Development of a fibre-rich snack made from baobab fruit pulp

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Schee wars ond ade!

Abstract

This thesis explores the development of a fibre-rich snack using baobab as the primary ingredient. Baobab has gained attention in recent years for its outstanding nutritional composition. The objective of this study was to create a snack that has rheological properties similar to a specified reference product, a nutritional claim regarding its fibre content and has a pleasant flavour.

Different sources of dietary fibre were screened regarding their suitability to use in a Baobab Pudding Snack. After three fibre sources were selected, rheological measurements were performed with a base formulation of the snack to achieve rheological properties that resemble the ones of a chosen reference product. Particle size analysis was carried out to assess the different fibres influence on the particle size distribution of the snack and consequently its mouthfeel. These analyses resulted in choosing a beta-glucan rich oat fibre as additional source of dietary fibre. Consumer perception of two final prototype formulations was evaluated via a hedonic sensory test. Yet no clear preference amongst the two products could be observed.

The nutritional claim “high in fibre” was reached for both final prototype formulations and due to the remarkable intrinsic nutritional values of the baobab fruit pulp also claims for the product to be “high in calcium and iron” can be made.

The utilization of baobab promotes sustainable practices by supporting local economies and offering new snack options with an added nutritional value. The development of the baobab pudding snack holds significant potential in improving the dietary fibre intake which goes along with various health benefits.

Future investigations should focus on scale-up production, shelf-life stability, and consumer acceptance in larger populations to determine its commercial viability.

Popular science summary

Baobab – underutilised superfruit of Africa applied in a snack

In the world of snacks, most products contain a lot of sugar, sometimes lots of fat too but not really any other nutrients. Thinking about how many times a week (or day) people eat snacks and then they are only loaded with sugar… does not sound good, right? That is why, it is time for a new product to come to the snack market in the future!

The Baobab Pudding Snack (BPS) is a spoonable snack with the main ingredient being baobab fruit and as an added benefit, it is high in dietary fibre. So, what are these two ingredients?

In the realm of extraordinary fruits, baobab stands tall as an astonishing wonder from the African savannahs. Revered for its unique shape, remarkable lifespan, and exceptional nutritional value, the baobab fruit has captivated scientists and health enthusiasts alike. The fruit pulp contains impressive amounts of minerals and vitamins yet very little fat or sugar for that matter. Great ingredient for a snack!

To add even more nutritional benefits, different sources of dietary fibre have been tested to combine with the baobab. Locally in Sweden sourced oat fibre was found to be the best match. Dietary fibres are a diverse group of indigestible carbohydrates. They emerge as an unsung hero in the world of nutrition, offering plenty of nutritional benefits from maintaining a healthy digestive system to promoting a flourishing gut microbiome to helping to regulate blood sugar levels.

The combination of these two ingredients was then studied regarding their flow characteristics to ensure that the snack prototype has a pleasant consistency resembling already known products. During the development process, also the particle size distribution was investigated. Measuring the size of the individual particles helps to figure out why certain ingredients might impair or improve the mouthfeel of the final prototype. Lastly, two different recipes of the snack were found to be the best ones from a sensory standpoint and regarding their flow properties. These two samples were tested in a sensory evaluation where participants were asked to rate the snack regarding different characteristics.

The prototype of this snack is now ready for some further improvements in the lab and then an upscale production so it can be with consumers as soon as possible to give them better options in the snack department.

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Abbreviations

LBB	Liquid Baobab Base
AFT	Arwa Food Tech
CCD	Central Composite Design
RDI	Recommended Daily Intake
BPS	Baobab Pudding Snack

1 Introduction

In recent years, there has been an increasing focus on developing healthy and nutritious snacks to address the rising demand for convenient yet wholesome food options. As the world becomes more health-conscious, the importance of dietary fibre in promoting overall well-being cannot be overstated. Fibre plays a crucial role in maintaining digestive health, managing weight, reducing the risk of chronic diseases, and improving satiety, among other benefits. Yet, people in Sweden (and many other parts of the world) do not eat enough fibre according to the recommendations of the national food agency (Livsmedelverket, 2012). Acknowledging the significance of dietary fibre and the need for innovative snack options, this thesis explores the development of a fibre-rich snack utilizing the baobab fruit.

The baobab tree (*Adansonia digitata*) is a imposing tree native to mainland Africa amongst other parts of the world. Its fruit, known as baobab fruit, has gained attention due to its exceptional nutritional profile. It is renowned for its high fibre content, along with a myriad of essential vitamins, minerals, and antioxidants. Baobab fruit pulp was recognised as a novel food by the European Commission (2008) but is not used as a main food ingredient yet. By using the nutritional potential of baobab fruit, the aim is to create a delectable snack that is not only tasty in flavour but also provides a significant amount of the daily dietary fibre intake. The resulting snack product shall represent a dairy free alternative to already known snacks and simultaneously stand for a more sustainable food production of the future (Aschemann-Witzel et al., 2021; European Commission, 2023).

This project intends to outline the development process of the fibre-rich baobab snack, covering various aspects ranging from ingredient selection to product formulation and sensory evaluation. By delving into these areas, the feasibility of incorporating baobab fruit as a key ingredient in snack manufacturing while ensuring palatability, convenience, and optimal nutritional value shall be explored. This research also aims to contribute to the existing body of knowledge on functional food development, highlighting the potential of underutilized and nutritionally rich ingredients in the snack industry. Using baobab as a food ingredient does not only have nutritional benefits, it also helps people in the respective region of origin to possibly create a stable income out of this underutilised fruit (Venter and Witkowski, 2013). By exploring the use of baobab fruit as a natural and sustainable source of fibre, this study not only seeks to address the current demand for healthier snacks but also promotes the utilization of traditional, indigenous ingredients in contemporary food formulations.

2 Aim

The main objective of this project was to develop a spoonable plant-based snack that is rich in fibre and based on Arwa Foodtech's (AFT) Liquid Baobab Base (LBB). Therefore, this project also was aiming at screening different fibres and find the most suitable for the formulation of the final snack prototype.

As specific aims, the developed snack should:

- reach at least the health claim "source of fibre", preferably get the claim "high in fibre"
- be plant-based and contain only such ingredients.
- have a similar texture compared to reference products and based on rheological measurements
- have an acceptable taste
- contain a high amount of baobab fruit (>10% dry basis)
- not contain any E-numbered additives

To reach these goals, first a selection of different fibre to add was made. These are then screened based on their rheological properties in a base formulation. With these results and the reference product, recipes was be set up to match the rheological goals and then the focus will be set the products taste.

3 Background

3.1 Baobab fruit

The baobab tree (*Adansonia digitata*) belongs to the family of Malvaceae and is the most common tree species within the genus Adansonia, the baobabs. It is native to the mainland of Africa, Madagascar as well as Yemen and Oman. The trees grow as solitary individuals and can be recognized by a broad but still tall trunk, with tree heights of up to 25 m (Wickens, 2008). Depending on the location, the bark can vary in colour from reddish brown to various shades of grey (Gebauer et al., 2016). Figure 1 shows a baobab tree in the savannah.

A. digitata is a multi-purpose tree and its use is ranging from providing shelter to clothing and food (Ismail et al., 2019). Traditional use of the tree varies between regions. The pulp of the fruit can be mixed with water to create a type of juice or mixed with milk for a porridge. Qualities to heal diarrhoea and stomach pain are known. The shell can be used for fires. Seeds can also be utilised for medicinal purposes. Furthermore is the bark a valuable product that can be used in medicine, cosmetics and as feed (Lisao et al., 2017).

Figure 1, Baobab tree (Reus, 2006)

The baobab fruit pulp is high in several micronutrients such as iron, calcium, potassium, phosphor and Vitamin C (Rahul et al., 2015). The macronutrient composition mostly consists of carbohydrates and a large amount of fibres. Depending on the origin of the fruit, the nutritional composition can vary. Nonetheless is the fruit pulp a valuable source of many macro- and micronutrients. Table 1 shows the main macro- and micronutrients in the pulp.

Table 1. Nutritional composition baobab pulp (Asogwa et al., 2021)

Nutrients per 100g	
Carbohydrates	78.3 g
Fat	0.7 g
Protein	3.2 g
Fibre	53.9 g
Calcium	370 mg
Magnesium	179 mg
Iron	9 mg
Sodium	31 mg
Vitamin C	163 mg

3.1.1 Dietary fibre in baobab

Dietary fibre is a crucial part of human nutrition. To sustain a healthy gut microbiome, a sufficient fibre intake is critical. Dietary fibre is part of plant-based foods that cannot be digested completely by the human digestive tract (British Nutrtion Foundation, 2023). Chemically, dietary fibre includes non-starch polysaccharides as well as lignin (Jha and Mishra, 2021). It is native to fruits and vegetables in various amounts and especially prevalent in legumes and whole grains. According to the Nordic Nutrition Recommendations, the Recommended Daily Intake (RDI) for adults should be about 30 g (Nordic Council of Ministers, 2014). The actual intake of adults in Sweden is significantly lower with approximately 20 g per day on average (Livsmedelverket, 2012). Dietary fibre helps with maintaining healthy bowel movements, lower cholesterol levels, a stable blood sugar (Jha and Mishra, 2021). A low fibre intake over a longer period of time is inseparably connected to a higher occurrence of inflammatory diseases in the gut (Zhang et al., 2022). Therefore, a sufficient fibre intake is important to maintain a healthy lifestyle.

The part of the baobab fruit with the highest amount of fibre is shell. Yet it holds a very low nutritional value and is therefore not suitable as a food ingredient. The pulp on the other hand contains valuable nutrients and still a high amount of dietary fibre. Baobab has been shown to be of use as a nutritional enhancement in custard powders. Replacing a synthetic mixture of micronutrients in a custard powder mix, baobab is improving not only the nutritional composition with a higher fibre and protein content but also improved rheological properties (Olatoye et al., 2021). Depending on the origin, the composition of dietary fibre in baobab is about 10-20% of insoluble dietary fibre and 20-30% of soluble dietary fibre (Chiacchio et al., 2022; Kaboré, 2011).

3.2 Other sources of dietary fibre

3.2.1 Oat bran

Oat bran is a by-product of various production steps during the processing of oats. While the endosperm can be used for flour and oat flakes for example, the oat bran is an outstanding source of dietary fibre (Cui et al., 2013). The outer layers of an oat grain make up the bran, as depicted in Figure 2.Figure 2, Oat grain (McGorrin, 2019)

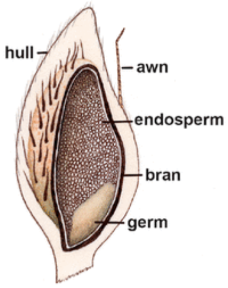

Figure 2, Oat grain (McGorrin, 2019)

Oats are grown in North America, Russia, Central and Northern Europe. They also grow abundantly in Sweden, with a yearly production of about 7,000,000 tons (Statista, 2023). It can be generally used to add dietary fibre to meals like granolas, smoothies or baked goods but can also act as a binder due to its water holding capacity. The fibre content of oat bran is about 15-20 %, depending on the variety and place where it has been grown. About 13-15% of the fibre is insoluble dietary fibre while the rest consists of soluble dietary fibre. In oat bran, soluble dietary fibre occurs mainly in the form of beta-glucans which make up about 3-5 % of the total weight (Duţă et al., 2018; Vitaglione et al., 2008). This source of fibre has been chosen to be used in this project because it can be locally sourced and has a natural beta glucan content while PromOat has a higher but fortified one.

