

White paper

# Optimising plant-based cheese production

Leveraging ingredients, equipment, and application knowhow

**Publisher**

Tetra Pak Processing Systems AB  
SE 221 86 Lund, Sweden  
[www.tetrapak.com](http://www.tetrapak.com)

**Published**

October 2024

© Tetra Pak International S.A

No part of this publication may  
be duplicated in any form without  
the source being indicated.

# CONTENTS

Introduction	5
Who is this white paper for?	5
What you'll learn	5
The evolution of plant-based cheese production	6
Market trends	8
Market growth for plant-based cheeses	8
Consumer drivers	11
Breakdown by product and region	12
Regulatory challenges	13
Ingredients	14
Raw material formats	14
Protein sources	14
Leading ingredients	16
Protein concentrates & isolates	16
Fat	17
Stabilisers	17
Cultures	17
Flavors, colours and spices	18
Line components	19
Process overview	19
Mixing	20
Moving ahead with the right mixing head	21
The problem with air in mixing	21
Heat Treatment	21
Fermentation	22
Formulation	23
Heat treatment downstream	23
Homogenisation	23
Filling	23
Cooling	24
Application know-how	25
Formulation efficiency	25
Ingredient choices	25
Heating and cooling issues	25
Mixing	26
Stabilisers	26
Optimising fermentation rate for safety and efficiency	26
Homogenisation and colouration	26
Putting it all together with adaptable and expandable lines	27

Summary	30
What Tetra Pak brings to the table	32
Expertise and capabilities	32
Partnerships with ingredient suppliers	32
References	35

## INTRODUCTION

### Who is this white paper for?

Production of plant-based cheeses, or vegan cheeses, is an exciting growth industry, particularly in Western Europe and North America. But while it is an emerging industry compared to dairy-based cheesemaking, it is currently undergoing rapid changes driven by consumer demand and enabled by new applications of technology.

The information we present here is thus relevant to a variety of producers who want to use advances in technology to leverage their positions:

- **Plant-based beverage, food and cheese producers** who want to increase their production and extend their product portfolio.
- **Traditional dairy cheese producers** who want to enter this area and broaden their current product portfolio
- **Innovative product developers** with new cheese ideas, but with limited food production experience.

This information is thus particularly relevant to you if you have one or more of the following roles:

- Production manager
- Plant manager
- Quality manager
- Sustainability manager
- Marketing manager
- Business developer concerned with portfolio development
- R&D concerned with products and recipes

### What you'll learn

We'll briefly cover current market trends and drivers defining the growth of plant-based cheeses, as well as defining the evolutionary steps cheese-making is now going through.

Because the chemical and biological processes involved in making plant-based cheeses are so different from the dairy world, we'll cover plant-based cheese making from three different perspectives:

- The ingredients involved, how they vary, and how they make special demands on equipment and processing parameters
- The individual technical processes, and the machines that make them possible
- Application know-how – optimally combining ingredients and technology processes to produce a given cheese with a given quality profile, and do it efficiently.

*With more than 100 years of experience in dairy and cheese products, and more than 40 years in plant-based production, we are ready to share our knowledge with you – a combination of technology, ingredients knowledge and application know-how.*

# THE EVOLUTION OF PLANT-BASED CHEESE PRODUCTION

Cheese is one of the most fascinating, complex, and diverse human-produced foods enjoyed today. And its global diversity makes it hard to define and categorise.

Most traditional classification systems use three elements to define the broad ecosystem of dairy cheese:

- Textural properties (firmness via moisture content)
- Coagulation method (acid or rennet, for example)
- Manufacturing process (cooking temperature, cheese composition, additives, aging, etc.).

These factors determine the sensory quality of the final cheese product as well as the vast diversity of cheeses produced worldwide.

Plant-based cheeses represent an entirely new approach to producing desirable, tasty, nutritious foods, but the quality markers of the end-products are the same: taste, texture and nutritional value.

