths and a higher alcohol, and brought in contact with the cells. Double staining followed by flow cytometry analysis was performed at set time points to determine the effect of solvents on the cell membrane integrity. To this end, the number of enzymatically active, altered and dead cells was estimated in the population. The ratio of enzymatically active cells in the sample vs control gives the survival ratio. Then, the Excess Mortality Rate (EMR) is calculated by using the following equation:

$$\frac{X}{X^*} = \frac{X_0}{X_0^*} e^{-EMR \cdot t}$$

Where X is the number of enzymatically active cells in the aqueous phase saturated with solvent.

X\* is the number of enzymatically active cells in the control.

X<sub>0</sub> / X<sub>0</sub>\* is the ratio of enzymatically active cells at time t<sub>0</sub> (survival ratio).

t is time and EMR is Excess Mortality Rate which represents the cell mortality due to the experimental setting, in this case, solvent toxicity.

In addition, one solvent was selected to determine the effect of toxicity on younger cells.

**Mechanical stress due to circulation in the membrane contactor:** The cells were brought

in contact with the membrane system at two shear stress conditions, i.e. moderate and high, by setting the fibres inlet pressure at 0.5 bar and 1.5 bar, respectively. The same experiment was repeated in younger cells. Similar to above, flow cytometry analysis was performed at set time points to determine the effect of shear stress.

**Comparison between Yeast Peptone Dextrose Medium (YPD) and ShimFessel mediums in bioreactor conditions:** Two different media were prepared, namely YPD and ShimFessel, using the same amount of L-phe. Bioreactors were set up and flow cytometry analysis was performed to determine the number of cells and High- Performance Liquid Chromatography (HPLC) analysis was performed to calculate 2-PE concentration.

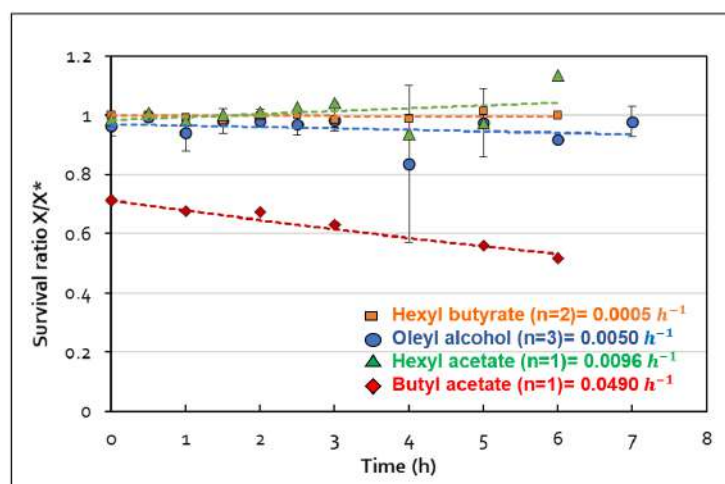
**Comparison of different media formulations to reduce other nitrogen sources besides L-phe and improve productivity:** Seven media compositions were prepared in flasks. Flow cytometry and spectrophotometry were used to determine the number of cells and optical density, these values were correlated with dry mass weight, to calculate biomass. HPLC measurements to calculate 2-PE, glucose and ethanol concentration and Liquid chromatography-mass spectrometry (LC-MS) measurements were performed to obtain L-phe concentration.

### Results and discussion:

**Solvent toxicity studies:** The impact of four preselected solvents namely oleyl alcohol, butyl acetate, hexyl acetate and hexyl butyrate on the physiological state of yeast cells harvested at 14 hours were studied using double staining technique in flow cytometry. From the survival ratio and EMR values in Graph 1, we can see that hexyl butyrate and oleyl alcohol showed very low toxicity and butyl acetate showed high toxicity and the effect of toxicity was seen to increase with time. It is known that younger cells are more

fragile, thus, the effect of solvent toxicity was higher when younger cells were used to study the solvent toxicity with butyl acetate.