3.2.2 PromOat

This product is different from conventional oat bran because it has a higher concentration in beta-glucans with about 34 % (Lantmännen Functional Foods, 2021). Beta-glucans are a group of high-molecular β-D-Glucose-polysaccharides that occur in cell walls of different plants and fungi. Especially beta glucans sourced from oats are associated with properties to lower blood cholesterol and therefore a reduced risk for cardiovascular disease (Gunness et al., 2017; Ho et al., 2016) .

Beta glucans can increase the viscosity of chyme and thereby slow down the resorption of nutrients into the blood cycle. Consuming products high in beta glucans results in a reduced spike in blood sugar after a meal and a lower insulin release. That reduces the risk for type 2 diabetes and other non-communicable diseases like a stroke or a heart attack. Soluble dietary fibre like beta glucans get fermented by the intestinal flora into short chain carboxylic acids like acetate, butyrate, and propionate. Consequently the pH is lower by the acidic components and that hinders a bacterial overgrowth of pathogenic germs (Kasper and Burghardt, 2021; Mäkelä et al., 2020)

3.2.3 Potato fibre

During the production of potato starch, a by-product is derived. After washing out all starch of the potatoes, the pulp remains. This pulp is high in fibre with amounts up to 60-70%. Therefore, it is known as potato fibre. A gluten-free alternative that can be used in baking or breading of foods. It has a high water-holding capacity and can consequently be used to form highly viscous dispersions (Ramasamy et al., 2015). Like oats, potatoes are locally grown in the south of Sweden.

3.3 High dietary fibre desserts

This fairly new range of products is still in its early stages of being established in the market. Most of the few existing products are dairy-based and not plant-based. Adamczyk et al. (2023) have tested to use buckwheat fibre instead of corn starch to make kissel, a fruit dessert of Russian origin. It was found that adding buckwheat fibre to the dessert increased the viscosity yet did not have a significant impact on the flavour. About 0,5% of added buckwheat fibre gave the best results. Due to the added nutritional value, the supplementation with dietary fibre from buckwheat in starch desserts is recommended.

Gurditta et al. (2019) used oat and wheat fibres, microcrystalline cellulose and inulin in various concentrations (5-10%) in Chhana-murki, a traditional Indian dessert based on a type of cottage cheese. Oat and wheat fibre had a vast impact on colour and texture as well as the overall perception being not as good as the reference product without any fibres. Sensory wise, microcrystalline cellulose gave the best results when 7,5% were added to the recipe. The higher the amount of added fibre was, the more did the viscosity of the dessert increase.

Ares et al. (2009) have shown that adding a small amount of high-amylose maize starch, a source of resistant starches, to milk pudding does not change the sensory perception too much yet still bring nutritional benefits with them. Here, up to 1,4% could be added without major changes in the consumer perception.

3.4 Methods for characterising high dietary fibre desserts

3.4.1 Rheology

Rheology is the science that deals with flow and deformation of matter. It studies the way in which materials respond to applied stress (Steffe, 1996). Rheology plays a vital role in this study because the flow of a food product vastly influences the consumers perception and acceptance.

To measure flow properties, the deformation of a sample is determined as a function of a force or load applied to it. A simple model for illustrating rheological measured variables and for describing shear tests is the two-plate model in Figure 3. Here, an upper plate with area A is moved by a tangential force F. The lower plate is stationary. Between them is the substance to be tested, for example the Baobab Pudding Snack (BPS). The force applied on a sample and the resulting deformation provide insights into the flow behaviour of the substance (Mezger, 2016).

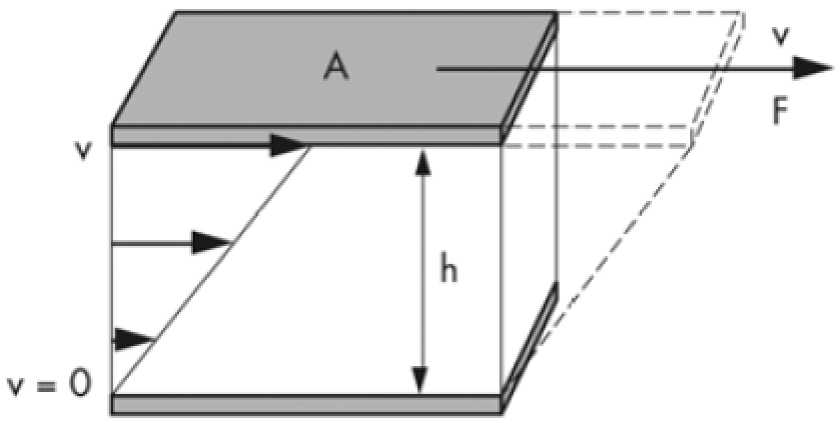

Figure 3, Two plate model (Mezger, 2016)

The ratio of force to liquid surface necessary for the flow of a liquid is called shear stress τ in Pa. If a liquid flows at a certain shear stress though a gap, a velocity drop in the laminar layer between the two plates will occur. The expression of this velocity drop is different, depending on the type of product. This is also called shear rate $\dot{\gamma}$ (Schramm, 2004). The ratio of shear stress to shear rate is proportional for Newtonian fluids, such as water for example. The proportionality factor is called viscosity η in Pa·s. Non-Newtonian fluids however do not have a linear relationship between shear stress and shear rate. This is oftentimes the case for complex food matrixes.

Emulsions such as BPS have a multidimensional rheological behaviour, as they have a non-Newtonian character and at the same time viscous as well as elastic properties. The rheological behaviour of foods is important to be studied as it has an effect on the storage stability, tendency to syneresis, texture or mouthfeel and consistency, pouring and pumping behaviour of the emulsion (Bylund and Bake, 2012).

To record a flow curve and thus be able to make statements regarding the viscous behaviour of the sample, the shear rate is specified as a linearly increasing ramp in a rotation test with a rheometer. The measurement must be carried out under constant temperature conditions, as friction between the individual particles in the sample can occur during the measurement and lead to an increase in temperature (Schramm, 2004). In the evaluation, special attention is paid to shear rates of 10-100 1/s for food, as this range reflects the chewing and swallowing process (Mezger, 2016).

Fibre-rich snacks/desserts are not common to find on the market yet. Addition of fibre is a practice done in the dairy industry quite frequently though, to improve stability and texture. Mostly soluble fibres are used here since insoluble fibres can give a gritty mouthfeel (Canada, H. D. Goff, University of Guelph, 2013).

Inulin has been used tested for application in custard desserts as a prebiotic dietary fibre. Here, the samples showed shear-thinning behaviour and concentrations of 7.5% added inulin were investigated. Long-chain inulin gave high shear stress results, especially after a storage period of 7 days while short-chain inulin had consistently lower shear stress results (Tárrega et al., 2011).

3.4.2 Particle size

Particle size plays a vital role in how a product will be perceived texturally. The human palate is able to detect particles from 25 µm on so therefore a product is only perceived as completely smooth if all particles are below this threshold. If a product only contains a small percentage of lager particles, grittiness can be noticed (Engelen et al., 2005a). This also applies to even smaller amounts of lager particles if they are irregularly shaped. When a product is fully made up from particles with a larger size, it can still be perceived as one mass, that is not necessarily smooth but uniform. When larger particles then get added to such a food product, they most likely stand out and are rather easily detected by the human palate (Engelen et al., 2005b).

3.4.3 Sensory evaluation

Sensory is the description, measuring and evaluation of characteristics of a food product that can be recognized with the human senses. These are used here like a measuring instrument to evaluate the sensorially detectable properties subjectively as well as objectively (DLG, 2023). Evaluations in this field might not be in the focus of the development of a product from the beginning but they should not be underestimated since people's perception of a (new) food product is one of the main factors of its success.

A hedonic test is usually carried out with untrained participants and it gives information on how well the tested products are liked by the panel or if the panel prefers a product over another one (Lawless, 2010). To determine which product people prefer out of two or more samples, a hedonic test can be used. One of the most common and used methods to let participants rank a product is a 9-point scale. Hereby 1 stands for “dislike extremely”, 5 stands for “neither like nor dislike” and 9 represents “like extremely”. In that way participants can rank their liking of a product and with the neutral centre of the scale are not forced to choose either side (DLG, 2023).

Gurditta et al. (2019) found that applying different fibre to a cottage cheese type dessert had major influence on the sensory perception of the product. In this study three different fibres were tested in a 9-point hedonic scale test and microcrystalline cellulose gave the best results in texture and overall acceptability over oat and wheat fibre. Yet it was determined that 7,5% added fibre, gave better results than adding 5% or 10%.

3.5 Nutritional claims for dietary fibre

Following a healthy diet can reduce the risk of getting a non-communicable disease like for example cardiovascular disease or diabetes dramatically and thus provide a longer and healthy life. Since this is something consumers pay attention to more and more, the food industry targets that by claiming certain properties for their products. These so-called health claims are all regulated by the Health Claims Regulation (1924/2006) of the European Union. Here, health claims are defined as a statement or indication about nutritional or caloric benefits of a product. Also any statement regarding a connection between health and food is defined as a health claim (European Parliament and European Comission, 2006).

Regarding dietary fibre, two different claims can be achieved. The first one is “source of fibre” which entails a fibre content of at least 3 g of fibre per 100 g of product or at least 1,5 g of fibre per 100 kcal (European Parliament and European Comission, 2006). The other claim is “high in fibre” and a product can claim that if it contains at least 6 g of fibre per 100 g of product or at least 3 g of fibre per 100 kcal respectively (European Parliament and European Comission, 2006).

4 Material and Methods

4.1 Raw Material

Raw baobab fruit pulp (Figure 4) from Sudan was the base for all experiments. Rapeseed oil (ICA, Sweden) was used to create an emulsion system. Fruit juice concentrates in different flavour varieties (Kiviks Musteri AB, Sweden) act as flavouring agents. Fibres that are evaluated in this study include oat bran (Lantmännen, Sweden), PromOat (Lantmännen, Sweden) and potato fibre (Semper, Sweden). The chosen reference products were Turkish yogurt (Skånemejerier, Sweden) and Turkish yogurt (Salakis, Croatia). Furthermore considered as possible refernce products but excluded in the end were Greek yogurt (Salakis, Sweden) and Greek yogurt (Fontana, Greece).

Figure 4, Baobab fruit pulp

4.2 Sample Preparation

In this chapter, not all relevant parameters can be stated mentioned due to AFT's intellectual property strategy and trade secrets. Therefore, some of the process parameters had to be removed.

The first step in the sample preparation process is to produce Liquid Baobab Base (LBB). This is done according to an internal standard operating procedure from AFT.

The Baobab Pudding Snack (BPS) was produced by emulsifying rapeseed oil with the desired amount of LBB by using Bamix Gastro 350 Pro (Bamix, Switzerland) with the whisk blade attachment at a speed of 22000 rpm for about 1 min. The fibre of choice was then added and shortly mixed in before the juice concentrate and plant drink were added along with salt, a sweetening agent and perhaps cacao. This process is illustrated in Figure 5.