We can divide plant-based cheeses into three different process maturity categories – basic, fermented, and engineered – as described in [Table 1](#). These categories differ in their quality focus, ingredients, and major processes. These differences are key to understanding the more complex microbiological and processing differences we explain later.

**Table 1** *The ongoing evolution of plant-based cheeses*

	<b>1 Basic</b>	<b>2 Fermented</b>	<b>3 Engineered</b>
<b>Quality focus</b>	<b>Visual similarity</b>	<b>Nutrition, taste and texture</b>	<b>Matching the quality requirements of dairy cheese</b>
<b>Ingredients</b>	<ul style="list-style-type: none"> <li>• Oil</li> <li>• Starch</li> <li>• Flavours</li> </ul>	<ul style="list-style-type: none"> <li>• Legumes, vegetables, nuts and grains, protein isolates or concentrates</li> <li>• Fermentation culture</li> <li>• Starch, hydrocolloids</li> </ul>	<ul style="list-style-type: none"> <li>• Engineered casein from plant-based raw materials</li> <li>• Vegetable fat</li> <li>• Fermentation culture</li> </ul>
<b>Key processes</b>	Mixing, pasteurisation, homogenisation	High-shear mixing, pasteurisation, fermentation, homogenisation	Production that closely matches the chemical processes of traditional dairy-based cheese production

The first category of basic cheeses is the “first generation”. Fat and starch are the main raw materials, and while they try to approximate the taste and texture of soft cheeses, they often show poor resemblance to dairy cheese counterparts. They have a very low protein content, as protein content exceeding 3% is usually perceived as bitterness.

The cheeses of the second category rely on fermentation and have a much higher protein content, varying between 5-15%. They will still rely on starch or hydrocolloids for their texture, but they are much better at approximating dairy cheese products in taste and texture, and can be produced as slices or sliceable semi-hard bricks. *This white paper will focus on production of this second category.*

The third category represents the future. These cheeses are produced with engineered or microbially grown caseins, using novel technologies like cell cultivation or precision fermentation. They are in all aspects equal to a dairy cheese, since the same protein molecules are used to build up the structure of the cheese. Dairy ingredients produced by these emerging technologies may eventually deliver ingredients on a scale that have thus far only been produced by animal farming. This development would thereby bypass the negative environmental impacts of animal farming and consumption. This third category, however, is still some distance from scalable commercial production due to the current cost and availability of raw material.

### **Cheese terminology and the law**

Terminology is always important. When we refer to “plant-based cheeses” in this white paper, we mean products that are similar in taste, appearance and texture to traditional dairy-based cheeses. Other terms in use are “plant-based cheese replacement products” or “plant-based cheese analogues” or similar phrases. But here we call them “plant-based cheeses” or just “cheeses” for the sake of simplicity.

The word “cheese” may be reserved for dairy products in many markets. You should verify your own market and legal requirements before deciding which term to use in communications and advertising, when referring to plant-based cheeses.

## MARKET TRENDS

### Market growth for plant-based cheeses

The global shift towards plant-based diets has sparked a revolution in the food industry, with major food manufacturers and retailers embracing the change. The global vegan cheese market size was estimated at EUR 1.4 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of around 7.2%, reaching EUR 1.9 billion by 2027, according to Statista (*Figure 1*).

