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Development of an Oat milk Recipe for Use in Coffee

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Titre / *Titel*

Development of an Oat Milk Recipe for Use in Coffee

Description / *Beschreibung*

The market for alternative milks for baristas has grown in recent years. Lately, oat milk usage has seen the highest growth. The challenge for these products is to offer organoleptic qualities similar to whole cow's milk when used in coffee, while maintaining foam structure properties during steam injection.
The aim of this study is to develop an oat milk which is stable at room temperature, with minimal sedimentation, and possessing all the functional properties expected by baristas: color, taste, texture, foam. It will focus on the exploration of the use of enzymes, stabilizers, and acidity regulators to obtain a recipe with good foaming properties. In a second stage, the use of aromatic solutions is explored to improve taste attributes.

Objectifs / *Ziele*

- Recipe development of oat milk on an oat flour basis (benchmarking, process, flow chart)
- Improve stability of oat milk and its foaming properties: Screening of additives like enzymes, stabilizers and acidity regulator
- Masking aversive notes and improving mouthfeel: Exploration of aromatic solutions.

<u>Oat milk characterization</u>

- Qualification of texture and organoleptic attributes (Trained sensory panel)
- Physicochemical measurements (foam stability, pH, turbidity, viscosity, particle sizes, imaging).

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Hes·so VALAIS WALLIS

Haute Ecole d'Ingénierie
Hochschule für Ingenieurwissenschaften



Development of an Oat Milk Recipe for Use in Coffee

Graduate Catherin Lingner

Objectives

The primary aim of this study was to develop a plant-based oat milk recipe with enhanced foaming properties, specifically tailored for barista-style applications. The study sought to identify additives that improve the stability of oat milk during foaming with various machines and its incorporation into coffee. Additionally, the research aimed to mask any off-notes in the oat milk using aromatic solutions provided by MANE

Methods | Experiences | Results

A benchmarking analysis was first conducted to align the product development process with industry standards and consumer expectations. Initial small-scale prototyping trials were undertaken to formulate stable oat milk recipes. The foaming characteristics of the selected oat milk prototypes, as well as their performance when mixed with coffee, were systematically evaluated. From these trials, five promising recipes were selected for sensory analysis, including profiling, comparison, and triangular tests. Two of these recipes were subsequently scaled up for larger production.
Physical properties, such as particle size, dry matter content, pH, Brix, color, and stability, were rigorously tested on the final large-scale recipes.
Throughout the prototyping phase, 158 different recipes were developed. It was found that pea protein isolate played a crucial role in achieving optimal foaming, while soy lecithin significantly contributed to the stabilization of the oat milk. Additionally, dipotassium phosphate was vital in preventing precipitation when the oat milk was combined with coffee.
The homogenization parameters during the upscale process had a substantial impact on the physical properties and taste of the recipes, resulting in enhanced foaming and improved stability. Among the aromatic solutions tested, one provided a neutral flavor profile, while another, Top-note 15, imparted a desirable dairy and vanilla note. The study recommends further exploration of mouthfeel agents and bitterness-masking solutions to refine the final product.

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2. Sustainable development

This work supports several Sustainable Development Goals (SDGs). For instance, it promotes good health (SDG 3) by enhancing nutritional content with added vitamins and minerals (SDG 2). Compared to dairy milk, which has a carbon footprint of approximately 1.39 CO2 eq/kg[1], plant-based alternatives like oat milk have a significantly lower environmental impact (SDG 13). Additionally, plant-based milks generally require less energy[2] and land for production, contributing to more efficient resource use (SDG 6 and 15). However, it's important to acknowledge that the production of plant-based milks can have higher water usage compared to some other alternatives.

3. Introduction

Plant-based milk alternatives[3] (PBMAs), also known as milk analogs, are classified into four main categories: nut-based, seed-based, cereal-based, and legume-based. Oat milk, a cereal-based alternative, was initially developed to cater to individuals with lactose intolerance. Over time, its popularity has grown, driven by its sustainability and appeal to those following a vegan lifestyle. Additionally, plant-based milk offers a valuable alternative for those with cow's milk allergies, which primarily affect infants and children. The first oat milk was developed by a Swedish scientist who founded the Oatly brand.

Oats are nutrient-rich[4], composed of approximately 60% starch, 11-15% protein, 5-9% lipids (predominantly unsaturated fatty acids like linoleic and oleic acids, along with saturated fatty acids[5] such as palmitic acid), and 2.3-8.5% fiber. Health-conscious[6] consumers may opt for PBMA beverages because they are high in fiber, particularly soluble fiber like beta-glucan, which contributes to a feeling of fullness by delaying gastric emptying. This fiber also slows digestion, reducing sugar absorption and lowering blood cholesterol levels. Oat milk also offers additional health benefits, as it is rich in antioxidants[7] like vitamin E, phytic acid, phenolic compounds, and avenanthramides, which help neutralize free radicals associated with aging, inflammation, and various diseases. Moreover, they prevent oxidation and extend the product's shelf life.

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[3] Reyes-Jurado, F., et al. "Plant-Based Milk Alternatives: Types, Processes, Benefits, and Characteristics." *Food Reviews International*, vol. 39, no. 4, 16 July 2021, pp. 1–32.

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[5] Capouchová, Ivana, et al. "Fatty Acid Profile of New Oat Cultivars Grown via Organic and Conventional Farming." *Journal of Cereal Science*, vol. 98, Mar. 2021, p. 103180

[6] Paul, Anna Aleena, et al. "Milk Analog: Plant Based Alternatives to Conventional Milk, Production, Potential and Health Concerns." *Critical Reviews in Food Science and Nutrition*, vol. 60, no. 18, 16 Oct. 2019, pp. 3005–3023.

[7] Peterson, David M. "Oat Antioxidants." *Journal of Cereal Science*, vol. 33, no. 2, Mar. 2001, pp. 115–129.

Despite its benefits, compared to a bovine milk, oat milk lacks nutrients[8] in certain amino acids, calcium, and vitamins[9] (B2, B12, D), as well as minerals like calcium carbonate and potassium iodide that are lost during processing. As a result, nutrient fortification is often necessary to align its nutritional profile with that of cow's milk. Many consumers choose oat milk as an alternative because its composition can be tailored, offering flexibility that traditional dairy milk does not. Unlike traditional milk, oat milk is a mixture of water and an oat base, which may include whole oats, flakes, flour, or syrup as it oat base. To produce a milk analog, various technologies such as fermentation and enzymatic hydrolysis are utilized[10]. Enzymes[11][12] like β-glucanase and α-amylase used for enzymatic hydrolysis, play a crucial role in this process, resulting in a controlled level of natural sweetness.

Oat milk for barista use is classified as a colloidal system, more precisely a microemulsion[13] as surfactants are added to the emulsion to obtain a good foaming. Ensuring the stability of such beverages presents a significant challenge, as the quality of the raw materials and processing methods greatly affect the final product. Consequently, various ingredients and instruments were tested and evaluated for this study (Annex 1 to 5).
In addition to ensuring the stability of the final product, the milk must also generate sufficient foam for beverages like cappuccinos and barista-style drinks. To achieve this, various thickeners and proteins were tested for their effectiveness in enhancing foaming propertie. Thickeners, including gums[14] (e.g., guar, xanthan, gellan), enhance emulsion stability and contribute to bubble formation, resulting in denser foam and improved mouthfeel by increasing viscosity.
Foam is created by introducing air into the milk. Effective foaming requires three key conditions. First, mechanical action to incorporate air. Second, the presence of surfactants to lower surface tension. Third, a rapid foam generation process to prevent bubble coalescence. Surface-active agents, such as free fatty acids, phospholipids, or proteins, form a film around the air bubbles, stabilizing them and preventing the coalescence. Barista oat milk contains emulsifiers that act as surfactants, reducing surface tension by gathering molecules at the surface, which makes it easier to incorporate air. By lowering the energy needed to break the bonds between surface molecules, emulsifiers enhance air incorporation. Since the beverage is often mixed with coffee, which typically has a pH[15] ranging from 4.85 to 5.10, an acidity regulator is crucial in the formulation of plant-based milk.

[8] Jeske, Stephanie, et al. "Evaluation of Physicochemical and Glycaemic Properties of Commercial Plant-Based Milk Substitutes." *Plant Foods for Human Nutrition*, vol. 72, no. 1, 5 Nov. 2016, pp. 26–33.
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[14] Vidyapeeth, Marathwada, et al. "Studies on Quality Evaluation of OAT Milk." ~ *2275 ~ Journal of Pharmacognosy and Phytochemistry*, vol. 9, no. 1, 2020, pp. 2275–2277
[15] Rao, Niny Z., and Megan Fuller. "Acidity and Antioxidant Activity of Cold Brew Coffee." *Scientific Reports*, vol. 8, no. 1, 30 Oct. 2018.

This prevents protein separation or precipitation when exposed to the acidic environment of coffee. Nespresso Livanto espresso capsules were chosen to test the milk's foaming performance in coffee.

After stabilizing the recipe, sensory properties can be further enhanced with flavors, including top notes that highlight specific aromas. Food additives influence not only the nutritional profile but also the flavor of the final product. Off-flavors can occur when lipoxygenases[16], enzymes found in oats and other plants, oxidize unsaturated fatty acids, leading to beany or other unwanted tastes. To address this, masking agents were used to reduce or hide these strong, undesirable flavors (off-notes) that may result from the manufacturing process or certain ingredients, such as pea proteins added for improved foaming.

To ensure the safety of plant-based products, various thermal and non-thermal treatments[17] are available, including pulsed electric fields, microfiltration, ultrasound, and ohmic heating. However, the tubular heat exchanger was selected for its reliability, efficiency, and widespread use in the beverage industry.

Compared to traditional oat milk, this beverage version for use in coffee includes emulsifiers and proteins to enhance foaming properties, as well as an acidity regulator to stabilize the milk when mixed with acidic beverages. Throughout the development process, various physical and microbiological tests were conducted to assess the product's stabilization and foaming properties. Additionally, sensory tests were performed to evaluate different oat milk formulations. Ultimately, four recipes from the prototyping phase were analyzed by MANE's sensory panel, with two of these recipes scaled up for production in the pilot plant at HES-SO Valais.

[16] Sethi, Swati, et al. "Plant-Based Milk Alternatives an Emerging Segment of Functional Beverages: A Review." *Journal of Food Science and Technology*, vol. 53, no. 9, Sept. 2016, pp. 3408–3423, https://doi.org/10.1007/s13197-016-2328-3.
[17] Mehany, Taha, et al. "Recent Innovations and Emerging Technological Advances Used to Improve Quality and Process of Plant-Based Milk Analogs." *Critical Reviews in Food Science and Nutrition*, 1 Mar. 2023, pp. 1–31.

4. Materials

Table 1 List of materials and raw materials used in this work.

Material	Supplier
Demineralized water	-
Hydrolyzed organic oat flour	Interquell
Oat syrup 18DE	Meurens
Oat syrup 28DE	Meurens
Sunflower oil qualité & prix	Coop
Rapeseed oil qualité & prix	Coop
Pea protein isolate Empro E86LS	Emsland group
Pea protein concentrate	GMSA
Soluble pea protein PURIS Pea 2.0	Navitalo
Soy lecithin 90%	Thermo Fisher Scientific
Soy lecithin granulate	Morga
Guar gum	Droguerie Valère
Guar gum	Tokyo chemical industry
Gellan gum	Thermo Fisher Scientific
Gellan gum	CP KELCO
Dipotassium phosphate	Carl Roth GmbH
Sodium citrate	Carl Roth GmbH
Crystallised sugar	Coop
Fine salt from Alpes	Coop
Masking 2, ref:M_0058561	MANE
Mask 3, ref: E24115163	MANE
Mask 5, ref: E24115162	MANE
Mask 7, ref: E24115161	MANE
Top-note 13, ref: M_0060392	MANE
Top-note 14, ref: E24115159	MANE
Top-note 15, ref: E24115161	MANE
Tryptic glucose yeast agar	Biolife
Buffered peptone water pH 7.2	Biolife
Maximum recovery diluent	Biolife
Stomacher bags	-
GENbox anaer	bioMérieux
Anaerotest	Merckmillipore
Analytical Scale	-
Steel lab spoon	-
Plastic weighting plates disposable	-
Inox bowls	-
Plastic funnel	-
Spatulas	-

Glass cylinder 250ml	-
Beaker	-
Microscope slides	Thermo Scientific
Plastic cups 0.25dl	-
Silicone oil M10	Carl Roth
Test tubes	-
Culture plates	

Table 2 List of instruments used in this work.

Instrument	**Supplier**
Thermomix TM6	Vorwerk
Ultra-turrax T25 with S25N – 25F dispersion ustensile	IKA
pH-meter edge	Hanna
Densimeter DMA 4100M	Anton Paar
Refractometer Abbemat 350	Anton Paar
Mettler Toledo	HB-46-s balance halogène
Mettler Toledo	HB-103 balance halogène
Laser diffraction	Microtrac
Rheometer	Anton Paar
Centrifuge Sigma 3-18KS + swing-out rotor	Sigma
Aeroccino 3	Nespresso
Sage Creatista Plus	Nespresso
Krups Inissia XN1005.WP	Nespresso
Blender, tank	Stephan
Homogenizer Ariete NS3006L	GEA
Hot water production machine	HES-SO
Centrifugal pump	Hilge
Tubular Heat exchanger	APV
Stomacher lab blender	-
Lab Incubators	-

5. Methods

5.1. Recipe development

A benchmarking analysis of oat milk for barista use was performed and tasted by sensory experts from the MANE company. This study also compared products from the market or competitors, helping to identify consumer expectations or draw inspiration from existing products (Table 3 and Annex 7). The products chosen for analysis were the ones available in the Swiss market, found in supermarkets like Coop or Migros. Ingredient lists and aromas are identified, providing valuable data for further analysis and the development of new recipes.

Table 3 Ingredient list of Benchmark products found in Swiss market.

Product	Ingredients
Oatly Oat milk Barista	Water, OATS 10%, rapeseed oil (huile de colza), acidity regulator (dipotassium phosphate), minerals (calcium carbonate, potassium iodide), salt, vitamins (D2, Riboflavin, B12)
Alpro Oat milk Barista	Oat base (95.6%) (Water, Oat (10%)), Sunflower oil, Chicory root fibre, Pea protein, Acidity regulator (Potassium phosphates), Sea salt, Vitamins (B2, D2).
Bio Karma Oat Barista	Water, OAT 13% (Swiss), sunflower oil, kitchen iodized salt, enzymes (amylase, amyloglucosidase).
Beleaf Oat Barista	Water, Oat IP-SUISSE 12%, sunflower oil, thickener (gellane gum), stabilizer (sodium citrate), kitchen salt, vitamins (D, B2, B12).

A range of ingredients (see Annex 5) was tested to create an oat milk with optimal foaming properties, stability in coffee, and desirable taste. The ingredients selected from the prototypes were then tasted and evaluated by sensory experts from HES-SO Valais and MANE.

The main raw materials include water, oat base, oil, acidity regulator, and salt. Optional ingredients such as proteins, enzymes, emulsifiers, thickeners, sweeteners, flavors, and other additives significantly impacted the final product's texture and flavor. To create the recipes, a benchmarking analysis of existing oat milk products was conducted. Initially, ingredient percentages were estimated, but these were later adjusted based on the raw materials tested Various masking agents and top notes from MANE's Masking Box 1.0 were tested for their effectiveness in masking off-notes and adding a milky top note, particularly to counteract the strong pea aroma from pea protein. All chosen masking agents and top notes are natural flavoring and vegan-compliant.

5.1.1. Prototyping

Trials of 500ml oat milk recipes were test in a prototyping kitchen using a Thermomix to blend all ingredients. Overall, a total of 158 recipes were produced. This method is chosen for its efficiency and speed, allowing for the preparation of multiple samples. Various times, speeds, and temperatures were tested. After blending in the Thermomix, the sample was poured into a beaker, homogenized with the Ultra-turrax, and then returned to the Thermomix for pasteurization. For the homogenization part, it was first tested with the Thermomix at speed 5, which although fast, it only mixes rather than homogenizing. In a second phase, the Ultra-turrax T25 was used at 12rpm x 1000 (rotation per minute) for 3min for 500ml.

Afterwards, for pasteurization it was heated till 90°C at speed 3.5 for 3 minutes. Following heat treatment, the milk was poured into Duran laboratory glass bottles, with a required 20% headspace, and cooled in a bowl of cold water (~15°C). Once adequately chilled, the milk was stored in the refrigerator. The final process is illustrated in Figure 1. To fasten the process, samples were prepared simultaneously using three Thermomixers. Foaming analyses were conducted the following day to adjust the recipe concentration or ingredient. The Thermomix sample n°110 (recipe in Annex 10) was taken in the upscale process to only test homogenization parameters.

