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NEW VALUE LANDSCAPES FOR PLANT PROTEIN PATHWAYS

D2.2: Storyboards (3) of innovative circular processing business

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Abstract:	This deliverable presents three storyboards developed within VALPRO Path's Work Package 2 to communicate technological and product-development opportunities for circular legume value chains. The storyboards cover processing on or close to farms, food product innovation using legume flours and fractions, and the development of a chickpea value chain that considers both protein-rich and starch-rich outputs.

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Introduction

In VALPRO Path, Work Package 2 (WP2) supports the project's innovation platforms by exploring how technologies can add value to legume crops and their proteins. Its systemic approach connects processing, ingredient functionality and food product development, considering how protein-rich fractions, other crop components and side streams can contribute to more circular value chains.

This deliverable presents three complementary storyboards. The first focuses on processing technologies for use on or close to farms; the second explores the development of food products from legume flours and fractions; and the third uses chickpea fractionation to illustrate the links between protein recovery, co-product functionality, processing inputs and environmental performance. Together, they show how technological choices and product applications can create opportunities to retain more value from the whole crop.

The storyboards are designed as short visual narratives that communicate key findings and opportunities from VALPRO Path to a broad audience of interested consumers, students, policy stakeholders and food developers. By combining visual narratives with practical examples, they translate technical work into accessible messages about ingredient use, product innovation and circular business opportunities.

STORYBOARD 1

Testing ‘on/close to farm’ technologies to enable the scale up of the protein crop value chain



EXECUTIVE SUMMARY

VALPRO Path validated several processing technologies for on-farm processing applications. These Innovative technologies were designed to add value across the supply chain by providing processing opportunities closer to the farm gate and utilising side streams to support waste recovery. In this storyboard technologies such as fractionation provide alternative business cases for crops such as faba beans, peas, chickpeas and lupins. Innovation started at the farm gate with field monitoring using drone technology for multispectral infrared analytics of yield and protein tracing of protein crops. The technology is a plugin for nutrient tracking simulation models also developed in WP2. The latter provides the platform for supply chain optimisation, planning and logistics to optimise biomass availability and quality. Further to this, demonstrations were undertaken, in collaboration with stakeholders, to evaluate the potential of simple, close to farm processing steps which can provide added value to crops. The technologies selected included efforts in evaluating side stream production and utilisation, to improve circularity. The activities of this task support the IPSs, with pilot scale processing, data collection for LCA analysis (WP 4), and analytical data interpretation (from Task 2.3). Data was used to support the assessment of economic feasibility of new processes and aid waste reduction.

Use of Multispectral Drone to determine the Influence of Crop status on yield of faba and pea crops

This technology was tested in the context of the intercropping of both fava and pea (completed in IPS3). Crops were tracked for crop development through processing NIR measurements via multispectral drone on four farms in Ireland, creating contrasting environments for assessing crop performance. Data was collected using a DJI Mavic 3 Multispectral drone fitted with the DJI RTK 2 module for centimetre-level positional accuracy and reliable vegetation mapping to yield Normalized Difference Vegetation Index (NDVI) measurements. Multispectral images (Red 650 nm, Red-Edge 730 nm, NIR 840 nm) were processed with DroneDeploy to generate radiometrically corrected NDVI maps.



Multispectral overlay using DJI Mavic 3 drone

This prototype works to classify fields into high-/low - yield potential zones based on NDVI thresholds. Representative crop samples were collected in duplicate from each zone at maturity, dried to stable moisture, and milled into flour. Protein concentration was determined by the Dumas method in dry basis. Yield was measured in the same areas, enabling an approximate calculation of total protein yield per hectare (Protein % × Yield).

These results highlight the potential value of integrating multispectral NDVI mapping into crop monitoring workflows. The ability to discriminate between high- and low-vigour areas before harvest provides a practical tool for precision agriculture, enabling estimations to be made on yield and ultimately protein yield based on crop performance under stress conditions. This work aligns also with the complementary approaches completed by Agricolus and FarmB in WP3 and WP4. Here, by linking remote sensing with laboratory-verified protein and yield data, the study demonstrates a clear route for improving resource efficiency and supporting European Union priorities on sustainable protein production and data-driven crop management.

Farm scale extraction of oil and high protein pressed cake from peanut

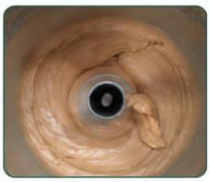
Work on a range of peanut varieties was carried out to support the business case for IPS1 using a small-scale oil and cake extraction / pressing process. The parameters (temperature, feed flow rate, and pressure) were selected to obtain peanut oil and cake from peanuts with varying composition (see composition table below for variants tested). Protein content varied from 25.3 to 28.1%, and fat content ranged from 39.5% to 43.3%. It was possible to extract the oil and cake using this farm-scale process.

Four of the most promising peanut lines based on in-field variety and yield trials, and considering potential EU market assessments, were selected. Using methods which could be replicated on farm or at farm processing hubs it was possible to produce peanut butters, oils, and high protein de-oiled cake from these 4 varieties and assess the differences in appearance, composition, and from that, identify which varieties may be most suited to each stream of added value processing.

Once the process parameters were identified, the production was optimised using the compact machine extrusion unit shown below. Because peanuts have high storage stability, processing operations can be easily scheduled during off-peak farming, creating extra work opportunities in off-seasons and providing an avenue for unused seed, particularly in the case of the high-protein seed cake, a byproduct of oil production. For larger peanut volumes, a range of suitable equipment sizes and capacities is widely available.



Peanut extrusion extraction unit for fractionation of oil and cake fractions

Peanut Varieties	1024	0016	0104
Protein	28.1% ± 0.08%	25.3% ± 0.26%	27.6% ± 0.17%
Fat	43.4% ± 0.34%	47.2% ± 0.17%	39.5% ± 0.23%
Moisture	5.4% ± 0.05%	5.1% ± 0.03%	6.4% ± 0.74%
Ash	4.2% ± 0.01%	3.6% ± 0.08%	5.5% ± 0.32%
Carbohydrates	19.0% ± 0.49%	18.7% ± 0.04%	21.0% ± 0.81%
			