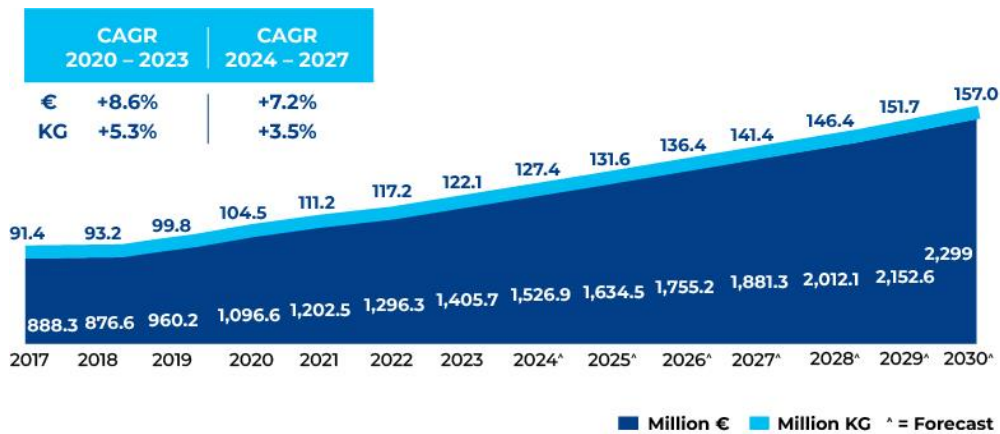


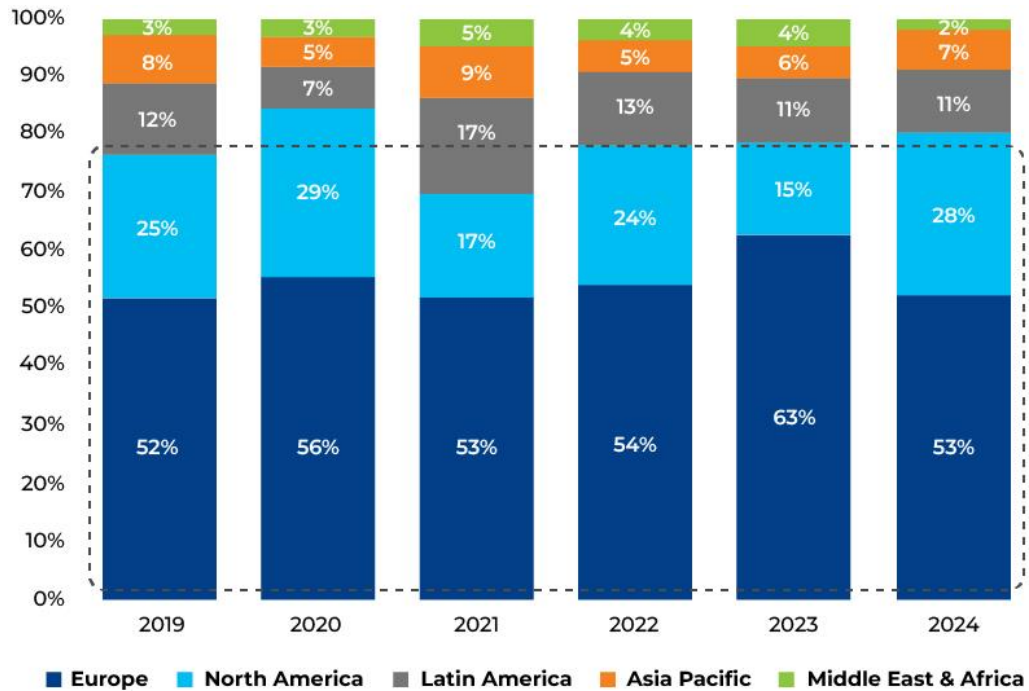
Figure 1 Steady growth in the plant-based cheese market. Statista market size database 2024

These figures are even more promising taking into consideration the impact of headwinds like ongoing military conflicts, global trade tensions, and inflation. The plant-based cheese retail market was not immune to these forces, experiencing a deceleration of growth in 2022. But both the value and volume of sales are continuing to grow, demonstrating consumer demand and a growing appetite for next-generation plant-based products that compete with conventional ones in terms of taste, price and convenience.



