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A plant-based milk powder that functions as a substitution for regular milk powder

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ABSTRACT

This project tested the potential of plant based milk powders to function as an animal-based milk powder by testing them on multiple characteristics. The powders were produced using spray drying techniques, obtained using formulations differentiating in protein amount, ratio of maltodextrin:sucrose and two different protein sources. The different ratios were 100% sucrose; 100% maltodextrin; 50% maltodextrin and 50% sucrose; 65% maltodextrin and 35% sucrose; 75% maltodextrin and 25% sucrose. The formulation with 100% maltodextrin was repeated with a double amount of protein. The similarities and differences between the samples, as well as compared to conventional milk powders are analyzed and reported with a focus on their abilities in reconstitution and food application. Analyses included the powders moisture content, water activity, wettability, sinkability, dispersibility, foamability, foam stability, fat encapsulation, and their performance in two food applications namely coffee and chocolate.

Changes in the different maltodextrin:sucrose ratios did not show a significant difference in performance of the powders in moisture content and water activity. For the samples with protein A there was not significant difference in fat extraction, and for protein B in foaming and wetting properties. Indicating that the type and amount of protein is more relevant for these properties. The powders made with protein A performed better overall in wetting time, dispersibility and fat encapsulation. For foaming capacity, the powder containing 50m/50s-A showed the best performance, but the other samples with protein A performed worse than the ones containing protein B. The foam stability was better in the samples with protein B. Overall, since the desired amount and stability of foam differs per application, this will dictate the following research. However, in the food applications it seems like the powders made with protein B performed better overall. They showed a lower amount of floaters and sediment in the coffee test, and a better visual representation when mixed in the chocolate bar. The taste panel also showed a high likability in flavor for the chocolate bar made with protein B. When comparing to full fat milk powder, the results are quite different, without one of the powders showing an overall better performance in everything and some powders score great on certain fields, and perform worse on others. It is therefore of importance to keep in mind the application in which the powder will be performing.

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2 INTRODUCTION

2.1 INTRODUCTION TO MILK POWDERS

Milk powders are commonly used in industrial food production processes as a substitute ingredient for fresh milk (Augustin et al., 2003). There are processes to produce different milk powders like skimmed and full fat milk powders, but also cream-, buttermilk and infant formula powders. All these milk powders have different compositions and functionalities(Wang & Lee, 2019b). Spray drying technique is most commonly used to dehydrate milk since it efficiently preserves and stabilizes its constituents (Schuck, 2002). The great difference in weight of milk powder compared to fresh milk is the reason for this technique's development, resulting in more efficient and sustainable handling and transportation (Patel, 2009). Another very important reason for milk powders to be used so frequently in food applications is shelf life. Because milk powders are a dry product, it is minimally prone to microbiological spoilage. However, the powder can easily take up moisture and start to cake, and is also sensitive to oxidation when containing fat. Storage circumstances of milk powders are therefore crucial for their shelf-life (Wang & Lee, 2019). Where fresh milk can be processed to achieve a decent shelf life, milk powders, when stored properly, can remain high product quality for several months or even years.

Dairy consumption is increasing due to increased incomes, internationalization of consumption patterns, broadening application possibilities, improved distribution systems and dairy industry extending to developing countries(Augustin & Margetts, 2003). Even though dairy products are generally identified as healthy foods, the focus from animal-based diets has recently started to shift towards more plant-based diets. Consuming less animal-based products has shown advantages in health aspects like blood sugar balance, blood pressure, cholesterol levels and the development of non-communicable diseases (Shanthakumar et al., 2022; McClements, 2020). On top of the health benefits, plant-based diets need significantly lower resources for production and processing while also bypassing the greenhouse gasses emitted by livestock. Plant-based diets therefore have a much lower environmental impact than animal-based diets(Espinosa-Marrón et al., 2022). Since dairy is so abundantly used in food applications, replacing it with plant-based alternatives could be an essential step towards a more sustainable food industry.

2.2 DESIRED POWDER PROPERTIES

The functionality and properties of these plant-based ingredients should closely resemble dairy in order to maintain today's food manufacturing processes. Some functionalities require extra processing steps like agglomeration to improve the reconstitution properties of the powder(Kinyanjui & Artz, 2003). Different food applications desire different functionalities in for instance wettability or sinkability which is the powders' ability to cross the water surface. A powder should wet fully when it comes in contact with water, since this is the first step towards its dissolvability(Auvinen, 2020). When the particle size is too small, this reconstitution ability decreases due to a high surface tension. The thin layer of powder that does wet in this case will create a viscous boundary, blocking the capillary flow between the particles(Jinapong et al., 2008). Other examples of difference in desired properties are for instance foamability and free fat. Where foaming capabilities of the powder would be important for a powder to function in a coffee machine or a milkshake, a high amount of surface fat would be desired in for instance production of chocolate bars

due to its facilitated production process and effect on texture and mouthfeel. In most other applications, foaming and a high amount of free fat would be considered a negative aspect (Augustin et al., 2003; Teehan et al., 1997; Liang & Hartel, 2004; Huppertz, 2010).

The formulation, machine settings and environment during and after running the spray dryer all highly influence the properties of the powder. Despite similarities in the composition of powders, its characteristics like moisture content, fat encapsulation or particle size, shape and density can differentiate heavily(Liang & Hartel, 2004).

The moisture content and water activity levels of the powder are one of the most important factors to prevent microbiological growth and to maintain powder stability over time. Spray dried powders typically need to have a moisture content below 4% (w/w) and a water activity level below 0.37(Augustin et al., 2003). The moisture content is highly influenced by the in-and therefore outlet temperature, as well as the moisture in the ambient air (Kent & McLeod, 2007). When the moisture in the powder is too high, risk of spoilage and oxidation increases greatly, when too low, the risk of oxidation increases(Augustin et al., 2003).

2.3 KINETICAL PROCESSES DURING DRYING OF MILK-LIKE POWDERS

Powder oxidation is a chain reaction which occurs with the presence of lipids, creating off-flavors, causing it to be the number one challenge for milk powder to maintain its quality and consumer acceptance over time. Lipid oxidation is highly dependent on the production process and storage, creating many issues for milk powder consumption and application. Poly unsaturated fatty acids are more prone to oxidation (De Souza et al., 2009; Clarke et al., 2021; Coughlan et al., 2022). Lipid oxidation occurs less when the present fat is sufficiently emulsified and encapsulated by the other ingredients during drying, since there is less free fat available for oxidation (Vignolles et al., 2007). The level of fat encapsulation also affects the stickiness, solubility and dispersibility properties of the powder(Millqvist-Fureby, 2003). The amount of free fat in power can be influenced by formulation and mechanical handling, where stronger mechanical handling increases the amount of free fat, possibly due to an increase in pores and cracks in the powder surface (Millqvist-Fureby, 2003; Sharma et al., 2012).

During dehydration processes, the control of the glassy state of sugar is crucial for its success(Roos, 2010). Glass transition in amorphous materials is a reversible change of state where, during heating, an increased mobility of molecules results in a substance appearing liquid-like (Roos, 2010). The temperature at which the glass transition occurs differs per substance, and decreases strongly when the water content increases. The glass transition temperature (T_g) of dry sucrose is about 60°C(fig. 1)

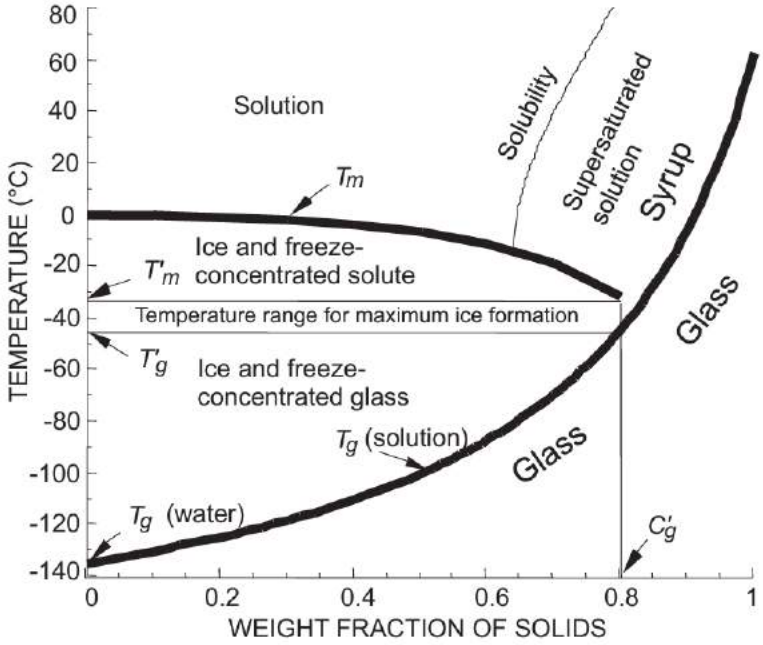

Figure 1. State diagram of sucrose(Roos, 2010).

When the temperature of the outlet temperature exceeds T_g, the sucrose changes to a syrupy state which results in particles sticking to the equipment. Even though the loss in yield decreases when the production scales up, the product lost due to it sticking to the machine compartments is one of the major obstacles in using spray drying technology(Sosnik & Seremeta, 2015). To overcome this challenge, the surface of the particles should be solidified in the early stages of the drying process. Maltodextrin can be used as drying aid, since it contains a mixture of carbohydrate polymers with higher T_g values, increasing the overall T_g of a mixture with low-molecular-weight sugars like sucrose(Roos, 2010; Nadali et al., 2021; Silalai & Roos, 2011)

Sugars with a low molecular weight have another function in spray drying processes, since they have the ability to somewhat protect proteins against denaturation by supposed direct interaction with the protein in replacement of water, or by their glass-forming properties. Proteins that are denatured during the drying process, due to high outlet temperatures, usually negatively affect powder properties due to reduced dissolvability and loss of functional properties(Haque & Adhikari, 2014). However, the damaged caused by heat should be limited, since the drying process is in a matter of seconds(Schuck et al., 2008).

2.4 SPRAY DRYING MACHINE

A spray dryer uses pressurized air to spray a usually concentrated sample through a nozzle into a chamber where hot air flows through co-currently. By passing the sample through the nozzle, which is called atomization, droplets with ideal evaporation conditions are formed(Pilotech, 2021). In the chamber, a possibility for droplet-air contact is created by blowing air, resulting in the water being evaporated from the formed droplets. This evaporation rate is quite constant as long as the moisture inside the droplet can sufficiently replace the moisture being removed from the surface(Patel, 2009).

As soon as the surface of the droplet is no longer saturated with moisture, evaporation is dependent on moisture diffusion through an increasingly thickening dried shell (Patel, 2009).

Under the drying chamber, there is a cone and a collection vessel. In this vessel, the particles that are too heavy to be carried by the airflow are collected. This occurs for instance when the droplets still have too much water in them. The air flows together with the dried droplets, which now create a powder, to the cyclone. Here the separation of powder and air occurs, where the powder falls down into another collection vessel, and the air flows further to be released. The smallest powder particles that might remain in the air, are commonly filtered out just before the air leaves the system. The uptake of water is what cools down the hot air entering the chamber. An example of a spray drying process is shown in figure 2.

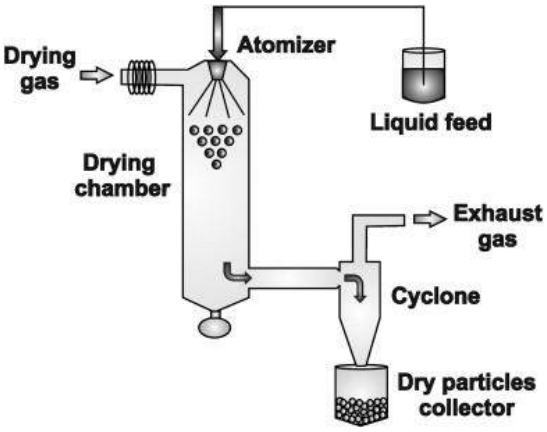

Figure 2- Spray drying process (Sosnik & Seremeta, 2015).

There are different parameters that can be adjusted when operating a spray dryer. First, the flow rate (in L/h), the speed at which the liquid is pumped into the machine. A higher flow rate creates smaller droplets because of the higher pressure at which the liquid goes through the nozzle(De Souza et al., 2009). Secondly, the nozzle size can be changed where a bigger nozzle size results in bigger droplets and therefore bigger powder particles. Next, the temperature of the inflowing air (T_{in}) can be adjusted, as well as the speed of this airflow with the air blower. Typically, you need a temperature high enough to sufficiently and rapidly evaporate enough water from the droplets, but low enough to utilize all capacity and minimally disturb the physicochemical properties (Patel, 2009; Kent & McLeod, 2007; Ray et al., 2016). Altering T_{in} can affect moisture content, particle size, solubility and encapsulation efficiency (Mayasari et al., 2020). The air needs to blow fast enough to dry, while also slow enough to give the liquid enough time in the chamber to dry. To collect a powder as homogenous as possible during the time of the run, T_{out} should be kept as stable as possible. When T_{out} gets lower than desired, the air blower or T_{in} can be increased or the flow rate decreased, or the other way around when T_{out} gets higher than desired. A combination of alterations can be used to prevent from altering a single parameter too much.