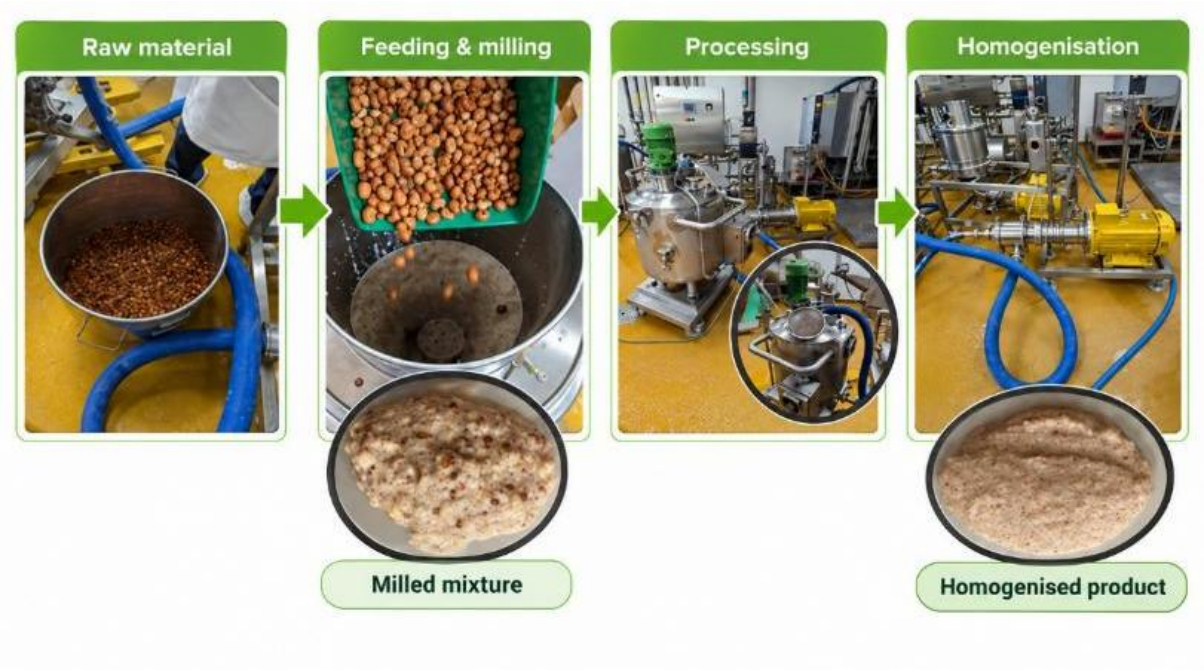
Compositional analysis of different peanut varieties; images of peanut butter made from these varieties. The higher firmness (G' = 7100 Pa) of variety 1024 compared to varieties 0016 (G' = 5150 Pa) and 0104 (G' = 3940 Pa) can be attributed to its elevated protein content, resulting in a higher viscosity peanut butter.

The findings provide further avenues to strengthen the value case for EU-grown peanuts for farmers wishing to grow peanuts in Europe and food product producers seeking increased protein content with added nutritional and functional benefits, without relying on less stable global peanut import markets.

Dual-stage wet milling process for fava and pea processing

As a means to improve the purity of plant fractionation, a dual-stage wet milling process was used to break down pulse seed and other feedstock materials for further separation and drying to develop new ingredients. The system, which is depicted below, uses a mild primary stage to soften and open the bean structure whilst a second fine milling stage releases protein, starch and fibrous bodies without degradation. The process provides an opportunity to process plant-based crops efficiently with fewer unit operations. The technology can be adapted for use in small factory environments suitable for local production, in line with VALPRO Path's strategic objectives. Feedstocks (fava beans, peas) were soaked before processing, with tooling selected for coarse and fine milling.

During project trials, it was possible to create different viscosities for subsequent drying applications, yielding different particle sizes in the finished powder. Dry milling further reduced the particle size of the powder from the high shear dryer, resulting in a fine powder. This process applies to many feedstocks, including those tested (fava beans and peas). The drying process (described in the next section for roasting applications) can reduce the microbial load of powders compared to the non-dried powders, extending the range of export applications, improving safety, and enhancing shelf-life. This system can dry highly viscous or powdered food products. It was also possible to remove the plant-based 'beany flavour' from the powder, also observed in the roasting application for the fava flour described below.



Dual stage wet milling process used for processing of Fava and Pea feedstocks. Left to right: Image 1 - Fava beans after soaking for 2 hours in 50C water; Image 2 - Course milling using a Ytron Z 'conticone' system with recirculation; Images 3 & 4 - wet milling circulation system with smaller tooling to create a fine mix suitable for drying in the high shear drying system.

Dry fractionation technologies

The potential of dry fractionation technologies to provide protein ingredients for the food industry was evaluated as a technology with added value potential. Chickpea and pea fractions obtained from pilot-scale trials carried out at Molino Peila were reported and compared with those from commercial sources.

Sample	Protein (%)	Carbohydrates (%)	Starch (%)	Amylose (%)	Fat (%)	Minerals (%)	Moisture (%)
Pea coarse fraction (Commercial)	7.8	82.0	59.3	19.2	1.1	1.6	7.4
Pea coarse fraction (Molino Peila)	12.5	72.7	52.4	16.0	1.7	2.1	11.
Faba coarse fraction (Commercial)	12.6	76.4	29.4	9.8	1.3	7.7	1.9
Chickpea coarse fraction (Molino Peila)	13.3	69.1	48	14.5	4.9	2.5	10.1
Pea fine fraction (Commercial)	39.5	35.6	7.7	4.9	4.5	5.3	15.2
Pea fine fraction (Molino Peila)	44	35.8	7.2	5.0	5.4	6.15	8.7
Faba fine fraction (Commercial)	48.5	28.2	9.3	6.0	3.03	14.4	5.8
Chickpea fine fraction (Molino Peila)	35.5	37.7	9	6.2	9.8	5.42	11.5

Compositional analysis of fine and coarse fractions from pea and chickpea, commercially available and prepared in the pilot plant. Note that the protein conversion factor used is 5.4.

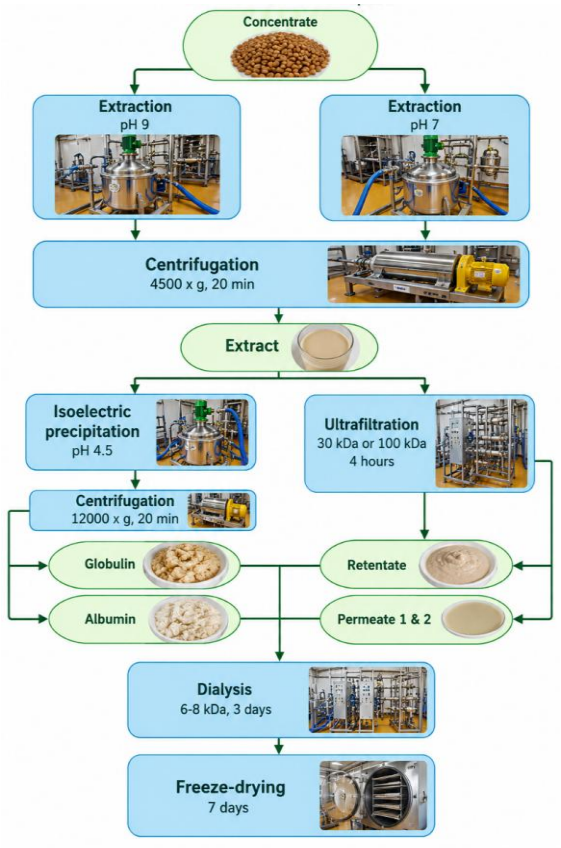
Extracting protein from dry-fractionated legume flour

Utilising the protein rich fraction a further trial was carried out using isoelectric precipitation and ultrafiltration to obtain protein isolates of even higher purity. The team evaluated new processing technologies to determine the potential to create value-added ingredients from faba bean flour or concentrates. For this work, faba bean served as the model legume, and isolates were produced by either conventional pH precipitation or membrane filtration. Extracting from a dry fractionated ingredient reduced starch, providing a good starting point for protein extraction. Membrane filtration was used to create an isolate with improved functionality and product application. The samples were produced in small quantities and freeze-dried. The resulting isolates were analysed for biochemical and protein composition, as well as key functional properties, including solubility, foam stability, surface tension, and viscoelastic behaviour.