Figure 2 Number of plant-based cheese product launches, global, 2019-2023, Innova NPD research 2024

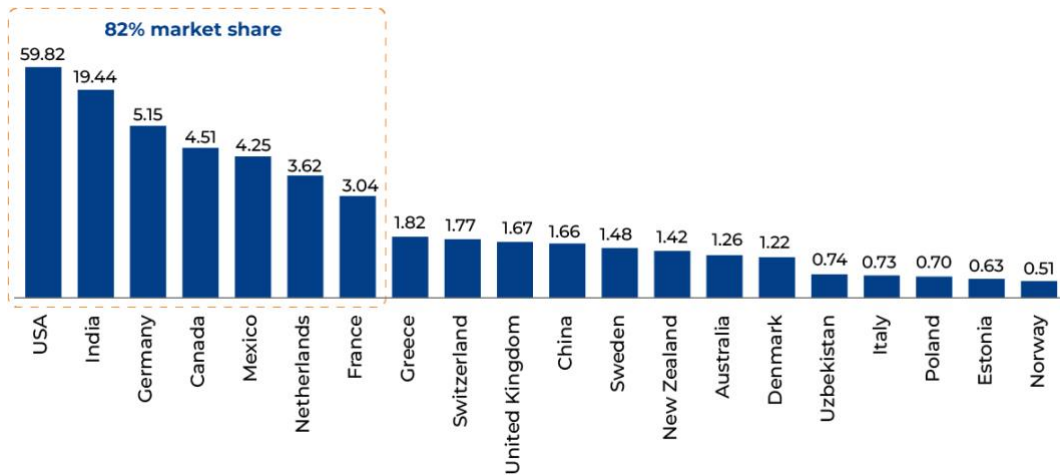
Another estimate of market growth comes from monitoring the number of product launches, which have grown by about 27% per year since 2019 (*Figure 2*). The number of plant-based cheese product launches showed a peak in the pandemic year of 2021, a dip in 2022, and then achieved a new high of 700 launches in 2023. Vegan cheese product launches continue to be highly dominated by two regions: Europe and North America, which together account for about 80% of product launches (*Figure 3*).



**Figure 3** Number of non-dairy cheese product launches, tracked by region 2019-2024. Mintel NPD research 2024

Even if consumption growth in North America has declined somewhat the last few years, there is great potential for expansion in other regions, which has been noticeable in recent years.

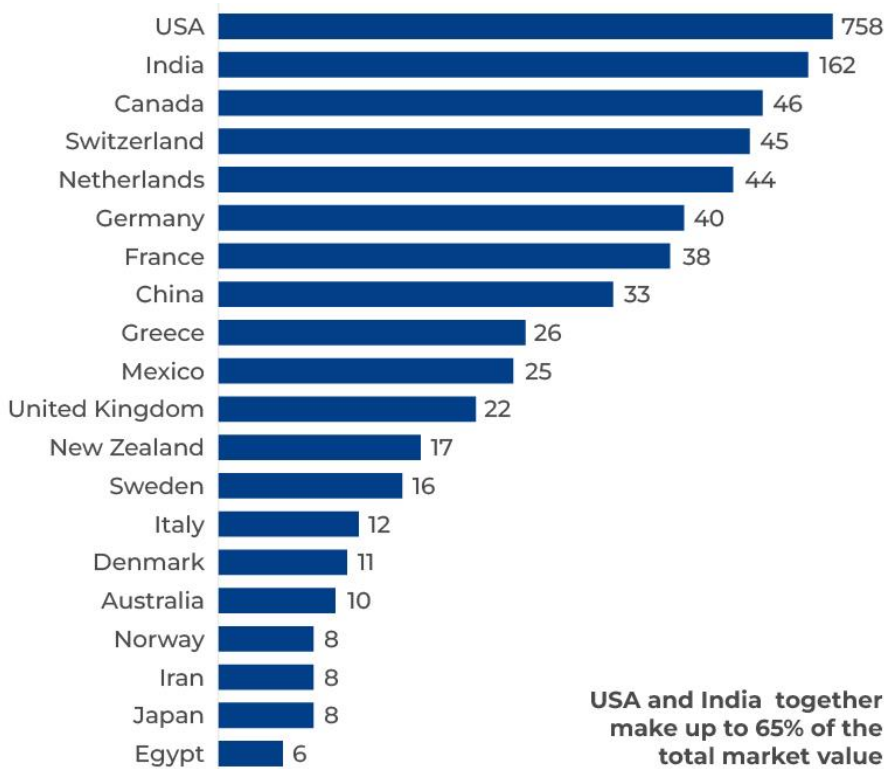
Germany tripled its volume over the past 5 years, serving as a leading market with a growing number of alternatives to traditional dairy products. While the French market faces more significant cultural barriers, there is a noticeable shift among younger consumers and urban populations towards plant-based diets (CAGR 19.2% '20-'23). This shift is supported by the rise of flexitarianism and increasing awareness of the environmental impact of the food and beverage industry.