2.5 RAW MATERIAL FOR NON-MILK BASED WHITENERS

Milk is a complex food emulsion due to fat droplets being dispersed in the aqueous phase, which also contains proteins(Kinyanjui & Artz, 2003). The emulsification is achieved due to the proteins unfolding at the oil-water interface, creating cohesive films around the fat droplets (Lu et al., 2019). Naturally, in a solution to function as a milk substitute, the emulsification properties of the used

protein are crucial. An example of such a protein is derived from peas. Pea protein has emulsification as its most valuable property due to its amphiphilic nature. The proteins are able to rapidly adsorb at the interface and stabilize it (Burger & Zhang, 2019). Peas have a protein content of 20-30%, with a globulin/albumin ratio depending on the plant species and production methods. Besides that, the conditions of isolation, environment and processing and the origin of the peas all can have an impact on the protein's functional properties (Burger & Zhang, 2019). Peas are increasingly used to reformulate different foods. Besides offering a suitable protein functionality, they align with WHO's balanced amino acid profile recommendations and score highly on availability, hypoallergenicity, affordability and sustainability(Boukid et al., 2021). Like other legumes, peas fixate nitrogen into the soil, need little water and fertilizers while also presenting a low carbon footprint(Boukid et al., 2021).

The Swedish company Sproud has made it their goal to use yellow split peas to create plant-based dairy alternatives. They prioritize limiting carbon emissions in all steps of the supply chain, choosing more sustainable ingredients, transportation, processing and packaging options. Besides using peas as a protein source, other ingredients like water, oils, sweetener, acidity regulators, salt and nutritional supplements are needed to mimic the appearance, texture and flavor of conventional milk.

2.6 AIM

To contribute to more sustainable and plant-based food processes, this project aimed to create a powder using spray drying technique followed by analyzing its potential to function as a plant-based milk powder alternative. Different powders were created by altering their formulations, and testing the effect of these changes on the powders functionalities, to answer the following questions

- Is it possible to obtain a powder from a plant-based formulation using spray drying technique?
- What effect does the ratio between maltodextrin and sucrose have on the powders properties?
- What effect does the source and amount of protein added to the solution before spray drying have on the powders properties?
- Will these plant-based powders give a desired effect that is comparable to that of conventional milk powders when incorporated in food applications?

To answer these questions, different methods are developed with the focus on understanding the changes in reconstitution abilities for different food applications. The aim of this project is to evaluate the differences in powder properties and functionalities when altering the formulation, under similar spray drying conditions.

3 MATERIAL AND METHODS

3.1.1 Sample preparation and formulations

The initial formulation (#1) was provided by Sproud, representing a simplified version of their 'Sproud Barista' product, leaving out the vitamins, calcium phosphates, gluten free oat oil and exchanging the agave syrup with sucrose. An overview of this and other formulations is shown in table 1. Pea protein isolate (Originated from China, min 85% protein content) was used in run #1-

#6, which will be referred to as protein A. De-oiled rapeseed lecithin was introduced in formulation #2 to improve rapeseed oil incorporation. Sucrose (Strösocker, Sweden) was replaced by maltodextrin in formulation #3 since it expected to improve the stickiness of the powder. In formulations #3-#4, maltodextrin A (DE-value 17-20) was used, while in formulations #5-#8 maltodextrin B (DE-value 17.00-19.90, Slovakia) was used, since they have a very similar DE value, the difference in functionality of the powders is neglected. Protein content was doubled in formulation #4 to investigate the role of the protein in the powder properties. Formulations #5, #6 and #7-#8 varied in maltodextrin:sucrose ratio, since it was expected to improve both spray drying circumstances and powder properties as dispersibility and sinkability. In formulation #7 and #8 the protein source was changed from protein A to pea protein isolate B (Originated from Europe, min 84% protein content) to more closely mimic Sproud's original recipe. All recipes contained the same amount of dipotassium phosphate in a 50% solution, and dehydrated dicalcium phosphate, which are marked grey (table 1). The amounts were based on advice from Sproud and no alterations were made on these ingredients. Due to the time available, all formulations were run once, except formulation 8 which was run in duplicate and used to determine the uncertainty.

Run #1.1 is not taken into account, since it was run at different spray drying conditions. Run #6.1 and #8.3 are not taken into account due to the run itself, and the powder obtained being more sticky and also less in amount than expected. Run #6 was therefore repeated. Since run #8.3 was run for a third time for statistical analyses, it was chosen to base the statistical test on two runs (#8.1 and #8.2) instead of three. If measurements were performed on samples 1.1, 6.1 and 8.3, the values are shown marked in grey, but they are not taken into account when discussing the results.

Table 1- Formulations overview

Recipe / Ingredient(g)	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
Protein A	30	30	30	60	30	30		
Protein B							30	30
Maltodextrin			201	171	100.5	150.75	150.75	130.65
Sugar	201	201			100.5	50.25	50.25	70.35
Rapeseed oil	60	57.75	57.75	57.75	57.75	57.75	57.75	57.75
Calcium carbonate	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Dipotassium phosphate	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5

Lecithin		2.25	2.25	2.25	2.25	2.25	2.25	2.25
Water	700	700	700	700	700	700	700	700

To prepare the formulations, the dry ingredients (sucrose, pea protein, dipotassium phosphate, calcium carbonate) were combined with water to a 30% solid mixture using a Bosch hand blender (450 Watt) for about 5 minutes, followed by the lecithin and slow incorporation of the rapeseed oil for an additional 5 minutes. The solution was then homogenized using the GEA Panda PLUS homogeniser, once at 130 and subsequently at 180 bar. For every new run only one change was made to the formulation. The formulations used in this project are shown in table 1 in g per kg of solution. The ingredients differentiating from the previous formulation are marked orange(table 1). All formulations contained a 30:70 solids:water ratio in weight. The initial recipe was provided by Sproud, and adjusted throughout the project.

3.1.2 Machine settings

Lab Spray Dryer YC-018 Pilotech(Shanghai Pilotech Instruments & Equipment Co, China) was used to spray dry the solutions, equipped with a two fluid nozzle with SUS316L stainless steel. Formulation #1-#4 were dried using nozzle jet 1.5mm, formulations #5-#8 using nozzle size 1mm. De-blocker frequency was set to every eight seconds.
All runs started with the same conditions, changes in T_{in}, pump speed and airflow volume were made throughout each run to regulate T_{out}. After literature research, expert recommendation and trials with run #1.1 and #1.2 resulted in the outlet temperature to be aimed between 83-87℃, but finally ranged from 75-88℃. Parameters were adjusted within the following ranges:

- The inlet temperature: 150-162℃
- Pump speed: 42-46 -> 2.3-2.5(L/h)
- Airflow volume: 30-34 -> 95-107(m^3/h)

The powder that is separated from the hot air in the cyclone, has fallen in the 'right collection vessel', while the particles that have fallen down under the chamber are in the 'left collection vessel'.

3.2 ANALYSES:

3.2.1 Moisture content.

GEA Niro Method No. A 1 a protocol was followed. Samples were dried in a drying oven at 102°C in duplicates for 4 hours and weighed before and after to calculate the moisture content. The method was tested by drying samples for 5 hours and weighing the samples every hour, where the weight did not change more than 0,005g per sample after 4 hours. All samples were measured as soon as possible after spray drying, and all within a week. The drying oven used for this and other analyses is Termarks TS 8056 (no.98638, Norway).

3.2.2 Water activity (aw)

All samples were measured for their water activity with a water activity meter at 21℃, AquaLab series 3 TE, RS232A (10059120B, Decagon Devices, United Stated) in duplicates.

3.2.3 Microscopy

An Olympus Optical Co., LTD. U-ULH (no. 6M11933, Japan) microscope was used to make images of all powder samples, as well as them dispersed in water and suspension oil.

3.2.4 Wettability and sinkability

IDF-Standard 87:1979 protocol was followed with further modifications. 1g of powder sample was dropped on 20mL of room temperature water in duplicates. The time it took for the powder to reach a visible equilibrium of dispersion into the water as well as the time for all the powder to be wetted and to sink was noted. If the time was more than 5 minutes, the experiment was stopped and the results are shown as >300s. Since most powders did not wet or sink completely within 5 minutes, the time it took for the powder to reach a visual equilibrium was noted.

3.2.5 Dispersibility

Dispersibility of the samples is determined using the method described by Cano-Chauca et al. (2005) with some modifications. 0.5g of sample was added to 40mL of distilled water at room temperature, and blended for 30 seconds using an automatic milk frother (IKEA 303.011.67, China). The samples were then centrifuged at room temperature for 5 minutes at 3000 x g. The used centrifuge for this and other analysis is Allegra X-15R Centrifuge(Beckman Coulter ALF 10 039, United States). 10 mL of the supernatant was then added to pre-weighed aluminum plates, which were dried in an oven at 102°C for 5 hours. Dispersibility is calculated as percentage using the weight differences. The test is performed on full fat milk powder, samples #2-#8 and on protein A and B. Using this method, the highest dispersibility would be when the dry weight of the powder is a quarter of the total weight of the powder added. The dispersibility is calculated by multiplying the weight fraction by four and shown as a percentage. The method was tested on the full fat milk powder and protein isolates A and B in duplicates, then singularly performed on samples #2-#8.

3.2.6 Foamability

For the foamability, the GEA Niro Method No. A 17 a method was followed with some modifications. The dispersion from the wettability and sinkability test was transferred to a 50mL tube and shaken ten times up and down in duplicates. After 10 minutes, it was noted if the foam was still present or disappeared. The foam layer was noted as the milliliter marks on the tube. This method was chosen to mimic the shaking of a product containing milk (e.g. ice coffee).

3.2.7 Fat encapsulation

Extractable fat content analysis was performed with the use of Soxtec Avanti 2055-11006 machine(Foss, Sweden), following Niro Atomizer method, No A 10a with some modifications. Petroleum benzine(Merck KgaA, Germany) was used as solvent. 3 grams of powder sample was used. The values for the free fat have been obtained by weighing the fat after extraction. The percentages

of extracted fat in relation to the total fat present in the powder and the thereby obtained percentage of encapsulated fat, are calculated (Appendix 8.2). The method was tested on full fat milk powder, and a sample retrieved from the cyclone of run #7 in duplicates, then performed on the other samples singularly.

3.2.8 Statistical comparison

To determine the effect of the machines' deviation on the results, one formulation (#8) is run two times. The analyses are performed on both obtained powders from both runs. For the moisture content, water activity, wettability(equilibrium), foaming capacity and coffee test and fat encapsulation, the standard deviation between the results of these two powders is then used to determine the relative standard deviation of the analyses. This value is then used to determine the standard deviation of each sample for the corresponding analyses.

$$relative\ st.dev = \frac{st.dev(8.1\ \&8.2)}{average\ of\ measurements\ 8.1\ and\ 8.2}$$

$$s = \overline{m} * relative\ st.dev \qquad where\ \overline{m}\ is\ the\ measurement\ of\ the\ sample$$

An approximate 95% confidence interval was calculated using:

$$\overline{m} \pm 2 * \frac{s}{\sqrt{2}}$$

The results are plotted per analysis. Two samples show significantly different results (at the 5 % level) if (and only if) the 95 %-confidence intervals do not overlap.

3.2.9 Food applications

3.2.9.1 Coffee test

ISO 15322/IDF 203:2005 was used. Where 2g of every powder sample was added to 0.8g of instant coffee with 100mL of boiling water at 80°C(Bellarom instant coffee classic, Germany). For the reference with Sproud Barista, 10.8mL and 18.5mL were added to the coffee to contain about 0.19g and 0.39g protein respectively. The contents were stirred 6 times clock- and anticlockwise, and a single gentle stir after 10 minutes. The contents were then divided over two 50mL tubes and centrifuged at 164G for 5 minutes. The test was performed in singular and the result is the combined sediments of both tubes estimated to the milliliter marks on the tube.

3.2.9.2 Chocolate

Homemade milk chocolate recipe was followed to prepare the chocolate bars for the sensory panel (Taylor, 2021). The method differed from the instructions on the fact that the powdered sugar (Florsocker, Dansukker) and all powders were also sifted, just like the cacao powder (Cacao Ögon, Fazer, Sweden). The ingredients were mixed with melted, deodorized coconut oil. The recipe was halved when the sample powders were added. The chocolate bars were stored in the fridge and tasted blind and randomly by 5 Sproud employees. The participants were inexperienced in tasting so they were asked to focus only on appearance, texture and taste, and their preference. The samples were obtained from the machine during disassembling due to the limited amount of sample in the right collection vessel, and assuming it would not affect the flavor profile.