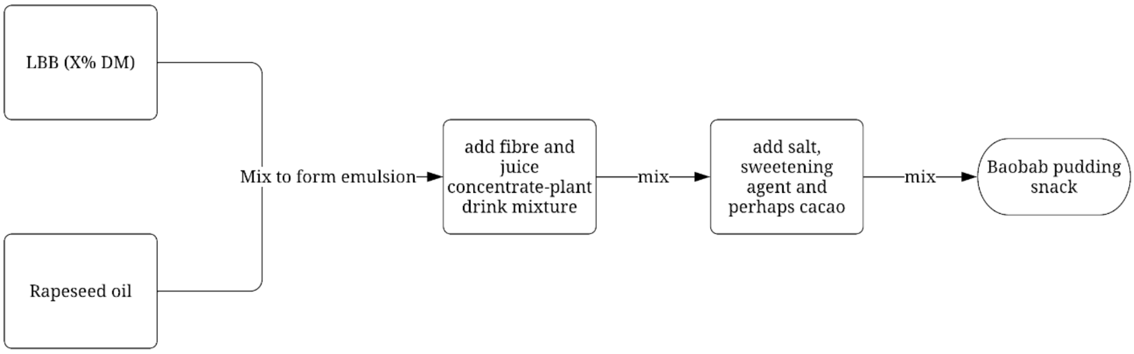

Figure 5, Sample preparation process

4.3 Fibre selection

A literature review was conducted to see what type of fibres could be fitting for a screening in the BPS. Criteria for choosing the sources of fibre for the experiment were a local (Swedish) source of fibre to have a climate friendly option and also possibly a by-product of some other food production to in terms of a circular economy. Furthermore, functional properties like water holding capacity have been considered. Also, only plant-based options were considered as a general guideline of AFT.

Consequently, two different locally produced oat fibres were chosen. First, oat bran from Lantmännen. Secondly an oat fibre that is rich in beta-glucans with a content of those of 34%, also from Lantmännen and known under the trade name of "PromOat". And lastly a potato fibre from Semper which is a by-product of the production of potato starch.

Since the oat bran and the potato fibre were rather coarse in their particle size (65% >1200 µm particle size for the oat bran and 50% > 1000 µm for the potato fibre), they were milled to a particle size of 500 µm with a Perten Laboratory Mill 3100 (PertenElmer Inc., USA). The PromOat had a satisfactory particle size and therefore could be used immediately. This is a modified version of the method Li Niu et al. (2023) used.

4.4 Experimental design

For the Central Composite Design (CCD), independent factors had to be chosen. These were determined to be the content of LBB at a dry matter of DM=X% and the amount of the respective fibre. This design of experiments was chosen since it is an effective tool to screen a wide range of combinations in formulation in a defined region with a relatively small number of samples. Extreme values for the independent factors had to be established first to set up the CCD. A total of 14 formulations for each of the three used fibres were produced.

4.4.1 Defining the CCD

To establish the extreme values of the CCD, a base recipe derived from a former project in AFT was used. This base recipe is shown in Table 2.

Table 2, Formulation of base recipe

Ingredient	Amount (in %)
LBB	67
Rapeseed oil	2
Wheat bran	3
Juice concentrate diluted with water	28

With this recipe (Table 2), trials were conducted to find the extreme values of the independent factors. Additionally, the final fibre content of the snack was considered to achieve a nutritional claim of “source of fibre” respectively “high in fibre”, according to the regulation on nutrition and health claims made on foods by the European Parliament and European Comission (2006). The extreme values are displayed in Table 3. Initial sensory evaluations validated that the texture and sensory attributes within these values are still acceptable to work with.

Table 3, Extreme values of the CCD

Factor	Extreme values (interval in %)
LBB (DM=X%)	65-85
Fibre	0-4

Based on these extreme values, the CCD was then set up with the program Minitab (version 21.1). Table 4 shows the results of this. The standard order (StdOrder) indicates that samples 1-4 represent the cube corners, 9-11 are the extreme values and 5-7 as well as 12-14 represent the centre points of the CCD. The suggested RunOrder was used during the experiments to avoid bias in the results.

Table 4, Result of CCD, number of independent variables added to samples.

StdOrder	RunOrder	Fibre (%)	LBB (%)
14	1	2.00	75.00
9	2	4.00	75.00
12	3	2.00	75.00
13	4	2.00	75.00
8	5	0.00	75.00
10	6	2.00	65.00
11	7	2.00	85.00
5	8	2.00	75.00
3	9	0.59	82.07
2	10	3.41	67.93
7	11	2.00	75.00
4	12	3.41	82.07
6	13	2.00	75.00
1	14	0.59	67.93

To compile these recipes, the amount of fibre source and LBB shown in Table 4 were added, resulting in 67-87% of the total amount of the BPS sample. Then 2% of oil were added to create an emulsion and acceptable mouthfeel. The remaining 11-31% of the total amount of the BPS sample have then been filled with the pear-juice concentrate.

4.5 Rheology

The rheological measurements were carried out on the Rheologica Viscometer with the software RheoExplorer (Version 5.0.40.38). The geometry used is a cylindrical bop with a diameter of 25 mm and the corresponding cup. To calibrate the equipment, a zero-gap measurement was carried out before every sample. Roughly 15 g of sample are used per measurement. Each sample was first loaded in the cup before the bop is lowered into that. The order the samples were run in, is determined by the CCD as shown in Table 4.

Firstly, different products from the market were evaluated for their rheological properties to set a standard for the BPS. Turkish/Greek yogurt was used for this reference and four samples were selected. The rheology test and therefore the recording of a flow curve was chosen to characterize the viscosity of the different samples. As a measurement profile, a rotation ramp with a shear rate from 0.1 to 100 1/s was set. Each sample was measured in three replicates. This is a modified method after Balaghi and Senge (2014).

4.6 Particle size distribution

The particle size was measured to determine if the added fibres are above a detectable threshold for the human palette, which is 25 µm. The Mastersizer 2000 (Malvern Pananalytical, United Kingdom) with the Hydro SM attachment unit for wet sample dispersions and the Mastersizer 2000 software (version 5.6) was used for this analysis. The method used here is an adapted one by Balaghi and Senge (2014). The measurement setting "Rapeseed oil – 0.01" with a particle refractive index of 1.473, a particle absorption index of 0.01 and an obscuration of about 10 % was chosen after testing the suitability of different settings. The sample measurement time was 12 s with 12 000 measurement snaps. Every sample was measured in 3 cycles with a delay of 1 s and then three replicates of each sample were taken. In between different samples, a background measurement was performed to ensure equal initial conditions for all samples.

4.7 Stability

To ensure basic physical stability of the final product, a stability test using centrifugation was performed, as described by Li et al. (2023) with slight modifications. A 5804 R Centrifuge (Eppendorf, Germany) was used at 10 °C to mimic fridge conditions. 10 g per sample was placed in centrifuge tubes and then run for 30 min with a speed of 5000 rpm. The emulsion stability ratio can be determined by calculating the ratio between the height of the stable layer (pellet) and the overall height of the entire sample. This method was carried out in three replicates per sample.

4.8 Sensory evaluation (hedonic)

The final formulation was prepared in two different flavour profiles. These cannot be fully disclosed in this project due to AFT's intellectual property strategy and trade secrets. The main difference was that one was prepared with the addition of cacao powder to give the BPS another flavour profile. The prepared samples were then presented to 22 participants to evaluate. The results were then analysed statistically to evaluate if there are conceivable differences between the products. This sensory evaluation is an adaptation of the method described in Beraldo et al. (2023).

The samples were handed out in randomised order to the participants. To mimic the conditions the product shall be consumed in, once on the market, the samples were served at 8°C. As palate cleansers, white, crustless bread and water were provided. The evaluation form for the sensory evaluation can be found in the Appendix.

4.9 Statistics

To create the CCD "MiniTab statistical software" (version 21.1, San Diego, USA) was used. Calculation of the response surface regression and creation of contour plots was also conducted with MiniTab. To test the normality via the Kolmogorov-Smirnov test was performed in GraphPad Prism (version 9.5.1, State College, PA, USA) as well as t-tests. The heat maps are also created in GraphPad Prism. Furthermore, Microsoft Excel (version 2302, Redmond, USA) was used to collect raw data, create the remaining graphs and plots.

5 Methodological overview

The product development process in this project was very interconnected so every step was highly dependent on the previous ones. All steps were aiming to bring the existing base from the beginning to a fibre-rich yet tasty prototype in the end. Figure 6 depicts an overview of this process.

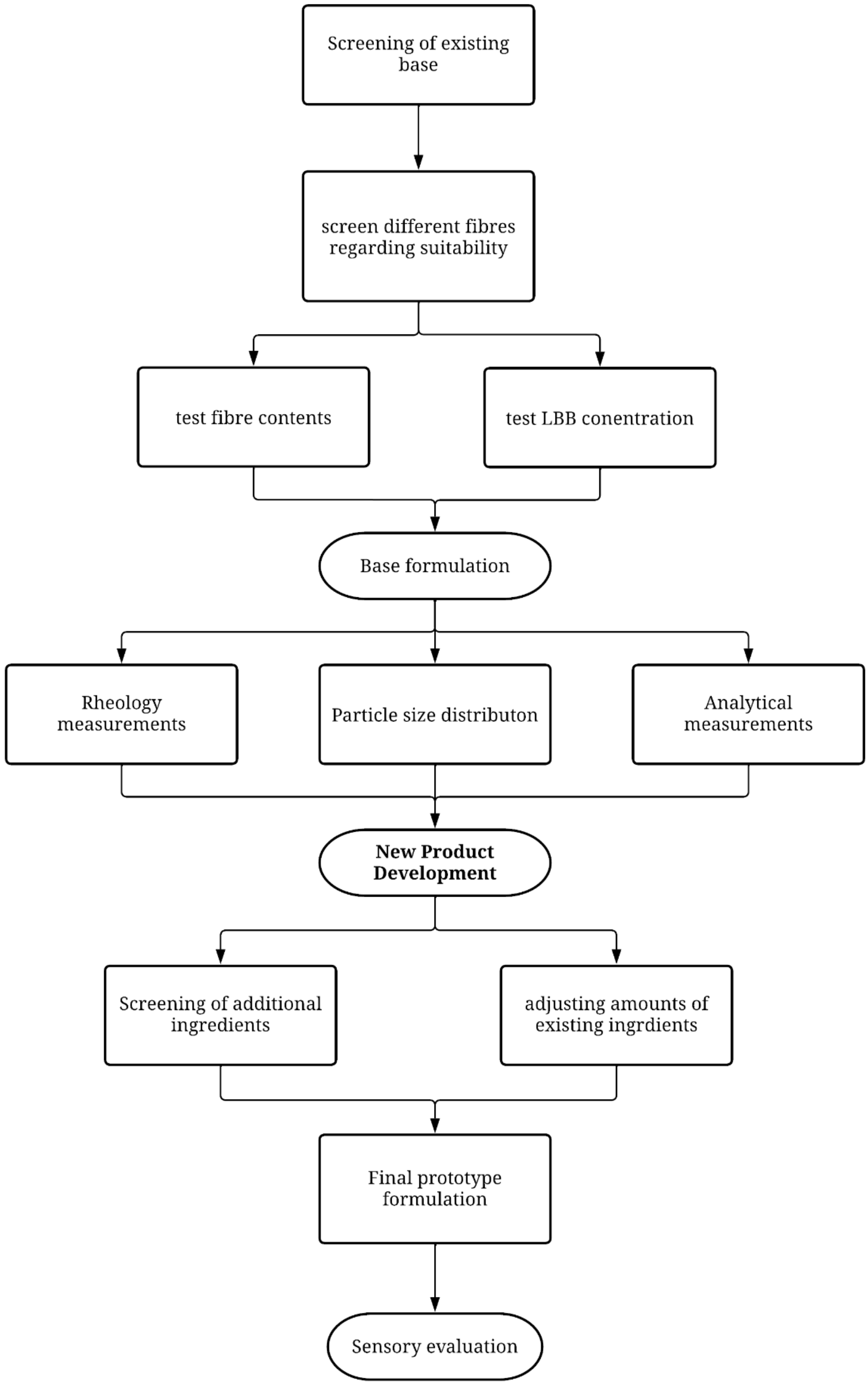

Figure 6, Flow chart of product development procedure

6 Results

6.1 Rheology

6.1.1 Defining a reference

The rheological properties of the selected references are displayed in Figure 7. To compare the samples, the shear stress is selected at a shear rate of 50 1/s.