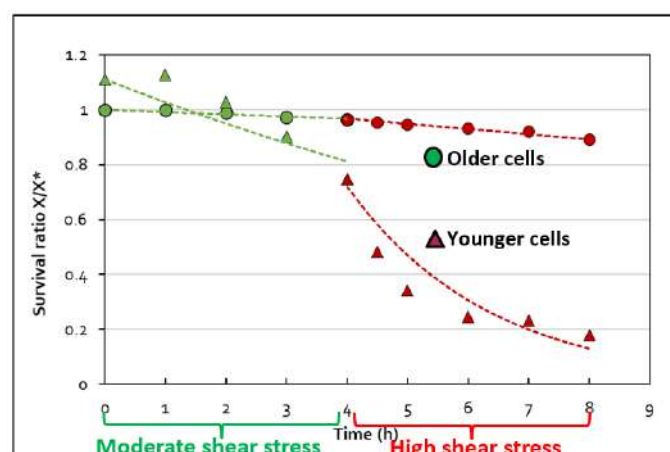
hour for the younger cells and older cells exposed to moderate and high shear stress conditions.  $n = 1$



**Graph 1:** Survival ratio calculated as a function of time for the cells in aqueous phases saturated with solvents (butyl acetate, oleyl alcohol, hexyl acetate, hexyl butyrate). Excess Mortality

Rate is represented in  $h^{-1}$ .  $n$  represents the number of repetitions.

**Mechanical stress due to circulation in the membrane contactor:** From the survival ratio in Graph 2, we can conclude that the membrane-based system leads to a shear stress effect and the effect is higher on younger cells as they are more fragile. Also, increasing the time of circulation lead to intensification of this effect.



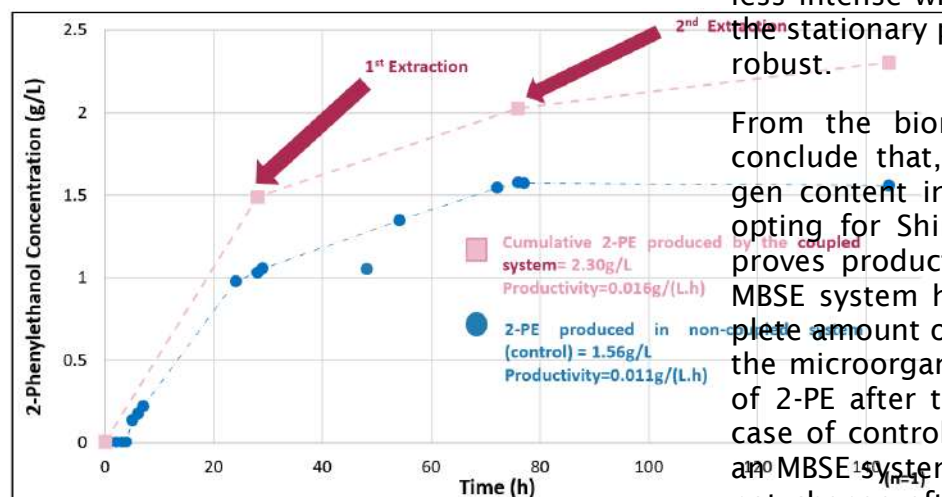
**Graph 2:** The survival ratio calculated at every

Thus, both the organic solvents used for extraction and the circulation in the membrane contactor can cause stress on the microorganism, which might lead to a detrimental effect on the growth of cells and productivity of 2-PE. For younger cells, the effect of these stress factors is more drastic. This information will help us select the right time to start the coupling between the extraction system with the bioreactor.

**Comparison between Yeast Extract Peptone Dextrose (YPD) and ShimFessel mediums in bioreactor conditions:** 2-PE, which is a product of the Ehrlich pathway, predominates only when the main nitrogen sources are represented by the amino acids (Etschmann et al., 2005). Thus, a different medium called ShimFessel, which is a semi-defined medium that has a lower nitrogen content was compared to the classical YPD, a rich fermentation medium. Even though the growth of cells in the two media were quite close, the amount of 2-PE produced was higher in the ShimFessel medium, proving that decreasing the source of nitrogen other than L-phe in the fermentation medium leads to an increase in 2-PE production.

The membrane-based solvent extraction process (MBSE), *in-situ* product removal (ISPR) technique was used to extract this 2-PE from the fermentation medium. Thus, coupling experiments were performed using ShimFessel media and oleyl alcohol as the extracting solvent. Even with the effect of solvent toxicity and shear stress due to the integrated MBSE system, 2-PE production was higher in the coupled system as compared to the control. Also, after one extraction, the cells continue producing 2-PE as 2-PE does not reach its threshold to show an inhibitory effect, thus the cumulative 2-PE produced is much higher than control (Graph 3). Therefore, the ISPR technique not only minimizes

the loss of the product by degradation and evaporation, but also improves the yield of the product (Freeman et. al, 1993).