3.2.10 Ingredients in analysis

To compare the obtained samples with conventional milk powders, skimmed milk powder(SMP) (Semper Mjölk pulver, Sweden), full fat milk powder(FFMP) (Nido Instant full cream milk powder, Nestle, The Netherlands), PLNT vegan topping (PLNT)(Pelikan Rouge Coffee Roasters B.V., The Netherlands), spray dried oat milk powders C15 and S30 (15% and 30% sugar respectively) were used. Some of them are analyzed under the same under the same conditions as the obtained samples.

4 RESULTS AND DISCUSSION

4.1 IN- AND EXCLUDED SECTIONS

Before the start of this research, it was not sure if the created formulations would result in powder at all. However, it quickly became clear that it was indeed possible to obtain a powder, and different formulations were created. The spray dryer has been run 13 times, of which the results of 10 runs are set out in this section. The dates of the run, the sample identification, a description of the solution and the weight of obtained powder from the left and right collection vessel are shown in Table 2. When referring to samples further on, the corresponding maltodextrin:sucrose ratio and used protein are named as shown in the column 'text reference' in table 2. Where the samples retrieved from the formulation with only sucrose or only maltodextrin and protein A are referred to as 100s-A and 100m-A respectively, the sample with only maltodextrin and the double amount of protein as 100m-dpA. The formulation containing protein A and half maltodextrin, half sucrose is referred to as 50m/50s-A, and with 75% maltodextrin and 25% sucrose as 75m/25s-A. The same ratio of maltodextrin but protein B is referred to as 75m/25s-B and the sample form the formulation containing 65% maltodextrin, 35% sucrose as 65m/35s-B.

Table 2- Sample overview

Date	ID	Description	Text reference	Yield left collection vessel (g)	Yield right collection vessel (g)
4-5-2023	#1.1	only sucrose (protein A)			0,9
4-5-2023	#1.2	only sucrose (protein A)	Base100s-A		2,3
12-5-2023	#2.1	only sucrose + lecithin (protein A)	100s-A	1,5	7,0
26-5-2023	#3.1	only maltodextrin (protein A)	100m-A	113,5	39,5
26-5-2023	#4.1	only maltodextrin + double protein A	100m-dpA	108,0	46,0
19-6-2023	#5.1	50/50 maltodextrin/sucrose (protein A)	50m/50s-A	33,0	19,0
19-6-2023	#6.1	75/25 maltodextrin/sucrose - 1		43,0	11,5
20-6-2023	#6.2	75/25 maltodextrin/sucrose (protein A)- 2	75m/25s-A	47,0	20,5
20-6-2023	#7.1	75/25 maltodextrin/sucrose + protein B	75m/25s-B	51,5	14,5

26-6-2023	#8.1	65% maltodextrin/35% sucrose (protein B)- 1	65m/35s-B	23,5	20,0
28-6-2023	#8.2	65/35 maltodextrin/sucrose (protein B) - 2	65m/35s-B	20,0	13,0
28-6-2023	#8.3	65/35 maltodextrin/sucrose - 3		0,0	6,0

For the results of the powders obtained by the formulations with 65m/35s and protein B, the average is taken of both measurements.

The obtained weight of powder from the different runs are shown to give an indication of the yields. There are no further calculations done on the yield of the runs, since they are not seen as a main indication for the quality of the powder. This is also due to the irregularities the machine showed in functionality causing powder to be stuck on the walls of the machine.

4.2 MOISTURE CONTENT & WATER ACTIVITY

Knowing the amount of moisture, and even more the amount of unbound water in a product, is of importance for the safety of that food, in terms of spoilage. More unbound water present in a food, makes it more likely to get spoiled by microbiological growth(Augustin et al., 2003). The average moisture content and water activity of all measured samples is shown in table 3, as well as the confidence intervals of these values(fig. 3 and 4). The value of the uncertainties can be found in Appendix 9.1.

Table 3- moisture content and water activity

ID	Average moisture content (%)	Average water activity (aw)
SMP	4,59	0,37
FFMP	2,67	0,24
PLNT	2,09	0,33
S30	3,40	0,21
C15	3,07	0,18
Base100s-A	3,04	0,27
100s-A	2,60	0,23
100m-A	2,78	0,14
100m-dpA	2,74	0,18
50m/50s-A	2,32	0,27
75m/25s-A	1,98	0,22
75m/25s-B	3,14	0,29
65m/25s-B	2,56	0,29

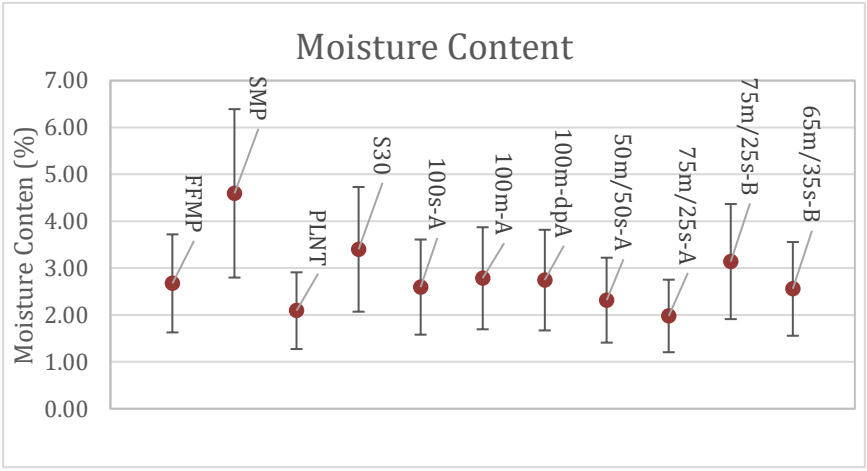

Figure 3- Confidence interval moisture content results

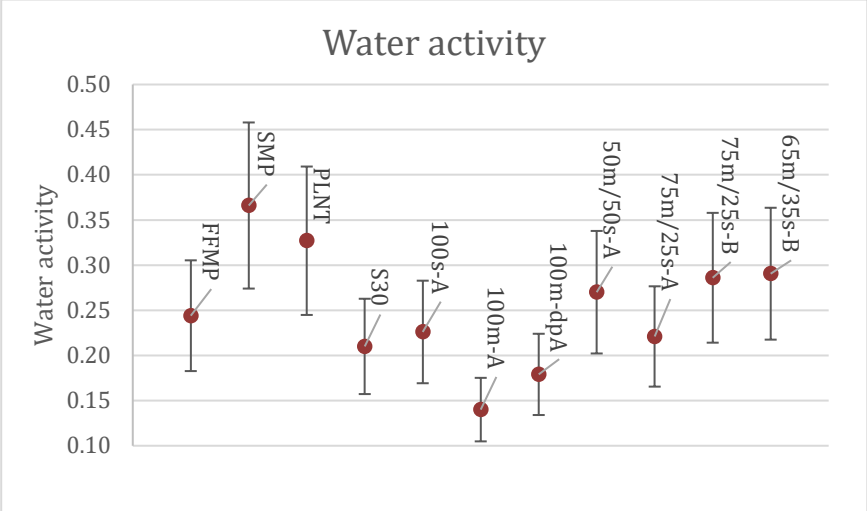

Figure 4- Confidence interval water activity results

The moisture contents of the samples are all lower than 3.5%. All samples should be considered safe against microbiological spoilage since they all have a water activity below 0.4, which is the critical value for microbiological growth(Augustin et al., 2003). Only the commercially bought powders SMP and PLNT have the possibility to be above this critical water activity level due to the uncertainty. As shown in figure 3, the moisture contents do not significantly differ between all samples, since their results overlap. Reasoning for the results of other samples is therefore just an indication.

Looking at the different maltodextrin:sucrose ratios of the samples containing protein A and B, it seems that these ratios did not have a great effect on the moisture content. The moisture content of the samples containing only sucrose and only maltodextrin are very similar (100s-A; 100m-A), while their water activity levels differ quite a lot, indicating that the presence of maltodextrin increases the water binding properties, reducing the amount of free water. This is in line with the water activity of the samples containing protein A and altering maltodextrin:sucrose ratio's (100m-A; 75m/25s-A; 50m/50s-A) increases with increasing sucrose content. The samples containing only maltodextrin show a very similar moisture content, and a quite similar water activity, despite having a different protein content(100m-A; 100m-dpA). The moisture content and water activity of the sample with 75m/25s and protein A is the lowest, while the moisture content of 75m/25s with protein B is the highest. Combining these results, indicates that the source of protein influences the moisture content more than the amount of protein and the changes in maltodextrin:sucrose ratios.

4.3 MICROSCOPY

To see if the powder samples have great differences in particle size or structure, all samples are looked at under the microscope. Images of the powders are shown in figure 5.

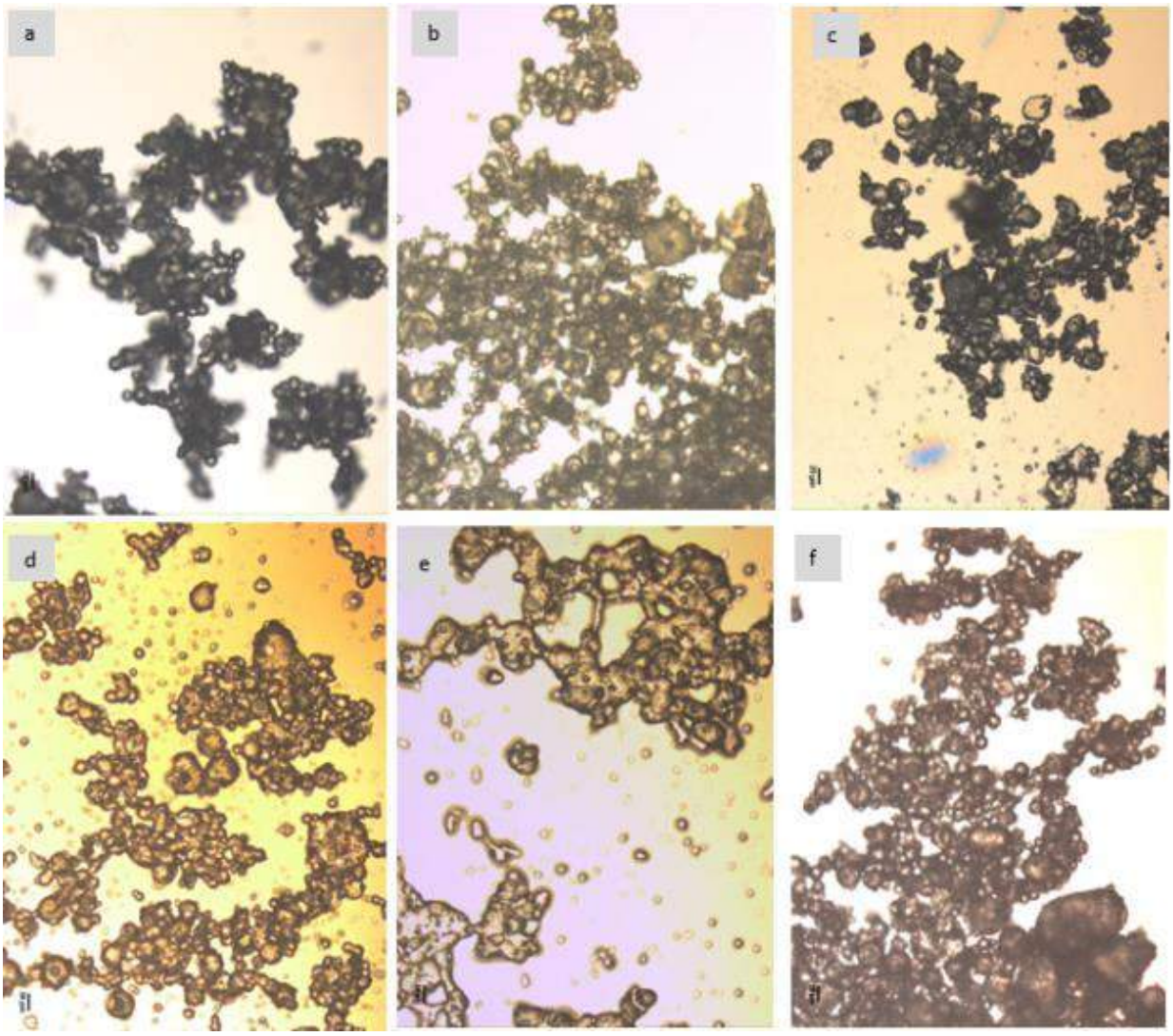

Figure 5- Microscopy images, scale bar 20µm. a) sample 100s-A; b)100m-A; c)100m-dpA; d)75m/25s-A; e)75m/25s-B; f)65m/35s-B

All images show particles that look aggregated to each other, varying in shapes and sizes(fig. 5). The aggregates seem to be larger in 100m-A and 65m/35s-B. Particle sizes of all obtained samples seem to be between 20 and 50µm. The particles themselves seemed quite spherical in all cases, except for the sample containing more protein, which also appeared to have less smooth surfaces (100m-dpA).