Five recipe shown in table 4 were selected for further analysis. . They are named according to: Recipe n°132 as "Proposal 1", Recipe n°145 as "T_neutral", Recipe n°157 with masking solution 3 as "T_mask 3", Recipe n°158 with masking solution 5 as "T_mask 5" and finally Recipe n°155 with masking 5 and top-note 15 as "T_mask 5 +15".
These products were evaluated by the panel of sensory experts from MANE to characterize their sensory properties. Recipe T_neutral and T_mask 5+15 was selected to produce in a larger scale. Furthermore, physical analysis was also performed only on these two main recipes as masking 3 and 5 were purely examinate for sensory purpose.

Table 4 Ingredient list of the final recipes from the prototyping phase subjected to sensory analysis.

Per 100g	**Proposal 1**	**T_neutral**	**T_mask 5+15**	**T_mask 3**	**T_mask 5**
Ingredients	[g]	[g]	[g]	[g]	[g]
Demineralise water	86,20	88,00	87,80	87,90	87,85
Oat Syrup 28DE	8,00	8,00	8,00	8,00	8,00
Rapeseed oil	2,00	2,60	2,60	2,60	2,60
Pea Protein isolate	3,50	1,00	1,00	1,00	1,00
Soy lecithin	0,15	0,25	0,25	0,25	0,25
Masking solution	0,00	0,00	0,15	0,10	0,15
Top-note solution	0,00	0,00	0,05	0,00	0,00
Dipotassium phosphate	0.10	0,10	0,10	0,10	0,10
Salt	0,05	0,05	0,05	0,05	0,05
Total	100,00	100,00	100,00	100,00	100,00

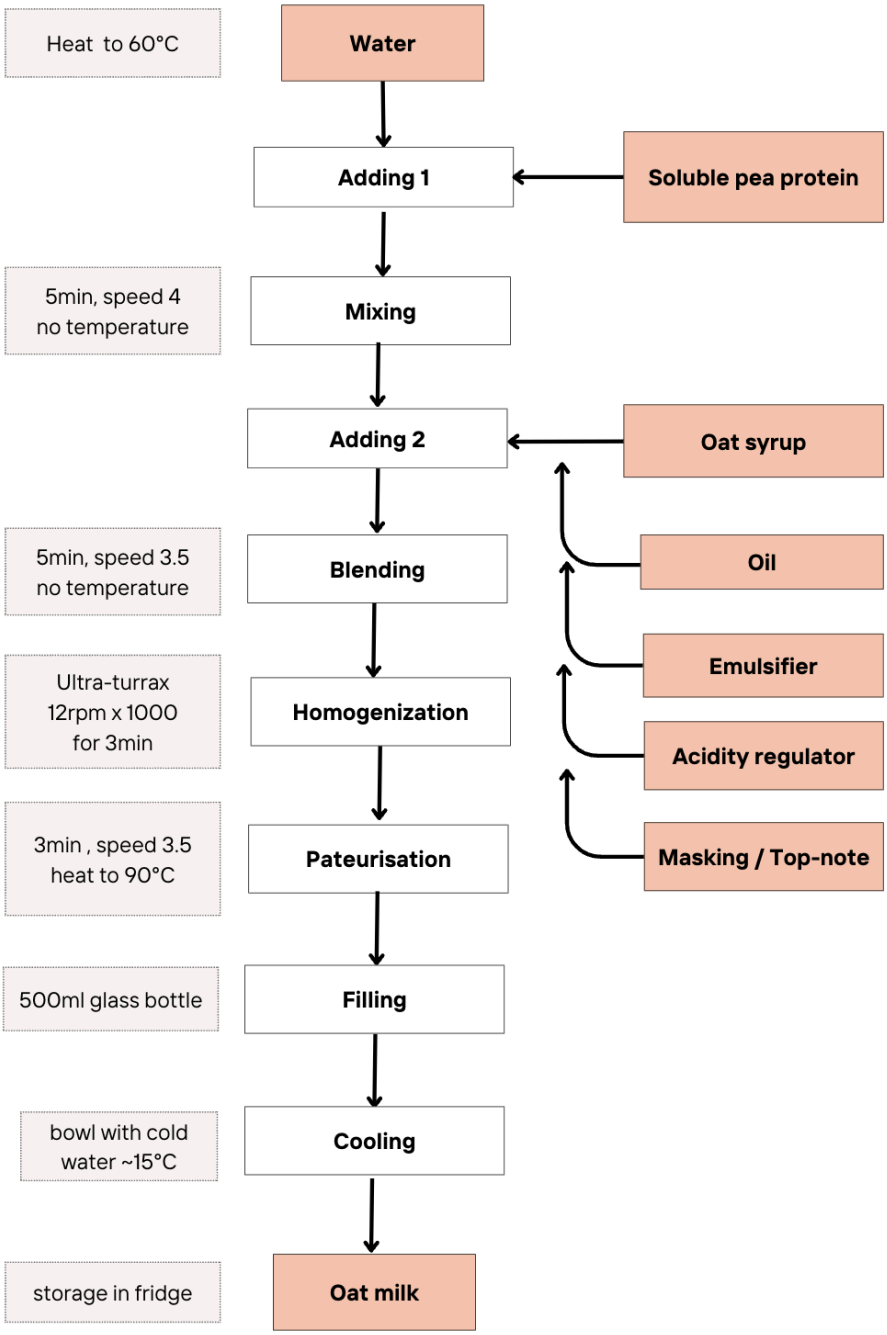


Figure 1 Prototyping process diagram of an oat milk. All steps done in the Thermomix Vorwerk, apart the homogenization with an Ultra-turrax.

5.1.2. Upscaling process

The process involves four key machines: the Stephan tank, a water heating machine developed by HES-SO Valais, a high-pressure homogenizer (Ariete NS3006L), and a tubular heat exchanger from APV.

For this experiment, the upscaling process closely follows the prototyping procedure, with adaptations for the larger scale (Figure 2). The main differences between Thermomix and upscaling process are that blade and scraper were used for mixing (Stephan tank), the blending step lasted 10min and not 5min (to ensure a good blending) and the homogenization parameters. Recipes were prepared for a 20L batch and were produced in the pilot plant of the HES-SO Valais. Only two recipes were tested for industrial process, n°145 T_neutral recipe becoming "S_neutral" and n°155 T_mask 5+15 as "S_masking 5+15". These two beverages were also evaluated in the sensory analysisis.

Initially, the measured water weight was heated to 60°C using direct steam and a scraper set to 50% speed in the Stephan tank. Once heated, pea protein concentrate was added and mixed for 5 minutes. The remaining ingredients were then added and mixed for an additional 10 minutes. Both mixing stages were performed at 50% speed with the scraper and blade activated, with no additional temperature control required. The mixture was then transferred to two 15L pans and immediately moved to the high-pressure homogenizer (Ariete NS3006L) for the homogenization step.
The first scaling-up trial comes from sample n°110 (Annex 10) and was used to test pressions parameters for the homogenization step. The high-pressure homogenizer (HPH) has two stages for pressure adjustment and can handle pressures up to 1500 bars.
For the homogenization trial, the pressures tested went from 200, 300, 400 to 500 bars (results shown Annex 11 to 13). While most dairy products are homogenized at pressures up to 30 MPa [18] (300 bar), there is little change in particle size and viscosity between 200 and 300 bar, even with foaming. To ensure optimal homogenization of all ingredients, a pressure of 300 bar was chosen for the upscaling process. Using an "open cycle," the homogenized oat milk exits through a tube and is poured into the large pans. The milk was then transferred to a small tank connected to the centrifugal pump Hilge, which moved the milk at 7 bars of pressure to the tubular heat exchanger.

For the pasteurization step, a Tubular heat exchanger (THE) was used with a Hot water machine (instrument's picture in Annex 1 to 4). Assembled by HES-SO Valais, this machine heats water to very high temperatures using direct steam, which helps the Tubular Heat Exchanger achieve the required temperature to heat the milk. Usually for HTST (high temperature short time) milk pasteurization, recommended parameters are 72°C for 15sec. The temperature of 90°C[19] for 1min was selected to heat longer the product and reduce contamination. Eight tubes were used in this process; to heat the product to 90°C, 2 tubes were employed, to maintain this temperature for 1 minute (for pasteurization), three tubes were used, and the remaining 3 tubes were used for cooling the product down to 15°C. Finally, the milk was transferred from the tube through a funnel into a 1.5L sterilized PET bottle, then stored in the refrigerator.

[18] R.A. Wilbey "HOMOGENIZATION OF MILK | Principles and Mechanism of Homogenization, Effects and Assessment of Efficiency: Valve Homogenizers", Encyclopedia of dairy sciences, 2011, pages 750-754.
[19] Lucey, John A. "Raw Milk Consumption." *Nutrition Today*, vol. 50, no. 4, 2015, pp. 189–193, www.ncbi.nlm.nih.gov/pmc/articles/PMC4890836/

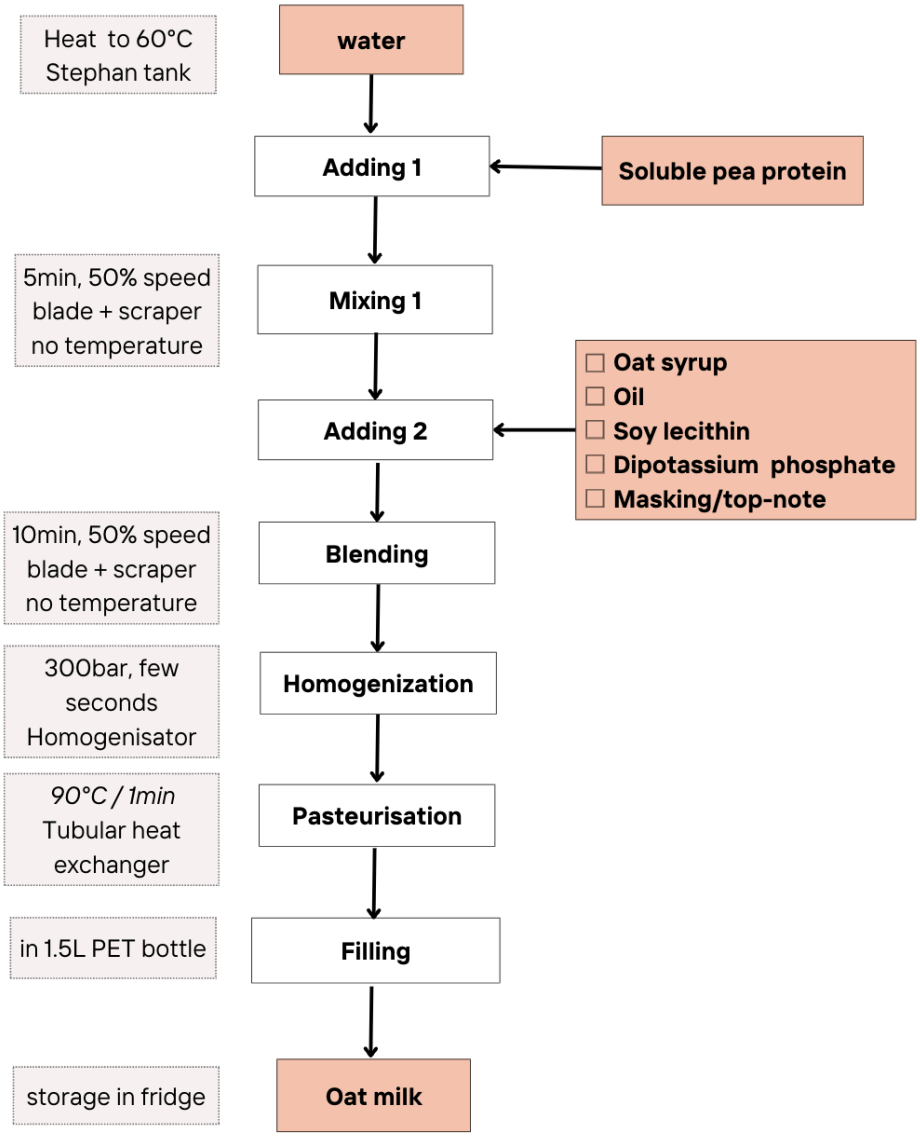


Figure 2 Scaling-up process diagram with different machines used.

5.2. Physical analysis

5.2.1. Particle size

Samples were diluted with ultrapure water and analyzed by Microtrac Laser diffraction. Particle size of samples was calculated based on Mie Theory considering refractive indices of 1.57 [20] for oat milk and 1.33 for water. Before analysis, each sample was shaken. Upon activating the stirring in the machine drops were added. Each analysis was conducted twice per droplet, in triplicate. After each drop analysis the machine was rinsed.

5.2.2. Dry matter

Two analyses were conducted: one for the syrup used in the recipe and one for the oat milk. Moisture Analysers (HC103 and HB43-S Halogen from Mettler Toledo) were used for drying the samples. The temperature settings were 90°C for syrup analysis and 160°C for oat milk analysis. Both analyses were performed in triplicate using the dry matter method (%DC).

5.2.3. pH + Refractive index and Brix + Density

The 913 pH-meter (Metrohm) was first calibrated before measuring the pH of the sample. The sensor tip was cleaned after each measurement. The refractive index and Brix percentage were measured using a Refractometer (Anton Paar) with a wavelength of 589 nm at room temperature. These measurements were conducted in triplicate. The refractive index is expressed in nm, and Brix in %. The Density Meter DMA 1001 was used for this analysis. After each analysis was done in triplicate, the machine was cleaned with water and dried with air.

5.2.4. Color + whitness index

The Spectrophotometer CM- 5 (Konica Minolta) was used with an open transparent cylinder cell as recipient to add the Oat milk. After machine calibration, each sample was analyzed in triplicate. Mode CIE L*a*b* colour system, SCE (Specular Component Excluded) was applied with D65 standard illuminant and 10 degrees viewing angle. To compare the overall results, the Whiteness index (WI)[21] was calculated.

Equation 1 Whiteness index

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}}$$

[20] Physical–Chemical and Sensory Quality of Oat Milk Produced Using Different Cultivars. *Foods*, *12*(6), 1165. https://doi.org/10.3390/foods12061165

[21] Evaluation of Physicochemical and Glycaemic Properties of Commercial Plant-Based Milk Substitutes. *Plant Foods for Human Nutrition*, *72*(1), 26–33.

5.2.5. Physical stability

To determine the separation of phases of the oat milk, two analyses were done.

- Sedimentation during 3 days at 4°C.
  10ml of oat milk sample was added to a 15 ml Tube Corning CentriStar tube. Pictures were taken every day for 3 days to track the evolution of the sediment.
- Centrifugation to weigh the sediment of the Oat milk.
  10ml of oat milk samples in 15 ml Tube Corning CentriStar tubes were centrifuged in a Sigma 3-18KS centrifuge at 1000 rpm for 30 min followed by 3000 rpm for 60 min[22] at room temperature. After centrifugation, the sediment was weighted.

5.2.6. Viscosity

The samples were analyzed at room temperature using a Rheometer (Anton Paar GmbH) with a concentric cylinder (CC27)[23] setup. Each sample produced and benchmarking products were measured at least twice. As a Newtonian fluid, the results did not vary significantly with additional measurements which were done in triplicate. After the homogenization parameter was chosen, the Proposal 1 sample was measured before homogenization and after heat treatment to detect possible changes in viscosity of the product during the process. All analyses were conducted with a shear rate ranging from 0.1 to 100 s^{-1} and apparent viscosity measured at 10 s^{-1}, referred to as "viscosity". After 4 days of storage, simulating home conditions, the tests were repeated to observe possible changes in viscosity, which could affect the foaming properties of the oat milk.

5.2.7. Contact angle and surface tension

Samples were analyzed with Tensiometer OCA 15EC with the Dataphysics optical contour analyzer software in triplicate.

Equation 2 Young's Equation, SV is the solid/vapor surface free energy, SL the solid/liquid surface tension, LV the liquid/vapor surface tension, and θ the contact angle.

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \times \cos\theta$$

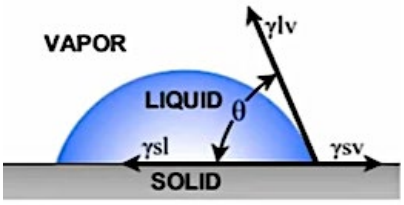


Figure 3 Contact angle of droplet theory.

In this work, the Sessile drop (SD) method is used to estimate the surface tension. SD measures the contact angle of liquid in contact with a solid phase.
To perform the measurements, 3-4 ml of the sample was drawn into a syringe and aligned with the tensiometer, ensuring the syringe tip was visible in the camera at a 0° angle. Before taking measurements, a small amount of silicone oil (paraffin oil is used in the literature) was gently applied to the needle tip with a tissue to prevent the needle material from affecting the results[24]. A 6 µl sample was dosed, and each density parameter was recorded. A movie was captured during 5 seconds, once the drop had stabilized from spreading rapidly. Both left and right angles were recorded during the video, and a picture was taken to capture the initial data.