A comparison between the two extraction methods is shown in the figure to the right.

Ultrafiltration yielded a protein isolate with a high protein content (87% DM), low ash content (4.3% DM), and low lipid content (~2.8%), closely resembling the composition obtained through isoelectric precipitation. However, ultrafiltration did improve solubility, with nearly complete solubility (~100%) at pH 7–9.

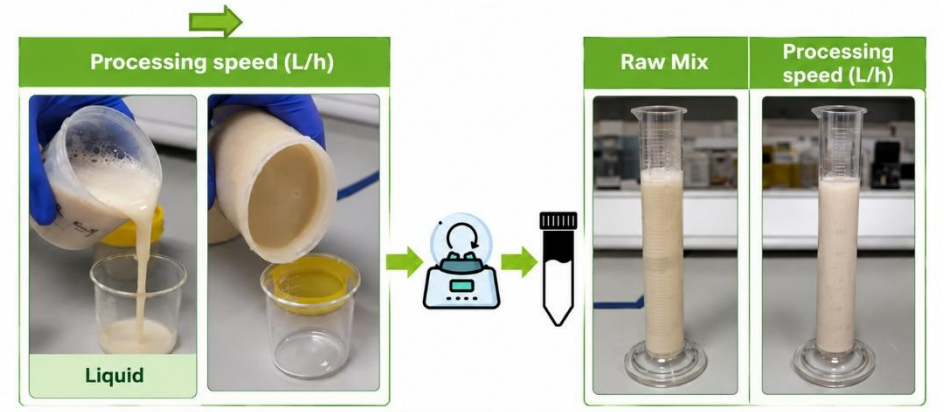
This performance surpassed both the globulins obtained via isoelectric precipitation (~80%) and a commercial protein isolate (~65%). In contrast, ultrafiltered proteins showed the lowest foam stability, whereas globulins and the commercial isolate showed unexpectedly high foam stability. Both treatments are energy-intensive and not suitable for close-to-farm processing.



Schematic view of protein extraction

Hydrodynamic cavitation

Hydrodynamic cavitation was tested as a more sustainable approach to processing pulses like faba beans and peas. Through localised micro turbulence it physically disrupts the cell walls detaching the starch from the protein matrix. It also proved to significantly affect the functionality of solutions made from fava bean flour. The process was designed to incorporate the hydrodynamic pump into a closed-loop system suitable for small-scale commercial processing of fava beans (or other) feedstocks. The trials were performed on dehulled fava beans, processed in solution to alter functional properties by modifying the starch component. Lowering processing speed resulted in a gel-like structure, likely due to increased residence time in the cavitation head, which raised temperatures and shear and caused gelatinisation of the starch granules. Hydrodynamic cavitation improved the physical stability of the fava bean solution compared with the raw mix. The gel-forming properties and effects on physical properties are shown here, with a significant improvement in stability against phase separation at 800 (L/h) processing speed. Hydrodynamic cavitation improved the soluble protein content in the serum phase for downstream separation.



Treatment	Protein yield in serum
Raw mix	14%
Processed (800 L/h)	37%

Images of fava bean flow behaviour after processing in the cavitation system

STORYBOARD 2

Product Innovation with Legumes



Executive summary

This storyboard follows on from the work carried out on fractionation of legumes to unlock versatile ingredients for innovative food product development. By separating the legumes into protein-, starch-, and fibre-rich fractions, each ingredient can be tailored to deliver specific functional and nutritional benefits. Ingredients were evaluated across a range of product concepts, including nutrition bars, beverages, and snack-based applications. Their properties supported important product attributes such as texture, stability, protein enrichment, and overall nutritional quality.

The opportunity: From crop → fractions → functional ingredients → food concepts → consumer products

The functional and sensory properties demonstrate how fava bean ingredients can create new market opportunities while generating greater economic value from the crop.

KEY MESSAGE

One crop. Multiple value pathways. A narrative of how fava-derived fractions can move from processing outputs into differentiated food applications—retaining more potential value across the chain.

The VALPRO PATH product-development work demonstrates a portfolio approach to legume utilisation. Rather than directing the crop towards a single output, processing creates fractions with different functional characteristics that can be channelled into distinct food concepts. The report supplied for this redesign describes protein isolate, a starch–fibre-rich side stream, soluble and insoluble protein fractions, and a wider set of fava-derived product concepts.

Circularity proposition: The core opportunity is not simply "less waste"; it is the deliberate matching of each recoverable fraction with a technically appropriate application so that more of the original crop remains in productive use.

1 FRACTIONATE	2 VALORISE	3 DIVERSIFY
Separate materials with different composition and functionality.	Treat side streams and secondary fractions as candidate ingredients.	Use functionality to create multiple product routes and market options.

Product work was undertaken with:

Whole milled bean

- Faba bean flour was optimized using high-turbulence thin-film heating to improve sensory and safety concerns
- Faba bean flour was optimized using fermentation to improve sensory aspects.

Protein fraction

- Recovered fava protein isolate was investigated in protein bars using HFCS and yacon binder systems.
- Reconstituted protein isolate was separated into soluble and insoluble fractions and used in distinct beverage concepts.
- Comparison of protein isolate and starch rich fraction in bakery applications.

Starch-Rich Fraction

- A starch-rich fraction arising from dry fractionation was fermented to create a vegan cheese spread.
- A starch-rich fraction from alkaline protein extraction was investigated in a crispy swirl snack formulation.
- Additional concepts—Fava Cube Snack and Fava Meat Crisps—extend the potential product portfolio.