The particle sizes of conventional milk powders differ quite a lot between researches, but variate somewhere between 55 and 130µm for skim and full fat milk powders(Pugliese et al., 2017). It was expected that the powders atomized with the smaller nozzle size, have a smaller particle size, but this is not clearly visible. Powder particles usually appear less spherical and with a less smooth surface when dried under higher temperatures(Both et al., 2020). The reason for the different sizes in aggregates could also be caused by the way the powder was spread on the object glass.

Some difficulties arose when getting the images with the microscope, since very rapidly after spreading the powders on the object glass, the particles started to merge together. The powders probably took up the moisture from the air, resulting in inaccurate readings for samples with

50m/50s-A. It must be noted that this analyzation was performed in June, when the relative humidity in the air is high overall. Images are taken of sample 65m/35s-B after 1, 4 and 10 minutes to give a visualization of the sensitivity of the powders when exposed to ambient air (fig.6).

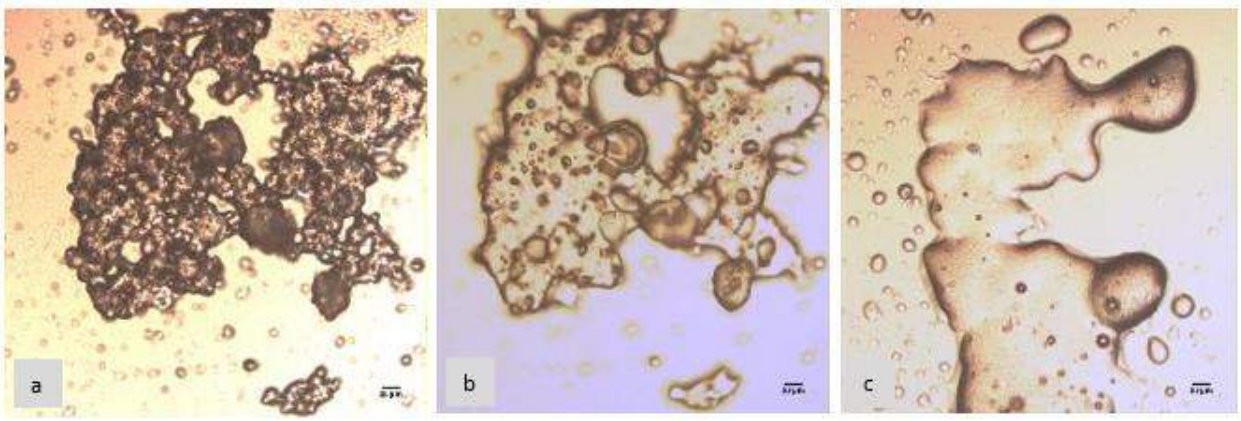

Figure 6- Microscopy images of sample 65m/35s-B. scale bar 20µm. a)t = 1min; b) t = 4min; c) t = 10min

Powders are known to be sensitive for taking up moisture, as is shown in this image. With this powder, the moisture uptake happened very rapidly, making the storage conditions and packaging something to be focused on in future research to maintain product stability (H. J. Wang & Lee, 2019).

To see if there was a great difference between the samples containing protein A and B, these protein isolates and one of their respective samples are shown dispersed in water in figure 7.

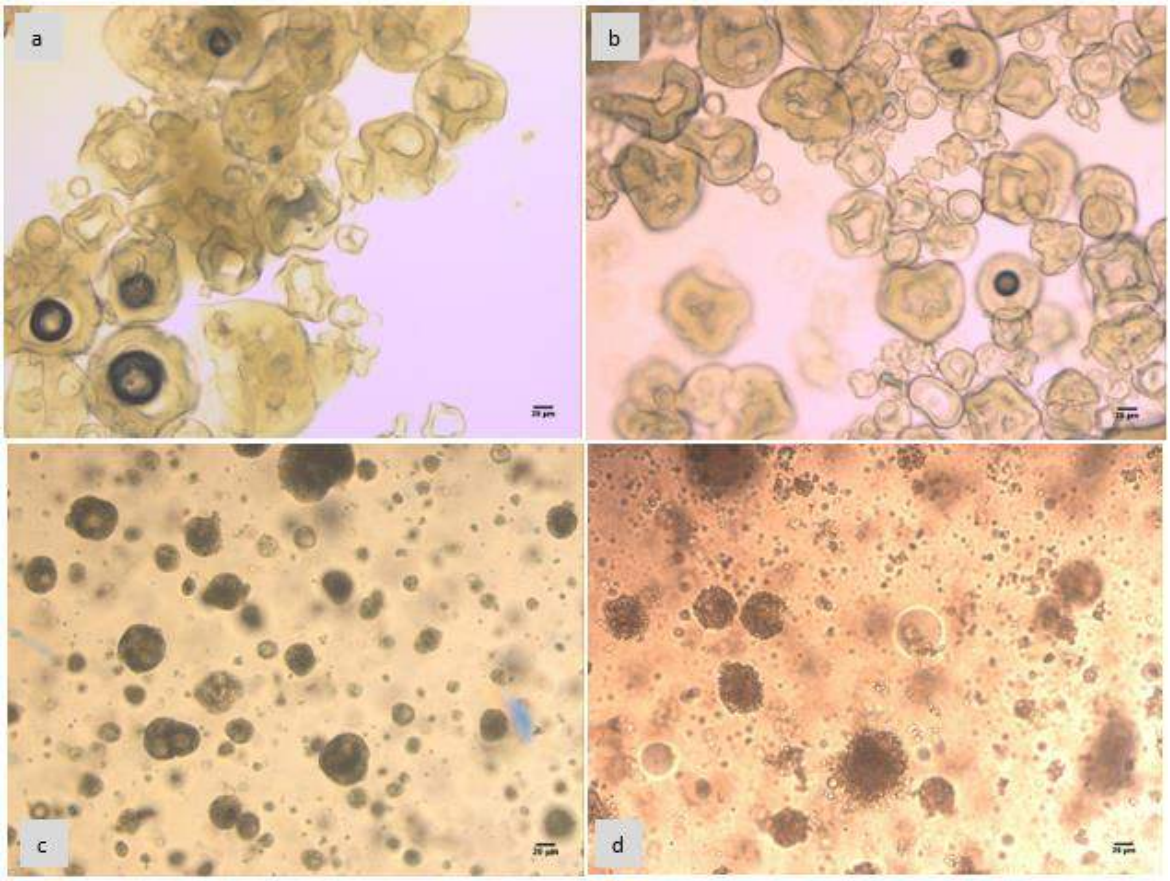

Figure 7-Microscopy images of protein A and B, and samples containing these proteins in water. Scale bar 20µm.. a) Protein A in water; b) Protein B in water; c) sample 100m-dpA in water; d) sample 65m/35s-B in water

The size and shape of both protein A and B in water appear to be similar(fig.7). The samples containing these respective proteins also are similar in size. The sample containing protein B however seems to have more particles present of smaller size, that are not clumped together. The surface of the sample containing protein B also seems less smooth, or having more smaller particles sticking to the surface.

4.4 WETTABILITY AND SINKABILITY

The results for the wettability and sinkability of the samples are shown in table 4. If all the power sunk quickly, not reaching a visual equilibrium, the time for equilibrium is marked (-). The confidence interval is determined based on the equilibrium time and shown in figure 8.

Table 4- Wetting- and sinking time results

Sample ID	Equilibrium time (s)	Sinking time (s)
PLNT	90	>300
FFMP	-	13
SMP	30	40
S30	-	16
Base100s-A	-	10
100s-A	-	6
100m-A	90	>300
100m-dpA	90	>300
50m/50s-A	70	>300
75m/25s-A	135	>300
75m/25s-B	35	>300
65m/35s-B	35	>300

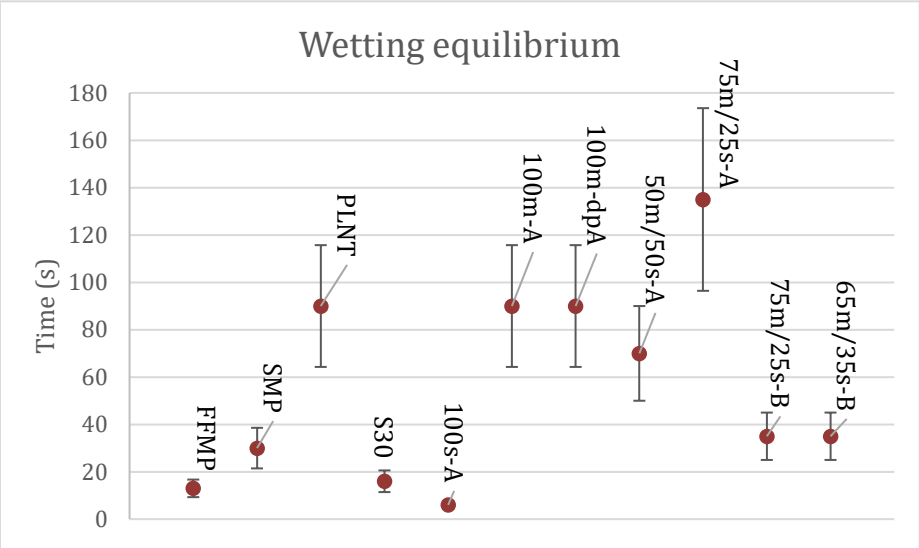

Figure 8- Confidence interval wetting time

The time it takes to wet and sink is one of the most important reconstitution properties of powders. It is of high importance for the powder to be properly used in food production processes (Hogekamp & Schubert, 2003). Wetting times are usually desired to be short, which is often correlated to higher amount of sugar and lower amounts of fat and protein at the surface of the particles, as well as larger powder particles with a size larger than 90µm (Fournaise et al., 2021). It is therefore expected that the sample containing more protein (100m-dpA) has a long wetting time. Since the overall particle sizes are usually smaller than 90µm in diameter, resulting in the expectation of the wetting times not being very short.

As seen in figure 8, the powder containing only sucrose (100s-A) has a very fast wetting and sinking time, which is even faster than the conventional milk powders. As soon as maltodextrin is added to the formulations containing protein A, the wetting times increase significantly, but remarkably not linear(100m-A; 50m/50s-A; 75m/25s-A). It would be expected that the wetting times would be longer with increasing amounts of maltodextrin, but the sample containing 75m/25s-A showed an even longer wetting time than the powder containing only maltodextrin(100m-A). The samples containing protein B (75m/25s-B; 65m/35s-B) took less than half the time to reach an equilibrium, with the biggest difference remarkably being between the samples with the same maltodextrin:sucrose ratio (75m/25s-A; 75m/25s-B). The final sinking times of the powders with protein B were comparable to the powders with protein A, indicating that protein B made the powder easier for the water to break the surface tension, but not sink. The double amount of protein in 100m-dpA did not seem to influence the wettability, which was not as expected, since Hailu et al. (2023) states that a higher level of protein on the surface, and thus hydrophobic protein, could create a problem in water penetration.

4.5 DISPERSIBILITY:

The results of the solubility test are shown in table 5, the confidence intervals are shown in figure 9.

Table 5- Dispersibility results

Sample ID	Dispersibility (%)
FFMP	96,12
PLNT	99,52
100m-A	100,90
100m-dpA	92,65
50m/50s-A	98,84
75m/25s-A	96,97
75m/25s-B	87,15
65m/35s-B	88,20
Protein A	21,63
Protein B	55,87

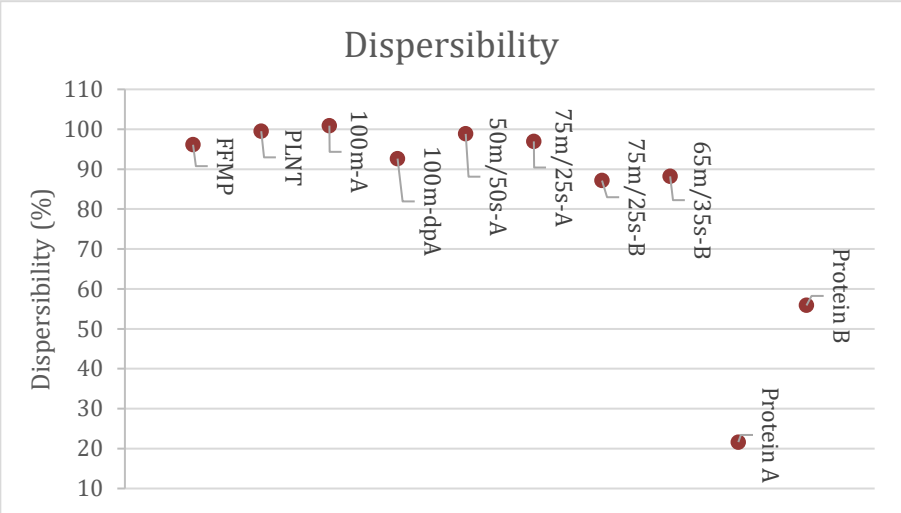

Figure 9- Confidence interval dispersibility test

Pure protein isolate B performs significantly better at the dissolvability test than pure protein isolate A. However, when this protein was present in the powders, these powders showed a significantly overall lower dispersibility compared to the samples containing protein A, even with the same ratio in maltodextrin and sucrose. This is in contrast with both the results from the wettability test and the expectation. The sample containing only maltodextrin also scored the best on this test out of all samples, even compared to the conventional milk powders, which is against the expectation. However, that 65m/35s-B scores slightly better than 75m/25s-B, and 50m/50s-A performed slightly better than 75m/25s-A does follow expectations, since these contain more sucrose. It must be noted that the difference between 65m/35s-B and 75m/25s-B is however not significant. The addition of protein in 100m-dpA decreased dispersibility significantly, possible due to the higher molecular weight of the protein.