**Graph 3:** 2-PE concentration in a bioreactor under normal fermentation conditions i.e. non-coupled vs. extractive fermentation (coupled with MBSE). Solvent oleyl alcohol used for extraction in the coupled system. The ---- line is only used to improve visual legibility.

### Comparison of different media formulations to reduce other nitrogen sources and improve productivity:

The experiments helped to conclude that, firstly, yeast extract is essential for 2-PE production, secondly, reduction of ammonium sulphate to half and or reduction of half of the yeast extract seems to form better media formulations, as they lead to improvement in yield and productivity. Plus, decreasing these compounds in the media will result in a decrease in the cost of the final formulation.

**Conclusion:** Solvent toxicity studies suggested that some solvents are more toxic than others like butyl acetate shows high toxicity while hexyl acetate, hexyl butyrate and oleyl alcohol do not. Also, the effect of solvent toxicity increases as the age of the cells decreases, as younger cells are more fragile. In addition, testing the mechanical stress caused by the circulation of the cells in the integrated system suggested that this system causes shear stress on the cells and the intensity of this stress increases

when younger cells are used. Thus, the effect of solvent and mechanical stress caused by the membrane-based extraction system is less intense when cells are older, such as at the stationary phase, when the cells are quite robust.

From the bioreactor experiments, we can conclude that, firstly, decreasing the nitrogen content in the fermentation media, i.e. opting for ShimFessel rather than YPD, improves productivity and yield. Secondly, the MBSE system helps recover almost the complete amount of 2-PE from the bioreactor and the microorganisms continue the production of 2-PE after the extraction. Whereas in the case of control, which is not integrated with an MBSE system, the 2-PE concentration does not change after a certain point, suggesting that the cells cannot produce 2-PE after a point in these conditions. Finally, studying different compositions of fermentation media by adjusting the concentration of ammonium sulphate and yeast extract provides interesting insights like, firstly, some amount of yeast extract is essential for growth and production of 2-PE. Secondly, the fermentation media can be further improved by reducing these two sources of nitrogen which will also lead to overall cost reduction of the media.

In recent years the consumer's demands for more natural food additives has seen an incredible rise. Thus, using these biotechnological processes for sourcing bio-based aroma and flavour compounds is not only innovative but also the need of the hour. These processes are natural, selective, environmentally friendly and also economical. Aided by *in-situ* product recovery techniques, like membrane-based solvent extraction system, to recover aroma compounds like 2-PE and prevent product inhibition while improving yield and productivity of the processes, makes this process a desirable option.

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## Evaluation of the Efficacy of Natural Preservatives Applied in Different Food Matrices: Sauces and Drinks

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In the recent years, the increased awareness of consumers on health and nutrition had rapidly put pressure in the food industry to meet the market demands. Consumers are now adapting into healthier diets and preference to food made with natural ingredients. Therefore, the use of chemical preservatives started to have a negative image leading companies to start developing food products made with natural ingredients for “cleaner” labels. Moreover, with the reduction of salt and sugar, products become more prone to spoilage and contamination, consequently decreasing microbial stability. In low pH products, pathogenic microorganisms are not of major concern but rather spoilage microorganisms, such as yeasts and lactic acid bacteria. In this light, companies started to invest more on research and development of natural preservatives. However, one of the major challenges the industry is now facing is finding the natural preservative that works with their product lines, cost-effective, exhibit similar microbial stability as chemical preservatives, and with minimal sensory impact. In this study, the efficacy of natural preservatives for microbial stability against lactic acid bacteria and/or yeasts applied in different food matrices were explored through challenge tests, in parallel with analytical analysis and sensory evaluation. Results of the study highlighted the importance of understanding that the effectivity of the natural preservatives is greatly influenced by the ingredient variability, nature of the food matrix, presence of other preservatives or compounds, and processing parameters.

*Confidential topic*



## Investigating the influence of moisture and temperature on adhesion and barrier properties in laminates

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### Introduction

Tetra Pak aims to achieve four strategies by the year 2030 - Deliver food safety and the best quality; Lead the sustainability transformation; Integrate and optimize customer operations; Innovate for customer growth. Presently, Tetra Pak has sold more than 190 billion packages in 2019 (Tetra Laval, 2020), out of which carton packages constitute the most and are used for various food and beverage products.

New packaging materials (NPM) are constantly being researched based on customer needs and sustainability.

A wide range of carton packages (mostly aseptic) are offered by Tetra Pak in various shapes and sizes along with consideration of consumer convenience, optimal shelf life and easy opening. Composite aseptic carton packages are constituted of paperboard, aluminium (Al) and plastic layers (Zhang et al., 2014).