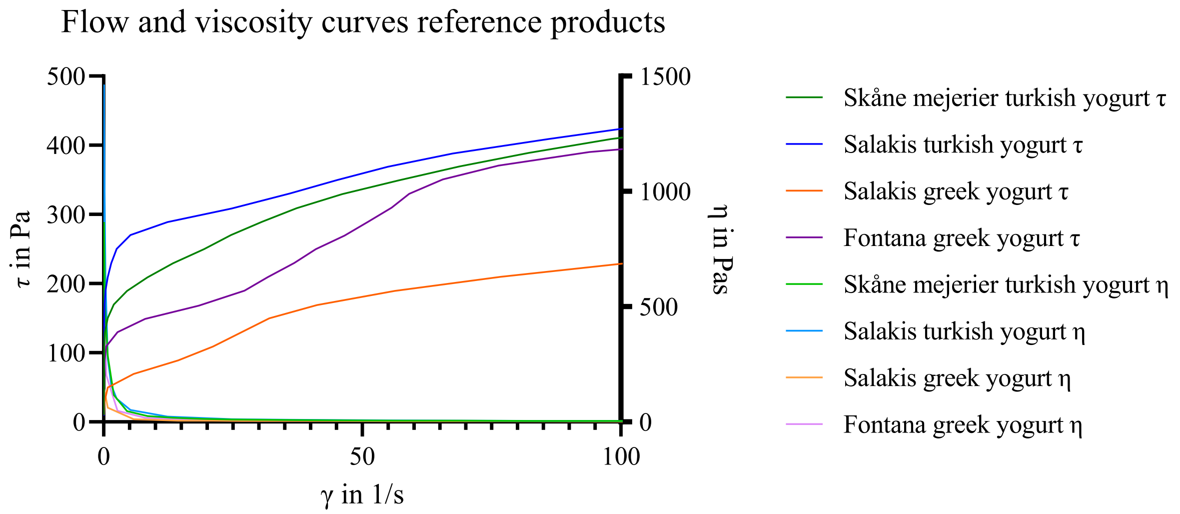

Figure 7, Flow and viscosity curves of reference products

Table 5 shows the shear stress and viscosity of the market reference products at the shear rate of 50 1/s. In both, Figure 7 and Table 5 it becomes clear that the varieties of Turkish yogurt do have a higher significantly higher shear stress than the Greek ones. Due to that and them being close in range with one another, they have been chosen to be the reference for the development of the BPS.

Table 5, Flow and viscosity curves of market products (n=3)

Product	**Shear stress in Pa at a shear rate of 50 1/s**	**Viscosity in Pas at a shear rate of 50 1/s**
Skåne mejerier Turkish yogurt	345 ± 4.5	6.4 ± 0.1
Salakis Turkish yogurt	358 ± 0.5	7.1 ± 0.2
Salakis Greek yogurt	182 ± 2.6	3.7 ± 0.1
Fontana Greek yogurt	289 ± 3.8	5.6 ± 0.4

6.1.2 Rheology measurements

First a flow curve for LBB was established to gain a better understanding for the range of the CCD. LBB has a quite high shear stress at the comparing shear rate point of 50 1/s with a measured value of 690 Pa. Figure 8 shows the curve for LBB.

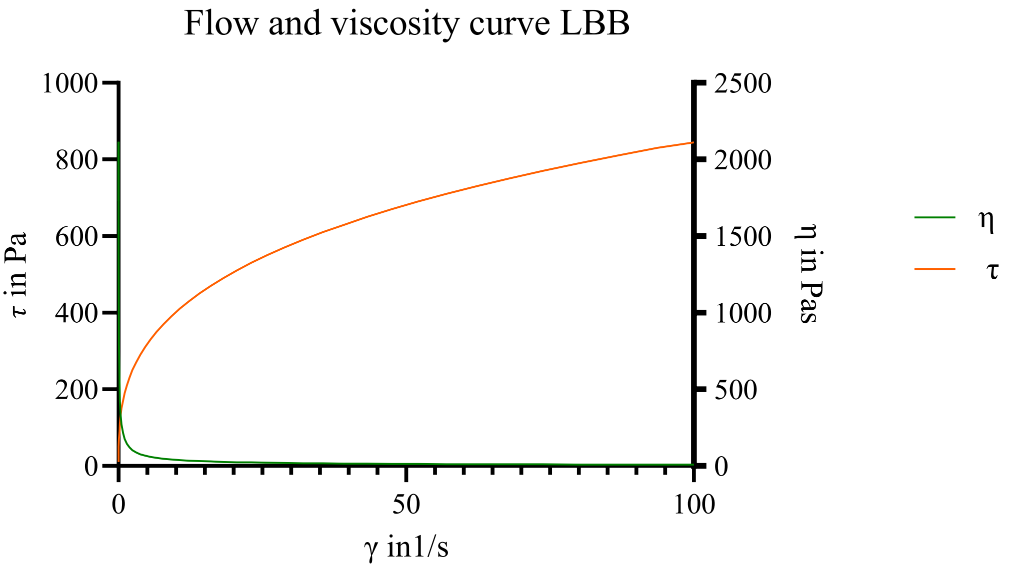

Figure 8, Flow and viscosity curve of LBB

To find a suitable recipe from the 14 options of the CCD, all have been evaluated for the three fibre sources. Contour plots were created for the respective fibre sources to assess which fibre content corresponds to which amount of LBB to achieve the goal shear stress of about 350 Pa at a shear rate of 50 1/s. These are displayed in Figure 9.

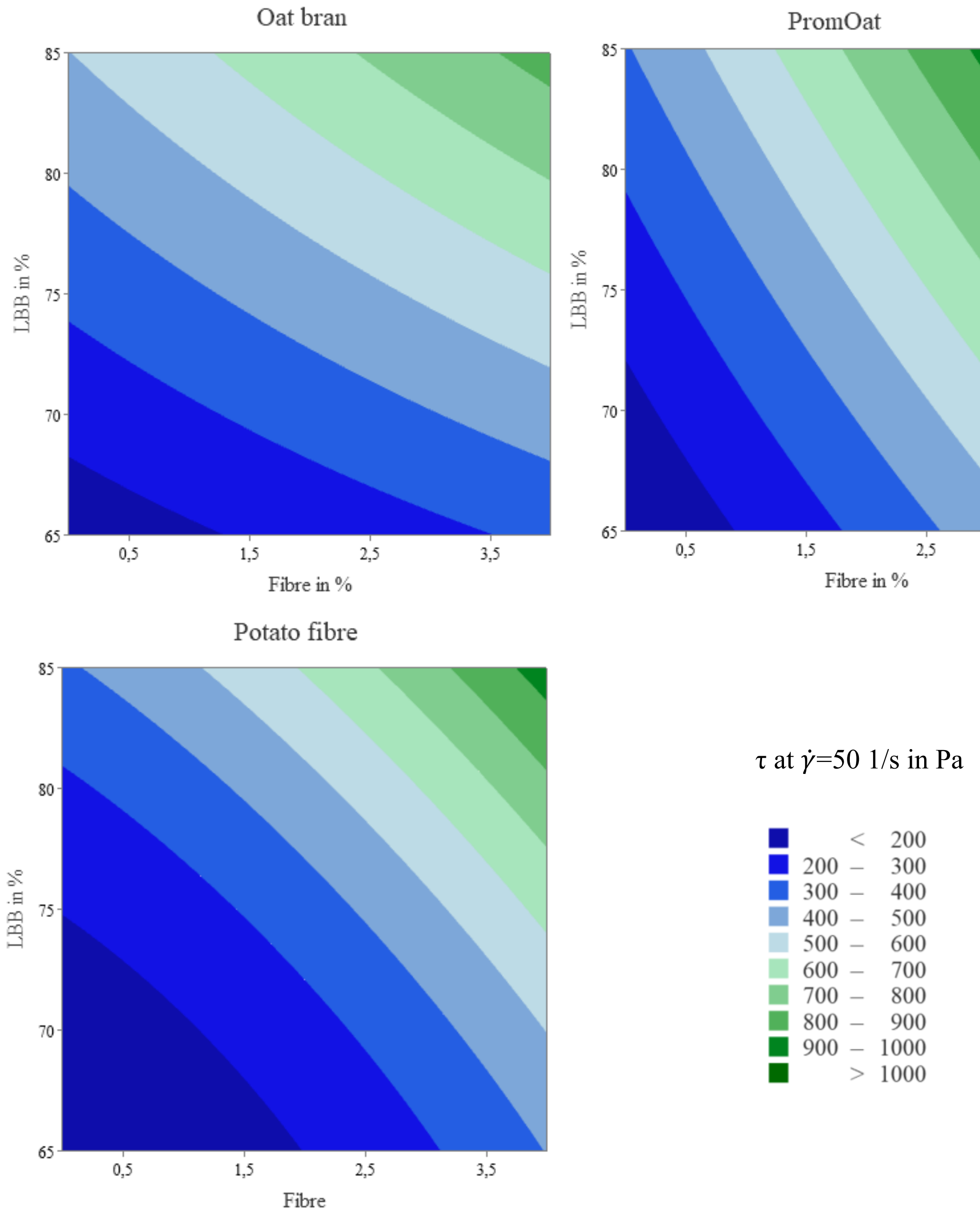

Figure 9, Contour plots shear stress for different fibres

The plot of Oat bran stands out since it is the only one where the amount of LBB has a stronger influence on the shear stress than the amount of added fibre. A slight interaction between the two independent variables is recognisable yet not statistically significant. For PromOat, the addition of fibre is more influential on the shear stress than the amount of LBB and no significant interaction for LBB and fibre is detectable. Lastly, the potato fibre has a clear interaction between the two independent variables while the fibre content in the samples is only slightly more influential than the amount of LBB. Table 6 shows the results of the response surface regression.

Table 6, Summary of response surface regression of the three fibres effect on shear stress. Significant values are shown in bold type.