The dispersibility of the powder is a very important component for the stability. In an ideal solution, the powder would disperse homogenously in the entire sample, and would not create a pellet when centrifuged. In this method that would translate to the dry weight to be 25% of the total weight. In a study of Trevino (2007) it is stated that some hydrophilic amino acids contribute more to a proteins solubility than others, specifically serine, glutamic- and aspartic acid (Trevino et al., 2007). When comparing the amino acid profiles in the specifications of protein A and B, these three amino acids are more abundant in protein B. When mixing the samples prepared using protein B with water, they would be expected to disperse more easily. Cano-Chauca et al. (2005) states that sucrose should disperse better than maltodextrin, but maltodextrins with high DE should also disperse better.

It must be mentioned that the results of this test give extremely high dispersibility rates for the obtained powders, especially considering there was still a visible pellet in the bottom of most test tubes after centrifugation. There might have been an issue that has been overseen when performing the experiment.

4.6 *FOAMABILITY*

A powders' ability to create and maintain a stable foam is of importance for some applications. When frothing milk this foam is desired, while it is usually undesired in food processing operations(Voderbet, 2007). The results of the tests is shown in table 6 and figure 10.

Table 6- Results foamability and foam stability

Sample ID	Average foam after shake (ml)	Foam stability
PLNT	3,0	-
FFMP	0,0	-
SMP	13,0	- ++
S30	4,0	+
Base100s-A	8,0	--
100s-A	5,0	-
100m-A	5,5	+
100m-dpA	5,0	+
50m/50s-A	7,5	+
75m/25s-A	5,5	-
75m/25s-B	5,5	++
65m/35s-B	5,8	++

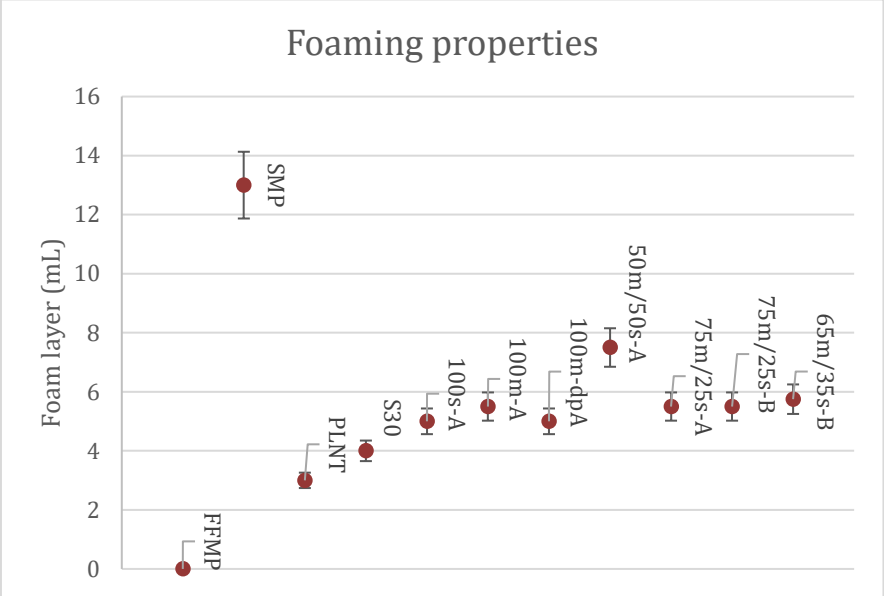

Figure 10-Confidence interval foaming properties after 1 shake

Figure 10 shows no significant difference between the samples containing protein A and B. The foaming capacity of the sample with 50m/50s-A was the highest, while of the sample containing only sucrose was the lowest(100s-A). Apparently, the presence of sucrose increasingly favored the foaming capacity, but to a certain extend. It is remarkable that the foaming capacity of the samples containing only sucrose and only maltodextrin (100s-A; 100m-A) does not differ significantly. Meaning there must be a ratio resulting in an optimal foamability. In Alavi et al. (2021) the addition of maltodextrin increased the foam capacity for faba bean protein isolate, but only when the pH of the solution changed and/or the temperature was increased. Foam stability is increased at a proteins isoelectric point since there is less electrostatic repulsion. Denaturation also increased the foaming stability and capacity of soy protein due to increase in surface hydrophobicity(Narsimhan & Xiang, 2018). It might be interesting to test heating and pH changes for these pea proteins in further research, together with other ratios of maltodextrin and sucrose.

The sample containing more protein (100m-dpA) was expected to have a high capacity to foam, which is not the case. Foam exists as a dispersion of gas in liquid, in a high-volume fraction. The capacity of a liquid to foam is its ability to trap gas. The surface tension decreases when they adsorb at the interface of water and air(Narsimhan & Xiang, 2018). Longer term foam stability is therefore connected to proteins and their conformation and flexibility, since they have an emulsification function. The foam is stable if this gas can be entrapped for longer time. More protein usually results

in a higher foaming capacity since it typically results in formation of globular proteins(Narsimhan & Xiang, 2018). The formation of foam depended on the amount of fat, the processing conditions, and frothing temperatures(Voderbet, 2007).

Looking at the stability of foam, a representation has been made on the time and amount of foam that was left in the tube after shaking it. Where in table 6, two positives(++) means the foam looked stable for longer time, one positive(+) when the foam was still there but a lot less. One negative (-) if the foam layer is almost gone or does not look even or stable and two negatives(--) when the foam disappears very quickly. The foamability of the powders containing protein B was not higher than the ones with protein A, but their foam stability was better than all other samples. This different was especially visible between samples 75m/25s-A and 75m/25s-B. More protein did not seem to influence foam stability. The addition of maltodextrin increased the foam stability, except for sample 75m/25-A.

The biggest difference between the samples is shown between the SMP and FFMP. The FFMP showed almost no foam, which can be explained by the presence of milk fat. The test was performed at lower temperatures, which could have caused this fat to not be fully liquid, which will decrease the foaming capabilities (Voderbet, 2007), but the overall presence of fat decreases foaming capacity. In animal-based milk, citrate salts have shown to enhance foaming properties(Sharma et al., 2012). Addition of calcium salts increased the stability of the foam since it helped adsorb micellar caseins (Voderbet, 2007). Adding these ingredients to the powders could be of interest in future research.

4.7 FAT ENCAPSULATION

As mentioned before, the amount of fat being encapsulated in the powder particles influences a powders reconstitution abilities. More fat on the surface of the powder, and therefore lower rate of encapsulation, usually has an undesired effect on the powders properties. Homogenizing the solution before spray drying, increases the amount of encapsulated fat since this process decreases the size of fat globules (Kim et al., 2009). Ray et al. (2016) states that maltodextrin is commonly used as an encapsulation agent, making it an expectation that the powders containing more maltodextrin will show a higher fat encapsulation capacity. The results of the fat extraction are shown in table 7 and figure 11. More information of calculations during the experiment can be found in appendix 9.2.

Table 7- Fat encapsulation results

ID	Percentage extracted fat/total fat (%)	Fat encapsulation/ total fat (%)
FFMP	12,3	87,7
100m-A	19,0	81,0
100m-dpA	32,9	67,1
50m/50s-A	12,8	87,2
75m/25s-A	14,8	85,2

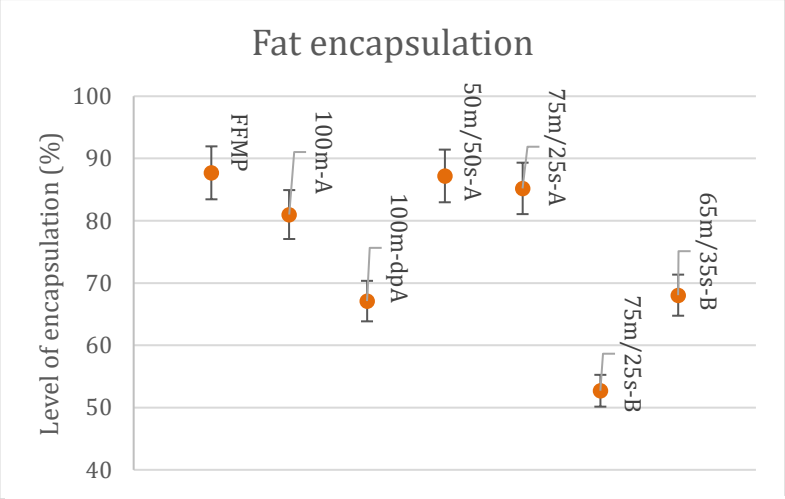

Figure 11- Confidence interval fat encapsulation

75m/25s-B	47,3	52,7
65m/35s-B	32,0	69,7

Samples with protein A and altering ratios in maltodextrin and sucrose (100m-A; 75m/25s-A; 50m/50s-A) show a remarkably high encapsulation of fat, even comparable to the conventional full fat milk powder. These samples are insignificantly different from each other. The samples containing protein B (75m/25s-B; 65m/35s-B), do differ significantly from each other, where more maltodextrin showed a lower encapsulation. Both of these findings go against the expectation that higher maltodextrin ratios would result in better encapsulation. There was not enough powder to perform the analyses on the sample containing only sucrose, but this would have been interesting for comparison. The samples with protein A perform better overall at encapsulating the fat than the ones with protein B, and a higher amount of protein negatively influenced the fat encapsulation. The type and the amount of protein seem to have more effect on the fat encapsulation than the ratio of sucrose and maltodextrin. Millqvist-Fureby (2003) states that the amount of insoluble protein could be correlated to the amount of free fat, but also states that larger protein aggregates encapsulate fat more efficiently, which is in contrast to these findings.

The runs for the formulations with only maltodextrin (100m-A; 100m-dpA) were performed with a larger nozzle size than the other runs, but does not seem correlated to the fat encapsulation. This counteracts Liang & Hartel (2004), who state that a higher flow rate or smaller nozzle size results in a higher amount of free fat. They correlate these differences in free fat to the level of mechanical handling like shearing and scraping, where more mechanical handling results in more free fat (Liang & Hartel, 2004).

A higher amount of fat on the surface of the particles is usually correlated to an undesired reconstitution properties like a longer wetting time(Fournaise et al., 2021). It would therefore be expected that the sample with 75m/25s-B has a long wetting time, which was not the case. On top of that, sample 75m/25s-A, which has a high amount of fat encapsulated, has the longest wetting time. Apparently the amount of surface fat did not influence the wetting times as expected. However, the results from the dispersibility test are in line with these results.

4.8 FOOD APPLICATION I- COFFEE

The coffee test was performed to see the effect of the powders in coffee due to the desire of the powders being used in coffee vending machines. Especially the visual effects are of importance, since a major part of the success of such a product is consumer preference.

4.8.1 Visual behavior of reference powders

The coffee test was performed on 4 reference powders (Fig. 12).