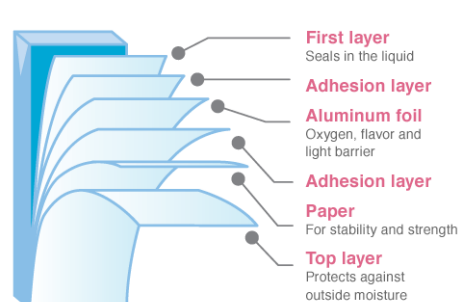


Figure 1: Layer composition of aseptic cartons

The material used in cartons must possess good barrier against oxygen, water and light. In terms of adhesion, the layers must not only be adhered well but also requires it to be easily re-cyclable by separating the layers.

The limitations in the recycling industry to recycle the laminates, especially Al and PE layers, makes it tedious to separate these into elemental components due to strong adhesion between them (Zhang et al., 2014). Even after being separated, there is limited infrastructure and market for a material that contains both Al and PE.

Tetra Pak's ambition is to deliver a package that contributes to low carbon circular economy (Sustainable-packages, n.d). Hence a value proposition was made aiming to improve the recyclability, further increase the renewability, and deliver a lower carbon footprint of the overall beverage carton. In this direction, Tetra Pak is working on new packaging materials which aims to decrease the amount of aluminium and polymer and increase the amount of fibre. Hence, as an alternative, they are looking into metallized surfaces and its adhesion to PE.

### Research objectives

To find out how moisture sensitivity and temperature levels over time affect adhesion mechanisms by performing qualitative & quantitative measurements. Also, to study the influence of moisture and temperature on oxygen transmission rate (OTR) and water vapor transmission rate (WVTR).

### Methodology

The methodology used consists of experimental analysis done on NPM for which three different tests were performed - testing the adhesion between the Al & LDPE layer (Adhesion test), and oxygen transmission rate (OTR) & water vapor transmission rate (WVTR). All the tests were performed on flat packaging material and at different temperature and relative humidity (RH) levels. Five packaging material (PM) variants were also provided for the tests with different coatings and two different blend types were used - blend type A consisting of two dif-

ferent components and blend type B consisting of two layers of the same component.

### Adhesion test

In the test method of NPM, it is important to note that all the measurements must be performed in a laboratory with controlled climate (23°/50% RH). The evaluation was performed in two steps - Quantitative evaluation by peel test using a tensile tester and Qualitative evaluation by visual grading of amount metallization on peel arm after peel test.

For the quantitative evaluation, 180° Peel test was used for NPM and was performed using the tensile tester. The evaluation was performed by grading the samples by visually observing the amount of metallization stuck on the peel arm after the peel test. The grading scale ranges from 0 to 6 indicating different percentages of metallization on the peel arm.

### OTR

For NPM, the samples were conditioned at 23°/50%RH, 23°/80%RH and 35°/80%RH. The samples were cut out depending on the cell size of Ox-Tran instrument used. The samples were placed in the test cell and depending on the parameters set, measurements were taken until the transmission rate had reached the equilibrium. The built-in software calculates the individual OTR results of the measured samples automatically. The environmental conditions along with the number of samples and mean values were also reported.

### WVTR

The test method developed for NPM is called 'Weight loss method' which is based on gravimetric measurement of WVTR through a flat sample like films or packaging materials. The typical chosen conditions are 50°/95%RH. Usually, the test is carried on for one to two weeks depending on the type of the sample.

## Data analysis

To analyze the large amount of data obtained from the tests, statistical analysis was performed. Since the OTR and WVTR tests had lesser samples, analysis was done by plotting suitable graphs using Microsoft excel.

## Results and discussions

### Adhesion test: Individual value plot

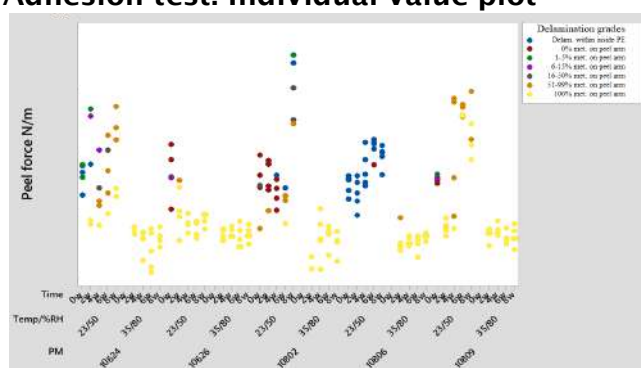


Figure 2: Individual value plot indicating the levels of delamination in the NPM

This plot helped to provide information on the variability of the data. The different coloured dots represent the grades 0-6 for 5 replicates of each PM variant. From the plot it can be seen that grade 6 is the most common grade obtained for the variants especially at 35°/80%. Grade 0 was obtained mostly for the variant PM 10806 at 23°/50%. PM 10802 at 23°/50% had more of grade 1. The rest of the variants had