[22] Jeske, Stephanie, et al. "Evaluation of Physicochemical and Glycaemic Properties of Commercial Plant-Based Milk Substitutes." *Plant Foods for Human Nutrition*, vol. 72, no. 1, 5 Nov. 2016, pp. 26–33
[23] Zhou, Sumei, et al. "Physical–Chemical and Sensory Quality of Oat Milk Produced Using Different Cultivars." *Foods*, vol. 12, no. 6, 9 Mar. 2023, p. 1165,
[24] Ponomar, Maria, et al. "Sessile Drop Method: Critical Analysis and Optimization for Measuring the Contact Angle of an Ion-Exchange Membrane Surface." *Membranes*, vol. 12, no. 8, 4 Aug. 2022, p. 765

5.2.8. Foamability and foam stability

In this experiment, two methods were used to test the foamability, mechanical mixing and steam injection.
Mechanical mixing was mainly adopted for this analysis. High speed movement is achieved using a high shear mixer to cut the milk surface and incorporate air to form foam. For quick and reproducible tests, the Aeroccino Nescafé was chosen rather than a hand whip. Its foaming process is automatic, it stops when the milk temperature reaches around 65°C, which takes approximately 1 min when the milk is out of the fridge.
For steam injection method a Nespresso Sage Creatista Plus machine was used. The Nespresso Sage Creatista Plus machine was used. The Cappucino mode was set to foam level 7 at a temperature of 65°C. The process is automatic after launching.
For both methods[25], 100ml of well shaked oat milk was poured into a cylinder and transferred into an Aeroccino or a milk jug. After foaming, the milk was quickly transferred with a spatula into a 250ml glass cylinder. Immediately, the height of the foam and milk was marked on the cylinder, or the volume ratios (in cm) of foam and milk was measured with a retractable ruler.

Foam stability analysis follows the foamability test. The ratios of foam and milk before and after 10min of rest were measured again using a retractable ruler or by marking the height. The time rest of 10min was chosen considering the average consumption time of foam-based beverages[26]. Foam stability was calculated with VF0 and VF10, volume of foam at t = 0 and t = 10 min, respectively. Results were expressed in percentage reduction of foam volume after 10 min (%)[27].

Equation 3 Reduction of foam after 10min

$$\%reduction\ V_f = \frac{V_{f0} - V_{f10}}{V_{f0}} \times 100$$

5.2.9. Foam in coffee

In the Cappuccino recipe[28] from Nespresso barista 40ml espresso and 100ml cold milk are combined.
The espresso was prepared with the Nespresso Krups Inissia XN1005.WP machine choosing the espresso program. For the foaming, either an Aeroccino (mechanical/frothing method) was used or the coffee machine Creatista Plus[29] (steam injection method). Both methods heat the milk to 65°C. Oat milk from benchmarking samples was used for the milk, and Livanto Nespresso capsules were used for the espresso. Livanto capsules are rated at level 6 out of 12, classified as mild intensity, with specific roasting, body, and bitterness characteristics defined by Nespresso. The cappuccino was observed during 10-15 min in order to check for any precipitation of the milk in the coffee.

[25] Xiong, Xiaoying, et al. "Foaming Properties of Milk Protein Dispersions at Different Protein Content and Casein to Whey Protein Ratios." *International Dairy Journal*, vol. 109, May 2020, p. 104758
[26] Zakidou, Panagiota, et al. "Foaming Properties and Sensory Acceptance of Plant-Based Beverages as Alternatives in the Preparation of Cappuccino Style Beverages." *International Journal of Gastronomy and Food Science*, vol. 30, Dec. 2022, p. 100623
[27] Xiong, Xiaoying, et al. "Foaming Properties of Milk Protein Dispersions at Different Protein Content and Casein to Whey Protein Ratios." *International Dairy Journal*, vol. 109, May 2020, p. 104758
[28] https://www.nespresso.com/recipes/ch/en/23077CAP-cappuccino.html
[29] https://www.sageappliances.com/ch/fr/products/nespresso/bne800.html

5.1. Microbiological analysis

Table 5 Methodology of Microbiological analysis containing a list of pathogens with their plating medium, incubation temeperature and time.

Pathogen	Plating medium	Incubation temperature	Incubation time
Mesophile aerobie/anaerobie	PCA (Plate Count Agar)	30 °C	3 days
Bacillus cereus	MOS	30°C	3 days
Staphylococcus aureus	RPFA	37°C	3 days
Enterococcus	VRBG	37°C	3 days

Total Viable Count (TVC) analyses were conducted under aerobic conditions to measure the total number of colony-forming units of aerobic bacteria, yeast, and mold present in the sample. For anaerobic conditions, analyses were prepared using a GENbox anaer bag from bioMérieux and an Anaerotest indicator strip from Merck Millipore. To prepare the stock solutions for dilution, 10 mL of oat milk was added to 90 ml of Buffered Peptone Water (BPW) with a pH of 7.2 from Biolife. This mixture was blended in a Stomacher bag without a filter using a Stomacher lab blender for 30-50 seconds. Dilutions from 10^{-2} to 10^{-5} were then prepared, with 1 ml of the stock solution or a previous dilution transferred to test tubes containing 20 mL of Maximum Recovery Diluent (VL) from Biolife. TVC analysis was performed using the plate pour method with PCA (Tryptic Glucose Yeast Agar from Biolife) and incubated at 30°C for 3 days (Table 5). This analysis is critical for ensuring the safety of the product for sensory analysis and assessing its shelf life.
For the shelf-life evaluation of pasteurized oat milk, a two-week storage test was conducted, with samples collected on days 1, 5, 7, 9, 12, and 14. The analysis was performed at three different temperatures: 4°C, 25°C, and 40°C for sample S_neutral (n°145). On the day following production, 10 mL of the sample was transferred from a sterilized bottle into a 15 mL Corning CentriStar centrifuge tube in sterile condition and stored in the respective incubators. Before repeating the TVC analysis three days later, the tubes containing the 10 mL samples were mixed using a vortex mixer before being transferred into the BPW solution.

For the analysis of Bacillus cereus (BCES) and Staphylococcus aureus, dilutions of the 10^{-2} sample were prepared, and the Surface Plate Method was employed. The Bacillus cereus medium (MOS) was incubated at 30°C for 3 days. Enterococcus analysis involved three steps: first, 20 ml of VRBG medium was poured, then a 10^{-2} dilution of the sample was spread on the dry medium, and finally, additional VRBG medium was poured to cover the sample. For Staphylococcus aureus analysis, the RPFA medium was used and incubated at 37°C for 3 days, similar to the Enterococcus analysis. These analyses, along with the Total Viable Count (TVC), were conducted on samples S_neutral (n°145) and S_masking 5+15 (n°155) two days prior to sensory evaluation to ensure the samples were safe for consumption. The results are presented in Tables 21 and 22 in Annex.

All results are expressed in logarithmic of colony-forming unit per mL of sample (log CFU/mL).

5.2. Sensory analysis

The sensory analyses were done on 4 different days. The first time, profile tests of each Benchmark products (Oatly and Alpro) and the Proposal 1 were analyzed. Afterwards, all final recipes (Thermomix and Scaling-up) were produced the same day to standardize the production between products. As the neutral recipe changed from Proposal 1 to T_neutral, a profile test of the new neutral recipe was made once again. Three comparison tests were also conducted with T_neutral. The day after, a triangular test was performed for the Upscale and Thermomix recipe. Finally, to understand the outcome of the oat milk in coffee, comparisons test was prepared as well as a profile test.

5.2.1. Benchmark products and neutral recipes

Profile test[30] is a quantitative descriptive analysis. A panel was trained to identify and quantify the product sensory attributes through an intensity scale of 1 to 10, from low to really intense. MANE trained their panelist with Oatly and Alpro oat milk barista. In total, 4 profile tests were executed and meticulously analyzed by the panel. Tested products included Benchmarking products, proposal 1, T_neutral and S_neutral and later on T_neutral on coffee. These results provide valuable data for the comparison test.

5.2.2. Thermomix final recipes

In the paired comparison test the sample is compared to the reference (REF) (Figure 4). The aim is to quantify the difference of an attribute from the sample in comparison to the reference. The scale goes from -5 to 5. A negative value indicates a lower intensity of an attribute and a positive value a higher intensity of an attribute. In total 6 comparison test were done. T_neutral was used as REFto evaluate T_mask 3, T_mask 5, T_mask 5+15. The same process repeated with oat milk in coffee too. Red lights were used in this test to avoid influencing the results, as a color difference between the products was observed.

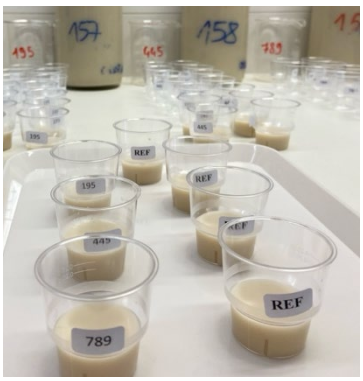


Figure 4 Comparison test was prepared with a plate containing all samples with T_neutral as REF.

5.2.3. Thermomix VS Scaling-up recipes

Triangular test was used to determine if a sensory difference or similitude existed between two products. It is a forced process because the taster needs to make a choice even if no difference or similitude was perceived. This test was conducted to determine if there was a difference between the Thermomix and Scale-up version for the same recipe.

Assuming that there is no physical effect of the maskings solutions on the recipe, T_mask 5+15 were chosen for this analysis. Two tests were done with the T_mask 5 + 15 (Thermomix) versus S_mask 5+15 (Scaling-up) in order to determine whether a perceptible difference existed between the upscale and Thermomix recipes.

Secondly, the S_mask 5+15 with masking solutions added during the mixing process (before blending step) versus added at the end of process (after pasteurization) were compared. The goal of this test was to determine whether the timing of masking solution addition affected the outcome. This experiment was particularly important as homogenization, which reduces particle size and heat from pasteurization could influence the effectiveness of the masking agent.

[30] Marques, Catarina, et al. "An Overview of Sensory Characterization Techniques: From Classical Descriptive Analysis to the Emergence of Novel Profiling Methods." *Foods*, vol. 11, no. 3, 18 Jan. 2022, p. 255.

Three samples were prepared with identical containers (transparent cup) and labeled with a three-digit code. Two samples were identical, and one was different. Assessors were asked to identify and characterize the different sample. For this test, the panel was composed of 20 judges[31] as it is the minimum required. Some assessors were trained (sensory experts) while others were naïve (recruited internally in MANE).

5.2.4. Thermomix final recipes in coffee

For the comparison test in coffee, the process preparation is the same as in method 4.3.7 Foam in coffe. The machines used were two Nespresso Krups Inissia XN1005.WP as coffee machine and for foaming, two Aeroccino Nespresso. In the cappuccino recipe[32] from Nespresso barista 40ml espresso and 100ml cold milk are combined.
Nespresso Livanto capsules were inserted in the coffee machine. Espresso and foaming of oat milk in Aeroccino were prepared at the same time. Both were mixed in a beaker with a spoon to avoid interference of the with the sensory analysis (Figure 5). The cappuccino was prepared just before each comparison test, poured in the cups and served to the panel.



Figure 5 Foaming of milk was mixed with the espresso

For each test, oat milk was poured into a transparent 0.25dl cup labeled with either "REF" or a three-digit code for randomization. Crackers and water were provided to the judges to cleanse their palates if needed. Statistical analyses were performed with a significance level of 5% using ANOVA for the profile test, and a 5% significance level with the Student t-test for the comparison test. The triangular test used an alpha risk approach. The tests were analyzed using FIZZ software and then transferred to Excel for more detailed data analysis

[31] Harker, F.R., et al. "The Use and Misuse of Discrimination Tests for Assessing the Sensory Properties of Fruit and Vegetables." *Postharvest Biology and Technology*, vol. 38, no. 3, Dec. 2005, pp. 195–201.
[32] https://www.nespresso.com/recipes/ch/en/23077CAP-cappuccino.html

6. Results and discussion

6.1. Development of recipes

In Swiss supermarkets, only few oat milk barista products are available. Four products were analyzed, Oatly, Alpro, Bio Karma and Beleaf Oat milk Barista.
Oatly having a thicker texture is the only one made with rapeseed oil. The main differences between them was that Alpro contains chicory root fiber, pea protein and is made with sunflower oil. Bio Karma and Beleaf Oat barista both have higher percentage of oat base and share similarities such as a watery texture and translucency (Annex 7). When comparing their nutritional values, Oatly and Alpro have equivalent values except for minerals (Annex 8).

Oatly and Alpro oat milk barista served as reference for recipe development according to their ingredient list and nutritional values, as being the most iconic products of oat milk. The ingredient list of the final recipes is shown in Table 6. Optional ingredients such as proteins, enzymes, emulsifiers, thickeners, sweeteners, flavors, and other additives significantly impact the final product's texture and flavor.

Table 6 Ingredient list of the final recipes from the prototyping phase subjected to sensory analysis.

Per 100g	**Proposal 1**	**T_neutral**	**T_mask 5+15**	**T_mask 3**	**T_mask 5**
Ingredients	[g]	[g]	[g]	[g]	[g]
Demineralise water	86,20	88,00	87,80	87,90	87,85
Oat Syrup 28DE	8,00	8,00	8,00	8,00	8,00
Rapeseed oil	2,00	2,60	2,60	2,60	2,60
Pea Protein isolate	3,50	1,00	1,00	1,00	1,00
Soy lecithin	0,15	0,25	0,25	0,25	0,25
Masking solution	0,00	0,00	0,15	0,10	0,15
Top-note solution	0,00	0,00	0,05	0,00	0,00
Dipotassium phosphate	0.10	0,10	0,10	0,10	0,10
Salt	0,05	0,05	0,05	0,05	0,05
Total	100,00	100,00	100,00	100,00	100,00

Two syrup concentration were tested: one with a higher dextrose equivalent (DE) than the other. A higher DE means the syrup has undergone more enzymatic hydrolysis, leading to more reducing sugars (dextrose), which makes it sweeter and more soluble. As a result, the 28DE syrup is sweeter and creates more foam than the 18DE syrup. The smaller sugar molecules in the 28DE syrup lower surface tension, which improved the foaming[33].
Concentrations above 10% of the syrup are not recommended due to differences in nutritional value compared to benchmark products and because a 15% concentration caused minor burning in the Aeroccino.

[33] Herceg, Zoran, et al. "Effect of Carbohydrates on the Emulsifying, Foaming and Freezing Properties of Whey Protein Suspensions." *Journal of Food Engineering*, vol. 79, no. 1, Mar. 2007, pp. 279–286, https://doi.org/10.1016/j.jfoodeng.2006.01.055. Accessed 9 May 2022.

Therefore, 8-10% concentration range of 28DE oat syrup was selected in the recipes. Additionally, the water content in the recipes was adjusted based on the main oat ingredients (syrup, flour, flakes) and the concentration of the other ingredients.
For oils, rapeseed oil was selected for its mouthcoating properties ("residual food that sticks to the oral surface after food ingestion"[34]). This characteristic helps mask the strong taste of pea protein and other off-flavors. In contrast, sunflower oil has a more pronounced mouthfeel but offers less masking ability. The optimal oil concentration ranges from 2% to 2.6%, with 2.6% being better for maximizing foam production. This concentration helps create an emulsion of oil droplets in water, which, with the help of surfactants, enhances bubble formation and foam stability.
Different pea proteins were evaluated as they serve as foaming agent. Pea Protein Concentrate from GMSA generated less foam and had a strong cardboard taste compared to Pea Protein Isolate from Emsland Group. Consequently, for creating barista oat milk, Pea Protein Isolate was the most suitable ingredient. Its concentration ranges from 2% to 4%, with higher concentrations resulting in more foam[35] but also giving and increase in sediment.

As food additives, gum, soy lecithin, dipotassium phosphate and sodium citrate were evaluated. Overall, two types of gums were tested, guar gum and gellan gum. Guar gum provided a thick texture that helped to stabilize the milk, while gellan gum offered better foaming properties and a creamier texture. When gellan gum recipe foaming was tested with a steam injection coffee machine, it turned into a pudding-like texture due to its hydrogel properties. Therefore, it was finally not added in the recipe.
Two soy lecithin were assessed. When this ingredient was added to the recipe it gave a gritty sensation in the mouth. The optimal concentration of soy lecithin in the recipe ranged from 0.15% to 0.25%, with the final concentration set at 0.25% to ensure effective foam stabilization and emulsion properties. Adding more than 0.30% did not improve the foaming.

Dipotassium phosphate and sodium citrate both come from Carl Roth were assed with the same recipes and concentration. Sodium citrate should be used at low concentrations (0.1% or less). When tested with the current raw materials, foams collapsed within 1 minute and showed precipitation followed by phase separation. For further experiments with sodium citrate, testing with alternative pea proteins is recommended. Additional details can be found in the pH results section.