**Figure 4** Plant-based cheese consumption, global volume per top 20 countries (2023). Statista market size database 2024

In Europe, plant-based food retail sales surged in recent years as new products and innovations have come to market. The market for plant-based cheese is expected to expand, with North America and Europe leading the charge, currently making up 79% of the total market value (Statista market size database, 2024). When it comes to market value, USA and India together make up 65% of the total.

The Asia-Pacific region is also emerging as a lucrative market, particularly in India, China, New Zealand and Australia, where cultural preferences, dietary shifts and increasing urbanisation are fuelling demand. These four markets grew their volume by ~30% since 2019, and growth is accelerating.



**Figure 5** Top 20 countries for plant-based cheese, by sales value, EUR millions Source: Statista market size database, 2024

As innovation in taste and texture continues, the plant-based cheese market is poised for robust growth globally, appealing to both health-conscious consumers and environmentally focused buyers.

### **Consumer drivers**

One of the strongest consumption drivers for plant-based cheese is perceived health benefits. Consumers continue to seek out products – both dairy and plant-based – that balance their intake of calories, nutrients and proteins in a way that enhances their health. And plant-based products are suitable for the growing number of people following vegetarian and vegan lifestyles.

Increasing acceptance of veganism, especially among millennials, has been fuelling market growth. The growing awareness regarding animal cruelty and the negative impacts on the environment associated with the dairy industry has encouraged consumers to opt for plant-based products.

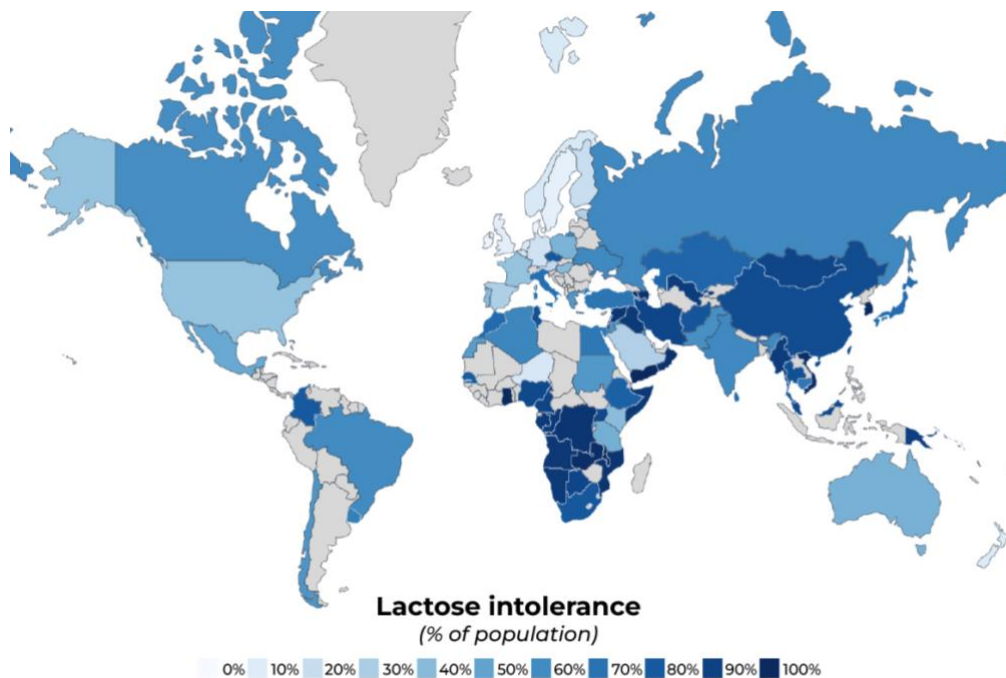
In a study we conducted in 2023 we looked at 5,000 participants in ten countries to better understand consumer preferences for vegan food. We learned that 43% of these consumers are trying to reduce meat, or are already excluding it, from their daily diets.