Evidence boundary

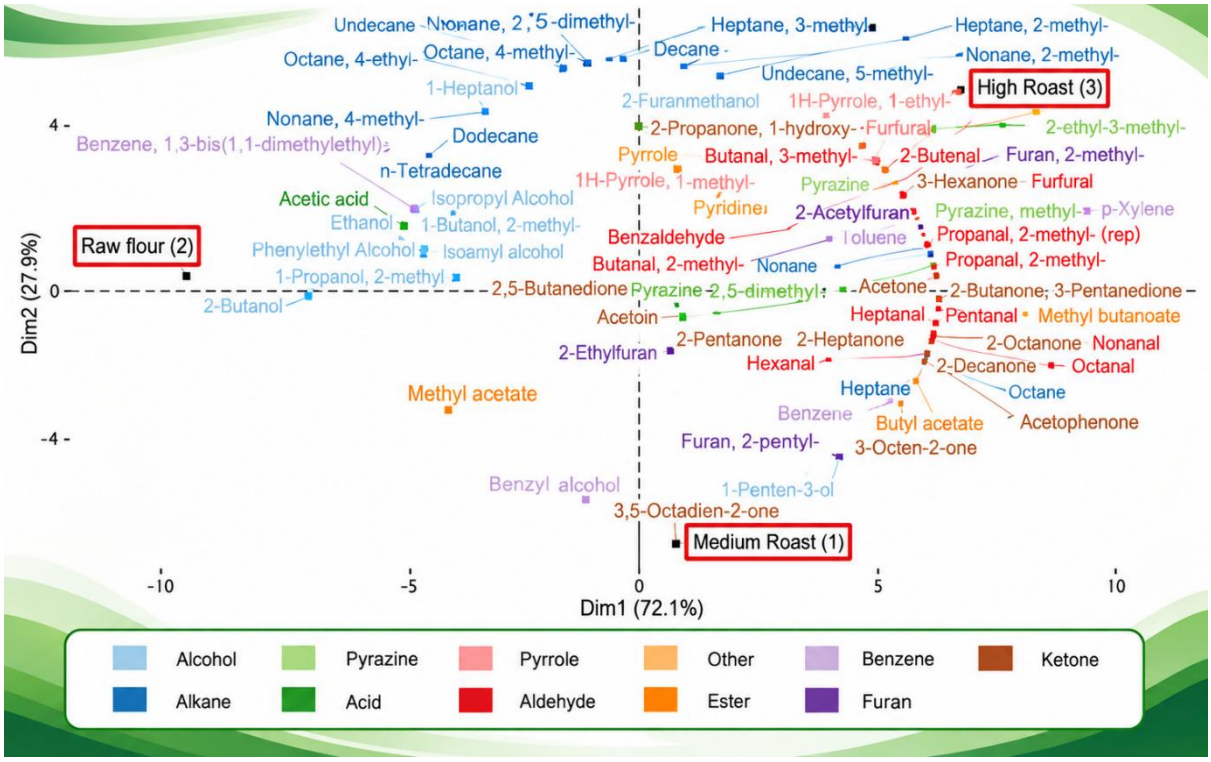
The supplied report does not provide measured energy consumption, water use, mass-balance yields, waste tonnages, recovery percentages or life-cycle impacts. This redesigned report therefore does not invent those values; instead, it identifies where they should be measured and reported.

Whole milled bean

Using High-Turbulence Thin-Film Heating to improve sensory and safety concerns in faba bean flour

A High-Turbulence Thin-Film Heating system (VOMM®) was used to dry viscous starch/fibre streams into powdered ingredients as part of the pre-commercial scale process described above. The system was successfully used to dry these streams coming from the decanter centrifuge after de-proteinisation.

The technology was also used to thermally treat (roast) faba bean flour at 200°C and 220°C for 5 minutes; the flour was then analysed and used in food applications. The process significantly reduced beany off-flavours, eliminated microbial loads (yeasts/moulds), and altered flour pasting curves. The approach demonstrated the ability to produce high-specification faba bean protein flours for use in nutritional beverages or bars due to their reduced microbial load. Volatile compounds measured using GCMS/MS were both created and removed by the heat treatment. The impact of heat treatment on changes in volatile compounds at 200 (medium) and 230 (high roast) is shown in the principal component plot. Significantly, the process increased aldehydes, ketones, pyrazines, and pyrroles, which contributed to roasted and nutty notes, while it reduced alcohols associated with green, leafy, vegetable, fusel, winey, fruity, and woody aromas.



Principle component analysis (PCA) of volatile flavour compounds from roasted fava bean flours. Raw flour, medium roast and high roast powders are highlighted by the red boxes.

The trials indicated that protein aggregation increased with heating, with colour increasing clearly with temperature. Roasting faba bean flour did reduce protein solubility, possibly due to heat-induced aggregation of denatured proteins. Roasting also affected emulsion activity; however, heat–induced aggregation still produced acceptable emulsion activity. The effect of roasting on colour of fava flour is shown in the pictures below, left to right (unheated, heated to 200 and heated to 230C) and in the powders directly



Sample	Protein (%)	Fat (%)	Moisture (%)	Ash (%)	Note
Raw flour	27.3% ± 0.17%	1.6% ± 0.02%	11.6% ± 0.71%	4.9% ± 0.61%	Dehulled faba bean dry milled
Medium-Roasted Faba Flour	30.6% ± 0.11%	1.7% ± 0.04%	2.8% ± 0.42%	5.4% ± 0.13%	Dehulled faba bean dry milled + roasted in VOMM dryer
High-Roasted Faba Flour	30.8% ± 0.14%	1.9% ± 0.01%	3.0% ± 0.34%	5.5% ± 0.44%	Dehulled faba bean dry milled + roasted in VOMM dryer

Roasted fava flour from left to right - raw flour, medium -roasted flour, high-roasted flour (also shown in the packages and trays in the bottom images.

The table below shows the microbiological results. The high-shear roasting process significantly reduced the microbial load of the fava flour, meeting specifications for use as a nutritional powder and extending its applications. The raw flour had a count of 7,000 CFU/g, while both the medium- and high-roasted powders had total counts below 10 CFU/g. The ability to reduce the microbial load of flour to this extent is a required quality attribute for ingredient powders used in foods. This provides a process that can be run at commercial scale to process large quantities of powdered ingredients, making a viable business case for flours and highlighting a new added-value opportunity.

Sample	Yeast	Moulds	Total count
Raw flour	<100 CFU/g	<100 CFU/g	7,000 CFU/g
Medium-Rosted Faba Flour	<100 CFU/g	<100 CFU/g	<10 CFU/g
High-Rosted Faba Flour	<100 CFU/g	<100 CFU/g	<10 CFU/g

As part of the study in WP2.2 and IPS4, dry fractionated fava bean flour was also treated using the high shear turbulent drying system. The results were similar to the unseparated flour, with a significant reduction in both colour and odour. These dry fractionated heat-treated flours were used to produce beverages in IPS4. The trials also showed that the solubility, and in some cases the viscosity, of solutions made with heated, dry-fractionated fava powder was lower than in the unheated samples. This suggests possible use cases for altering beverage functionality. The process can be applied to other flours/protein concentrates or by-product streams and provides new opportunities for ingredient development based on locally milled/dry-fractionated powders. For example, the flavour profile of the functionality heat-treated flours provided a suitable platform for new biscuit formulations by the Kerry Group. The biscuits showed good colour and sensory properties.

Using fermentation to improve the sensory aspects of faba bean flour

Fermentation was also investigated as a way to generate new functionality into faba bean flour. L. plantarum was selected from the Teagasc culture bank and showed good growth and lactic acid production in a yoghurt type product. Sensory evaluation by Kerry indicated that fermentation reduced the typical green and beany flavour of faba bean, highlighting its potential to create sensory attributes. Further optimisation of taste and texture is still required, particularly to control acidity and mouthfeel. The results show the potential of fermentation to develop functional faba bean ingredients for food applications.

Protein fraction

FAVA PROTEIN BAR



Recovered fava protein isolate was formulated with binding syrup, glycerol and cocoa ingredients to produce a firm, sliceable snack bar. Two binder systems—HFCS and yacon syrup—were tested; the yacon formulation required further texture optimisation.