Factors	Oat bran	PromOat	Potato fibre
Fibre	**<0.0005**	**<0.0005**	**<0.0005**
LBB	**<0.0005**	**<0.0005**	**<0.0005**
Fibre*LBB	0.076	0.164	**0.005**
R-sq (adj) (%)	98	96	99

LBB and fibre individually have a significant influence on all three datasets. Yet the interaction between Fibre*LBB only has significant impact on the samples with potato fibre. The R-sq (adj) values are displayed in the table to express if the full range of variance is included in the model. Since the values are all high (>95) this can be confirmed.

6.2 Particle size analysis

6.2.1 Mastersizer

To evaluate the influence of the different fibres, the particle size has been analysed. Particles that are too large in size can significantly impact the mouthfeel and therefore acceptance of the BPS. As a starting point, the particle size distribution of LBB has been evaluated.

Figure 10 depicts the particle size distribution for plain LBB. Most of the particles (75%) are within the range of 35-100 µm. Some significantly smaller particles seem to be present with a size between 2-12 µm but they only make up 4% of the total particles.

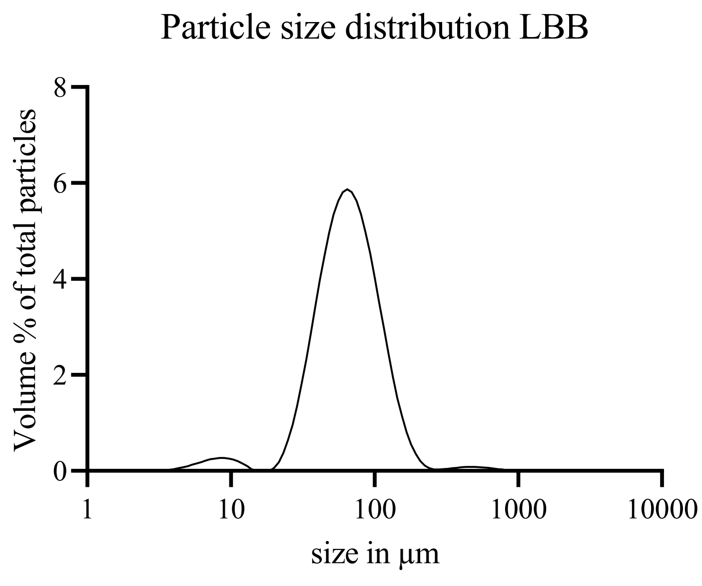

Figure 10, Particle size distribution LBB

The amount of added fibre acts as the main influence on the particle size distribution. Sample number 8 and 9 (CCD, StdOrder) stand hereby for extreme values regarding fibre content and the cube centre points for a mean. Figure 11A shows this distribution for BPS with added potato fibre, Figure 11B depicts the addition of oat bran and Figure 11C has the distribution with added PromOat shown.

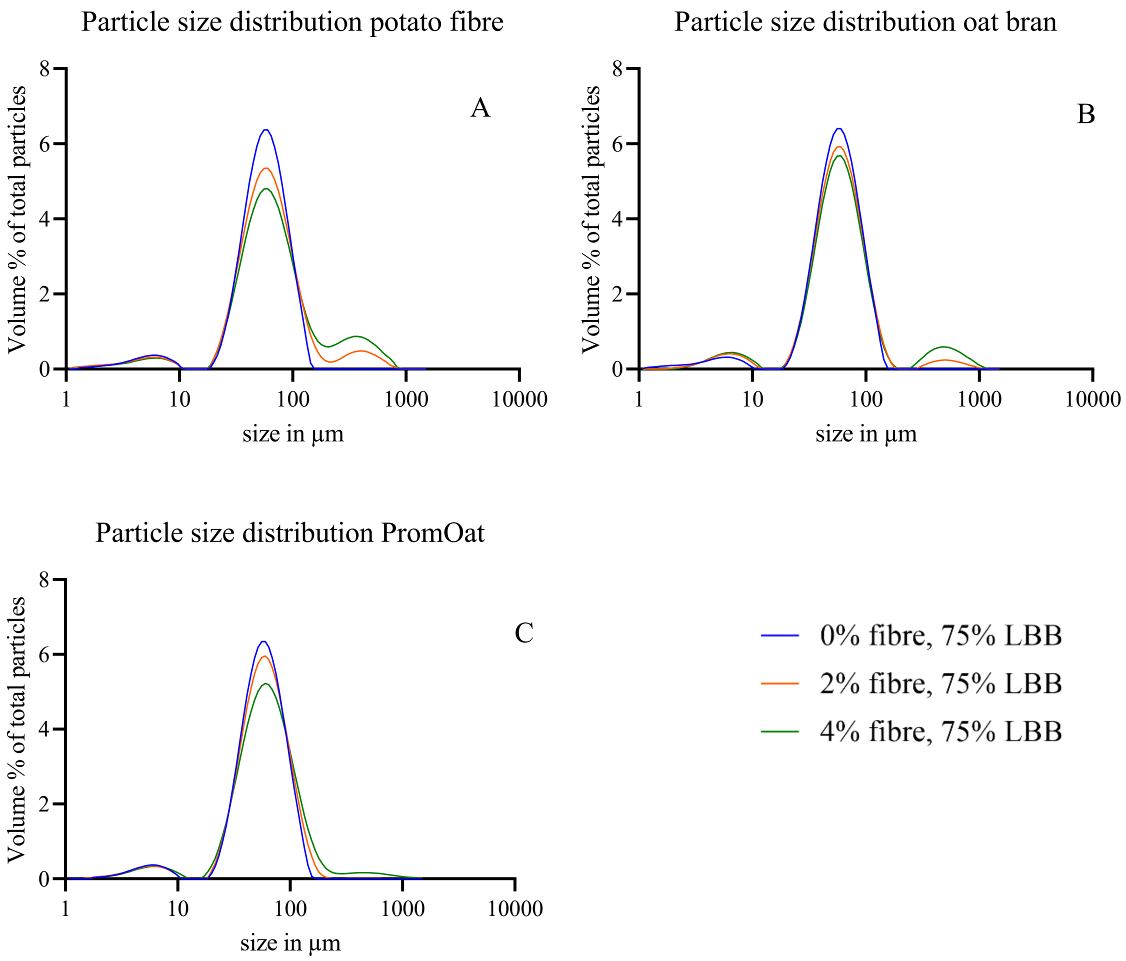

Figure 11, Particle size distribution of (A) potato fibre, (B) oat bran and (C) PromOat

It is visible in Figure 11A that the samples with added fibre not only have two peak range where most of the particles are sized in but rather three. The second peak is significantly smaller but also the particles are much larger with sizes ranging from 240-730 µm. For the sample with 2% added fibre, about 5.5% of all particles are in this range and for the sample with 4% additional fibre, there are about 11.5% in that range.

For Figure 11B a similar pattern as in Figure 11A occurs. The first peak at a range from 35-100 µm is still the main one yet less pronounced for the samples with added fibre. They have then a smaller second peak ranging from 400-700 µm for the sample with 2% fibre and from 300-900 µm for added 4% of fibre. The 2% sample has about 2,8% of all particles in this range or larger particles while 7% of the sample with 4% added fibre lie in that range. The sample without any additional fibre does not have this last peak.

Figure 11C differs from the two previous figures due to the lack of a peak in larger particle size ranges. The volume of particles in the main range (35-100 µm) is lower, the more fibre is added. Instead of another peak with larger particles, the “main” peak is not as high but slightly wider than in the sample without fibre. This is more pronounced in the sample with 4% than in the one with 2%. Yet, especially for the sample with 4% of added fibre, a small peak in the larger range of 240-730 µm is recognisable.

6.2.2 Central Composite Design

The CCD has also been used to determine the influencing factor of the particle size. Figure 12 depicts contour plots of the selected fibres. The percentages are taken from the mode and therefore where most of the particles lie within each sample. That is at a size of 60 µm. As shown in the three figures above, the more large particles are present, the lower is this first major peak.

Especially for the potato fibre it is visible that the percentage of particles at 60 µm differs vastly depending on the amount of fibre added. For all three fibres, the influence on particle size distribution is the fibre at a statistically significant level and not the LBB.

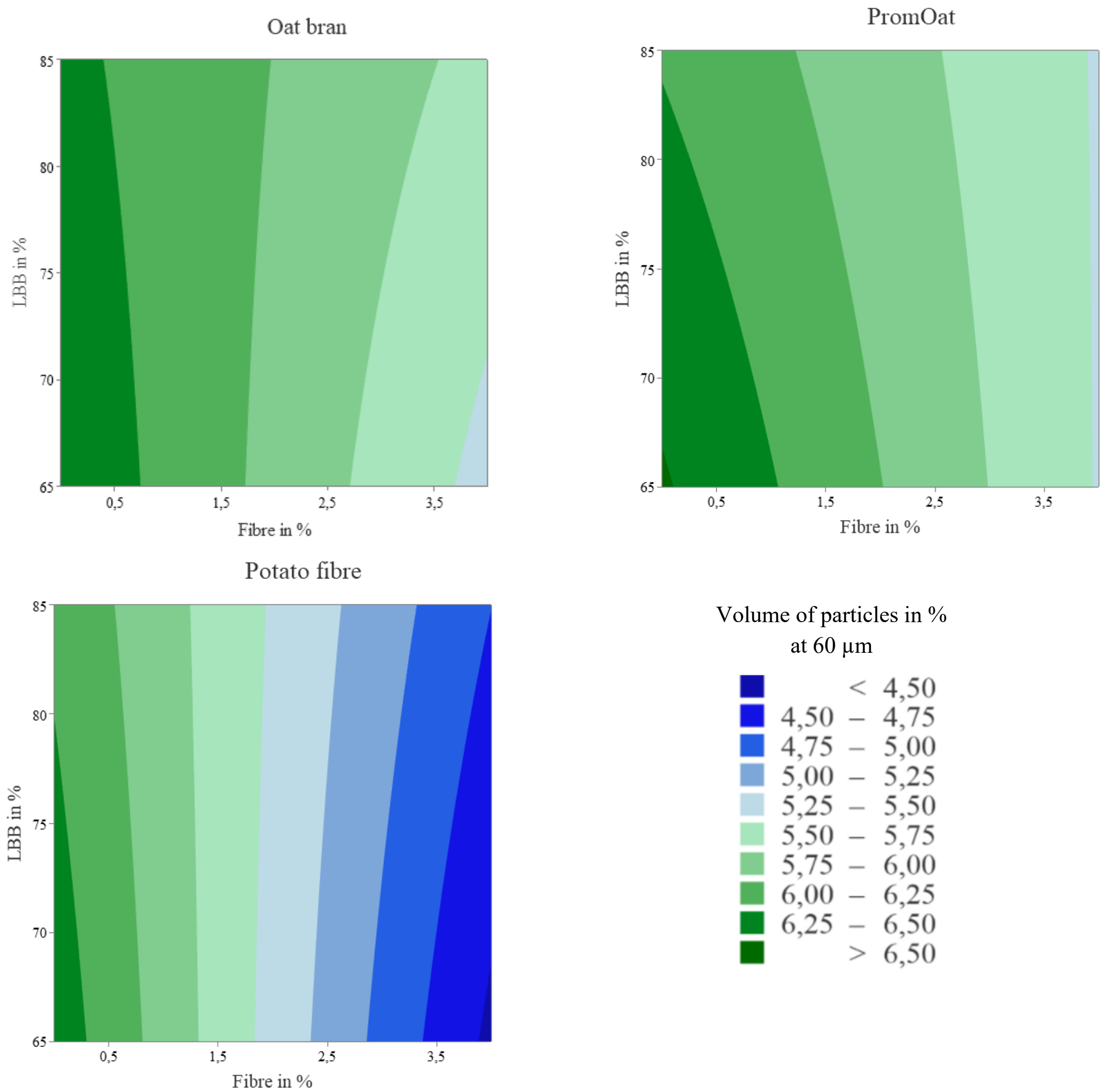

Figure 12, Influence of different fibre and LBB in the respective particle size distribution

6.3 Final prototype formulation

6.3.1 Choice of fibre

After conducting the rheological measurements and determining ranges in which the fibre-LBB combinations are at a desirable shear rate, a final blend could be set. Taking the results for the particle size distribution into account, PromOat is the least detectable fibre of the selection both regarding mouthfeel and particle size distribution. It has the lowest number of particles larger than 150 µm. Also, an initial sensory evaluation resulted also in PromOat having the most neutral flavour. Therefore, it was chosen to be in the final prototype formulation.