[34] Repoux, M., et al. "Solid Cheese Consumption: Quantification of Oral Coating." *Archives of Oral Biology*, vol. 57, no. 1, Jan. 2012, pp. 81–86.
[35] Zakidou, Panagiota, et al. "Foaming Properties and Sensory Acceptance of Plant-Based Beverages as Alternatives in the Preparation of Cappuccino Style Beverages." *International Journal of Gastronomy and Food Science*, vol. 30, Dec. 2022, p. 100623.

Four masking agents and three top-notes solutions, from the Masking box 1.0 from MANE, are put to testOnly Mask 3, Mask 5, and Top-note 15 are used in the final recipe (Table 4) because they provide better and more neutral masking compared to the other options tested, with Top-note 15 offering the most desirable milky aroma.
A mixture of masking 5 and top-note 15 was also tested aiming to convert the pea protein taste into a more neutral and milky taste. As aroma, mask 3 gave a vanilla taste which was considered unsuitable. Top-note 15 emulated the milk-like taste of dairy milk. Furthermore, although the masking solutions were used in small concentrations, they are primarily composed of dextrose contributing to a slight increase in nutritional value (Table 7).

Table 7 Nutritional values of the benchmark products and the Thermomix recipes used for Sensory analysis.

	Energy	Lipides	Carbohydrates	Sugar	Fibres	Proteins	Salt	Vitamins	Minerals
	[Kj]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
Oatly	257.00	3.00	7.10	3.40	0.80	1.10	0.10	0.00	0.12
Alpro	248.00	3.00	6.70	3.30	1.00	0.80	0.13	0.00	0.00
T_neutral	216.05	3.07	4.63	0.86	0.00	1.42	0.08	0.00	0.11
T_mask 3	217.62	3.07	4.72	0.95	0.00	1.42	0.08	0.00	0.11
T_mask 5	218.28	3.07	4.76	0.99	0.00	1.42	0.08	0.00	0.11
T_mask 5+15	218.28	3.07	4.76	0.99	0.00	1.42	0.08	0.00	0.11

When comparing the nutritional values of Oatly or Alpro oat milk barista to the neutral recipe, similar results were seen. The main differences observed with the Thermomix were a slightly higher protein content, likely due to the type of protein used in the recipe, and the absence of fibers since the syrup was highly refined (see nutritional value in Annex 9). Additionally, the sugar content was three times lower because the syrup is primarily composed of dextrose. Therefore, the final recipes meet the ingredient list and nutritional value requirements of the benchmark products. However, to achieve an even closer match, additional fiber can be included.

6.2. Physical analysis

6.2.1. Particle size

The difference in homogenization between an Ultra-turrax and a high-pressure homogenizer is significant. For the neutral recipe, particle size is reduced by at least 20 times from Thermomix neutral to the upscaling process and by 12 times with mask 5 and top-note 15 (Figure 6). Larger particles in suspension lead to increased sedimentation (Figure 8). It was also observed that recipes with masking have larger particles compared to those without. This is likely because masking solutions, which contain dextrose, increase the viscosity slightly (Figure 9) due to its sugar like properties. This increased viscosity may impact the homogenization process, leading to larger particle sizes.
A limitation of the Camsizer is its inability to distinguish air bubbles from particles due to stirring, resulting in a high standard deviation; therefore, at least three samples in duplicate are required per product.

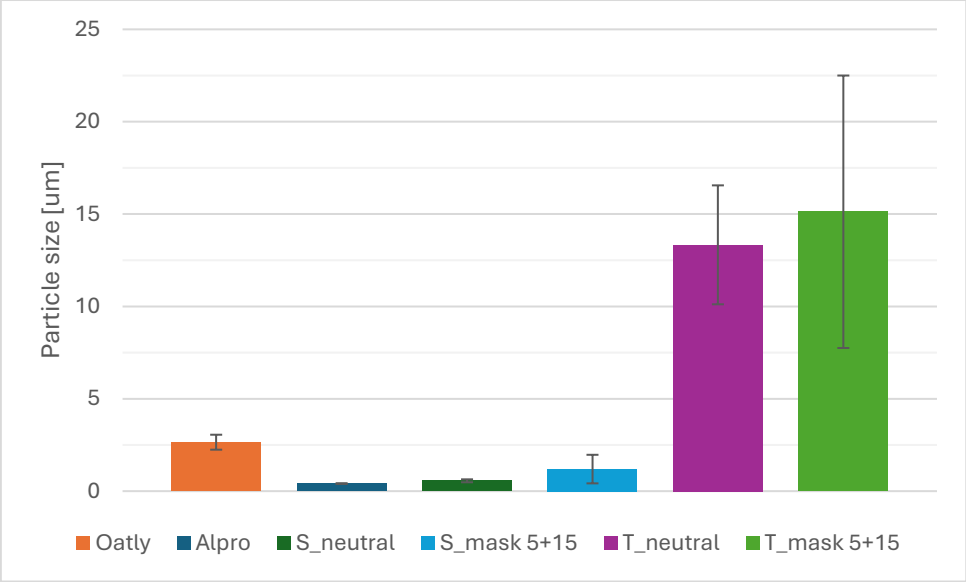


Figure 6 Mean of particle size for each product done with Camsizer machine, in duplicate. Three trials were executed.

6.2.2. Dry matter

Compared to Oatly and Alpro, the oat milk recipes created had less dry matter (Figure 7). Oatly having more dry matter was expected to have more sedimentation as seens in the physical analysis results. This indicates that more syrup can potentially be added to have a similar dry matter matching the benchmark recipes, therefore a higher °Brix will also be obtained. Alternatively, solid ingredients like fibers can be incorporated, as the innovative recipes currently have lower fiber content compared to Oatly and Alpro.

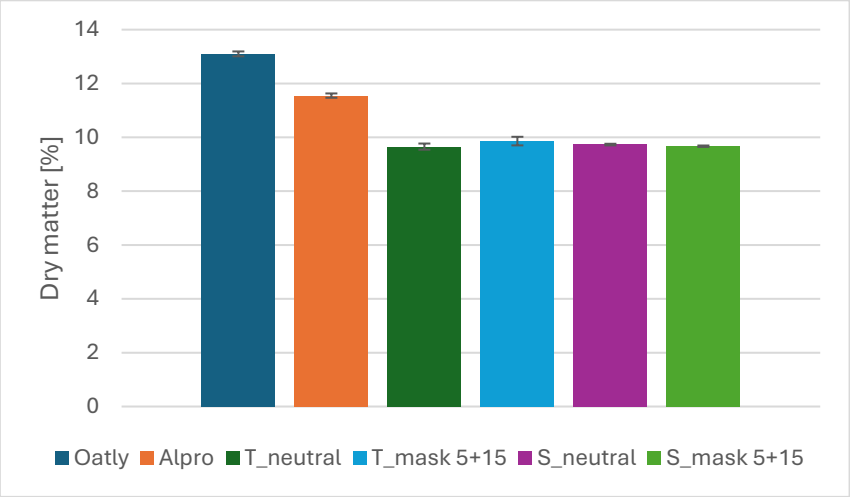


Figure 7 Dry matter of each product is measure in triplicate. Test is analyzed with the Moisture analyzer machine.

6.2.3. pH + Refractive index and Brix + Density

All products have a pH range of 7.34-7.51. To note, pH of milk[36] is around 6.64.

In experiments with sodium citrate on prototypes, precipitation occurs because sodium citrate increases the milk's alkalinity by raising its pH. This pH change impacts protein stability, as proteins remain soluble and stable only within a specific pH range. When the pH moves outside this range, proteins can become unstable and start to precipitate[37].

Refractive index is the same for all products (Table 8). However, Oatly and Alpro show a higher °Brix (1g sucrose in 100g solution)[38]. This suggests that the recipes created contain less sugar and that additional sugar could be added (aligning with the nutritional values in Table 7). Theoretically, concentration of oat syrup 28DE from T_neutral and T_mask 5+15 can be increased to 11-12% to match the carbohydrate and sugar content of the benchmark products. Interesting to observe, the same recipe from Thermomix to Scale-up gives different °Brix result. The higher the homogenization pressure was and more the °Brix was impacted[39]. This could be explained by the solution having smaller particle size appearing more concentrated as more ingredients are dissolved.

Density data were used for the contact angle analyze. All products had nearly the same density (around 1.03 g/cm^3).

[36] Reyes-Jurado, F., et al. "Plant-Based Milk Alternatives: Types, Processes, Benefits, and Characteristics." *Food Reviews International*, vol. 39, no. 4, 16 July 2021, pp. 1–32.

[37] Alcântara Pessôa Filho, P. A., Medeiros Hirata, G. A., Watanabe, É. O., & Miranda, É. A. (2011, January 1). *2.46 - Precipitation and Crystallization* (M. Moo-Young, Ed.). ScienceDirect; Academic Press. https://www.sciencedirect.com/science/article/abs/pii/B978008088504900132X

[38] Ryan, R. "Safety of Food and Beverages: Soft Drinks and Fruit Juices." *ScienceDirect*, Academic Press, 1 Jan. 2014, www.sciencedirect.com/science/article/abs/pii/B9780123786128002961.

[39] Liu, Jie, et al. "Effects of High-Pressure Homogenization on the Structural, Physical, and Rheological Properties of Lily Pulp." *Foods*, vol. 8, no. 10, 10 Oct. 2019, p. 472, https://doi.org/10.3390/foods8100472. Accessed 9 Dec. 2021.

Table 8 This table contains four analysis results for 2 benchmark product and two final Thermomix recipes with their upscale. The pH is done in duplicate with pH-meter. The refractive index and Brix are analyzed in triplicate with a Refractometer. The density is assessed in triplicate with a Density meter.

	pH	Refractive index -	Brix [%mas]	STDEV Brix	Density [g/cm3]
Oatly	7,51	1.35	12.31	0.16	1.04
Alpro	7,34	1.35	11.76	0.04	1.03
T_neutral	7,45	1.34	8.04	0.08	1.02
T_mask 5+15	7,38	1.34	8.11	0.08	1.02
S_neutral	7,38	1.34	10.13	0.02	1.01
S_mask 5+15	7,40	1.34	10.08	0.05	1.02

6.2.4. Color and Whiteness index

The whiteness index (WI) provides a clear indication of color differences in oat milk. Benchmmark products have the same WI. It is interesting to notice that Thermomix recipes are darker and more yellowish, while the upscaling recipes appear much whiter than any products tested, variation of colour is seen on Annex 14. As information, WI for bovine milk[40] is 81.89.

Smaller particle size resulting from higher homogenization (from Ultra-turrax to High Pressure Homogenizer) parameters can make an oat milk appear whiter (Table 9). In contrast, the Thermomix recipe may appear more yellow-brown due to Maillard reactions that occur during heating.

Table 9 Mean Color and Whiteness index of each product, in triplicate with standard deviation, done with Spectrophotometer.

	L*(D65)	a* (D65)	b* (D65)	Whiteness index
Oatly	78.20	1.69	16.55	72,58
STDEV	0.02	0.08	0.04	
Alpro	78.11	1.64	16.97	72,25
STDEV	0.01	0.03	0.04	
T_neutral	74.08	0.72	15.42	69,83
STDEV	0.06	0.11	0.07	
T_mask 5+15	73.48	0.98	15.64	69,20
STDEV	0.07	0.03	0.03	
S_neutral	80.49	0.48	11.93	77,13
STDEV	0.02	0.06	0.04	
S_mask 5+15	80.13	0.62	12.10	76,73
STDEV	0.10	0.15	0.07	

[40] Jeske, Stephanie, et al. "Evaluation of Physicochemical and Glycaemic Properties of Commercial Plant-Based Milk Substitutes." *Plant Foods for Human Nutrition*, vol. 72, no. 1, 5 Nov. 2016, pp. 26–33.

6.2.1. Physical stability

After 3 days of sedimentation, fat separation is visible in the Thermomix recipes but nearly absent in the upscaled recipes (Annex 16). The observed brown sediment was likely stemming from denatured pea proteins after heating. Oatly had a whiter sediment compared to Alpro, and neither showed significant phase separation on the surface.
For the centrifugation analysis, Oatly and Thermomix recipes exhibited the most sediment (Figure 8). While Alpro and upscaling recipes had three time less sediments, suggesting a more homogenous micro-emulsion beverage.

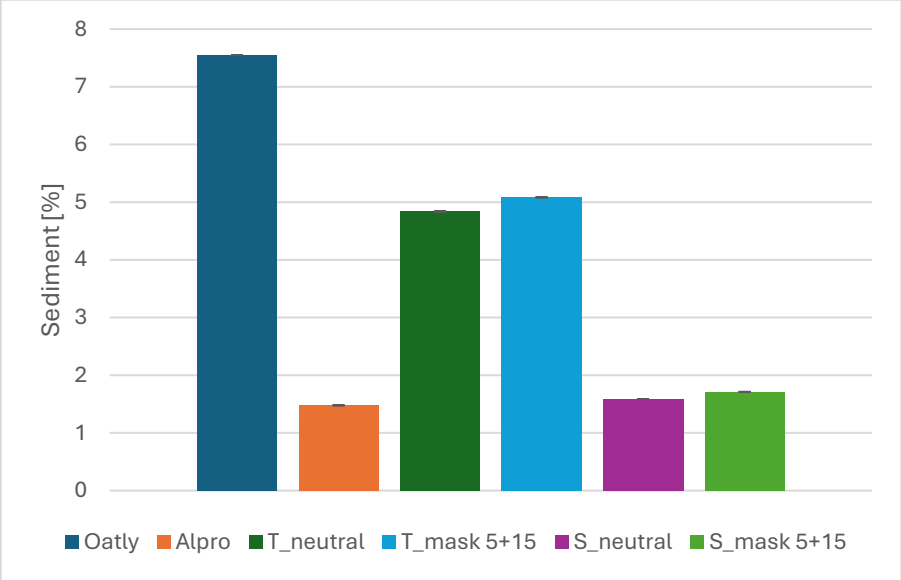


Figure 8 Percentage of sediment from each product after two centrifugations in Sigma 3-18KS, in triplicate, with standard deviation.

6.2.2. Viscosity

It's worth noting that cow's milk has a viscosity of 3.15 mPas[41]. The recipes created using the Thermomix and Upscaling methods have almost the same viscosity, with the Thermomix prototypes being slightly thicker. This suggests that the viscosity of the oat milk prototypes depend on the type of ingredients rather than the process. When compared to benchmark products, such as Oatly, which has a viscosity of 4.5 mPas, the innovated recipes had 50% less viscosity (Figure 9). This difference in viscosity was also reflected in the sensory profile tests, where Oatly was perceived to have more mouthfeel. Among the tested products, Alpro was the closest in properties to the innovated recipes. To achieve a viscosity like Oatly, it could be beneficial to test again the addition of guar gum to the final recipes or to increase the protein content of the oat milk.

[41] Yu, Yonghui, et al. "Oat Milk Analogue versus Traditional Milk: Comprehensive Evaluation of Scientific Evidence for Processing Techniques and Health Effects." *Food Chemistry: X*, vol. 19, 3 Sept. 2023, p. 100859.

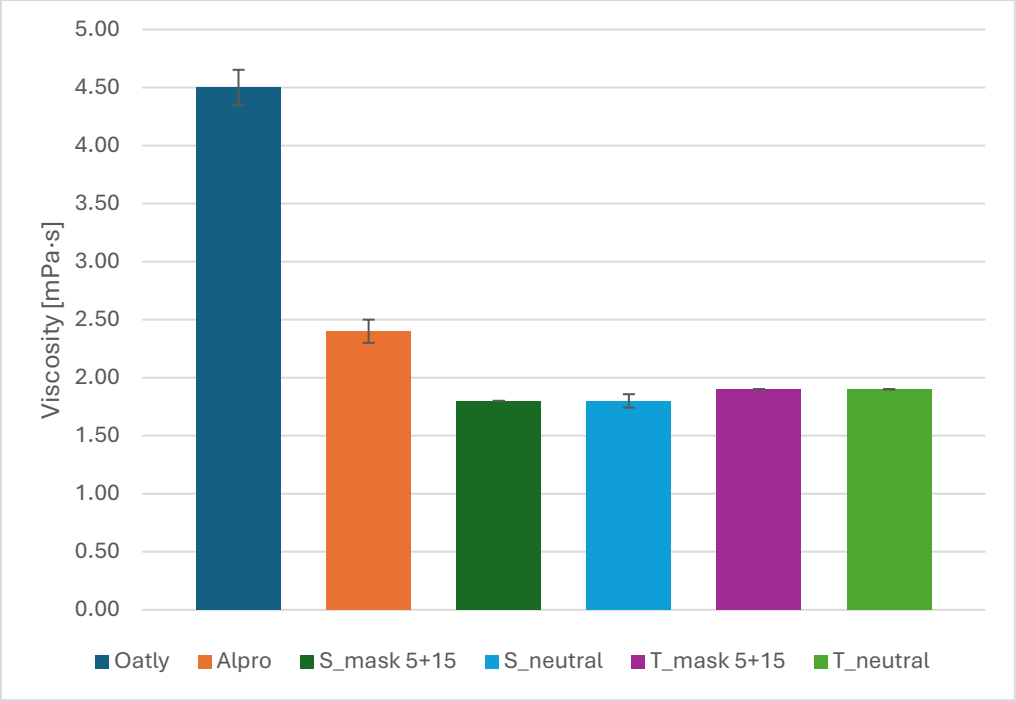


Figure 9 Mean viscosity at shear rate 10 [1/s] per product, in triplicata with standard deviation, done with Rheometer.