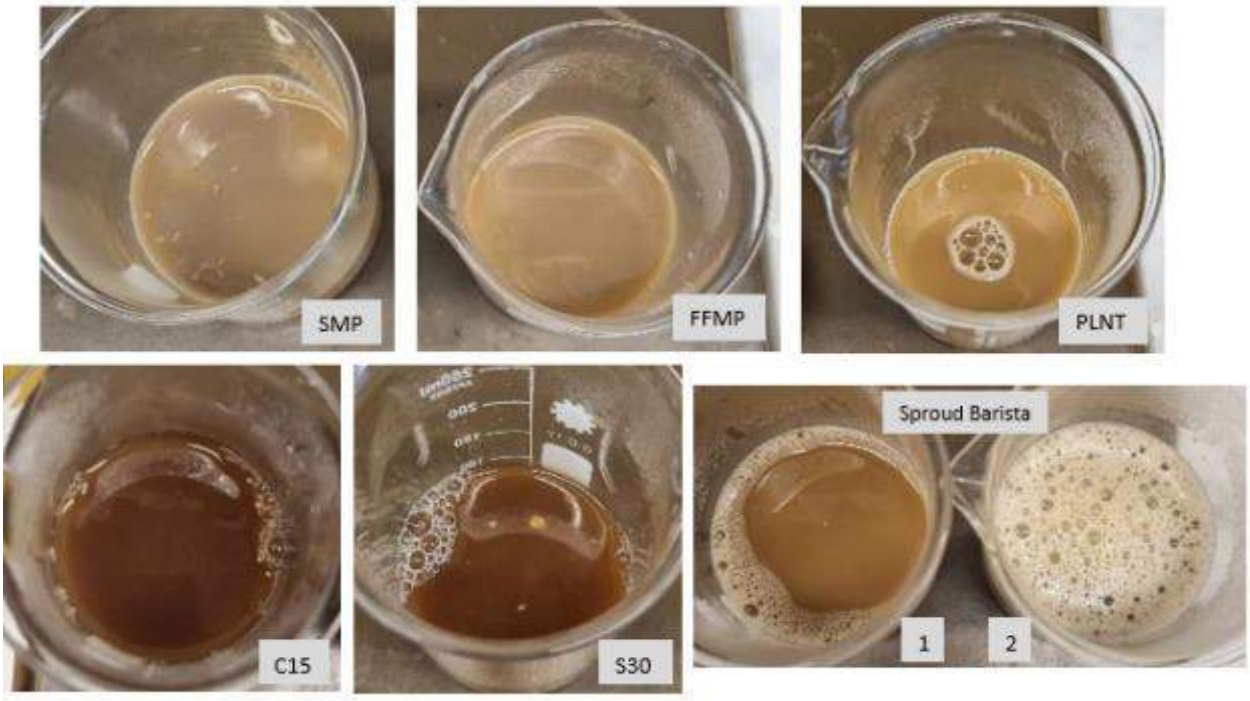

Figure 12 Visual representation of the coffee test references showing SKM: Skimmed Milk Powder, FFMP: Full Fat Milk Powder, PLNT: PLNT vegan topping, S30: Spray dried oat milk 30% sugar, C15: spray dried oat milk 15% sugar; Sproud barista (1) containing approximately 0,2g protein; Sproud barista (2) containing approximately 0,4g protein.

Figure 12 shows that the coffee with added SMP had a small amount of floaters, while adding full fat milk or PLNT powder did not. The powder seemed to disperse well in these samples and all showed a change in the color of the substance from dark brown to light brown, which is what the consumer would expect since it is similar to adding regular milk. The coffee with the spray dried oat milk powder had minimal floaters, but mostly aggregates on the bottom of the beaker.

Sproud Barista milk product is used as a reference, to show what effect a similar amount of protein added in the form of Sproud product would have when added to coffee. As expected, when adding Sproud Barista, no floaters appeared, and the color of the coffee turned lighter, similar to the reference samples (SMP, FFMP, PLNT). Both samples showed more foam on the top, with more foam in the sample containing more barista product.

4.8.2 Visual behavior of obtained powder samples

An image of each sample during the coffee test is shown in figure 13. The powder obtained from formulation #1 was not enough to perform this test.

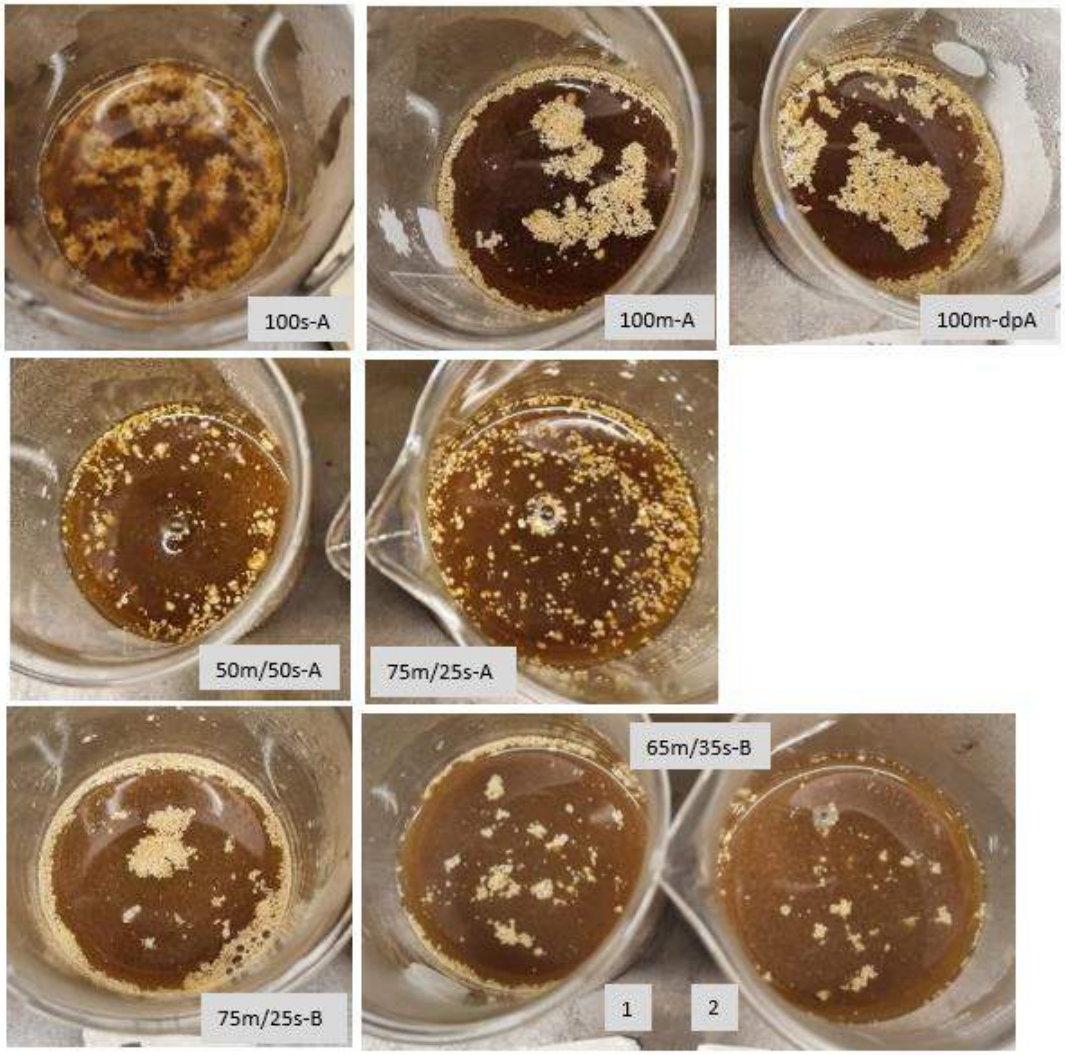

Figure 13. Visual representation of coffee test with obtained powder samples

As seen in figure 13, the samples containing only maltodextrin (100m-A; 100m-dpA) did not result in a lighter color, all other samples had a slightly lighter color, but not comparable to the samples with conventional powder(SMP, FFMP, PLNT). The powder containing only sucrose (100s-A) did not show floaters on the surface of the coffee, but did clump together in 'cloud-like' structures. All samples containing maltodextrin showed spherical floaters and also sinkers in the bottom of the beaker, despite their protein source(100m-A; 100m-dpA; 50m/50s-A; 75m/25s-A; 75m/25s-B; 65m/35s-B). By appearing grainy and dark, all samples do not meet consumer expectation and therefore standards. From the powders with protein A, the samples containing only maltodextrin (100m-A; 100m-dpA) showed the most, and the powder containing 50m/50s-A showed the least amount of floaters. The amount of protein did not seem to have a great influence. From the samples containing protein B, the powder containing 75m/25s-B also showed more floaters than the sample containing 65m/35s-B. This indicates that a higher amount of maltodextrin in the formulation results in more floaters. The sample with 65m/35s-B had the least amount of floaters

4.8.3 Interpretation of differences between formulations and reference samples

As mentioned before, the visual aspects of the powders in coffee are extremely important for the consumer preference. When dissolved in coffee, the proteins in the milk powder can precipitate which is called 'feathering', in dairy this is caused by whole casein micelles binding to fat particles(Sharma et al., 2012). In plant-based materials this can occur with fat droplets being coated by plant proteins (McClements, 2020). The samples contain about 20% fat in their solution, while in the full fat milk powder this is more, reaching almost 30%(Hailu et al., 2023)). Because the feathering did not take place in the sample with FFMP(fig.13), the amount of fat probably did not cause the feathering in the samples. Coffee is an acidic liquid with its pH around 5. When introducing protein to an environment close to their isoelectric point, there is a decrease in negative charge, lowering the electrostatic repulsion between droplets, decreasing their solubility properties. For yellow split pea protein, precipitation occurs in this environment, since the isoelectric point is at a pH between 4 and 5(McClements, 2020; Boye et al., 2010; Hansen et al., 2022). Besides denaturation by these electrostatic forces, denaturation can also have occurred by temperature raise since the coffee test is performed at 80℃. Boukid et al. (2021) states the denaturation temperature (T_d) for pea protein to be around 69-77℃, while the T_d of milk proteins is around 70-100℃(Syed et al., 2021). The question however remains why the proteins in Sproud Barista milk do not seem to precipitate when adding the same amount of protein to the coffee compared to the powder. The replacement of agave syrup with sucrose and maltodextrin in different ratios could have been a reason, since there is already such a great difference between the samples with and without sucrose. Another reason can be the change in fat source, Lecithin has shown to improve regular milk powder stability in coffee by decreasing the amount of free fat, making it interesting to vary this amount in further research (Żbikowska & Żbikowski, 2006). While both cases contain an acidity regulator, that increases heat and protein stability (Bende, 2023), its function could have been affected by the spray drying process. Hoyt et al. (2023) states that the intensity of heat treatment in regular milk, negatively influenced the milk powders stability. They also stated that the strength and temperature of the coffee, as well as water hardness used to infuse primarily affected the test results.

4.8.4 Sedimentation results coffee test

The coffee test is performed since the level of sedimented material is a measure to the powders' stability, where a high amount of sedimentation indicates a high instability. Results of the coffee test are shown in table 8 and figure 14.

Table 8- Coffee test sedimentation

Sample	Estimated sediment (mL)
PLNT	<1
FFMP	6
SMP	2
S30	6
C15	6
Sproud 0,2g	<1
Sproud 0,4g	1
100s-A	8
100m-A	7
100m-dpA	10
50m/50s-A	5
75m/25s-A	7
75m/25s-B	<1
65m/35s-B	<1

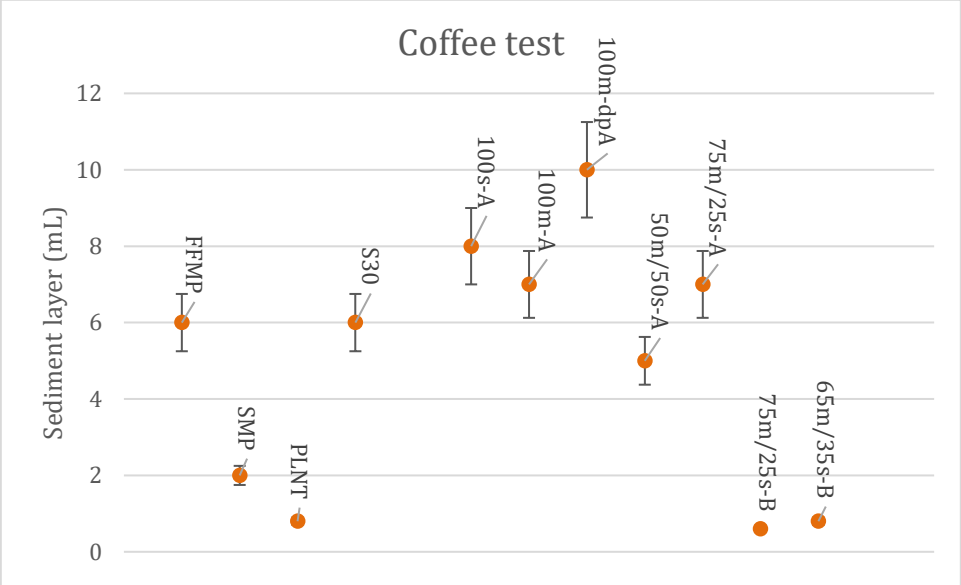

Figure 14- Confidence interval Coffee test

The samples containing protein B (75m/25s-B; 65m/35s-B) show the least sediment, which is remarkably low and comparable to PLNT and skimmed powders. Indicating that the dispersibility properties of this protein might be more favorable in coffee compared to the protein A, apparently, a better performance in wettability and dissolvability does not translate to a better performance in coffee sedimentation. The sample containing 50m/50s-A showed significantly less sediment compared to the other samples containing protein A (100s-A; 100m-A; 75m/25s-A), while they surprisingly do not differentiate significantly from each other. Combining these results indicates that the sedimentation is more affected by the amount and type of protein source, than the ratio of maltodextrin and sucrose. Following that, the sample containing more protein(100m-dpA) is significantly different from 100m-A, and resulted in the most feathering and sedimentation of all samples. Its recipe however, is most comparable to Sproud Barista when looking at the ratios of solid content. The difference could be caused by the higher amount of protein coagulating and sinking to

the bottom. The solubility of amino acids in these pH conditions are different than in water. Since this environment is more acidic, the solubility of aspartic- and even more glutamic acid decreases(Salazar et al., 2016). In (Trevino et al., 2007) it is stated that the solubility of aspartic acid and serine show a dramatic decrease in solubility when the pH was lowered from 7 to 4.25. The solubility of these amino acids decreased more than three times, compared to others that decreased in solubility less than two-fold. This, in combination with these amino acids being abundant in these protein sources, could explain the powders not dispersing well in the coffee. This however does not explain why the samples containing protein B sedimented less.