6.3.2 Base formulation

Since the fibre and the goal shear stress were set, the range of fibre-LBB combinations could be investigated with the contour plot. To reach a high amount of baobab in the end product yet not have too much tartness, the amount of LBB was set to 70%. With the goal shear rate of 350 Pa at 50 1/s, the fibre content could be determined. Using the contour plot of PromOat, the amount necessary to reach both the correct amount of LBB and the desired shear rate, the fibre content could be derived from the graph to be 1.45%, as shown in Figure 13.

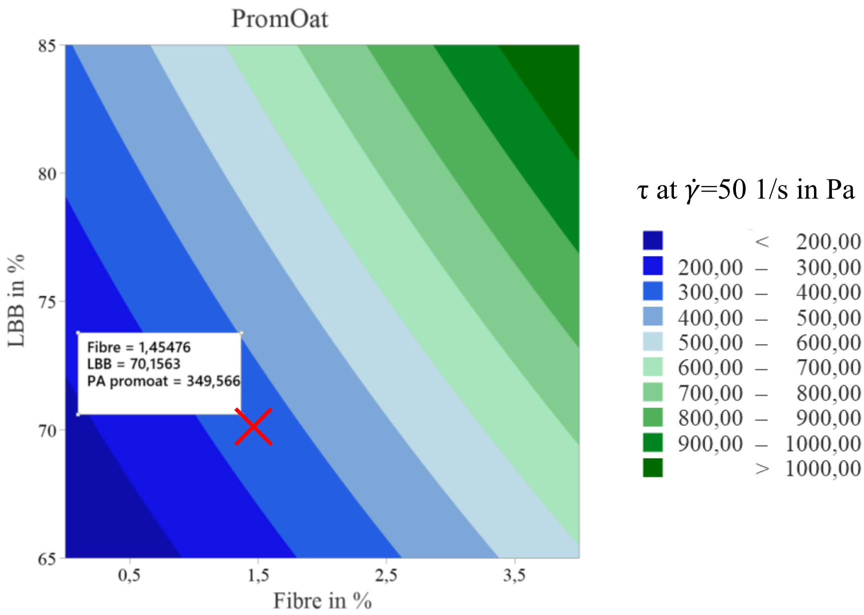

Figure 13, Determining final LBB and fibre content

6.3.3 Mouthfeel

Since the base formulation for the prototype has been decided on, the next step in the development process was to improve the texture/mouthfeel of the prototype. Brief sensory evaluations showed that the product has a somewhat dry mouthfeel. To counteract that, the amount of oil was increased stepwise until a better mouthfeel was achieved yet no oiliness was detectable. The resulting emulsion made the difference to get the improved mouthfeel.

6.3.4 Taste

One downside of the use of baobab in food products in high amounts is its tart taste. To counteract this, several ingredients were tested to give the final prototype a pleasant flavour.

Fruit

In the first trial, mango puree was added to the BPS as a flavouring agent. This was found to not be the best solution since it also had significant impact on the products viscosity due to the consistency of the mango puree itself. This made it difficult to adjust rheological behaviour and sweetness separately. Consequently, the puree was replaced by a mixture of a fruit juice concentrate and water. With that, it was possible to adjust the sweetness and viscosity individually by changing the ratio of both components. Later it was found to be a bit masking the baobab flavour when only using one single juice concentrate. Hence, a one-to-one mixture of two fruit juice concentrates was found to give the best result. Thereby, the flavour of baobab is still noticeable while having a pleasant fruit flavour alongside.

Other

To bring out the other flavours in the prototype, the addition of salt was tested. Many products on the market also have a marginal salt content. A range from 0-0.2% of salt has been tested and within that, an optimal amount was determined. While bringing out other flavours and rounding off the profile, it was not perceived as too salty.

Another factor that was tested for flavour improvement was honey. Bringing a slight sweetness, the thought was that it could help with balancing the acidity. Yet, the flavour of the honey was too strong even in low concentrations and it was overpowering the baobab. So, the addition of honey was omitted. Instead adding other natural, plant-based sweetening agents was tested and a fitting one was found with a similar sweetness to honey, yet less of a taste of its own. Analogous properties were expected and achieved. Here, concentrations of 0-2% were tested and an addition of 1% was found to be optimal.

Another ingredient that was added to mellow the acidity was a plant-drink. Thereby it was considered to not add any allergens. The chosen plant-drink also comes with a bit of sweetness which again helps with the acidity of the baobab. This then resulted in one of the final ingredients of the prototype.

Then, adding a component that changes the flavour profile of the BPS was considered. The baobab-elderflower version was established first and since it is rather fruity, something else was looked for and the search resulted in the addition of cacao powder. The strong flavour and bitterness of it were thought to be complementary to the existing profile of the BPS. A range from 0-3% was investigated here, also taking into account that a large amount would have an influence on the viscosity. A brief sensory evaluation gave the result that adding 2% of cacao powder will be the most beneficial.

6.3.5 Stability

The stability for the final formulations has been tested as described in 4.7. Figure 14 shows the in duplicates executed centrifuge tubes where it is visible that there is no supernatant and therefore, also after calculating it, the stability of both samples is 100 %.

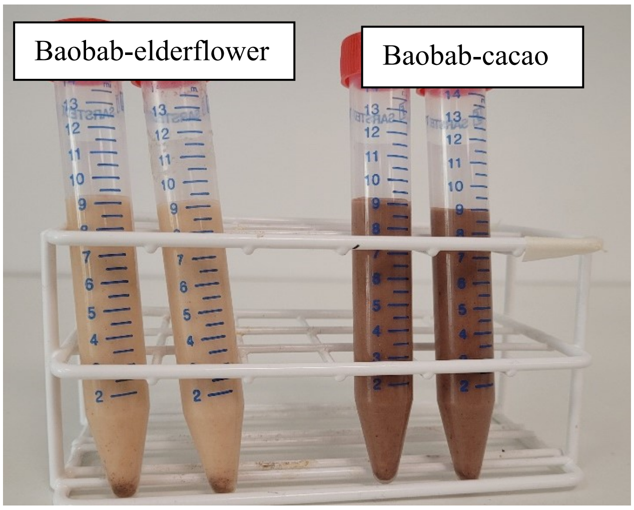

Figure 14, On the left: baobab-elderflower sample; on the right: baobab-cacao sample. Both after centrifugation.

6.3.6 Nutritional values

The main goal here was to reach a high enough fibre content to be able to get the nutritional claim “source of fibre” or if possible “high in fibre”. Having a high amount of LBB contributes a large part of that aim, but also of course the addition on PromOat to the BPS. This combination resulted in 8.3g of fibre per 100g of BPS for both the baobab-elderflower version and the baobab-cacao one. The full nutritional composition is displayed in Table 7.

Table 7, Nutritional values of both final prototypes

Nutritional value	Per 100 g baobab-elderflower	Per 100 g baobab-cacao
Energy value (kcal)	99.7	106
Fat (g)	3.7	4.1
Of which is saturated (g)	0.1	0.4
Carbohydrates (g)	10.3	10.2
Of which is sugar (g)	8.6	8.4
Fibre (g)	8.3	8.3
Protein (g)	1.4	1.9
Salt (g)	0.1	0.1
Calcium (mg)	326	326
Iron (mg)	11	11
Polyphenols (GAEs)	208	208

6.4 Sensory analysis

Two different samples were prepared for the final sensory evaluation with differing flavour profiles. These two are named "baobab-elderflower" and "baobab-cacao". Figure 15 shows the response that the participants provided on a 9-point-scale to the attribute "colour". On this scale, 1 stands for "dislike very much" and 9 stands for "like very much". The legend on the right shows how many participants have answered with a certain score.

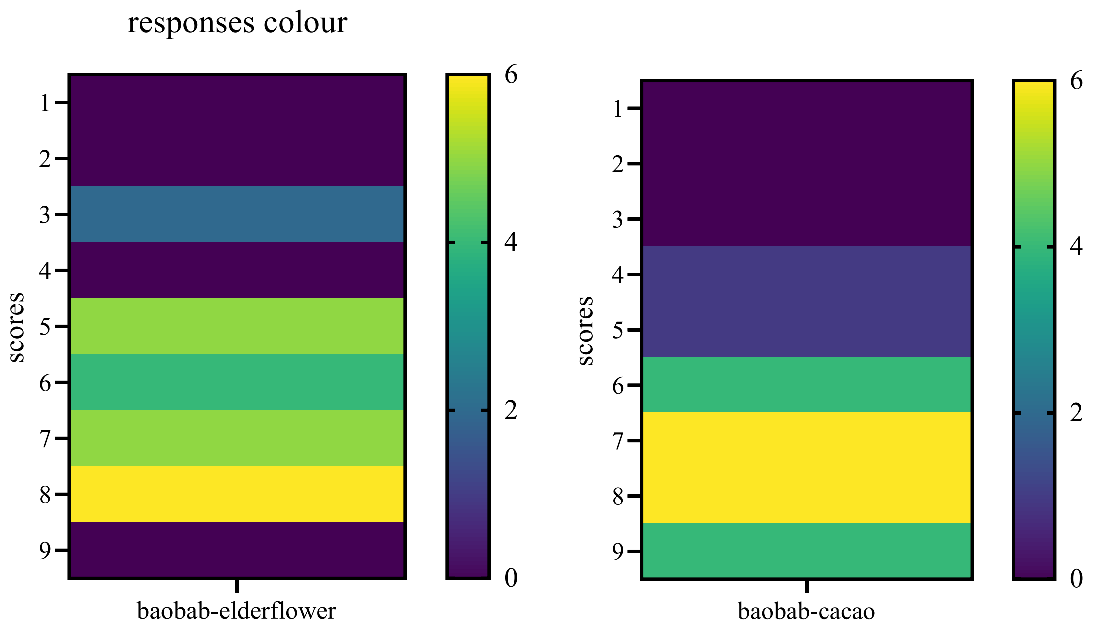

Figure 15, Sensory evaluation responses to colour

It is shown that the participants have answered with higher scores for the baobab-cacao sample than for the baobab-elderflower one. In contrast to that are the answers to the attribute "mouthfeel" rather similar as depicted in Figure 16 (1 stands for "dislike very much" and 9 stands for "like very much"). The colour distribution and therefore number of responses with the same score is more homogeneous than in Figure 15.