After simulating 4 days storage the viscosity of the oat milk remained stable (Figure 10). This stability suggests that the ingredient blend effectively maintains consistency when exposed to external factors like air, room temperature, and shaking.

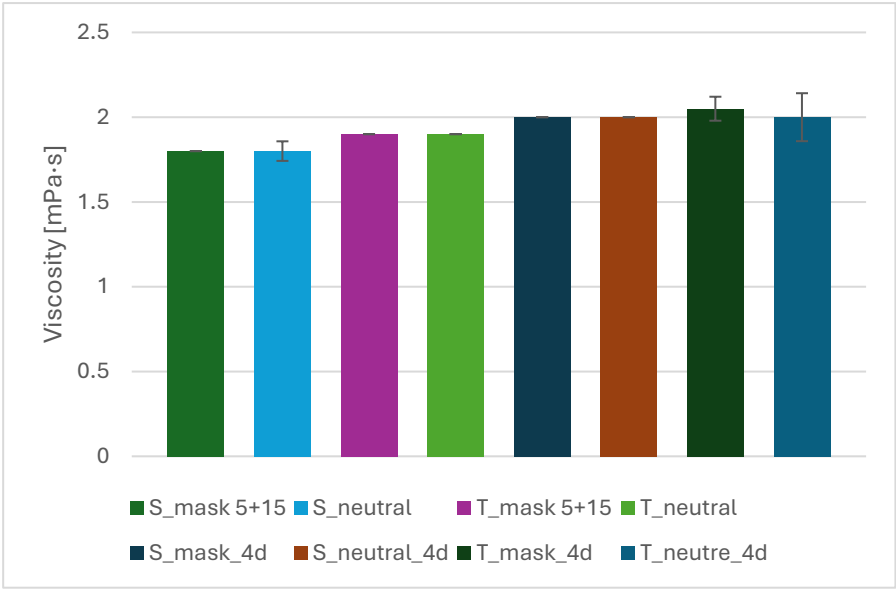


Figure 10 Viscosity analysis of S_neutral and S_mask 5+15 after 4 days of use during experiments. Results of day 1 and day 4 are shown to observe the differences.

6.2.3. Contact angle and surface tension

The measurements of contact angle and surface tension were sensitive to timing after shaking, as particles tended to settle during analysis. Therefore, measurements were repeated multiple times. Alpro showed the smallest average contact angle, followed by Oatly and then the upscale recipes (Table 10). Thermomix recipes had the largest contact angles. The larger particle size in thermomix recipes caused faster sedimentation due to poor homogenization, making them less stable and consistent compared to upscale recipes and benchmark products.

The contact angle data revealed how surface tension affects foamability. Oat milk, with its surfactants, has a lower contact angle than water on hydrophilic surfaces like glass, indicating better spreading and foam stability. For instance, water has a contact angle of about 55°[42] on uncoated glass, showing that higher surface tension leads to a rounder drop shape and larger contact angle (view of angle drop during analysis in Figure 11).

Table 10 Mean angle between right and left angle of 3 drop. Sessile drop test is done in triplicate with standard deviations. The machine used was the Tensiometer OCA 15EC, a syringe with needle and microscopes slides.

	[°]	STDEV
T_neutral	31.27	0.96
T_mask 5+15	40.47	0.50
S_neutral	28.50	0.47
S_mask 5+15	29.65	1.45
Oatly	26.77	0.75
Alpro	22.20	0.27

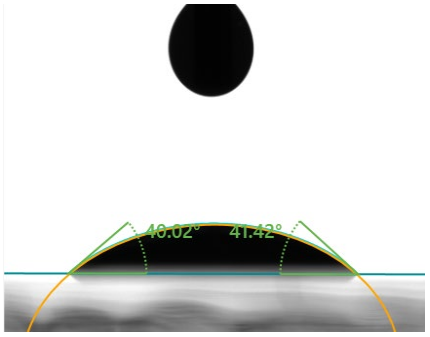


Figure 11 View of Sessile drop on Dataphysics optical contour analyzer software.

Several factors can affect tensiometer readings[43], including the quality of the oat milk, timing before measurement, temperature of the product and environment, needle tip placement, dosing rate, drop size, and surface characteristics. To address variations in drop size and shape, adjustments were made to the needle tip, and silicone oil was used, though this oil influenced the results by changing drop size and morphology. Lower surface tension, which results in a lower contact angle, helps create more foam because it requires less energy to mix air into the liquid. Generally, a lower contact angle can indicate lower viscosity, meaning the liquid spreads more easily and flows with less resistance, which can improve foam stability. However, in our tests, Oatly had the highest viscosity but did not have the lowest contact angle, so the expected relationship between contact angle and viscosity did not apply. More research is needed to fully understand how contact angle and viscosity are related.

To improve the Sessile drop method, it's recommended to take 5-10 consistent contact angle measurements per product for accurate results.

[42] Mohsin, H., et al. "Development and Characterization of Cobalt Based Nanostructured Super Hydrophobic Coating." *IOP Conference Series: Materials Science and Engineering*, vol. 146, Aug. 2016, p. 012038.
[43] Chau, T.T, et al. "A Review of Factors That Affect Contact Angle and Implications for Flotation Practice | Request PDF." *ResearchGate*, vol. 150, no. 2, 30 Sept. 2009.

6.2.4. Foamability and foam stability

Foamability was assessed using the Aeroccino Nespresso machine and the Nespresso Sage Creatista Plus (Annex 20 and 21)). Generally, the foam produced by the Aeroccino (a mechanical method) was creamier and denser than that produced by the other machine. Both devices use heat, but the steam injection method of the Sage Creatista Plus had a greater impact on foaming, potentially causing protein denaturation in coffee.
Due to its homogenization process, the upscaled recipes demonstrated superior foamability, as they make the more foam compared to the benchmark products in a 250ml cylinder (Figure 12). Thermomix recipes performed similarly to the benchmark products when the pea protein concentration was 3-3.5%. But with only 1% concentration in the final recipes, they produced just half the foam, as expected. Despite its ability to create substantial foam in prototypes, reducing the pea protein concentration was necessary to facilitate masking the strong aroma.

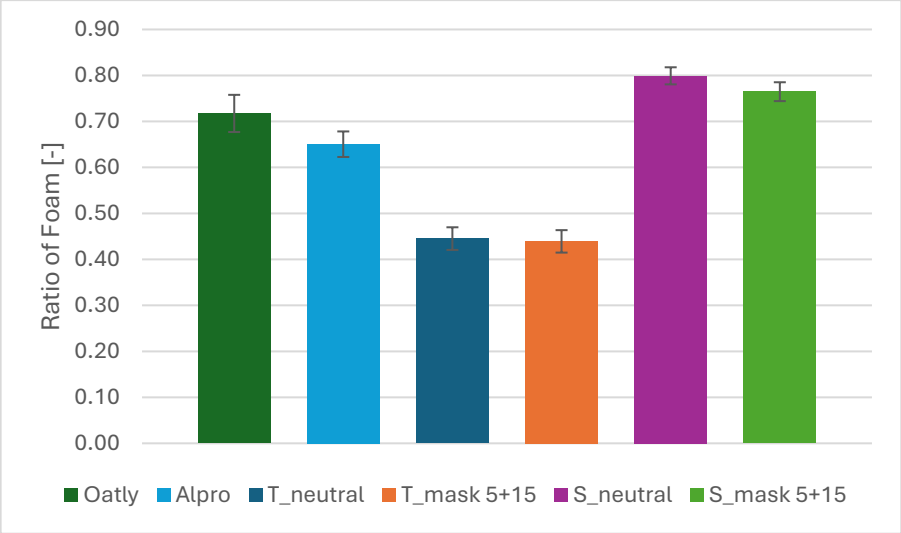


Figure 12 Ratio of foam from 10ml oat milk, in triplicate with standard deviation. Aeroccino Nespresso and a 250ml cylinder was used in this analysis.

A crucial requirement for barista-style oat milk is its ability to produce foam that remains stable for 10-15 minutes, making it suitable for coffee drinks. This analysis confirms that the foam from the innovative oat milk meets this standard. Additionally, the results reveal a correlation between surface tension and foamability: lower surface tension, and thus a lower contact angle (as seen in scaled-up recipes and benchmark products, Table 10), leads to increased foaming (Figure 12).

A causal link is supported by the fact that Thermomix recipes, which exhibited the highest contact angle created less foam than the benchmark products, which had smaller contact angles.

After 10 min rest from the foamability test, Alpro foaming shows to be the most stable as less reduction of foam was observed (Figure 13). Products produced on lager scale created the most foam and had consequently the highest foam lost after 10 min. Both the Thermomix and Upscale prototypes with masking 5 and top note 15 exhibited slightly lower foam formation and stability compared to the neutral prototypes. This difference is likely due to the slightly higher viscosity caused by the dextrose.
After 10 min rest, Alpro foam showed the be the most stable as less reduction of foam was observed (Figure 13). The upscale recipes created the most foam but showed lower foam stability. Both Thermomix and Upscale recipes with masking 5 and top note 15, showed slightly lower foam formation and stability than the neutral.

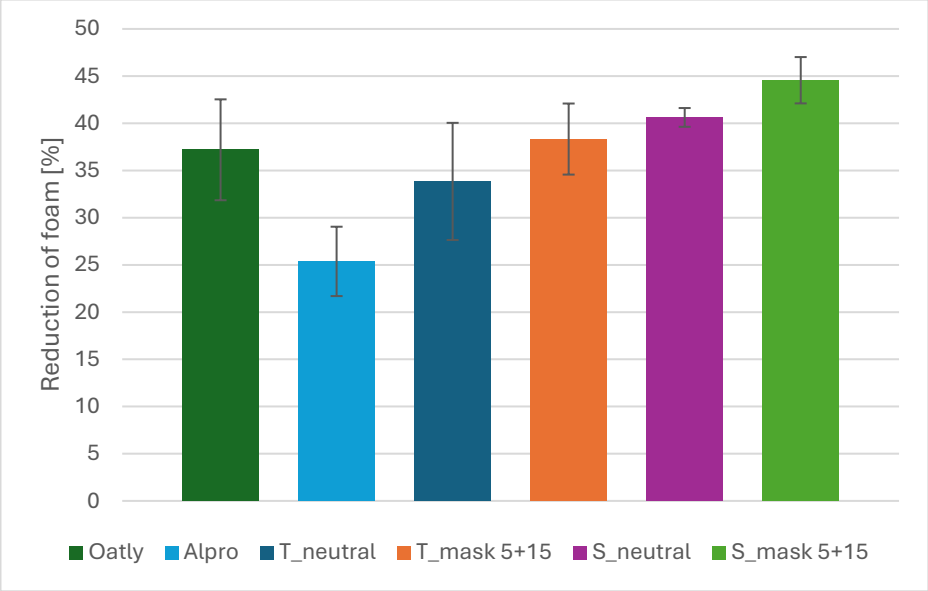


Figure 13 Mean reduction of foam after 10 min.

6.2.5. Foam in coffee

Heat from steam injection in the oat milk prototypes creates a potential precipitation in coffee. When less than 0.1% concentration of dipotassium phosphate was used in the recipes, a precipitation occurred when foaming was executed with the steam injection method. Steam injection involves high temperatures and pressure, which can denature proteins and destabilize emulsions (Annex 19), leading to precipitation. In contrast, mechanical foaming occurs at gentle aeration, which helps maintain protein integrity and emulsion stability, resulting in a stable foam without precipitation.

6.3. Microbiological analysis

Plant-based milk being a source of nutrients is a good source for the growth of micro-organisms. From the information letter[44] of Microbiological guide values for good practice control, for heat-treated foodstuffs ready for consumption under bakery and confectionery products table, the mesophilic aerobic germs should not exceed 1E+6 CFU/g for consumer use. A pasteurized dairy milk (HTST process heated to 72°C for 15 s) shelf-life can be stored up to 12-14 days at 4°C[45] and an UHT milk (heated to 125–138 °C for 2–4 s) can be stored for up to 3 months[46] under refrigeration.

Shown in Table 11, the oat milk was still consumable after 9 days of storage at 4°C and even after 12 days at 25°C. It was also determined that the beverage could still be drinkable after 5 days at 40°C. However, Bacillus cereus spore count (BCES) [47] and Yeast & mold count (YMC) analyses should be performed to confirm safety. Unexpectedly, more microorganisms grew at refrigerated temperatures, suggesting the presence of psychrotrophic bacteria like Bacillus cereus. This group also includes anaerobic facultative bacteria, which may explain the reduced growth in low-oxygen conditions. The heat resistance of Bacillus cereus spores could account for the slower growth at higher incubation temperatures. Additionally, fluctuations in refrigerator temperature may have contributed to bacterial growth during storage.

For a commercial product with extended shelf life, sterilization is the most effective option. Extending pasteurization time could also be explored, though it may affect the taste of the oat milk. According to the literature, ultrahigh-pressure homogenization (UHPH) at 300 MPa and 60°C[48] can improve stability and significantly reduce microbial load, thereby increasing shelf life.

Table 11 Shelf-life analysis in 14 days of S_neutral with 3 different temperatures. Total viable count method is used in aerobic and anaerobic atmosphere with PCA as media. The pour plate technique was applied. Results are express in CFU/ml.

	4°C		25°C		40°C	
Day	aerobic	anaerobic	aerobic	anaerobic	aerobic	anaerobic
1	9.10E+02	8.75E+02	-	-	-	-
5	1.25E+03	1.18E+03	>3.00E+05	>3.00E+05	unaccountable	unaccountable
7	Too diluated	Too diluated	1.25E+06	1.25E+06	9.00E+07	1.50E+06
9	>3.00E+05	>3.00E+05	1.70E+04	4.45E+05	5.05E+06	Too diluated
12	9.60E+06	1.01E+07	3.00E+05	2.45E+05	5.30E+06	6.70E+06
14	3.70E+07	2.45E+07	7.00E+05	1.26E+06	-	-

[44] lettre dinformation-2021-2.pdf
[45] "Shelf-Life of Dairy Products." *Www.dairysafe.vic.gov.au*, www.dairysafe.vic.gov.au/consumers/keeping-dairy-food-safe/shelf-life-of-dairy-products#:~:text=The%20period%20of%20time%20each.
[46] Cole, Sheri, et al. "Pasteurized Milk☆." *ScienceDirect*, Academic Press, 1 Jan. 2022, www.sciencedirect.com/science/article/abs/pii/B9780128187661001422.
[47] Kyrylenko, Alina, et al. "Levels and Types of Microbial Contaminants in Different Plant-Based Ingredients Used in Dairy Alternatives." *International Journal of Food Microbiology*, vol. 407, 1 Dec. 2023, pp. 110392–110392
[48] Sethi, Swati, et al. "Plant-Based Milk Alternatives an Emerging Segment of Functional Beverages: A Review." *Journal of Food Science and Technology*, vol. 53, no. 9, Sept. 2016, pp. 3408–3423,

6.4. Sensory analysis

6.4.1. Benchmark products and neutral recipes

An initial ANOVA analysis was conducted on the profile test results for the two neutral recipes and the two benchmark product references (Table 12). Of the eleven attributes evaluated, seven showed significant differences among the four beverages. These descriptors are Beany, Green, Dairy notes, Vanilla, Cardboard, Bitter, and Mouthfeel. To provide further insight, data from multiple pairwise comparisons in the ANOVA are presented as letters. Products sharing the same letter for a descriptor belong to the same group, indicating similarity.

Overall, Oatly and Alpro consistently fell into the same group, despite their distinct characteristics, suggesting that when compared to the Thermomix recipes, they are quite similar. T_neutral was more closely aligned with Oatly than with Alpro, as they shared more common attributes. Specifically, Oatly and T_neutral matched on green, sweet, and bitter notes. Proposal 1, which contains slightly less oil and soy lecithin but three times the pea protein concentration of T_neutral, differed significantly only in mouthfeel, due to the thicker texture resulting from the higher protein content. However, T_neutral, as the improved version of Proposal 1, was less green, less astringent, and less bitter (Figure 14).
In terms of Mouthfeel, Alpro was comparable to T_neutral, as viscosity results showed that Alpro is less viscous than Oatly. Since both Thermomix recipes used the same pea protein isolate, they exhibited similar attributes. Furthermore, although Alpro and Oatly were rated differently across six attributes, with a more pronounced contrast in Beany and Green notes, they were still considered similar overall.
To create a beverage equivalent to Oatly or Alpro, T_neutral would need to improve on the beany, green, dairy notes, vanilla, and cardboard attributes. This could be achieved by incorporating masking agents or modifying the recipe. Additionally, mouthfeel could be enhanced by adding gums, oils, or other mouthfeel agents.