4.9 FOOD APPLICATIONS- CHOCOLATE

While the fat encapsulation is important for the dispersibility and dissolvability of the powder in water, in chocolate production it will help to stabilize blooming(Liang & Hartel, 2004). As mentioned before, a higher level of free fat is desired in chocolate production, causing manufacturers to usually add even more cacao butter when using spray dried milk powder(Liang & Hartel, 2004).

To test the performance of the powders in a food application, chocolate bars were made with powders: FFMP; 100m-A; 50m/50s-A; 75m/25s-A; 75m/25s-B. The reason for these samples was to test if the taste panel could notice the differences in maltodextrin:sucrose ratios, in protein source and if they could spot out the dairy powder. Pictures of the front and backside of the chocolate bars are shown in figure 15.

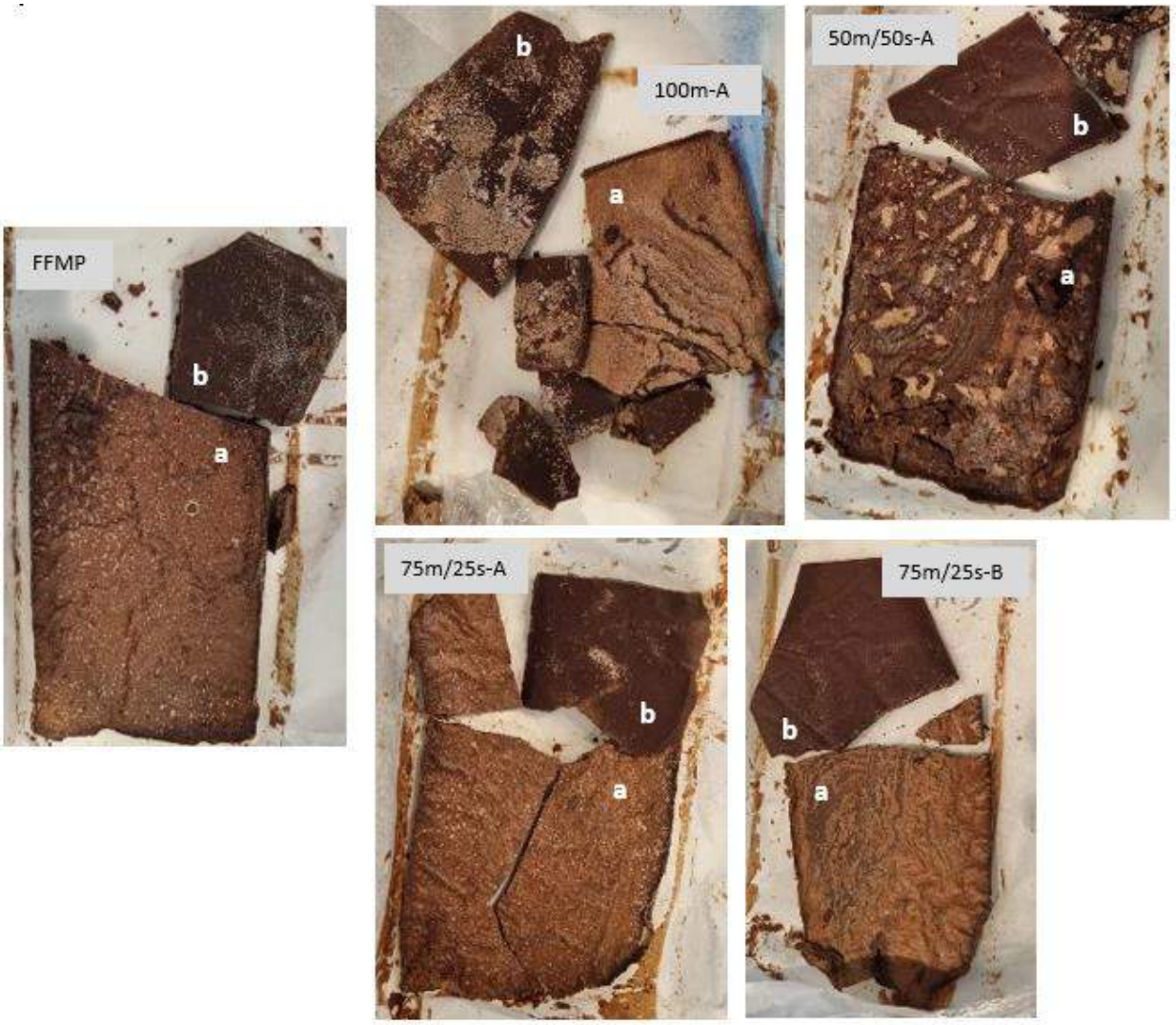

Figure 155- Visual representation of the chocolate bars, prepared with different powders (food application). Top sides of the chocolate bars are labeled 'a', bottom sides 'b'.

The chocolate bar with full fat milk powder was made as a reference and showed an overall light color on the frontside, with white dots all over. The backside of the bar had the darkest color, also with white dots spread on the bottom. The bar made with only maltodextrin (100m-A) had the lightest color on the front of all bars, with a marbled effect. The backside was slightly less dark compared to the bar with FFMP, but had the most and biggest white dots. The bar made with 50m/50s-A showed the most uneven and darkest surface on the front, with a very smooth and even appearing backside. The bar made with 75% maltodextrin and 25% sucrose and protein A(75m/25s-A) had visually the closest similarity to the one prepared with FFMP, both on the front and backside, because some white dots are present and quite clustered. The bar made with the same maltodextin:sucrose ratio and protein B (75m/25s-B) had a frontside with lighter coloration in a marbles effect, the backside looked most similar to the bar prepared with 50m/50s-A with a little amount of white dots.

All chocolate bars showed blooming on the top, which is probably caused by the storage in the fridge. All bars were stored in the same fridge for the same amount of time, but still show a big difference in appearance. At first it seemed that the high amount of maltodextrin in 100m-A caused the higher amount of white dots at the bottom. This hypothesis is supported by the fact that the bar with 50m/50s-A shows the least white dots, while the bar made with 75m/25s-A sucrose showed an amount of dots somewhere in between. However, the bar made with 75m/25s-B showed even less white dots than 50m/50s-A, despite having a higher maltodextrin rate. Apparently, the presence of protein B, affects the amount of white dots.

The participants contributing to the sensory analyses were not trained in tasting. Due to the small number of participants (6), a panel discussion setting was chosen. The participants were numbered 1-6 and asked to focus on the appearance, texture and flavor of the different chocolates, while also stating their overall liking. Some participants had one favorite, others had two favorites. The preferences of the participants are shown in table 9.

Table 9- Sensory analysis likeability results

Participant	**Preference**
1	50m/50s-A and 75m/25s-A
2	75m/25s-B
3	75m/25s-B
4	50m/50s-A and 75m/25s-B
5	50m/50s-A and 75m/25s-B
6	50m/50s-A

Overall, most participants named the chocolate made with 50m/50s- as their favorite chocolate, followed up by the chocolate made with protein B. It is interesting that the panel preferred the taste of the chocolates that also showed the least amount of white dots visually. It was expected that the participants realized which sample was prepared with the dairy containing milk powder, and which with pea protein, but no one could identify the chocolate prepared with FFMP. It is important to state that 4 out of 6 participants work at Sproud, and therefore regularly consume products containing pea protein, which may have caused them to be used to this flavor. It was also expected that the bars containing 75m/25s would be perceived similarly, despite their difference in the origin of the protein, but the one containing protein A was presumed way less appealing instead. The most preferred chocolates were perceived to be very similar, while they differ in both maltodextrin:sucrose ratio and protein source. Apparently, the less appealing taste of protein A was less noticeable when the sucrose content was higher. In future food application tests on chocolate, it would be interesting to try different ratios of maltodextrin:sucrose and protein B.

Because the sensory analysis was performed in a panel discussion setting, the participants could discuss their opinions, which therefore could have been influenced. In a panel discussion, you lose some information from the separate participants, but in this panel, the participants mostly agreed on what was said, and also on their most favorite chocolate samples. It is also important to mention that

everyone has their own idea and interpretation while tasting food. It can be difficult to align the meaning of words people use to describe a taste or texture. A detailed explanation of the test panels tasting is shown in appendix 9.3

4.10 COMPARING TO CONVENTIONAL MILK POWDERS

The tests are performed on the obtained samples and one or more conventional milk powders to compare. To function in current food production processes, one could aim to achieve the same powder properties, and therefore score the same on all analyses as these conventional powders. Looking at the moisture content and water activity, it is mostly important that the powders are not prone to microbiological spoilage, which none of the samples were. For the wettability and sinkability, only the sample containing just sucrose and protein A is comparable to the FFMP, but this sample did not specifically perform better in other applications like when added to coffee. The samples containing protein B did not perform the best in the dispersibility test, but did show the least sediment in the coffee test, where the FFMP did not function desirable. Sample 50m/50s-A performed great in the foamability test and was preferred in the chocolate, while the FFMP did the opposite. These findings show that it might not be the goal to directly mimic the conventional powders, but to put more focus on what the desired properties for the expected application are, and base the formulations on that.

4.11 OTHER DISCUSSION POINTS

All samples were stored in similar plastic containers with a tightly closed lid, and kept in a dark room to keep the quality as stable as possible. Over summer, some samples were stored in a desiccator. The samples were transferred to their containers as quickly as possible. The analyses were mostly performed as soon as possible after obtaining them, but for logistical reasons not always within the same week. The analyses were not always performed in the same order. For every analysis the container had to be opened while taking the sample out. Despite the efforts to open the containers as shortly and less often as possible, every time they were opened, moisture entered the container. As mentioned before, the humidity in the air in the duration of this project was high, and unstable. This could have caused analyses to give a less accurate result.

4.12 LIMITATIONS

During the project, there were some problems and inconsistencies when running the spray dryer. At times, the machine and powder behaved differently than expected, and the machine settings needed quite a lot of altering during some runs to maintain a stable T_{out}.

In this section, the runs that created extensive problems are explained, followed by the possible reasons that could have been the reason for this behavior. 75m/25s-A had to be run a second time, since T_{out} kept dropping during the first round, and the powder did not look representable for the changes made. Solution 65m/35s-B was initially performed three times to perform statistical analyses for batch comparison. However, the amount of powder from the third run was very low and unable to be retrieved from the vessel. The left collection vessel even contained some milliliters of solution. In the first 5 minutes of running this solution, there was some droplet formation on the glass windows, which were tightened more when noticed. The humidity in the pilot hall was very high, since the floors were wet from cleaning them. It is expected that one or both of these reasons resulted in a sticky powder, disturbing the airflow in the beginning of the run, causing the run to fail. Because

of this it was chosen to leave out the results from the initial run for 76m/25s-A and the third run for sample 65m/35s-B. It is possible that results of earlier runs have also shown problems, but were less noticeable due to inexperience.

The first possible explanation could be an inconsistent inflow of solids during the runs. The solutions were placed on the shelf and the tube connected to the pump was placed in the bottom of the bucket. While the machine was running, the liquid was occasionally stirred through, but not consistently. When a solution of higher solids enters the machine, there is less water to cool down the system, resulting in a higher $T_{out.}$. When a solution is unstirred, sedimentation occurs. If this sedimentation occurs quickly, and the solution is pumped from the bottom of the tank, the drop in temperature during the run could then be explained by the fact that the tube pumps up high solid solution first, and low solid solution at the end. Even though this could have been an influence, it seems unlikely since the solution is homogenized two times. When a sample of the homogenized solution was stored refrigerated over the weekend, there was also no sedimentation visible. In addition to that, the solution for the third run of 65m/35s-B was prepared in the morning, but the first solution for 75m/25s-A was prepared just before running the machine.