BEVERAGE FRACTIONATION



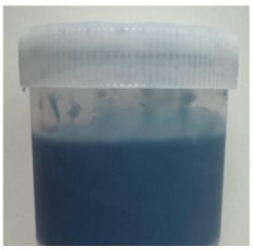
Reconstituted fava protein isolate was separated into soluble and insoluble fractions. The soluble fraction was combined with guar gum, heat treated and homogenised for a thick smoothie-like beverage. The insoluble fraction was diluted and used in a separate blueberry-flavoured thick shake.





Smoothie-like beverage
Soluble fraction





Blue thick shake
Insoluble fraction

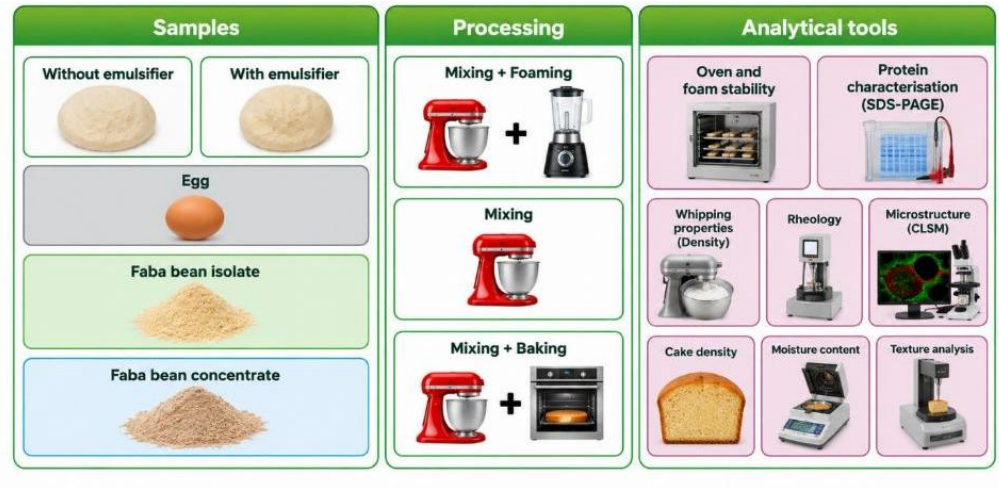
Functional design principle Different fractions can have different functional roles. Product development therefore becomes a matching exercise—fraction characteristics → process conditions → texture/function → product concept.

Circular implication

The soluble fraction is not the only resource. By testing both soluble and insoluble material in separate products, the project broadens the number of potential destinations for material generated during fractionation and increases the possibility of retaining value from the original ingredient.

Utilisation of fractionated faba bean protein for value added applications.

A systematic comparison between faba bean protein isolate (FPI) and faba bean protein concentrate (FPC) was performed to evaluate their functionality in bakery applications, namely in the production of sponge cake. The motivation stems from the need to assess whether dry-fractionated FPC is a more sustainable and less resource-intensive product and can perform comparably to the more refined FPI in food systems. FPI contains approximately 80% protein, while FPC ~ 60%. Although FPI offers higher purity, its production involves more complex processes and generates additional side streams and energy requirements. In contrast, FPC is derived from dry fractionation, a simpler and more sustainable technology. To investigate this further, a model sponge cake system was developed using both FPI and FPC, with and without emulsifiers, and compared to a control cake made with egg protein. The experimental setup is illustrated in Figure 8, which outlines the steps taken to prepare and analyze the different cake formulations. The study focused on evaluating batter aeration, rheological behaviour, baking performance, and final cake texture and was aligned with Valpropath objectives. The results showed that emulsifiers significantly influenced the mixing process by increasing batter aeration, which led to lower-density cakes.



Experimental setup for sponge cake formulation using FPI and FPC.

The effect of emulsifiers varied depending on the protein source. Cakes made with FPI and FPC were less able to retain air bubbles during baking compared to control cakes obtained with egg proteins. Among the faba-based cakes, those made with FPI were softer. Despite these challenges, the study demonstrated that it is possible to produce acceptable sponge cakes using FPC, if formulation and processing parameters are carefully optimized, thereby demonstrating an added value opportunity.

Also, the cohesiveness of the cakes depended solely on the protein source, emphasizing the importance of protein denaturation and starch gelatinization—particularly the extent and timing of structure setting during baking. Faba proteins exhibited superior foaming capacity compared to egg proteins. However, this led to cracking during baking, as the batter expanded too rapidly in the oven. This suggests that process parameters need to be adjusted when using faba proteins to avoid structural issues. Additionally, colour remains a challenge: faba-based cakes tend to be grey, which may affect consumer acceptance. Potential solutions include advanced milling techniques or the use of colour-enhancing ingredients to improve visual appeal. The visual comparison of the final cakes highlighted differences in texture and appearance across the formulations. While the faba-based cakes did not fully match the performance of egg-based controls, they showed promising results, especially considering the sustainability advantages of using dry-fractionated proteins.

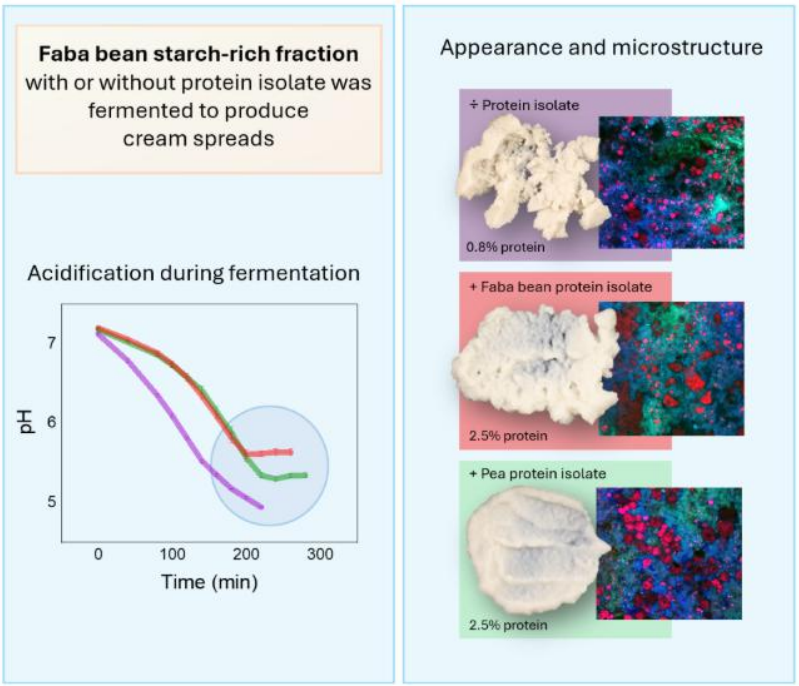
Starch-Rich Fraction

Using fermentation technology to develop a vegan cream cheese spread

Fermentations were evaluated using the challenging system of the coarse fraction of faba bean. This fraction typically has low value but is rich in starch and has fewer pasting properties of the pea starch rich fraction. Fermentation was carried out with a commercial starter culture of Lactobacillus delbrueckii subsp. bulgaricus and Streptococcus thermophilus. Success of this trial could provide another avenue for the utilization of this side stream as a functional ingredient, this time in a vegan cream spread. As previously mentioned, the lack of food applications for these co-products of dry fractionation is currently limiting the business viability of this technology and a goal is to overcome these challenges.