Table 12 Profile test of the two neutral recipes innovated and two benchmark products. The test is conducted by a panel of 13 sensory expert judges. It is analyzed with 11 descriptors and a scale from 1-10. Mean results were obtained from ANOVA analysis with significance level of 0.05. Also, data from multiple pairwise comparisons from ANOVA were inserted as letters.

Attribute	**Beany**	**Cereals**	**Green**	**Dairy notes**	**Vanilla**	**Rancid**	**Cardboard**	**Sweet**	**Bitter**	**Astringent**	**Mouthfeel**
T_neutral	6.775 a	5.261 a	5.080 ab	1.723 b	0.490 b	2.115 a	4.181 a	1.896 ab	3.215 ab	4.489 ab	3.190 b
Proposal 1	6.405 ab	4.102 a	5.954 a	1.416 b	0.462 b	2.428 a	3.831 a	0.902 b	4.282 a	5.337 a	5.062 a
Oatly Barista	4.878 bc	5.300 a	3.256 bc	4.264 a	1.501 a	1.039 a	2.621 ab	2.404 a	2.484 b	4.008 ab	5.482 a
Alpro Barista	4.057 c	5.021 a	2.479 c	4.592 a	1.268 a	1.208 a	1.662 b	2.408 a	1.894 b	3.398 b	4.349 ab
Pr > F(Product)	0.004	0.505	0.002	<0,0001	0.008	0.160	0.007	0.057	0.015	0.087	0.007
Significant	**Oui**	Non	**Oui**	**Oui**	**Oui**	Non	**Oui**	Non	**Oui**	Non	**Oui**

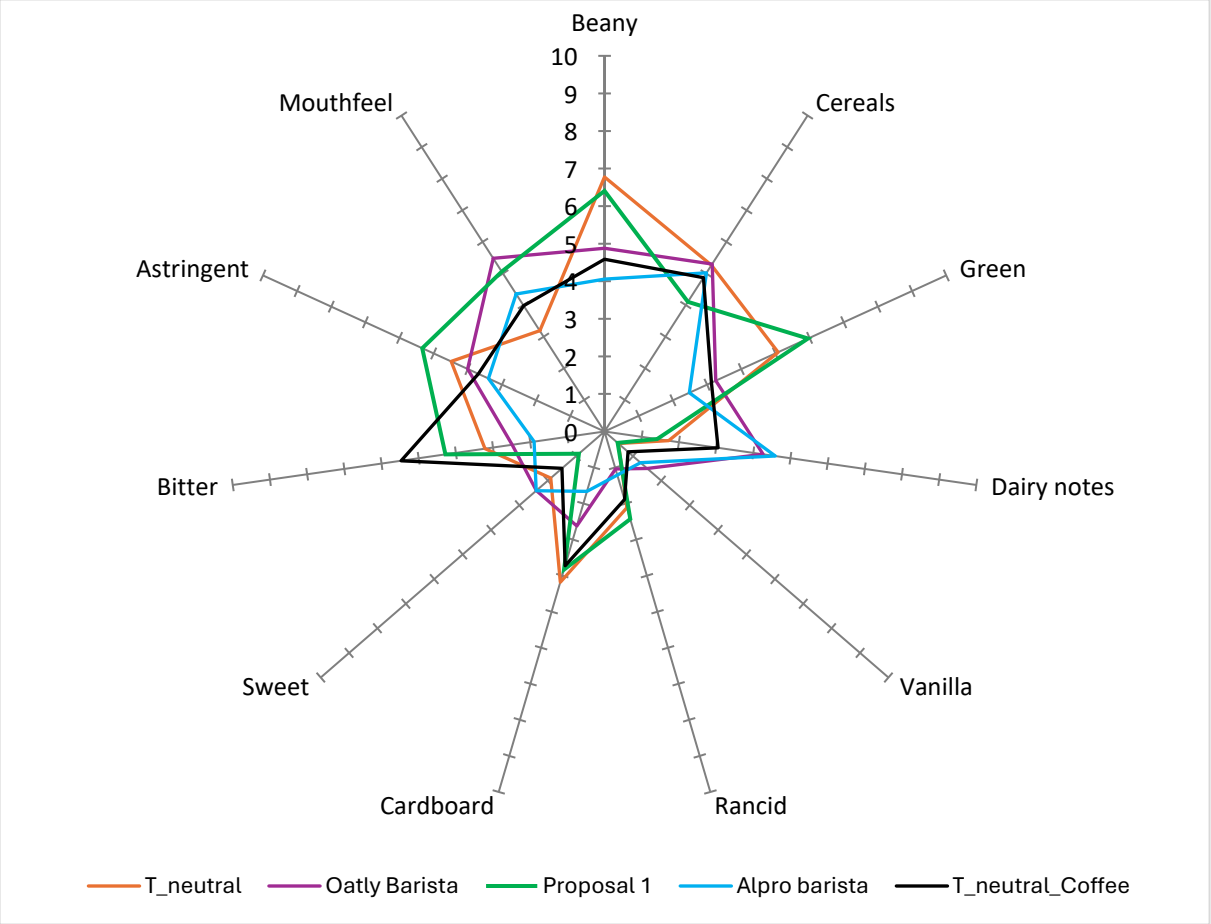


Figure 14 Radar plot from sensory profile of Table 12. T_neutral_Coffee profile data were added to have an overview of all profil test results.

6.4.2. Thermomix Final recipes

T_neutral is the only Thermomix recipe that underwent a profile test with a masking agent. The results of a comparison test, scored on a scale from -5 to 5, were added to the T_neutral results to create a radar plot (Annex 25 and 26). Significant differences were observed in the beany, dairy, and cardboard notes compared to the reference (T_neutral), indicating that the masking agent effectively masked these attributes.

Among the three tested recipes, T_masking 3 was the least effective in masking the Green and Bitter aromas, failing to do so significantly. In contrast, Masking 5 was considered the most neutral and successfully masked the T_neutral recipe's off-notes, particularly the Green and Bitter notes, better than Masking 3 (Figure 15). As anticipated, T_masking 5+15 provided the most effective masking, as it combined masking solution 5 with top-note 15. The top-note contributed to masking the beany, green, cardboard, and astringent attributes, but its strong milky and creamy aroma also significantly enhanced the dairy, vanilla, and sweet notes.

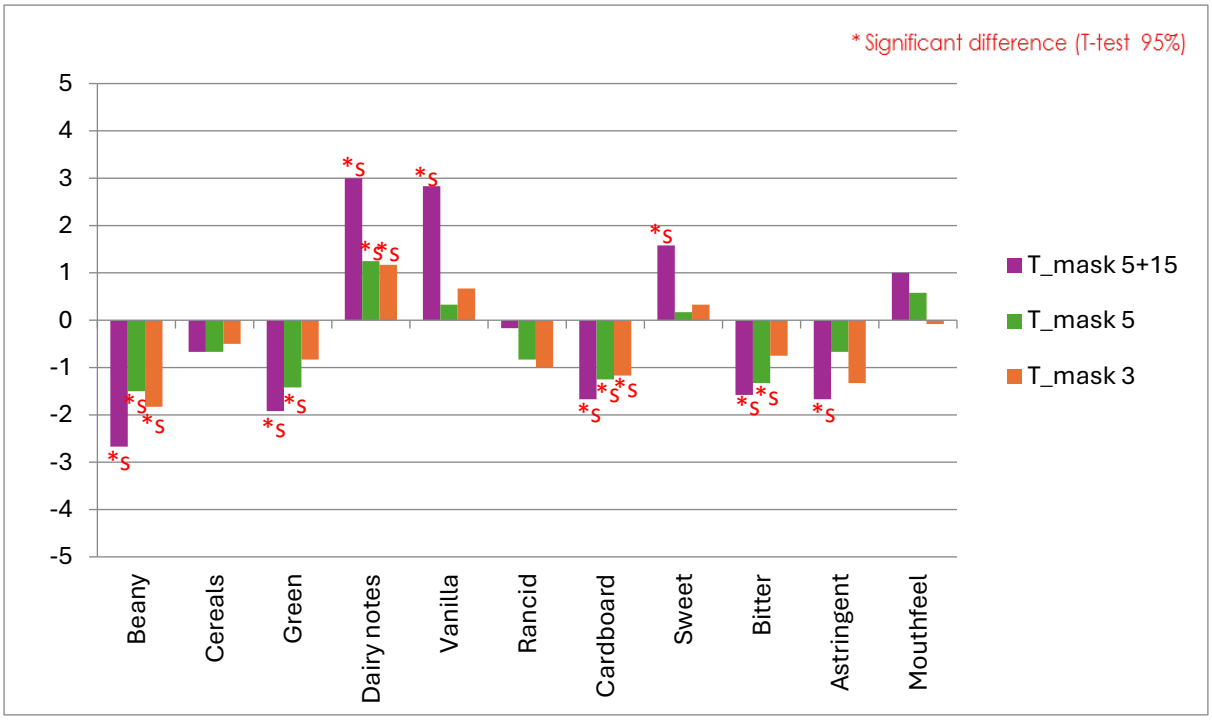


*Figure 15 Comparison test graph from Annex 27. Reference is considered as 0 in the graph, *S indicates significant difference between the reference and a product.*

6.4.3. Thermomix VS Scaling-up recipes

Two triangular tests were conducted. The first test compared two samples made from the same recipe, with the only difference being the production method: one was prepared using a Thermomix, and the other through an upscale process. The chosen recipe included a mixture of Masking 5 and Top-Note 15, as the addition of masking solutions was expected to have no physical impact on the beverage.

Out of a panel of 20 judges, comprising both experienced evaluators and internal recruits, 17 detected a difference between the samples (Annex 28). Given the significant difference, feedback from this test was considered. The upscaled recipe was perceived as having a greener, more earthy taste, with increased bitterness, creaminess, sweetness, and a more pronounced oat flavor compared to the Thermomix version (Annex 29).
This difference is attributed to the superior homogenization[49] which was achieved in the upscaled process, which results in a smoother and more uniform texture, thereby enhancing taste and mouthfeel. A profile test of the upscaled recipe is planned to further identify the impacted attributes.

[49] Park, Curtis W., and MaryAnne Drake. "The Effect of Homogenization Pressure on the Flavor and Flavor Stability of Whole Milk Powder." *Journal of Dairy Science*, vol. 100, no. 7, July 2017, pp. 5195–5205, https://doi.org/10.3168/jds.2017-12544. Accessed 3 Jan. 2019.

In the second test, the same recipe was used, but this time with the masking mixture added either during the blending step or at the end of the process after pasteurization. The results indicated that the timing of the masking agent addition did not affect the taste. Therefore, it can be concluded that the masking solutions are stable and resistant to external factors such as heat and homogenization.

6.4.4. Thermomix recipes in coffee

The thermomix neutral recipe combined with the espresso Nespresso Livanto had a strong bitter aroma (Figure 16). Overall, all attributes were lessened in their intensity a part mouthfeel and dairy notes. It is likely that the acidity of coffee masks the strong aroma of pea protein in the mixture.

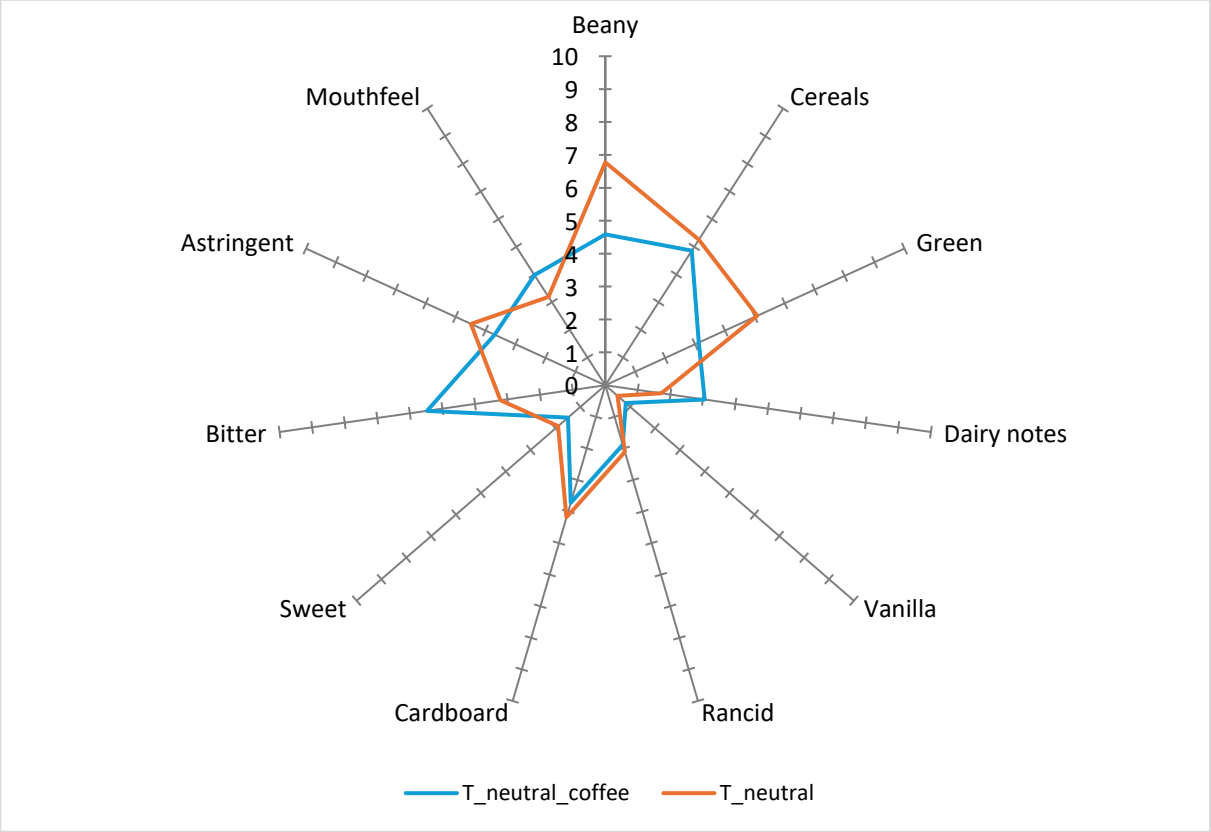


Figure 16 Radar plot from sensory profile of Annex 30.

The comparison analysis revealed that T_mask 5, when added to coffee, significantly reduces the beany and cardboard aromas compared to the T_neutral (REF) sample. This indicates that the masking effect remains effective in coffee applications. In contrast, mask 3 has a weaker impact on coffee flavor. As expected, the milk top-note 15 in T_mask 5+15 is also well-received (Figure 17). Overall, mask 5 is more effective at concealing beany notes.
For future experiments, increasing the concentration of masking solution 5 (currently at 0.15%) may be beneficial, as the pea protein flavor is still noticeable. However, the concentration of top-Note 15, currently recommended at 0.05%, could be reduced by half due to its overpowering dairy aroma. Additionally, conducting a profile test on espresso alone would provide better insight into which masking solution is most effective in coffee applications, as the masking effects have only been evaluated in oat milk thus far. Exploring the use of bitter masking agents could further enhance not only coffee recipes but also other innovative formulations.