The second explanation could result from the fact that there was an inconsistency of the air entering the machine. As mentioned before, the quality of the air going into the system has an effect on the quality of the final product. The liquid is sprayed into the machine with pressurized air coming from a central point. If there was something changing in this air from the central point, it could affect the results. There is also an abundance of literature stating that running a spray dry machine in the summer can be particularly challenging due to the high moisture in the air. As mentioned before, it also highly influences the powders properties like moisture content (Kent & McLeod, 2007). Spray dryers usually have built-in humidity regulation on the air flowing into the system, which in this case was not available. When checking weather logs for the relative humidity in the air during the spray drying days, the values are not remarkably high. It is however interesting to note that in both cases, the runs that underwent problems were performed in the afternoon. The machine and floor is cleaned with water causing the environment around the machine to be wet. There were two days where the machine was also run a second time in the afternoon (100m-dpA & 75m/25s-B), where there were no problems noticed at the time. Here, solution 100m-dpA was prepared in the morning and did not show a great drop in temperature and stayed quite stable during the entire run, while the solution with 75m/25s-B was prepared just before the run and did need quite some changes in the parameters due to temperature drop. It should be noted that 100m-dpA did not stick too much to the machine, but did form a thick layer in the chamber, where 75m/25s-B did results in a thick sticky layer in the chamber and also a thicker layer in the tubing. It could be possible that these powders were also affected due to running in the afternoon but were unnoticed either because the recovery rate was quite high (100m-dpA) or because the change could be expected due to the alteration of ingredients. When changing the recipe of a run it is hard to expect how it will affect the run and the powder.

The last explanation results from the way the machine is started up. During this project, the method used initially, where the machine was heated up reaching a steady in- and outlet temperature was, at a later stage identified as possible problem. The water was added to the machine, and when everything looked dry, the tube was placed in the tube. The outlet temperature would then drop quickly and eventually stabilize. It might have been a better option to let the temperature stabilize with the water inflow, to not have an outlet temperature too high, potentially causing the powder not

being uniform throughout the process. Too high T_{out} could also have caused decreased fat encapsulation by cracks appearing in the surface of the powders particles(Sharma et al., 2012).

5 CONCLUSION

It was successful to obtain a powder with plant-based materials using spray drying technique and to test and incorporate them into different analyses and food applications. The different formulations resulted in different performances. The moisture contents of all samples are comparable to the conventional milk powders, and the water activity levels are all below 0.4, which is below the critical value. This indicates that these powders are not prone to microbiological spoilage when stored properly.

Looking at the microscopy, the particle sizes are quite small compared to conventional milk powders found in literature. Smaller particle sizes usually decrease reconstitution properties like wettability and sinkability, which could be overcome by agglomerating the powders in further research. Overall there were no great differences observed between the different powders, despite their differences in formulation.

The formulation containing only sucrose resulted in difficulties during the spray drying process, perhaps due to its low glass transition temperature, but the obtained powder had the shortest wetting and sinking time(100s-A). While higher amounts of protein were expected to decrease wetting time, the source of protein actually seemed to have more influence, where the samples containing protein B performed better. Increasing amount of surface fat was expected to increase the wetting time, but seemed to have no negative effect.

It was expected that the samples containing protein B scored higher on the dispersibility test, due to its higher amount of hydrophilic amino acids. When comparing the protein isolates, this was the case, but when spray dried into the powders, the samples containing protein B scored lower than the ones with protein A despite their faster wetting time. Increasing the amount of protein however decreased the dispersibility.

Against expectation, the sample containing more maltodextrin showed worse fat encapsulation, but was only significantly lower when protein B was present, indicating that the type and amount of protein affected the encapsulation capacity more than the ratio in maltodextrin and sucrose. Samples containing protein A performed better overall at encapsulating the fat. Increase of protein A did not result in a higher encapsulation contrasting the expectation. Mechanical handling in the form of decreasing the nozzle size, did not result in more free fat.

Milk powders eventually are desired to function well in food applications, where in this research the focus was put on two examples, namely coffee and chocolate. Adding any of the samples to coffee visually would not meet consumer acceptance criteria, where increasing amounts of maltodextrin increased the amount of floaters probably caused by the coffees acidic environment being close to the proteins isoelectric point. The amount of sedimentation however seemed more effected by the type and amount of protein, where less protein and protein B were favored. The performance of the powder in the other food application, chocolate, was tested by a small untrained taste panel. The appearance of the chocolate bar was affected by the presence of maltodextrin, where a higher amount increase the amount of unappealing white dots on the bar. The biggest

effect however was shown by the presence of protein B, resulting in the least amount of dots, despite its higher maltodextrin content (75m/25s-B). The tase panel did not identify the chocolate prepared with animal-based full fat milk powder, and preferred the chocolates containing 50m/50s-A and 75m/25s-B evenly.

As shown in this research, there was not one specific formulation performing best in all analyses and applications, but rather showed positive and negative aspects in all of them. Further research in development of plant-based milk powder alternatives should therefore be focused on the desired characteristics of the powder for its intended application, taking advantage of the freedom in endless possible formulations.

6 FUTURE PROSPECTS

In the limited time available during this project, and the initial knowledge of spray drying principles, the focus was set on finding differences or resemblances between different formulations. It was chosen to only alter the maltodextrin, sucrose and protein levels, but it would be interesting to try and alter the other ingredients also. Similarly, testing maltodextrins with different DE-values could be valuable, to find a balance between the dissolvability and stickiness during the process. Since the operation of the spray dyer was often hard to control, it was chosen to operate under similar circumstances to not have too much differentiation in the results. It would be interesting to run the same formulations under different circumstances, to get an indication of the sensitivity of the process, and gaining information on what to focus on. A sensitivity analyses over certain aspects of the process could be of high value. For example, the relative humidity in the air flowing in the machine has been proven to influence the drying time and therefore the product. During the spray drying days, some experiments might have failed due to the high humidity in the pilot hall, since the inflowing air was not regulated or tested on its relative humidity. On top of that, the complete project has been performed between May and July. It could be of value to repeat the project in the winter.

The energy consumption of spray drying processes is high, but could be lowered by decreasing the water content in the solution before drying. A less energy consuming method can be used like evaporation by heating. Because the strength of the feed-pump was unknown, the solid content of the formulation was set at 30%, which is quite low compared industrial spray drying processes. Increasing the solids content and therefor viscosity too much is however also not desired since it could need more pressure and therefore energy to pump the feed, or hinder the formation of drops(Patel, 2009). Since sustainable use of resources and energy is a core value of Sproud, higher solid contents should therefore be tested for their effect on the powders properties.

For the time available, the powders have not been through an agglomeration process, which is usually performed on conventional milk powders to increase its wettability(Hailu et al., 2023). In future development this could be of interest.

In the interest of Sproud, there was a focus on reconstitution properties in water and coffee. Since cold water is used in the analyses, it could be interesting to perform some tests on warm water, possibly facilitating the reconstitution properties. On top of that, milk powders are usually mixed with hot water or steam in current coffee machines. Testing the powders in these coffee machines would give a better insight on its performance in for instance foaming properties.

With the production of milk powders being developed over 120 years ago, the process is evolved close to perfection. Industrial food production has been developed around this product since its functionalities are so well known. Ideally, a plant-based powder should be developed that can simply substitute conventional milk powders in food processes. However, having unlimited possible formulations with different ingredients and ratios, makes developing a product with the same functionalities as milk powder extremely challenging. The question can be asked if creating a product identical to conventional milk powder is even possible and/or desired. Maybe the focus should be on creating powders with properties that are personalized for specific food applications, taking advantage of the freedom in developing a formulation from scratch, instead of having milk as a starting product. It could therefore be of value to test the powders on foods like soups, baked goods or ice creams during the development stages. Ingredients that have properties that increase stability, reconstitution, or maybe even nutrition could be added for different applications. An example is the addition of salt, which was not used now, or a mixture of maltodextrins with different DE-values. Cano-Chauca et al. (2005) states that maltodextrins with lower DE-values showed less caking, while higher DE-values increased solubility properties containing shorter glucose chains. Blending maltodextrins with different DE values could result in a combination of desired functional properties.

Processing steps could also be adjusted depending on different applications. For instance, if freeze drying instead of spray drying processes are used, the structure of pea protein would supposedly be preserved better, increasing water- and oil holding capabilities. However, the foamability and emulsification properties would decrease. These properties might be of high importance for some applications, while irrelevant for others. Whatever the focus will be on, developing a plant based powder to function in current food systems will take a fair amount of talent, time and creativity, but the challenge should be taken on.

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8 APPENDIX

8.1 UNCERTAINTY / CONFIDENCE INTERVALS

The standard deviations and relative standard deviations, as well as their resulting uncertainty based on the differences between the measurements of 8.1 and 8.2, are shown per analyses in table 8 and 9.

Table 10- Overview standard deviation and relative standard deviation based on measurements 8.1.1 and 8.2.1

	Moisture content	Water activity	Wetting equilibrium	Foam shake 1	coffee	Fat encapsulation	dispersibility
st dev	0,71	0,05	7,07	0,35	0,07	2,33	0,45
relative standard deviation	0,277	0,178	0,202	0,062	0,088	0,034	0,005

Table 11- values of uncertainty for the samples per analyses

sample ID	moisture content	water activity	Wetting equilibrium	foamshake1	coffee	fat encapsulation	dispersibility
FFMP	1,046	0,061	3,714	0,000	0,750	4,253	0,706
SMP	1,797	0,092	8,571	1,130	0,250		
PLNT	0,818	0,082	25,714	0,261	0,100		0,731
S30	1,330	0,053	4,571	0,348	0,750		
2.1	1,015	0,057	1,714	0,435	1,000		
3.1	1,088	0,035	25,714	0,478	0,875	3,928	0,741
4.1	1,073	0,045	25,714	0,435	1,250	3,24	0,680
5.1	0,906	0,068	20,000	0,652	0,625	4,229	0,726
6.2	0,774	0,056	38,571	0,478	0,870	4,132	0,712
7.1	1,228	0,072	10,000	0,478	0,075	2,556	0,640
8.12	1,000	0,073	10,000	0,500	0,100	3,300	0,640
Protein A							0,648
Protein B							0,645

8.2 FAT ENCAPSULATION

In the second column, weight if the extracted fat is shown. The third column shows the solids per gram of powder, which are calculated using the respective moisture contents. The fourth column shows the amount of extracted fat per solids by dividing the weight of the extracted fat by the solids in each gram of powder. The fifth and sixth column show, in fraction and in percentage respectively, the amount of extracted fat in relation to the total fat present in the powder. The last column shows the amount of fat that is encapsulated, by subtracting the extracted from the total fat.

ID	Weight of sample	WEIGTH OF EXTRACTED FAT (GFAT/GPOWDER)	SOLIDS PER GRAM POWDER SAMPLE (GSOLIDS/GPOWDER)	EXTRACTED FAT PER GRAM SOLIDS (IN POWDER) (GEFAT/GSOLIDS)	(G EFAT / G TOTAL FAT)	PERCENTAGE FREE FAT/TOTAL FAT (%)	fat encapsulation /TOTAL FAT (%)
FFMP	3,0397	0,023	0,973	0,024	0,123	12,3	87,7
3.1.1	3,0140	0,035	0,966	0,037	0,190	19,0	81,0
4.1.1	3,0120	0,061	0,969	0,063	0,329	32,9	67,1
5.1.1	3,0052	0,024	0,970	0,025	0,128	12,8	87,2
6.2.1	3,0133	0,028	0,974	0,029	0,148	14,8	85,2
7.1.1	3,0041	0,089	0,972	0,091	0,473	47,3	52,7
8.1.1	3,0107	0,057	0,973	0,058	0,303	30,3	69,7
8.2.1	3,0058	0,063	0,977	0,065	0,336	33,6	66,4

8.3 DETAILED DESCRIPTION FOOD APPLICATION SENSORY PANEL

The chocolates were labeled with random letters and tasted in a random order, but the results are summarized in the order above.

Nestle full fat milk powder chocolate looked like it had a double layer due to a color difference halfway through the sample, where the top layer looked slightly lighter. It reminded the participants of a brownie, both in looks and texture. Both participant 2 and 4 preferred the flavor of this chocolate over #3.1.3. Participant 5 noticed a roasted flavor. Everyone agreed on the texture being too grainy to their liking.

#3.1.3 chocolate showed quite some white coloring on the top (blooming). Participant 1 thinks it looks more premium than the other chocolates while participant 3 and 4 think #7.1.3 looks better. Participant 3 said this chocolate was very soft and crumbles more than it breaks. The participants stated this chocolate had a bit of a raw feeling to it, like batter. They compared it to a fudge-like texture where the flavor is not as rich and does not distribute through the mouth like the other samples. They stated it tastes like not their favorite type of chocolate.

#5.1.3 chocolate has a less appealing look to it, but also looks more compact. It is noticed that this chocolate melts slightly faster than others. Participants 3 and 4 state the taste is more full, and participant 1 and 6 add that it blossoms more in the mouth when melting. Everyone agrees that the flavor of this chocolate is one of their favorites.

#6.2.3 chocolate participant 4 states this one has the most appealing look, where it is shiny instead of matt. Participants 3 and 4 think this chocolate is more creamy but still has a slightly grainy consistency. All participants prefer #5.1.3 over #6.2.3.

#7.1.3 chocolate has the best appearance for participant 2 and 4, and was compared to an A-brand chocolate. The smell reminds them more of dark chocolate.