Therefore, preliminary trials were performed with varying concentrations of the coarse fraction (62–100 g/kg) to assess the influence of concentration on product performance. Based on these results, a concentration of 62 g/kg faba bean starch-rich fraction (FSF) was selected for subsequent experiments. In addition, the effect of substituting part of the FSF with protein isolate (PI) either faba bean protein isolate (FPI) or pea protein isolate (PPI) was evaluated, targeting a final protein content of 25 g/kg. The use of two different protein isolates was intended to provide a scientific basis for tailoring the amino acid profile of the product in future applications.

Fermentation of the FSF by lactic acid bacteria reduced the pH from neutral to 4.8 within 4 hours, confirming its good fermentability and allowing conditions comparable to dairy cream cheese. When FPI or PPI were added, fermentation stalled at higher pH values (5.3 and 5.6, respectively). This stagnation may be due to protein degradation by Lactobacillus delbrueckii subsp. bulgaricus, the natural buffering capacity of proteins, or contamination of the protein isolates.



Fava Snacks

Fava Swirl

The starch–fibre-rich fraction was combined with rice flour, corn flour and spices to create a firm dough and a crispy final product. In circular-value-chain terms, the important innovation is the route itself: a processing fraction is given a potential food application, creating another possible outlet for the processor.



Fava Swirl Snack concept using the starch–fibre-rich fraction.

Value retained Side stream → formulation input → differentiated snack concept. The processor gains a potential additional utilisation route rather than relying on a single protein-output pathway.

What should be quantified at scale

Mass recovery kg side stream recovered / kg fava input	**Avoided disposal** kg residue diverted from disposal or low-value use	**Energy intensity** kWh per kg usable snack ingredient	**Water intensity** L process water per kg ingredient/product

Fava cube and crisp

The supplied report extends beyond the three more detailed concepts. Fava Cube Snack and Fava Meat Crisps show how fava-derived materials can be considered across a wider range of formats. A portfolio approach can give processors and manufacturers more routes to test technical feasibility, market fit and scale-up potential.



Fava Cube Snack — an additional fava-based product concept.



Fava Meat Crisps — a further format within the wider concept portfolio.

Portfolio logic: More applications → more opportunities for utilisation → more potential value retained from the crop.

Decision gate for each concept

1 **Fraction fit**	2 **Process fit**	3 **Sensory/texture**	4 **Scale-up**	5 **Market route**

STAKEHOLDER VALUE

The circular value chain: give-and-take across the system

The report positions circularity as a chain of exchanges. Each actor contributes an input or capability and receives a potential benefit. The model becomes stronger when material, information and value flows are visible in both directions.

Actor	Gives to the chain	Receives from the chain	Evidence to track
Fava growers	Crop supply	Potential new market opportunities	Volumes, quality specs, price signals
Processors	Fractionation capability; protein and additional fractions	Multiple potential value streams	Mass balance, yield, energy, water, side-stream destinations
Ingredient & product developers	Formulation and functionality knowledge	New innovation opportunities	Functional performance, formulation success, recovery routes
Food manufacturers	Scale-up and commercialisation capability	Potential products and markets	Throughput, quality, cost, waste, consumer acceptance
Consumers	Demand and feedback	New plant-based food choices	Acceptance, repeat purchase, product performance

System flow Fava crop → processing → protein & side streams → product development → multiple food applications → consumer value.

Feedback loops that make the chain more circular

- Product developers communicate functional requirements back to processors.
- Manufacturers provide scale-up, throughput and quality data to ingredient developers.
- Consumer response informs which fractions and products merit further investment.
- Recovery, energy and waste data feed back into process optimisation and future product selection.

EVIDENCE FRAMEWORK

Resource, energy and waste accounting

A credible circular-value-chain claim needs a measurable resource account. The source report establishes the material pathways but does not provide quantitative energy, water, waste or recovery data. The following reporting framework should be completed during pilot and scale-up trials so that the "new realities" can be demonstrated with evidence.

Stage	Input to measure	Output / side stream	Energy & utilities	Circularity KPI
Crop preparation	kg fava beans/flour	Hull, fines, off-spec material	Electricity; water if used	% crop entering productive processing
Protein extraction	kg flour; water; reagents	Protein-rich stream; insoluble starch–fibre cake	Mixing/heating kWh; water L	Protein yield; side-stream recovery %
Fractionation	kg reconstituted isolate	Soluble fraction; insoluble sediment	Separation + heating/homogenisation kWh	% of both fractions directed to applications
Product manufacture	kg ingredient + co-ingredients	Saleable product; trim/off-spec	Mixing, heating, baking, cooling kWh	Product yield; rework/recovery %
End-of-run cleaning	Water; cleaning agents	Wastewater	Hot water/steam/electricity	L water/kg product; recovery/reuse where applicable

Minimum mass-balance equation

Material accountability Fava input = protein fraction + starch/fibre fraction + soluble/insoluble fractions + product incorporated material + recoverable losses + unrecovered waste. Report every term in kg and as % of starting input.

Energy reporting

Record electricity, thermal energy and any other fuel use by unit operation, then express the result both per batch and per kg of useful output. This allows product pathways to be compared on a common basis and identifies where process optimisation has the greatest leverage.

STORYBOARD 3

Advancing Legume value chains



Executive summary

This storyboard explores how novel processing approaches such as dry fractionation can create value from both the protein-enriched and starch-rich fractions of legume crops, such as chickpea. The findings highlight the need to balance protein enrichment and recovery with ingredient functionality, processing inputs and environmental impacts. By considering useful applications for both fractions, the storyboard demonstrates a whole-crop approach to developing more resource-efficient, circular value chains, rather than focusing on protein purity alone.

Chickpea: From one crop to two valuable ingredients

Chickpea is a valuable source of plant protein, and dry fractionation is attracting growing interest as a route for producing protein-enriched pulse ingredients. VALPRO Path investigated this process at industrial scale, asking a broader question: can protein fractionation be achieved while also creating value from the rest of the crop and reducing the environmental effects of processing?

The opportunity: More value from every chickpea

Protein fractionation is often evaluated by how much the protein concentration can be increased. But protein purity alone does not determine the value or sustainability of the process. A substantial part of the original crop may remain in other fractions, and these materials can also have useful nutritional and functional properties.

VALPRO Path therefore considered the chickpea as a whole raw material, asking how value could be created from all the fractions generated during processing.

KEY MESSAGE

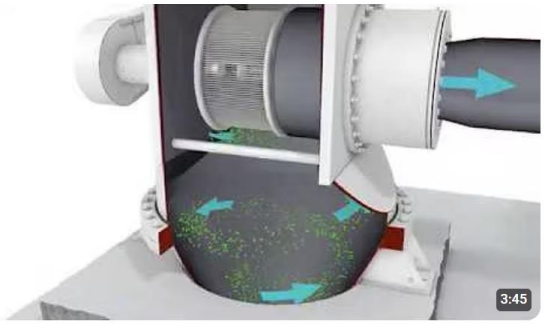
The goal is not simply to obtain a more concentrated protein ingredient, but to create value from more of the original crop.