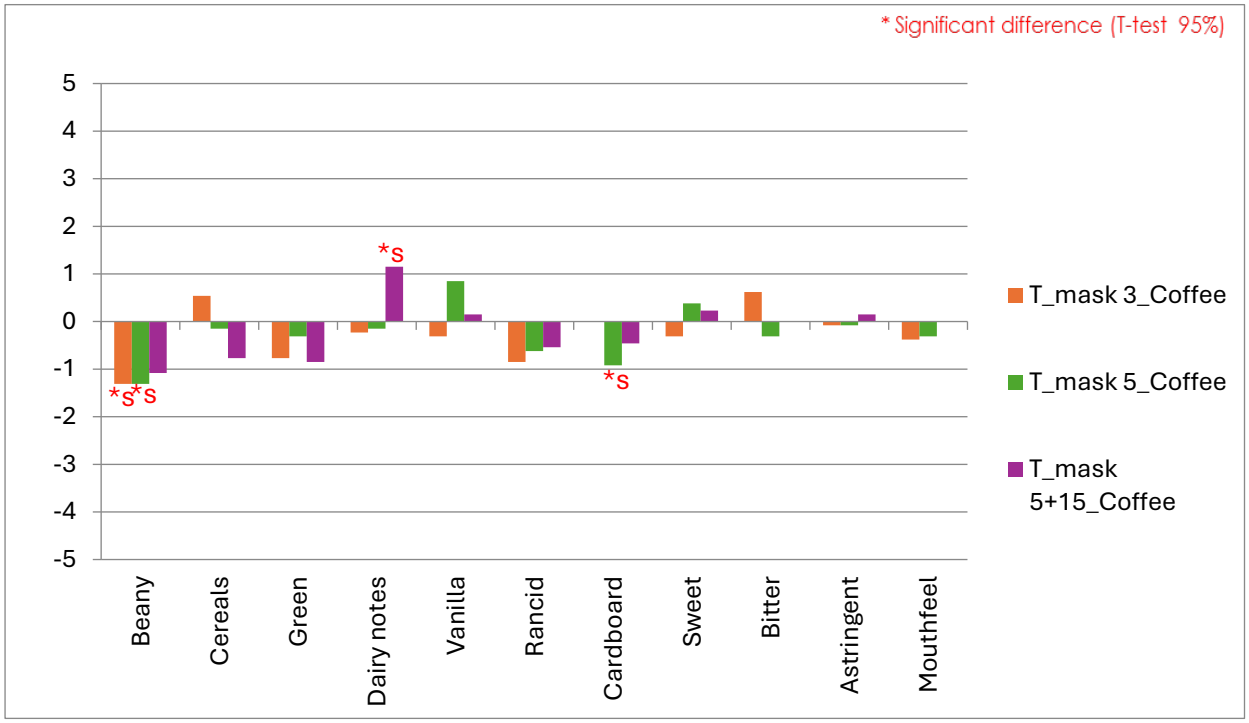


*Figure 17 Comparative test graph of Annex 31. Reference is considered as 0 in the graph, *S indicates significant difference between the reference and a product.*

7. Conclusion

From the 158 recipes developed during the prototyping trials, only 5 Thermomix recipes and 2 scaling-up recipes were selected for sensory analysis. The upscale process, particularly the homogenization parameters, significantly influenced both the physical and sensory properties of the oat milk.
For instance, particle size in the Thermomix samples was substantially larger compared to the upscale recipes and benchmark products. This resulted in higher °Brix readings, whiter color measurements, better physical stability with less sediment formation, and notably more than double the foaming capacity compared to the Thermomix samples.

Regarding shelf-life analysis, it was determined that the upscale oat milk recipes can be stored at 4°C for up to 9 days. However, potential contamination with Bacillus cereus was identified, necessitating BCES and YMC tests to confirm the specific microorganism present.

In terms of sensory analysis, the transition from Proposal 1 to T_neutral, with reduced pea protein content, resulted in lower green, astringent, and bitter attributes, marking a significant improvement in the recipe. To further align T_neutral with benchmark products, enhancements to mouthfeel are needed. While T_mask 5+15 effectively masked the beany, green, cardboard, and astringent attributes, its strong milky and creamy aroma significantly enhanced the Dairy, Vanilla, and Sweet notes, suggesting that a lower concentration of this mixture is advisable.

For future improvements, achieving optimal homogenization during the prototyping phase can be enhanced by using an Ultra-turrax set to 12,000 rpm for 5-10 minutes. To extend shelf life, consider exploring longer pasteurization or sterilization processes. Further experimentation should focus on incorporating gums such as guar or gellan at concentrations of 0.1-0.2%, or utilizing mouthfeel solutions from MANE. Additionally, testing bitterness-masking solutions is advisable, as bitterness was still evident in coffee applications. It is also noted that upscale recipes demonstrated more pronounced aromas compared to those produced with the Thermomix.

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ChatGPT

9. Annex

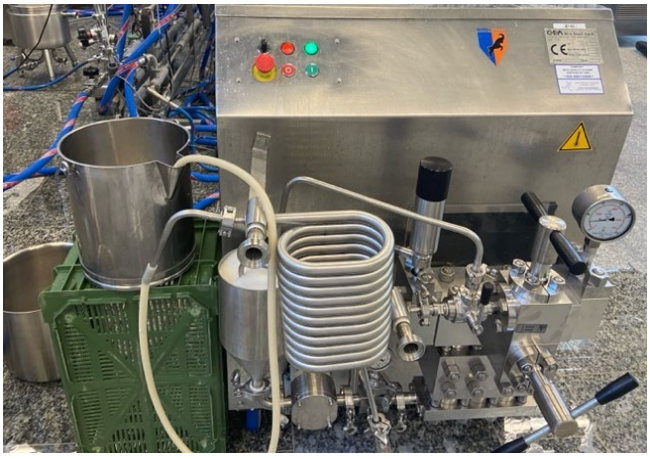
9.1. Oat milk upscale process



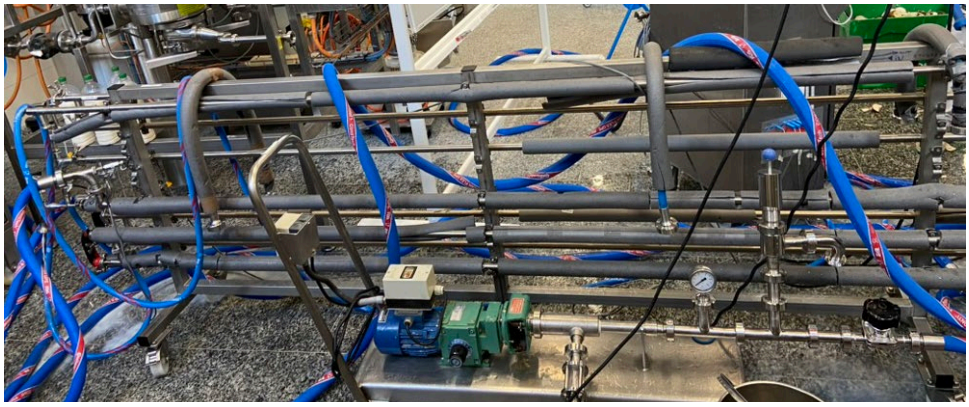
Annex 2 Blender Stephan



Annex 1 Heating water machine HES-SO



Annex 3 High pressure homogenizer Ariete NS3006L (with 2 stages pression) and pan of 15L.



Annex 4 Tubular Heat Exchanger from APV with centrifugal pump Hilge.

9.2. Development of recipes

Annex 5 Table of all ingredients tested in the prototyping phase with the concentration tested and explanation of properties in the recipes.

Raw material	Properties	Conc.	In recipe? Yes/No	Why?
Distilled water	Dilution, help mixing	86-88%	**Yes**	Adjusted to achieve the desired beverage consistency.
Hydrolyzed Oat flour	Oat flour already treated with alpha-amylase	10.2%	No	Prototypes exhibited instability due to sedimentation of flour. Higher flour concentrations are required compared to syrup. Sugar is incorporated with flour but not with syrup.
Oat syrup 18DE	Hydrolyzed syrup	15%	No	Syrup performs better than flour with minimal sedimentation.
Oat syrup 28DE	Hydrolyzed syrup	8%	**Yes**	It is sweeter and exhibits slightly better foaming compared to 18DE syrup. Longer hydrolysis is required for syrup compared to 18DE syrup, enhancing sweetness. Sugar content comparisons for equivalent quantities are detailed in Annex 6.
Sunflower oil	Create better foaming, creamy texture	2%	No	Early trials indicated that rapeseed oil provided better mouthfeel and masking compared to sunflower oil. Mixing sunflower and rapeseed oil with hydrolyzed oat flour yielded slightly less foam than using rapeseed oil alone.
Rapeseed Oil	Create better foaming, creamy texture	2.6%	Yes	Mouthcoating properties which helped mask better the strong pea taste.

Pea protein Navitalo	Create more foam	0.45%	No	Tested only at at 0.45% concentration, providing adequate pea flavor with minimal need for off-note correction. Less foaming compared to other pea proteins.
Pea protein isolate Emsland	Create more foam	1-3%	**Yes**	Pea protein isolate, with smaller particles and higher concentration than pea protein concentrate, had a stronger pea flavor and slightly better foaming (15-16 cm foam on average). Increased concentration of isolate leads to more foaming.
Pea protein concentrate GMSA	Create more foam	2-4%	No	Exhibits slightly reduced foaming compared to the isolate and has a pronounced cardboard taste.
Guar gum	thickener	0.1-0.15%	No	Produces a thicker texture with a more pronounced cardboard flavor and less foaming compared to other thickeners.
Gellan gum	thickener	0.2-0.25%	No	Less thick, milk-like texture with a more homogeneous milk mixture compared to guar gum. Steam injection with gellan gum results in a pudding-like texture (hydrogel).
Soy lecithin	Emulsifier, stabilize foaming	0.25%	Yes	Stabilizes foaming effectively but imparts a gritty mouthfeel. Granules must be finely ground to achieve optimal results.
Dipotassium phosphate	Acidity regulator, stabilize in coffee	0.1%	**Yes**	Maintains stability in coffee, though it introduces a more astringent note.
Sodium citrate	Acidity regulator	0.1%	No	Exhibits significant phase separation and precipitation even at low concentrations, resulting in unstable foam that collapses rapidly.
Masking 2	High masking of vegetal off-notes, bitterness and off-tastes	0.2%	No	Tasted like oily aroma.

Masking 3	High masking of vegetal off-notes and cereal off-notes	0.1%	Yes	Mask pea protein and had a vanilla aroma.
Masking 5	High masking of vegetal off-notes, bitterness and off-tastes	0.15%	**Yes**	Mask pea protein and had more neutral taste than masking 3
Masking 7	High masking of cereal off-notes, bitterness and off-tastes	0.05%	No	Liquid format and almost perceived as slightly salty
Top-note 13	Add milky top note	0.03%	No	Liquid format and has condensed milk and vanilla taste. Concentration test was too strong
Top-note 14	Add milky top note	0.008%	No	Fresh milk taste (from the cow)
Top-note 15	Add milky top note	0.05%	**Yes**	Added mouthfeel and was perceived as creamier with cereal taste and no off-notes
Crystallized sugar	sweet	1%	No	With hydrolyzed oat flour test sugar was added but not with oat syrup.
Fine salt	salty	0.05%	**Yes**	To enhance the sweet taste.

Annex 6 Table of nutritional values of raw materials tested in the prototyping phase

		Energy	Lipids	Carbohydrates	Sugar	Fibres	Proteins	Salt	Vitamins	Minerals
Fourisseur	**Product**	[kJ]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
Interquell	Hydrolyse oat flour	1662.00	5.10	76.90	0.70	3.00	8.40	0.03	0.00	0.80
Meurens natural	Oat syrup 18DE	1314.00	6.00	62.50	5.60	0.00	2.60	0.03	0.00	0.40
Meurens natural	Oat syrup 28DE	1262.00	4.50	57.50	10.50	0.00	7.10	0.10	0.00	0.15
Coop qualité & prix	Sunflower oil	3404.00	92.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Coop qualité & prix	Rapeseed oil	3404.00	92.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Navitalo	Soluble pea protein	1670.53	6.00	0.00	0.00	4.00	80.00	0.00	0.00	5.00
GMSA	Pea protein concentrate	1395.00	3.80	18.00	3.30	12.00	50.00	0.10	0.00	0.00
Emsland Group	Pea protein isolate Empro E86 LS	1783.00	9.50	0.50	0.50	0.00	85.00	2.50	0.00	0.00
Carl Roth GmbH	Diphosphate de sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Carl Roth GmbH	Citrate de sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Thermo Scientific	Soy lecithin	2873.16	90.00	8.00	0.00	0.00	0.00	0.00	0.49	0.00
Morga	Soy lecithin granulate	3503.00	91.00	8.00	4.00					
Coop qualité & prix	Crystallised sugar	1700.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00
Coop qualité & prix	Fine salt Sel des Alpes	0.00	0.00	0.00	0.00	0.00	0.00	99.80	0.00	0.00

Annex 7 Tasting table of Benchmark products from Swiss market analyzed with MANE sensory specialists.

Product name	Oatly Oat milk Barista	Alpro Oat milk Barista	Bio Karma Oat Barista	Emmi Beleaf Oat Barista
Product image				
Aromatic notes	green, cereal, astringent, sweet	+creamy, not much off-notes, neutral	+++sweet,green	Astringent,beany, cereal
Texture	Thick in mouth	-thick	Watery, translucent	Watery, translucent
Particularity	-	Pea protein, chicory root fibre	Enzymes, no acidity regulator	Thickener, emulsifier

Annex 8 Comparison table of nutritional values of Benchmark products.

per 100g	**Energy**	**Lipids**	**Carbohydrates**	**Sugar**	**Fiber**	**Proteins**	**Sel**	**Vitamins**	**Minerals**
Benchmark products	[Kj]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
Oatly oat milk barista	257kJ	3.00	7.10	3.40	0.80	1.10	0.10	0.00	0.12
Alpro Oat milk barista	248 kJ	3.00	6.70	3.30	1.00	0.80	0.13	0.00	0.00
Bio Karma Oat barista	222kj	1.50	9.20	5.70	0.00	0.60	0.04	0.00	0.00
Beleaf oat barista	238 kJ	2.10	8.50	5.70	0.00	0.60	0.07	0.00	0.00

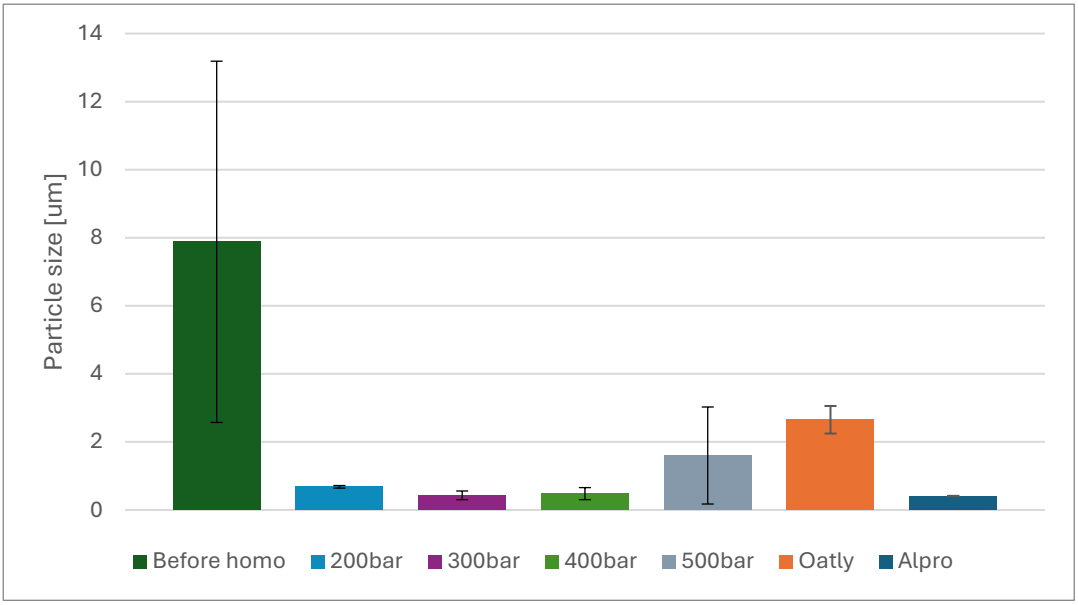
Annex 9 Ingredient list of first proposal and the four final recipes analyzed with the sensory panel.

per 100g	**Ratio**	**Energy**	**Lipids**	**Carbohydrates**	**Sugar**	**Fiber**	**Proteins**	**Sel**	**Vitamins**	**Minerals**
Ingredients	[%]	[kJ]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
Demineralised water	88,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Oat syrup 28DE	8,00	100,96	0,36	4,60	0,84	0,00	0,57	0,01	0,00	0,01
Rapeseed oil	2,60	88,50	2,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pea Proteins isolate	1,00	17,83	0,10	0,01	0,01	0,00	0,85	0,03	0,00	0,00
Soy lecithin	0,25	8,76	0,23	0,02	0,01	0,00	0,00	0,00	0,00	0,00
Dipotassium phosphate	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10
Salt	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,00	0,00
Total	100,00	216,05	3,07	4,63	0,86	0,00	1,42	0,08	0,00	0,11

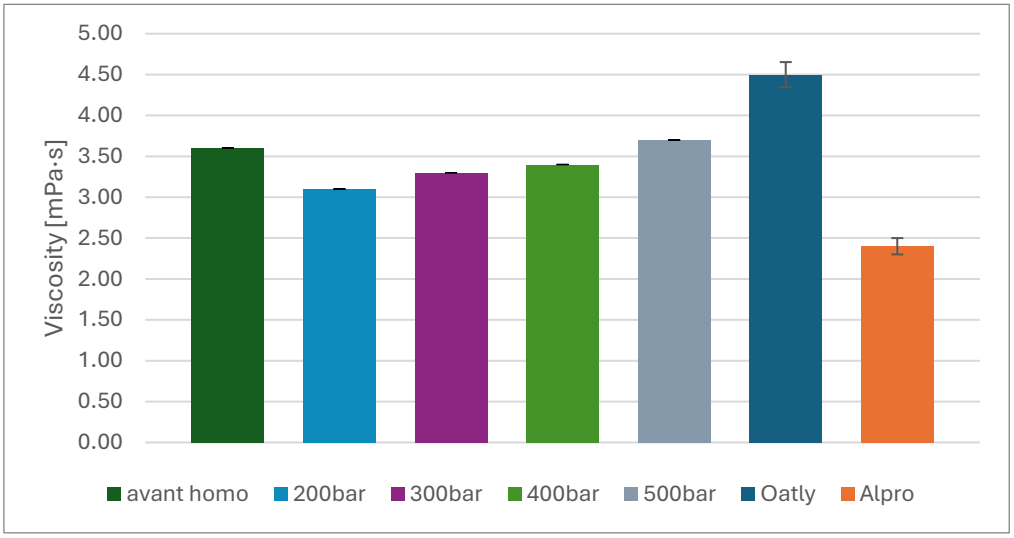
9.1. Homogenization pression tests

Annex 10 Thermomix recipe n°110 used to test homogenization pression parameter for upscale process

Per 100g	**Recipe n°110**
Ingredients	[g]
Demineralise water	86.28
Oat Syrup 28DE	8.00
Rapeseed oil	2.00
Pea Protein isolate	3.50
Dipotassium phosphate	0.02
Soy lecithin	0.15
Salt	0.05
total:	100.00



Annex 11 Particle size analysis of recipe n°110 before homogenization, after homogenization at 200 bar, 300 bar, 400 bar, 500 bar pressure with standard deviation. Oatly and Alpro particle size are added to compare particle size of final product.