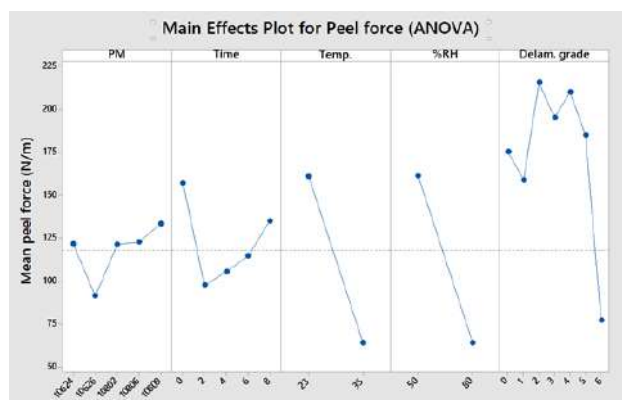


Figure 3: ANOVA showing the main effects of five factors on mean peel force

grades varying between grades 2-5.

Further the data was analysed statistically by performing ANOVA. This plot helped to show the relationship between mean peel force and several other factors.

### OTR

The packaging material must be able to provide an adequate oxygen barrier and must be able to maintain a low oxygen concentration inside the packages. The evaluation showed that the OTR values at 23°/50% and 23°/80% for NPM variants were higher (ranging between 1.5-8 times) when compared to the values of the reference material.

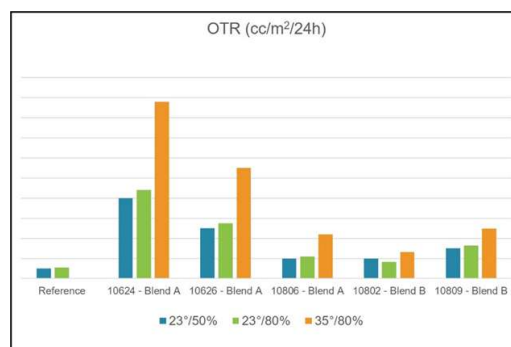


Figure 4: Comparison of OTR values between the 5 variants and reference at different temp./RH

### WVTR

As shown in the figure, the weight loss value obtained for NPM material was 6-8 times higher than the reference value. Lower value refers that the water transmission rate through the material is less which means better moisture protection.

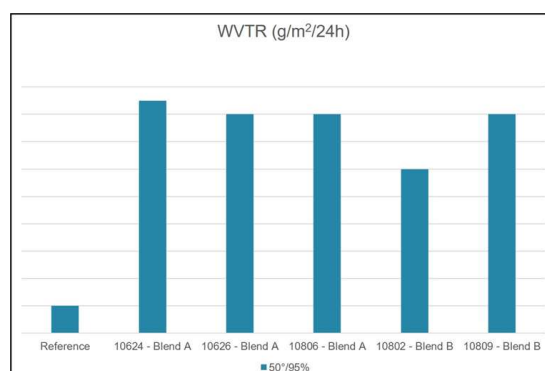


Figure 5: Comparison of WVTR values between 5 variants and reference

## Conclusion

All the three objectives of the research were linked to studying the influence of moisture and temperature on the key parameters of the material. Limited information about the studied phenomena cited therein made it quite difficult to understand certain material properties and the influence of moisture and temperature on them. However, the experimental analysis revealed that the temperature and moisture had an influence on adhesion and barrier properties of the laminates.

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## Banana by-products in Thailand: Exploring its feasibility as bioplastic feedstock for food packaging

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### Introduction

Studies have claimed that carbon dioxide (CO<sub>2</sub>) is one of the greenhouse gases that causes global warming. Plastic, a low cost and high-performance fossil-based polymer, has been used worldwide and is one of the main contributors to greenhouse gas emission.