This can also be validated by looking at the results of the statistical t-test where the means of two datasets get checked for similarity respectively their differences. Since the majority of the data is normally distributed according to the Kolmogorov-Smirnov test, the t-test was chosen to test for significant differences over the Mann-Whitney test. A two tailed t-test was performed and for the attribute colour, the p-value was 0.035 which indicates a significant difference between the two samples. Figure 17 shows the means and the bars depict the standard error of the mean. The mean for the baobab-elderflower sample was 6.27 while the mean for the baobab-cacao sample lies at 7.23.

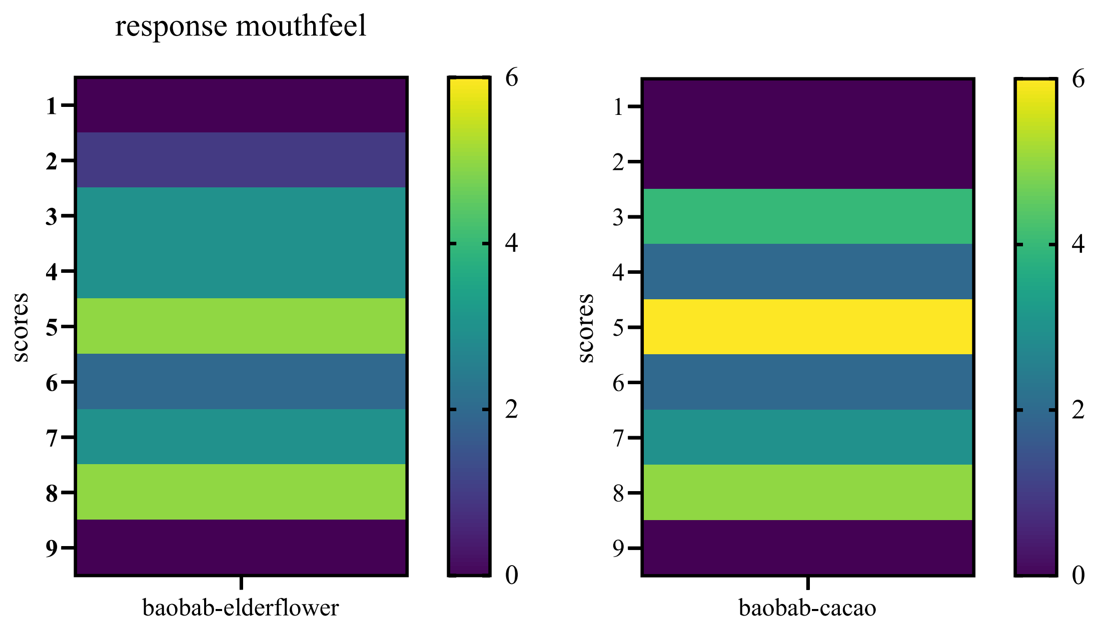

Figure 16, Sensory evaluation responses to mouthfeel

On contrary to the attribute “colour” are the other four parameters that have been tested in the sensory evaluation (mouthfeel, acidity, flavour and texture). The selected example for this case is again the attribute “mouthfeel”. Here the mean for the baobab-elderflower sample lies at 5.5 while the one for the baobab-cacao sample is 5.73. After testing for normality with the Kolmogorov-Smirnov test, the t-test has been applied to see if there is a significant difference but with a p-value of 0.7 there is no difference, and the two samples are rather similar. Figure 17 shows the two means of the test along with bars for the standard error of the mean.

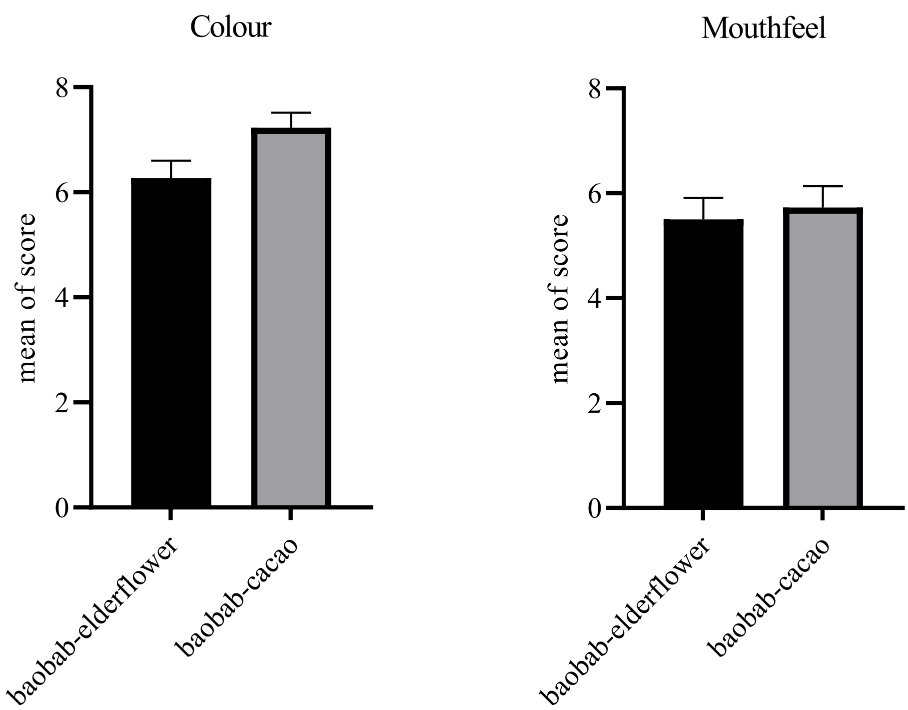

Figure 17, Means of sensory evaluation for “colour“ on the left and "mouthfeel" on the right

Figure 18 depicts the remaining results of the sensory evaluation in a radar chart. It becomes clear that except for the attribute colour, there is not too much of a preference between the two samples. For colour, the difference lies at 0.9 rating points (scale from 1 to 9) and for the other samples the difference is marginal with 0.2 for texture, flavour, and mouthfeel and 0.3 for acidity.

The resemblance can be seen by the overlapping datapoints for each attribute and the general size of the pentagon that gets formed by connecting the means of all attributes. The larger the area of the then formed shape is, the more a product is liked by the participants of the survey.

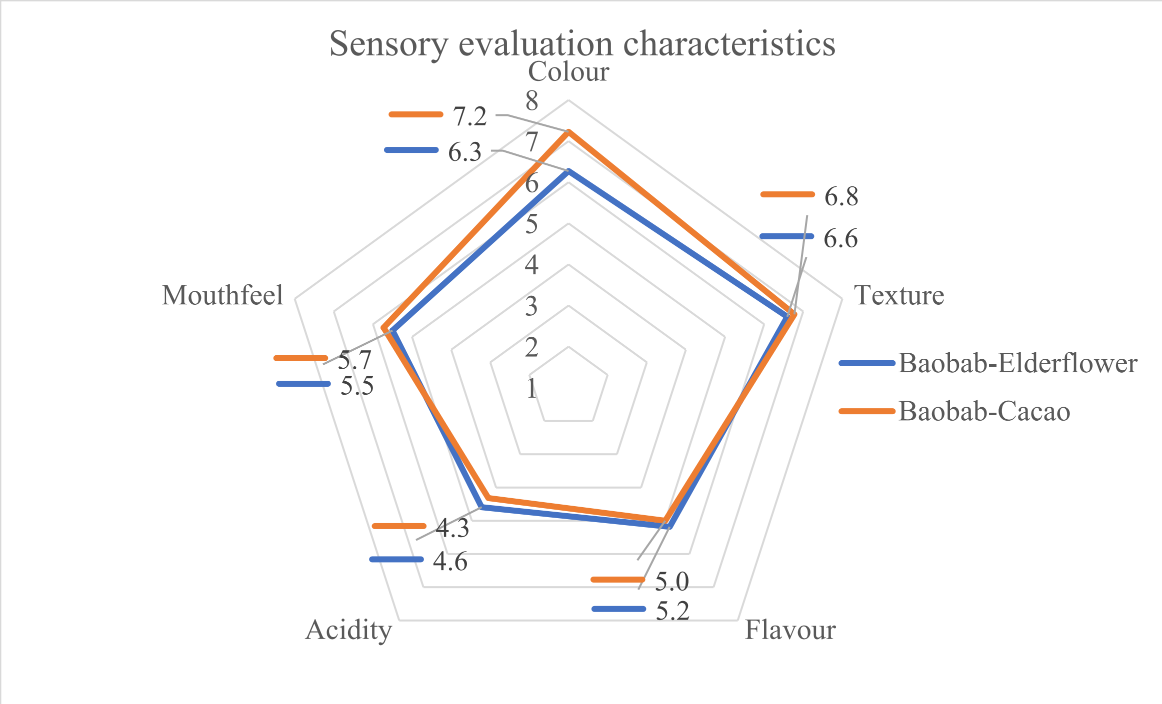

Figure 18, Radar chart sensory evaluation results

7 Discussion

7.1 Influence of rheological measurements on final prototype formulation

For all three selected fibres, both LBB and the amount of fibre added have a significant impact on the shear stress of the BPS. This can be explained by looking at the shear stress of unadorned LBB since that is the main ingredient in both final recipes. At a shear rate of 50 1/s, the stress is at $\tau = 690$ Pa (Figure 8) and therefore notably higher than the shear stress of BPS at that reference point ($\tau = 350$ Pa as a goal shear stress). Therefore, the more LBB is added, the higher the shear stress will be of the resulting BPS. As for the correlation between the amount of fibre and the increase in shear stress, the fibres have the capacity to hold water (Kanwar et al., 2023). Dietary fibre can engage in various interactions with water, including polar and hydrophobic interactions amongst others (Chaplin, 2003). When water and the corresponding fiber are combined in an isolated environment, they form a hydrogel. The viscosity of this hydrogel is higher than the viscosity of water itself, and it varies based on the type of fibre used and the ratio at which water and fibre are mixed. (Kanwar et al., 2023). Within the BPS matrix, the fibre interacts with the water present in the plant drink and the water contained in LBB, resulting in the formation of a hydrogel. Chiacchio et al. (2022) investigated the properties of baobab fruit pulp and shown that the water holding capacity of the pulp is 3.2 g water/g DW. Fibre derived from oats has according to Kurek et al. (2015) a higher capacity to capture water with about 5.8 g water/g DW per gram of dry weight. Beta-glucan rich sources of dietary fibre might differ in that number though. The hydrogel formation and water holding capacity of these two ingredients then augments the product's viscosity.

The potato fibre is the only one of the three test fibres that shows a significant interaction effect for the two independent variables of the viscosity ($p=0.005$). That means that the combined effect of LBB and amount of fibre is not only the sum of their individual effects, but it suggests that they are depending on each other. A very high R-sq values for all three fibres indicates that the model implies nearly all variation of the dependent variable. The independent variables (amount of fibre and amount of LBB) in the model are successful in capturing and explaining the patterns in the dependent variable (shear stress in Pa) and consequently that the model provides a good fit to the data (Kronthaler, 2016).