Dry fractionation: Separating without water-based extraction

Chickpeas are dehulled and milled into flour before being separated by air classification. The process exploits differences in particle size and aerodynamic behaviour: smaller protein-rich particles preferentially enter the fine fraction, while larger starch-rich particles remain in the coarse fraction.

Unlike conventional aqueous protein isolation, dry fractionation does not require protein solubilisation in large volumes of process water followed by recovery and spray drying. Instead, it produces two dry ingredient streams through physical separation.

The animation preview on the right shows the particle-separation principle inside a Zirkoplex classifier.

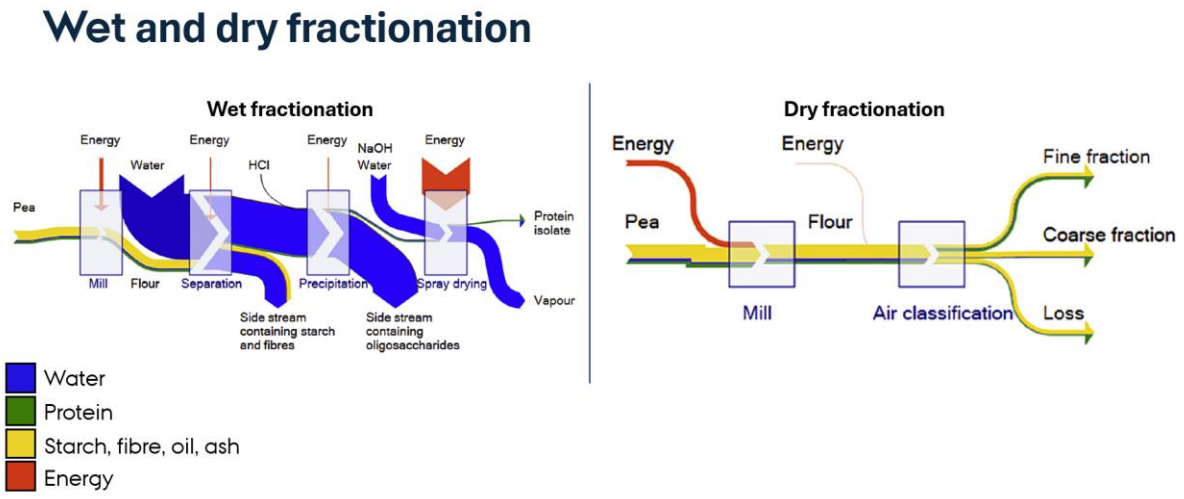


Protein shifting - 3D animation of the Hosokawa Alpine Zirkoplex ZPS.

Dry fractionation—process animation.

Dry fractionation can also offer sustainability and economic advantages by reducing the need for process water, chemicals and energy-intensive recovery or drying steps. Its simpler process train may therefore lower resource use, material losses and processing costs compared with wet fractionation.

The diagram below compares the main processing steps and input streams for conventional wet fractionation and the simpler dry-fractionation route.



Comparison of wet and dry fractionation routes. Schutyser et al., Trends Food Sci. Technol., 2015

Dry fractionation: *One process, two product streams*

Dry fractionation does not produce a purified protein isolate. Instead, it creates two compositionally different ingredients: a protein-enriched fine fraction and a starch-enriched coarse fraction.

The intended continuous process assumes that the mass balance closes between these two fractions, with material losses expected to be negligible. This makes the coarse fraction impossible to ignore: most of the processed material is in this stream. The circular-value-chain opportunity is therefore to treat it as a functional co-product rather than as a low-value residue.

KEY MESSAGE

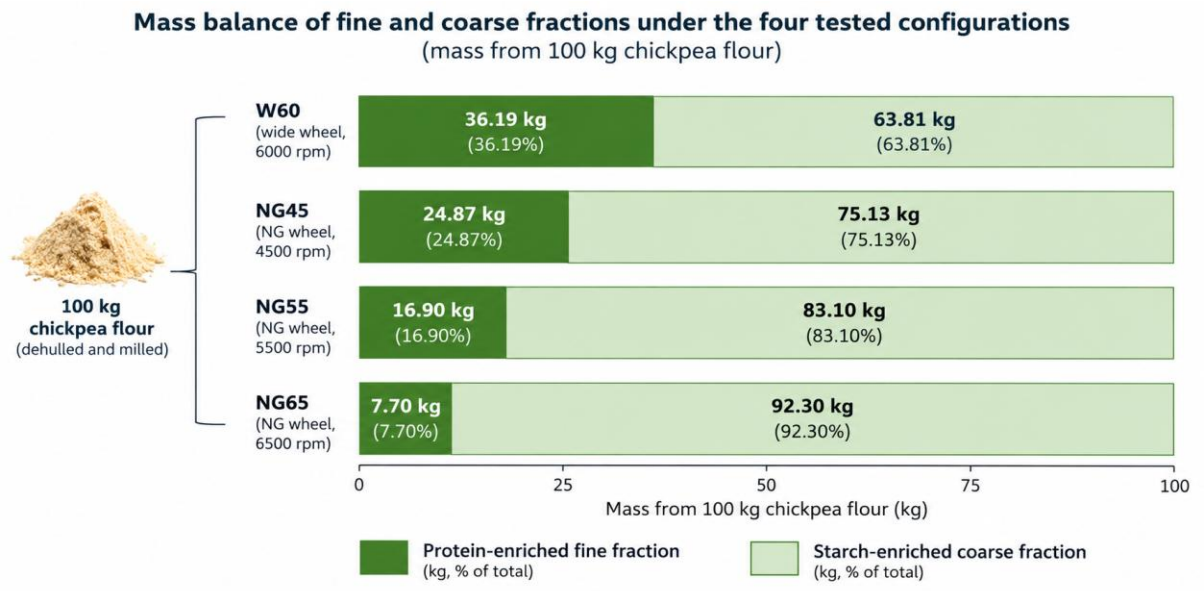
Dry fractionation creates two ingredient streams - and value can potentially be generated from both.

How VALPRO Path tested the process

VALPRO Path evaluated dry fractionation of chickpea at the industrial-scale facility of Hosokawa Alpine AG (Augsburg, Germany) under four air-classifier configurations with different wheel designs and speeds: one configuration with a wide classifier wheel at 6000 rpm (W60), and three with a New Generation (NG) wheel at 4500, 5500 and 6500 rpm (NG45, NG55 and NG65). These settings were selected to create different degrees of separation between the protein-enriched fine fraction and the starch-enriched coarse fraction.

The different settings changed how the chickpea flour was distributed between the two product streams. From 100 kg of flour, the fine-fraction yield decreased from 36.19 kg under W60 to 7.70 kg under NG65, while the coarse fraction increased from 63.81 kg to 92.30 kg. The intermediate NG45 and NG55 conditions produced progressively smaller fine fractions.

The mass-balance graphic below shows how the split between fine and coarse fractions changed across the four tested configurations.



Mass balance of fine and coarse fractions under the four tested configurations.