Many countries have made attempts to initiate the curb of plastic production and consumption. In European and other developed countries, most of the plastic wastes are sorted, recycled, and incinerated for energy recovery (Gironi and Piemonte, 2011; WWF, 2019). While among Asian countries including many developing countries with greater numbers of population and high consumption demand, more than 50% of plastics wastes were mismanaged leading to plastic-related pollution (Geyer et al., 2017). In the context of Thailand, there is also a call to reduce the usage of plastics and to increase the demand for bioplastic as an alternative to fossil-based plastic. The government has launched several policies in cooperation with major business firms to ban single-use plastics and to promote research and development of sustainable innovations (Vassanadumrongdee and Marks, 2020). These protocols can be seen to comply with many of the United Nations (UN) - Sustainable Development Goals (SDGs).

Thailand is also known as an agricultural country; the agricultural sector contributes 9.9% of the country's GDP (FAO, 2021). The country has exported almost 200 billion euros of agricultural goods in 2020 (OPS, 2021). Banana is one of the top five exported fresh fruits of the country with 1.12 million tonnes

produced in 2019. On the downside, banana generates a lot of organic wastes, as only the fruit – which accounts for 12% of the whole plants (Sakharkar, S., 2019), while the rests are discarded. In addition, there are studies related to value addition of the banana by-products including being utilized as a raw material for bioplastic production.

This leads to the approach of this study to understand the value chain and to investigate the operational feasibility of utilizing by-products obtained from banana cultivation as an alternative raw material for bioplastic production in Thailand.

### Research objectives

To be able to analyze the feasibility of utilizing banana by-products in bioplastic industry, the main task is to capture the broad picture of banana cultivation, bioplastic production value chain, and the involved stakeholders. The main purpose of this study is therefore:

*To explore the operational feasibility of utilizing banana cultivation by-products as an alternative raw material in bioplastic production, replacing bio-based feedstock that is otherwise used as food in Thailand.*

To gain a deeper understanding in the topic of interest, the following research questions (RQs) were asked:

1. Who are the stakeholders involved in the banana cultivation value chain and the bioplastic value chain?
2. What are the by-products obtained from banana cultivation and how are they handled?
3. How can the banana by-products be used in the bioplastic industry as an alternative to the current bio-based feedstock?
4. What are the barriers and success factors in using banana by-products to produce bioplastic that can be used as food packaging in Thailand?

### Methodology

The research following the interpretivism philosophy by using an inductive approach, is aimed to report the findings based on knowledge of those who have experienced. The research begins with a purpose instead of a hypothesis. (Dudovskiy, 2018; Mills and Birks, 2014). This exploratory research helps improve understanding of the situations and provides new set of data and insights. The approach started from the secondary research to obtain a general background on bioplastic, banana cultivation, and the situation of both industries in Thailand and global scale. Further steps were aimed to explore more details with the identified stakeholders through qualitative interviews, guided by a semi-structured questionnaire. The information is reviewed, coded, categorized, and analyzed which later developed into a finding of this study (Mills and Birks, 2014). The information that were unable to obtain from the interview was complemented by the study of literatures, reports, and publications.

### Results and discussions

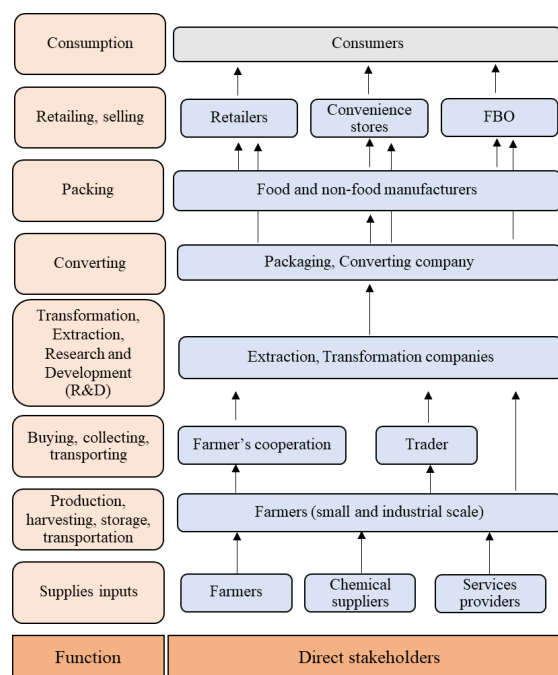


Figure 1. Value chain map illustrating the flow of utilization of banana by-products into bioplastics and food packaging industries

There were eight function stages together with direct stakeholders, supporters, and influencers, identified as shown in Figure 1. After harvesting for the fruits, except for the small portion of banana trunks and leaves from specific strains of banana that goes towards traditional utilization, e.g., food and food wraps, religious activities, and animal feeds, the rest of the wastes were unused and discarded to landfill. The government sector together with other identified players play an important role in supporting and influencing stakeholders in the value chain throughout the idea of using banana by-products for bioplastic industry and initiating an evaluation of its feasibility. There is no evidence that banana by-products have crossed over for utilization in the bioplastic industry, at least, not beyond preliminary research activity. However, the stage of extraction, transformation, and R&D could be a connecting point to link between the value chain of banana cultivation and bioplastic. Moreover, by looking into examples of how other biomass feedstock like cassava and sugarcane have been used, we can have some references of how to potentially introduce banana waste into the bioplastic value chain.