Annex 12 Viscosity analysis of recipe n°110 at shear rate 10 [1/s] with Rheometer and CC27 at room temperature. Benchmark products viscosity is also added to compare results.

Annex 13 Foaming of recipe n°110 from differenthomogenization pressure tested. Aeroccino Nespresso and 250ml glass cylinder were used for this analysis.

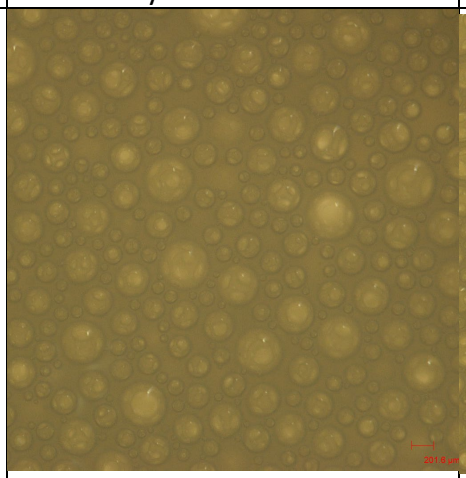
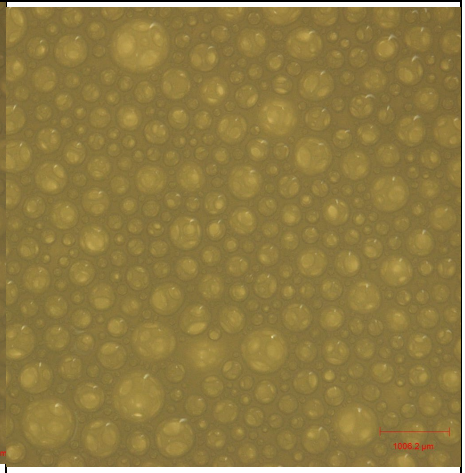
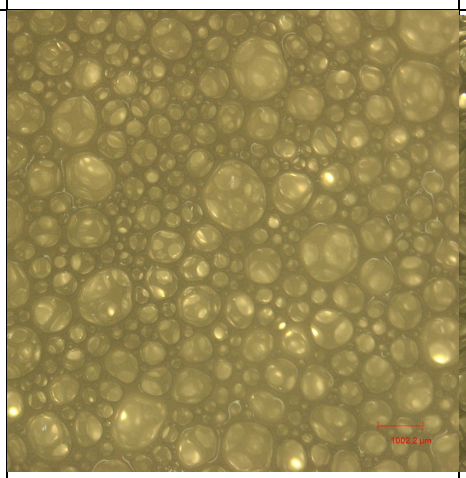
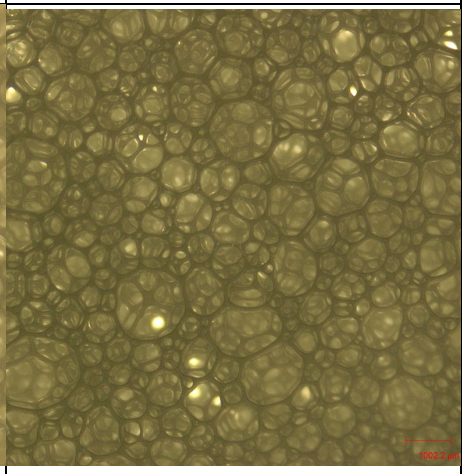
before homo	200bar	300bar	400bar	500bar
20cm foam and remain 9.2cm	21.5cm foam and remain 12.2cm, bubble less stable	21cm foam and remain 12cm, foam stability ok	20cm foam and remain 14.5cm bubble stable	21cm foam and remain 11.5cm bubble not stable

9.2. Physical analysis

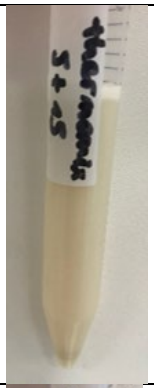
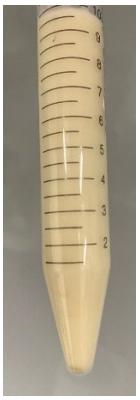
Annex 14 Color of Thermomix and Scaling-up samples.

Thermomix	Scaling-up
	

Annex 15 Surface pictures of foams from Oatly and Alpro Oat milk Barista, at 0 and 10min after foaming with Aeroccino. Microscope Stemi 2000-C and camera Olympus XC10 were used to realize this analysis.

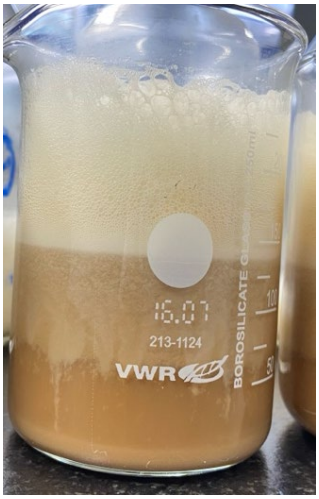
Parameters	Oatly Oat milk Barista	Alpro Oat milk Barista
T= 0min Lens zoom: 1.6x Bubble Size: ~200-300µm		
T= 10min Lens zoom: 0.65x Bubble Size: ~700µm -1mm		

Annex 16 Physical stability analysis by sedimentation method for the two benchmark products and Thermomix neutral and masking 5+15 with their upscale recipe. Pictures taken after sedimentaiton fo 3 days.

Product	Day 3		Product	Day 3	
T_neutral			T_mask 5+15		
S_neutral			S_mask 5+15		
Oatly Oat milk barista			Alpro Oat milk barista		



Annex 17 Foaming test reslized with different machines. Left, foaming from Creatista Plus machine (steam injection method) and right, from Aeroccino (mechanical method).



Annex 19 Precipitation of oat milk proteins in coffee Livanto Nespresso after few minutes.



Annex 18 Oat milk when it was stabilized in coffee after 10min



Annex 22 Foamability and Foam stability done in a cylinder.



Annex 21 Nespresso Sage Creatista Plus coffee machine was used for foaming, steam injection



Annex 20 Aeroccino 3 Nespresso, was used for foaming, mechanical application.

9.3. Microbiological analysis

Annex 23 Microbiology test for Bacillus cereus, Staphylococcus and Enterococcus executed for sample n°145 (S_neutral) and n°155 (S_mask 5+15). Test was conducted for the safety of the sensory panel.

Test	**Bacillus cereus**		**Staphylococcus**		**Enterococcus**	
Sample	145	155	145	155	145	155
UFC/ml	1100	-	-	-	-	-

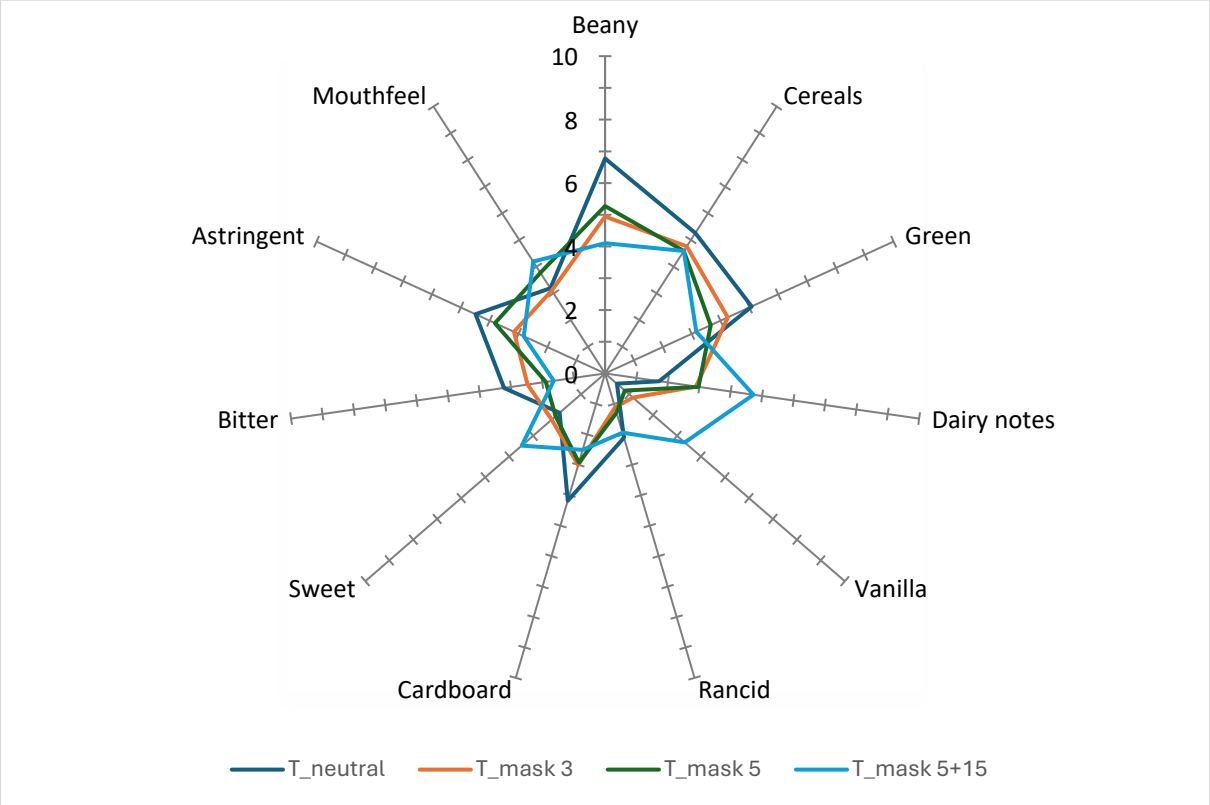
Annex 24 Total Viable Count (TVC) analysis with PCA media and pour plate method on sample n°145 and 155. Test was conducted for the safety of the sensory panel.

Sample	**145**		**155**	
	Aerobie	Anaerobie	Aerobie	Anaerobie
UFC/ml	2050	918.18	205	140

9.4. Sensory analysis

Annex 25 First a profile test of T_neutral was analyzed with 11 descriptors and a scale from 1 to 10. After, mean results of the comparison test (scaled from -5 to 5) of T_mask 3, T_mask 5 and T_mask 5+15 was added to the results of T_neutral. The panel was composed of 11 judges.

	Beany	Cereals	Green	Dairy notes	Vanilla	Rancid	Cardboard	Sweet	Bitter	Astringent	Mouthfeel
T_neutral	6.78	5.26	5.08	1.72	0.49	2.12	4.18	1.90	3.22	4.49	3.19
T_mask 3	4.95	4.76	4.25	2.89	1.16	1.12	3.01	2.23	2.47	3.16	3.11
T_mask 5	5.28	4.59	3.66	2.97	0.82	1.29	2.93	2.07	1.89	3.82	3.77
T_mask 5 + 15	4.11	4.59	3.16	4.72	3.32	1.95	2.51	3.48	1.64	2.82	4.19



Annex 26 Radar plot from Annex 25 results.

Annex 27 Comparison test of T_neutral as reference with three other products, T_mask 3, 5 and mask 5+15. The grading is from -5 to 5, and 0 as there's no difference. Calculation of T-test student is done with a probability of 0.05 for significance difference.

	T_mask 3			T_mask 5			T_mask 5+15		
Attribute	Mean	T calc.	Proba.	Mean	T calc.	Proba.	Mean	T calc.	Proba.
Beany	-1.83	3.74	0,0032	-1.5	2.57	0,0261	-2.67	5.53	0,0002
Cereals	-0.5	0.8	0.4382	-0.67	1.48	0.1661	-0.67	0.89	0.3944
Green	-0.83	1.89	0.0854	-1.42	3.03	0,0115	-1.92	3.62	0,0040
Dairy notes	1.17	3.02	0,0116	1.25	3.56	0,0045	3	6.09	<0,0001
Vanilla	0.67	1.61	0.136	0.33	1.77	0.1039	2.83	7.34	<0,0001
Rancid	-1	2.17	0.0527	-0.83	2.06	0.0642	-0.17	0.41	0.6887
Cardboard	-1.17	2.31	0,0413	-1.25	3.04	0,0112	-1.67	3.58	0,0043
Sweet	0.33	0.94	0.3683	0.17	0.52	0.6147	1.58	5.06	0,0004
Bitter	-0.75	1.24	0.2406	-1.33	2.97	0,0128	-1.58	3.17	0,0089
Astringent	-1.33	1.94	0.0791	-0.67	1.17	0.2657	-1.67	3.71	0,0035
Mouthfeel	-0.08	0.17	0.8705	0.58	1.05	0.3172	1	1.82	0.0966

Annex 28 Two Triangular test results. First, T_mask 5+15 (Thermomix) versus S_mask 5+15 (scaling-up) was analyzed. Second, S_masking 5+15 with masking solutions added during the mixing process versus added at the end of process (after pasteurization) was analyzed. Results from 20 participants including sensory experts and judges recruited internally by MANE.

	Correct answer	Significance (Risque)
1 -T_mask 5+15/ S_masking 5 + 15	17	<0.0001
2 -Before process/After process	5	0.8485

Annex 29 Triangular test comments of Thermomix and Scaling-up mask 5 + top note 15 products.

	Comments
T_mask 5+15	greener taste, more aromas
S_mask 5+15	greener taste, more earthy taste, more bitter, creamier, sweeter, better oat taste

Annex 30 Profile test of T_neutral recipe inserted in coffee and results of T_neutral added to compare data.This test was composed of 11 descriptors with a scale from 1 to 10.

	Beany	Cereals	Green	Dairy notes	Vanilla	Rancid	Cardboard	Sweet	Bitter	Astringent	Mouthfeel
T_neutral_Coffee	4.59	4.87	3.13	3.05	0.82	1.89	3.72	1.50	5.47	3.69	3.98
T_neutral	6.78	5.26	5.08	1.72	0.49	2.12	4.18	1.90	3.22	4.49	3.19

Annex 31 Comparison test in 40ml Livanto Nespresso of T_neutral as reference with three other products, T_mask 3, 5 and mask 5+15. The grading is from -5 to 5, and 0 as there's not difference. Calculation of T-test student is done with a probability of 0.05 for significance difference.

	T_mask 3 _Coffee			T_mask 5_Coffee			T_mask 5+15_coffee		
Attribute	Mean	T calc.	Proba.	Mean	T calc.	Proba.	Mean	T calc.	Proba.
Beany	-1.31	2.50	0,0280	-1.31	2.94	0,0123	-1.08	1.50	0.16
Cereals	0.54	0.89	0.39	-0.15	0.26	0.80	-0.77	1.35	0.20
Green	-0.77	1.28	0.22	-0.31	0.77	0.45	-0.85	1.53	0.15
Dairy notes	-0.23	0.38	0.71	-0.15	0.37	0.72	1.15	2.96	0,0119
Vanilla	-0.31	0.55	0.59	0.85	1.94	0.08	0.15	1.00	0.34
Rancid	-0.85	1.82	0.09	-0.62	1.34	0.21	-0.54	1.05	0.32
Cardboard	0.00	0.00	>0,9999	-0.92	2.80	0,0160	-0.46	1.58	0.14
Sweet	-0.31	1.30	0.22	0.38	0.89	0.39	0.23	0.61	0.55
Bitter	0.62	0.90	0.39	-0.31	0.53	0.61	0.00	0.00	>0,9999
Astringent	-0.08	0.19	0.86	-0.08	0.21	0.84	0.15	0.25	0.80
Mouthfeel	-0.38	0.84	0.42	-0.31	0.55	0.59	0.00	0.00	>0,9999