7.2 Influence of particle size distribution on final formulation

The particle size distribution of LBB (Figure 10) shows that most particles are in a size range above 25 µm. That indicates that products made from LBB manufactured according to the study protocol will most likely not be perceived as completely smooth, since the human palate is able to detect particles from a size of 25 µm and above (Engelen et al., 2005a). When fibres are added, the distribution shifts towards more larger particles in the system ranging from 200 µm to about 700 µm. Especially the oat fibre stands out with a comparatively high number of particles larger than 200 µm. Consequently, the mouthfeel of BPS with potato fibre and oat bran was not perceived as pleasant. During initial sensory tests, they stood out a lot due to the gritty mouthfeel they provided. The particle size distribution in Figure 11 also confirms that clearly with oat bran and potato fibre having not only one but two peaks whereof the second one shows the larger fibre particles. The CCD of the amount of particles present in BPS at the first major peak (particle size of 60 µm) also shows that especially the potato fibre has a lower number of particles at that size with an increasing amount of fibre added to the BPS (Figure 12). Lopez et al. (2016) have also shown that products with larger particles (>127 µm) impair the general perception of products due to the perceived grittiness.

One main difference between these two larger particle fibres and PromOat was that the latter was already available in a powdered form while the other had to be ground first due to their large size. This did not give the same initial conditions for the three fibres. The mill that was used to grind the fibres did not have a sufficiently small setting to grind the raw materials in a finer powder. That could have given a smoother result in application within BPS.

The results (Figure 11) show that after adding PromOat to the BPS, the particle size distribution still has a similar spread. Concluding thereof that it should be not as detectable as the other fibres. This was also confirmed by brief sensory testing. Given that as well as no prominent off-flavour, out of the screened batch it was found that PromOat is the most suitable source of fibre and will be used to continue the development.

Another factor that was important here is the production of LBB. The sieve used to separate the seeds from LBB after being heated and stirred has a mesh size of 700 µm. A smaller mesh size could help in getting a smoother end product and to eliminate the sandiness that was ascertainable in the produced samples. Nevertheless, further trails must be conducted in order to test if it is feasible and brings the desired results.

Furthermore, could a high-powered blender with a blade attachment help in reducing the main particle size, if the BPS is blended long enough at a sufficient speed. More literature and practical research should be carried out on this topic though since it is unclear how well blending works with such a high-viscosity product and if it is efficient.

7.3 Sensory analysis and nutritional values

7.3.1 Sensory analysis

The characteristic "colour" was the only one of the five evaluated attributes that showed a significant difference for the two tested samples. This was expectable since the cacao does give a darker brown colour in comparison to the baobab-elderflower sample that is more neutral-beige (Figure 14). The results show that the baobab-cacao variety is preferred over the elderflower formulation. This can be due to the connection with chocolate which is positively associated for some people. Meier et al. (2017) have shown that products containing chocolate can have a positive impact on peoples mood. This positive connection can be one reason why the sample containing cacao got a higher score for the attribute colour.

For the other evaluated attributes, no significant difference between the two samples could be determined. This means, cacao does not have a significant impact on mouthfeel. Bisig and Kelly (2021) found that commonly the particle size of cacao powder is usually between 10-30 µm and only 0.5% of all particles shall be larger than 75 µm. Henceforth the cacao powder blends well with the larger particles already present in BPS and that explains the similarity in mouthfeel of the two samples.

The parameter "flavour" did not show a difference which was unexpected to some degree. Cacao changes the flavour profile with bringing in some bitterness as well as slightly more acidity (Mohamadi Alasti et al., 2019). Therefore, it was thought to bring some difference in the result, either by decreasing the score due to the enhanced acidity and bitterness or by increasing it due to the connection with chocolate. Yet this did not influence the flavour in a way that the participants preferred one sample over the other. As for the other factors (texture and acidity) there was also no significant difference detectable which was also what was sort of expected.

The overall scores for the product are acceptable but can still be improved with further development of the BPS. One reason might be that people are not familiar with the tart flavour of baobab yet. As a novel food in the European Union it is not widely used in products on the market so far.

7.3.2 Nutritional values

Table 7 shows the nutritional values of the final prototype. It is shown that the goal to reach a nutritional claim has been exceeded and both formulations can be labelled as "high in fibre" (European Parliament and European Comission, 2006). With that, one of the main aims of this project has been fulfilled. In comparison to other products on the market, the energy value of both formulations of BPS is quite similar (Table 8). The sugar content though is distinctly lower than comparable market products. BPS can be categorised as functional food and therefore a low sugar content is favourable to emphasise the health aspect of this category. Compared to other snack/dessert products, the fibre content is evidently much higher. Most competitors do not even specify the amount of fibre present in their products.

Table 8, Energy value and fibre content of market products and BPS

Product	Energy value (kcal)	Fibre (g)
RisiFrutti Hallon	112	Not specified
Keso snack hazelnut/blueberry	140	Not specified
Alpro chocolate dessert	95	1.5
Salakis Turkish yogurt	130	Not specified
BPS	100	8.3

Since baobab itself is rich in micronutrients such as iron and calcium, nutritional claims can also be made for the high amount of these micronutrients. According to the directive on nutrition labelling for foodstuffs (90/469/EEC) by the European Commission (1990) the BPS can be labelled as "high in calcium and iron". To be able to reach that claim, a product needs to contain at least 120 mg calcium per 100g and respectively 2.2 mg iron per 100g. Yet BPS entails 326 mg calcium per 100 g and 11 mg of iron.

For this project, the nutritional values were calculated from the nutritional information given from the ingredients present. Since especially the baobab is subject to natural fluctuations (origin, batch, year of harvest amongst others), a nutritional analysis of the BPS would have been interesting. Particularly for the fibre content could this be interesting yet due to time limitations, it could not be included in this project.

7.4 Formulation in general

There was a slight sandiness which led to a gritty mouthfeel in the LBB and consequently also in the BPS. This can have several causes that lie with the baobab. Firstly, it was noticed that the sandiness only occurred in the batch used for this project but not in an older batch. Therefore, it can be concluded that it is only a problem for this specific batch of baobab and not in general. One method of removing the sandiness could be the use of a finer mesh size when separating the seeds from the LBB. Alternatively, the LBB can also be strained again with a fine sieve (around 150 µm) after the seeds have been separated.

The aim to avoid food additives that require labelling with an E-number was reached. No additive was supplemented that requires that label. Therefore, the clean label concept could be complied with. However, the acidity was the lowest rated attribute throughout the sensory evaluation so some improvements to mask the intrinsic acidity of baobab. One way would be to use an acidity regulator in a small amount. Until now, there has not been found a suitable one yet that is conform with the clean label concept.

8 Future studies

Due to time restrictions and the scope a few things have not been investigated further which albeit would have been interesting to include in this project. Firstly, the water holding capacity of the different sources of fibre is one study that could be conducted in the future. This would help to understand their behaviour in BPS better and optimise their use further.

Secondly, investigating more sources of fibre to potentially add to the BPS can be a project for the future. For example, exploring other options in the range of press cakes from oil production like rapeseed or sunflower press cake. For a more circular approach, even press cake from the oil production of baobab seed can be looked into further. Or, if desired, more synthetic fibre like inulin or microcrystalline cellulose could also be interesting.

Furthermore, new flavour profiles can be explored, either with other fruit juice concentrates or by using fruit purees, making sure to not use any food additives and keep the clean label. One category of fruits that have not been investigated yet are stone fruits although plum and apricots (amongst others) could be good additions to BPS. Through the addition of the plant-drink and the juice concentrate, still a considerable amount of sugar is added to BPS and in further trials that could maybe be reduced to some degree to lower the total amount of sugar.

To be able to characterise BPS more precisely in a rheological way, amplitude sweeps to determine yield and break point would have been very interesting to perform. This could not be carried out because the available equipment was not fully functional.

9 Conclusion

In conclusion, a prototype for a fibre-rich, spoonable snack based on baobab fruit pulp, called Baobab Pudding Snack was developed. The BPS has aimed for characteristics such as being plant-based, using a high amount of baobab fruit pulp, achieving sufficient rheological properties in comparison to a reference product and having an acceptable taste. Also, food additives which have to be labelled with E-numbers according to EU law have been avoided. Not only the nutritional claim "high in fibre" could be reached but also nutritional claims for two of the micronutrients the baobab fruit is rich in, calcium and iron.

Rheological properties and how they are influenced by different fibres and amounts of LBB used in the BPS were investigated using a rheometer. To obtain a deeper comprehension of the effects resulting from the utilization of three fibre sources in different proportions, alongside varying amounts of LBB, an experimental design tool known as CCD was used. The particle size distribution of three screened fibres contributed to make an informed decision on which fibre source to choose.

After optimal proportions of LBB and the most fitting fibre source was found, the formulation development process was started. PromOat was found to give the best results both regarding the particle size distribution and mouthfeel. Here, different other flavouring agents were explored to counteract the baobab's intrinsic tartness and give the BPS a pleasant taste. These final formulations were then given to participants in a hedonic sensory evaluation to see how the samples are perceived by 22 people.

It is important to highlight that more development needs to be done on this prototype of the BPS to improve the flavour further and also some of the rheological properties could not be measured due to unavailability of equipment so in the future that can be explored.

The project demonstrates the potential of baobab fruit pulp as a valuable ingredient fibre rich snack. It presents an exciting opportunity to offer innovative snack options with a nutritional benefit as an alternative to conventional snack options.

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11 Appendices

11.1 Template sensory evaluation

Sensory evaluation for a prototype of a baobab pudding snack

Welcome. Thank you for joining my sensory evaluation.
Please note this is the initial prototype and not the final formulation.
The aim of this sensory evalutaion is to get feedback to help improving the snack further.

Both samples have a slight sandiness to them, the reason for this lies with the batch of baobab used and shall be eliminated in the future. Please try to work around it as best as possible.
Taste the samples from left to right.

To neutralise your palate, take a bite of the bread, chew thoroughly, and swallow; then take a sip of water and swish it around your mouth to remove any bread.

Baobab pudding snack # ______	Dislike very much				Neither like nor dislike				Like very much
Have a look at the snack. • How you like the **colour** of the snack?	1	2	3	4	5	6	7	8	9
Give it a stir. • How do you like the **texture** of the snack?	1	2	3	4	5	6	7	8	9
Now taste it. • How you like the **flavour** of the snack?	1	2	3	4	5	6	7	8	9
• How you like the **acidity** of the snack?	1	2	3	4	5	6	7	8	9
• How do you like the **mouthfeel** of the snack?	1	2	3	4	5	6	7	8	9

Please neutralize your palate.

Baobab pudding snack # ______	Dislike very much				Neither like nor dislike				Like very much
Have a look at the snack. • How you like the **colour** of the snack?	1	2	3	4	5	6	7	8	9
Give it a stir. • How do you like the **texture** of the snack?	1	2	3	4	5	6	7	8	9
Now taste it. • How you like the **flavour** of the snack?	1	2	3	4	5	6	7	8	9
• How you like the **acidity** of the snack?	1	2	3	4	5	6	7	8	9
• How do you like the **mouthfeel** of the snack?	1	2	3	4	5	6	7	8	9

Comments or thoughts on the samples (if any):

____

____

Thank you for your participation