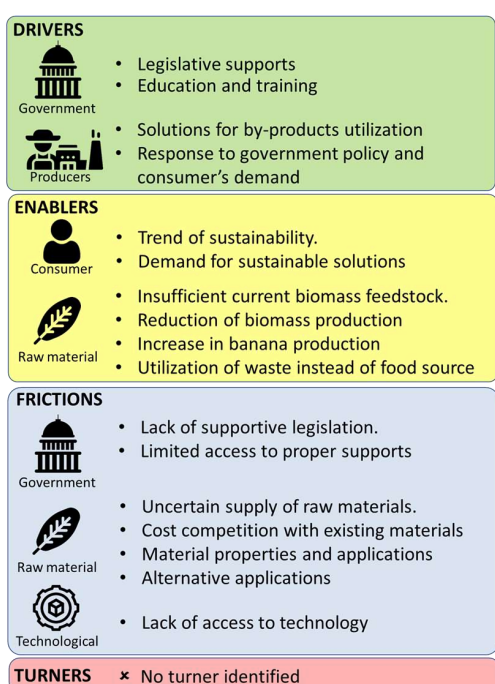


Table 1. Summary of DEFT Analysis

DEFT was used as a tool to analyze the operational feasibility of utilizing banana by-products in Thai bioplastic industry. There are drivers from the government sectors through policies and strategies in supporting the utilization of bio-based and bioplastic products, as well as the upstream sides of producers and manufacturers acting in response to the government's plan and market needs. The drivers receive supports from the two enablers which are the consumer factors from the trend of sustainability and demands for more sustainable solutions. The other enabler is the raw material factor from the mismatch of biomass where the demand is greater than rate of supply, reduction in the main biomass feedstock production, the increase in the cultivation, and conflicts over the food supply chain, which make the banana by-products could potentially be an alternative of interest as it is a waste which could be utilized into something valuable.

On the other hand, there are some obstacles that may negatively affect the feasibility, such as lack of proper support in legislation, education, and training from the government sectors. This makes a big impact on the feasibility of the approach, as the by-product from banana is not currently in the focus of the government. More time is needed for the new legislation to support the utilization of new materials. Other obstacles from the raw material side include insufficient and inconsistent supply of the raw materials and competitions with existing or other bio-based alternatives in terms of cost and limitations from the material properties and applications. Other alternative agricultural wastes like rice straw, corn cob, and applications. Other alternative agricultural wastes like rice straw, corn cob, and sugarcane bagasse seems to be more attractive in the aspect of supply, as well as research and production technology.

## Conclusion

The value chain was mapped following the approach of Saunders et al (2019). The direct and in-direct stakeholders, as well as their relationships were identified. According to the study of the possibility in utilizing by-products obtained by Banana cultivation, most parts of the plant can be used. Where cellulose as a major component found in the by-products could potentially be used as a second-generation feedstock for bioplastic production. With the aim to explore the operational feasibility of the approach, DEFT was used. It revealed that cellulose extracted from banana by-products could potentially be used as a second-generation feedstock. However, considering all the success and barrier factors identified in this study, it is therefore concluded that utilizing banana by-products in Thailand as bioplastic feedstock could be possible but might not likely to happen in the near future.