More protein purity comes with a trade-off

Increasing classifier selectivity raised the protein concentration of the fine fraction from about 36.5% to 46.1%. But the gain in purity came with a substantial loss in recovery: protein extraction efficiency fell from about 59% to about 16%, and fine-fraction yield dropped from 36.19% to 7.70%. In other words, maximising protein percentage does not automatically maximise value or resource efficiency. The optimum must balance purity, recovery, the functionality of the coarse fraction, and the environmental burden of the process.

The graph on the right shows this trade-off directly: higher protein concentration in the fine fraction is associated with lower protein extraction efficiency.

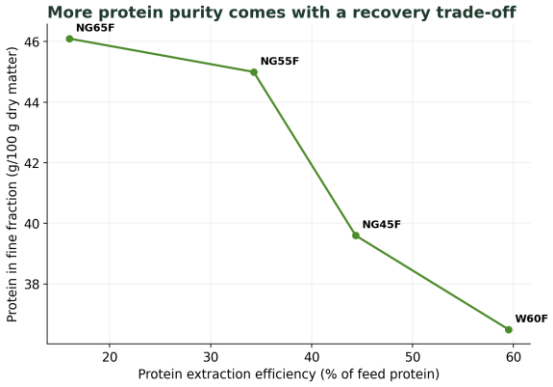


Figure 4. Dry-fractionation performance across classifier configurations: fine-fraction protein content versus protein extraction efficiency relative to the feed.

Processing also has an energy cost

Circularity is not only about material recovery; processing inputs also matter. In the chickpea case study, milling 100 kg of chickpeas used 32.4 MJ of electricity. The dry-fractionation step used about 18 MJ per 100 kg of chickpea flour across the tested classifier conditions. Because the fractionation energy input was similar across trials, configurations that produced much less fine fraction carried a larger environmental burden per unit of recovered product. Resource-efficient processing therefore means using only the degree of refinement needed for the intended food applications.

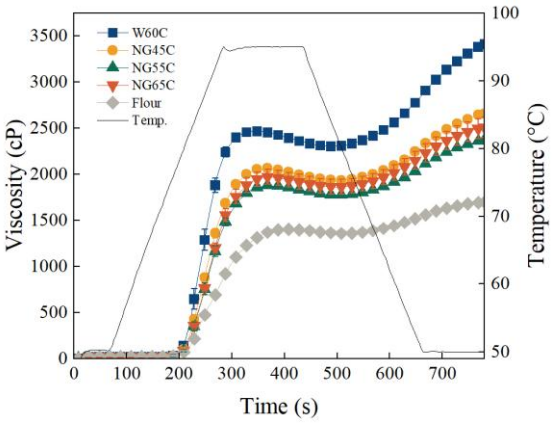
The callouts below summarise the electricity inputs used in the analysis.

32.4 MJ **Milling** **per 100 kg chickpeas**	**≈18 MJ** **Dry fractionation** **per 100 kg chickpea flour** ***similar across all four tested conditions***

The coarse fraction is not waste

VALPRO Path did not stop at measuring the protein-rich fraction. The starch-rich coarse fractions were tested for pasting, gelation and microstructure to understand whether it could function as a food ingredient. The tested coarse fractions showed potential to provide useful structure in foods, developing viscosity during heating and forming gels after cooling. This functionality, however, depended on the fractionation conditions. The W60 coarse fraction, which had the highest starch content at about 47.6%, showed the strongest viscosity development and gel-forming behaviour. The results show that the coarse stream can provide useful structure in foods and should be considered a functional output of the process, not simply a side stream to be disposed of.

The graph on the right shows how the viscosity of the chickpea flour and coarse fractions changed during heating and cooling, with W60C showing the strongest pasting response.



Pasting curves of chickpea flour and coarse-fraction samples, obtained at 10% (w/w) on a dry-matter basis.

Could the chickpea co-product become pasta?

VALPRO Path has already demonstrated the use of pea and faba-bean coarse fractions in legume-based pasta. Chickpea coarse fraction has not yet been tested in the same application, but its starch-rich composition and demonstrated structuring properties suggest that the same route is both technically plausible and practically accessible. This offers a potential pathway for turning the chickpea coarse fraction into a food product rather than leaving it as a low-value side stream. Such a product could also support gluten-free pasta development and offer a different nutritional profile from conventional semolina pasta, with legume proteins contributing a more lysine-rich amino-acid profile.

The photographs on the right show pasta production using pea- and faba-bean coarse fractions within VALPRO Path, providing the reference pathway for the proposed chickpea application.

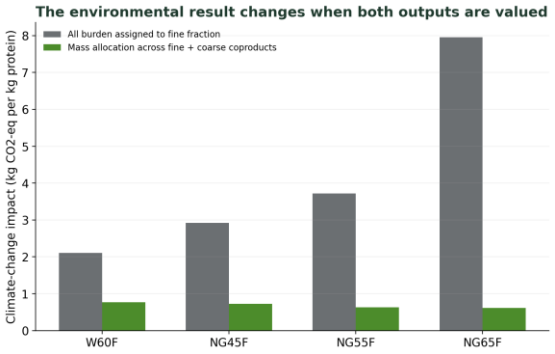


Potential application of the chickpea coarse fraction, informed by pasta production using pea- and faba-bean coarse fractions within VALPRO Path, carried out by Antignano Prodotto Tipico di Tealdi Roberto.

When the co-product gains value, the environmental picture changes

Life-cycle assessment shows why the treatment of the coarse fraction matters. If the full environmental burden is assigned only to the protein-rich fine fraction, climate-change impact per kilogram of protein rises markedly as refinement becomes more selective. When the coarse fraction is instead recognised as a valuable co-product and the burden is allocated across both outputs, the calculated impact changes substantially. The key message is methodological as well as practical: the sustainability of fractionation cannot be understood by looking at the protein stream alone; both useful outputs must be considered.

The chart on the right shows the contrast: assigning all burden to the fine fraction makes the calculated impact rise sharply with selectivity, whereas mass allocation across both co-products produces a much flatter profile.



Effect of co-product allocation on the climate-change impact of chickpea dry fractionation.

From a linear process to a circular value chain

In a protein-only view, the process is optimised around one high-value stream and the larger coarse fraction risks being treated as secondary. In the VALPRO Path system view, both streams are designed for useful destinations: the protein-rich fraction serves protein-food markets, while the starch-rich fraction is treated as a functional co-product with its own food applications. Circularity therefore comes from retaining function and value in both material streams while also accounting for energy and environmental performance.

WHOLE-CROP VIEW

Two ingredient streams, two useful food pathways.

The new reality: Optimise the whole system

The most refined protein is not necessarily the most sustainable product. VALPRO Path shows that chickpea dry fractionation should be optimised across several objectives at once: protein enrichment, protein recovery, co-product functionality, processing intensity and environmental impact. The best process setting is therefore the one that delivers on all these objectives.

By defining useful destinations for both the protein-rich and starch-rich fractions before choosing the degree of refinement, the process can avoid unnecessary intensity and create a more resource-efficient, multi-product value chain.

CLOSING MESSAGE

Process only as much as needed

Design product destinations before processing