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## Wheat flour Dry Heat Treatment - (DHT)

### The effect of time-temperature parameters on wheat flour functionalities

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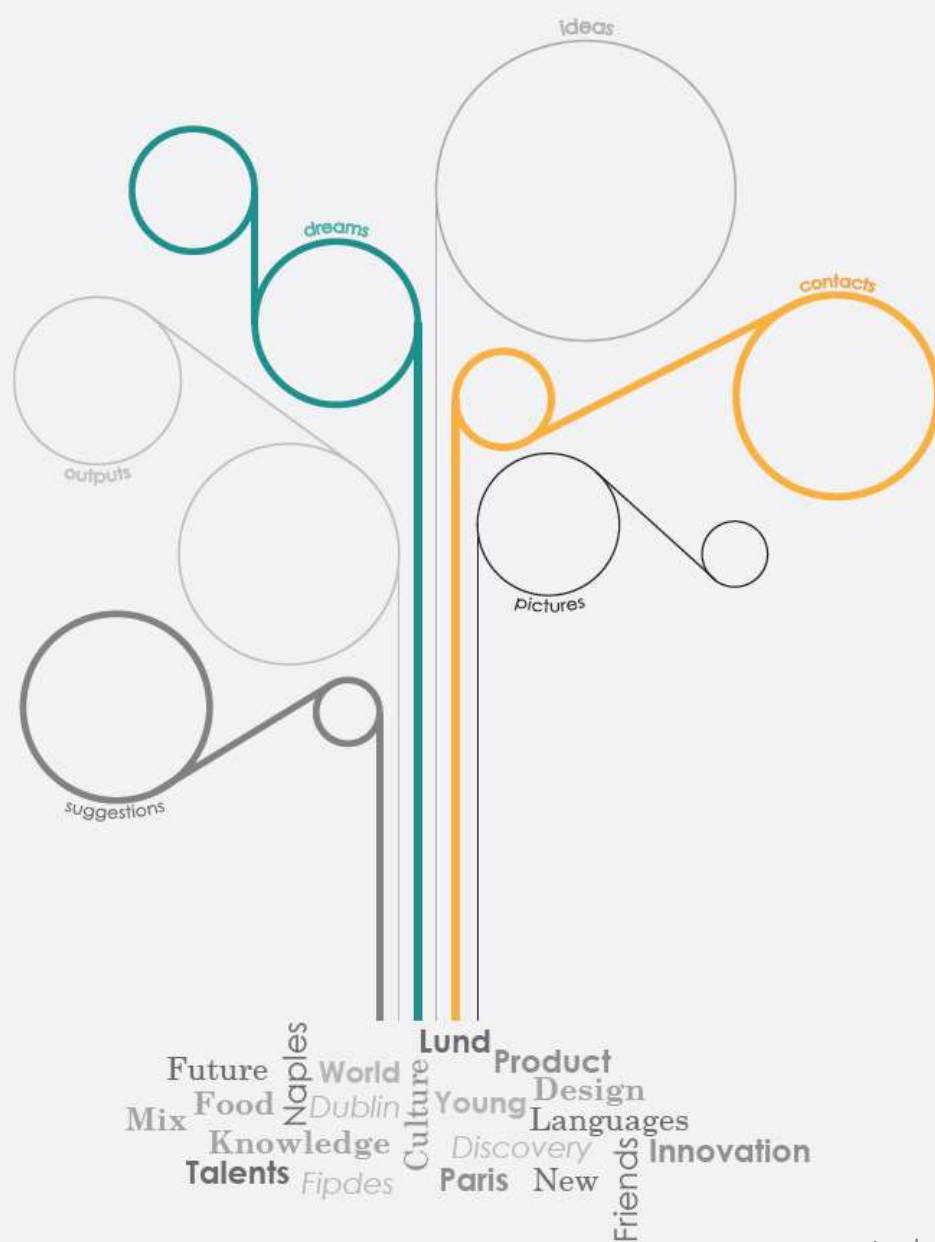
PhD. Stéphanie PASSOT



This study focused on the effect of Dry Heat Treatment (DHT) on wheat flour functionalities. DHT is known to cause a denaturation of the proteins located at the starch granules surface resulting in improved or new flour functionalities for baking applications. In particular, a facilitation of starch gelatinization and a “surface-active” functionality due to the increase in the starch granules hydrophobicity (Pickering effect) were reported. In this project, the temperature and time of the DHT process ranged from 108 to 150 °C and from 10 to 40 min, respectively. A third parameter kept confidential was also explored. The flour functionalities were benchmarked in the case of a high ratio cake (i.e. sponge cake in which the sugar / flour ratio is higher than 1) with a focus on its volume and the collapse of its structure after baking and cooling. The DHT flour was used at 10% and 100% substitution rates in order to evaluate extreme cases. DHT flours have shown enhanced functionalities compared to the standard one that are suitable for a clean label high ratio sponge cake. The recipe and the baking conditions also appeared as important levelers in terms of final quality of the cake. The DHT flour could be used in different food matrices as a clean label functional product, representing great value in the clean label context.

*Confidential topic.*





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