The COVID-19 pandemic offered some respite to the market as people around the world took an unprecedented interest in cooking at home. Hence, the demand for vegan food products increased significantly during this period, although this has been tempered in recent years by the impact of price increases due to general inflationary trends.

Factors such as increased consumer disposable income levels and willingness to spend on premium products have led to a rise in the demand for plant-based products. In addition, easy product availability in supermarkets and convenience stores has boosted the growth of this segment.

Many consumers are choosing more sustainable products, with the aim to fight climate change by reducing their environmental impact, even if this means paying a premium for environmentally friendly brands and products. The environmental effects of greenhouse emissions coming from the dairy industry are under particular scrutiny. In many cases this means that plant-based cheeses, in their role as “dairy alternatives” may be perceived as not only good for the consumer but also good for the planet. However, it is important to consider the full value chain when evaluating a food product’s impact on the environment, including how and where different raw materials are produced.

In addition, there is growing awareness of the extent of lactose intolerance, as this map based on data from 2023 indicates (*Figure 6*). Plant-based cheeses are a welcome alternative.



*Figure 6 Lactose intolerance is a strong motive for favouring plant-based alternatives to dairy products. Global lactose intolerance, % of population, 2024. World Population Review – Lactose Intolerance by Country, 2024*

### **Breakdown by product and region**

Vegan cheeses are produced and consumed in every region of the world.

Formats are wide-ranging, including blocks, spreads, shreds, cream cheeses, slices, cheese sticks and crunchy cubes. These allow a wide range of consumer applications, such as snacking, sandwich ingredients, or ingredients in cooked meals.

Looking back at cheese types, vegan mozzarella cheese held the largest revenue share of 34% in 2021, followed by cheddar with 32%. Mozzarella is widely used in Italian dishes, such as pasta, pizzas, croquettes, and caprese salad, and is available in the form of slices, cubes, shredded, and spreads. The demand for mozzarella is significantly high in countries where Italian cuisine is popular. The growing application scope of ricotta in Italian dishes, such as manicotti, lasagna, roll-up, high tea, and ravioli, has been fuelling its demand, thereby augmenting the segment's growth. In addition, vegan cheese is being produced in formats and flavours that aim to match consumer expectations for cheddar, feta, gouda, edam, and many other popular traditional cheeses.

## Regulatory challenges

Naturally, with all new product categories, barriers are often erected to market entry. Here are a few that we are tracking that may impact your market planning.

<b>Labelling terminology</b>	From 2022, brands are not allowed to recognise vegetable proteins as 'meat' or 'milk' (e.g. a patty made mainly of agglomerated lentils, the presentation of which is close to a steak). This has made new challenges for plant-based manufacturers to introduce a labelling strategy. This law does not apply to the entire EU but France has stated that it wishes the decree to be implemented throughout the EU.	France
<b>Vegan food ban</b>	In 2022, the Turkish Ministry of Agriculture and Forestry announced the ban of all vegan products that give the impression of cheese. This will create challenges for plant-based manufacturers to align their formulation strategy with government regulations.	Turkey
<b>European GMO authorisation law</b>	For GMO foods such as soy-based protein, all manufacturers since 2003 have to get their products approved by the European Commission before commercialising in the region. The points of authorisation take production strategies into consideration such as traceability and labelling.	EU

# INGREDIENTS

## Raw material formats

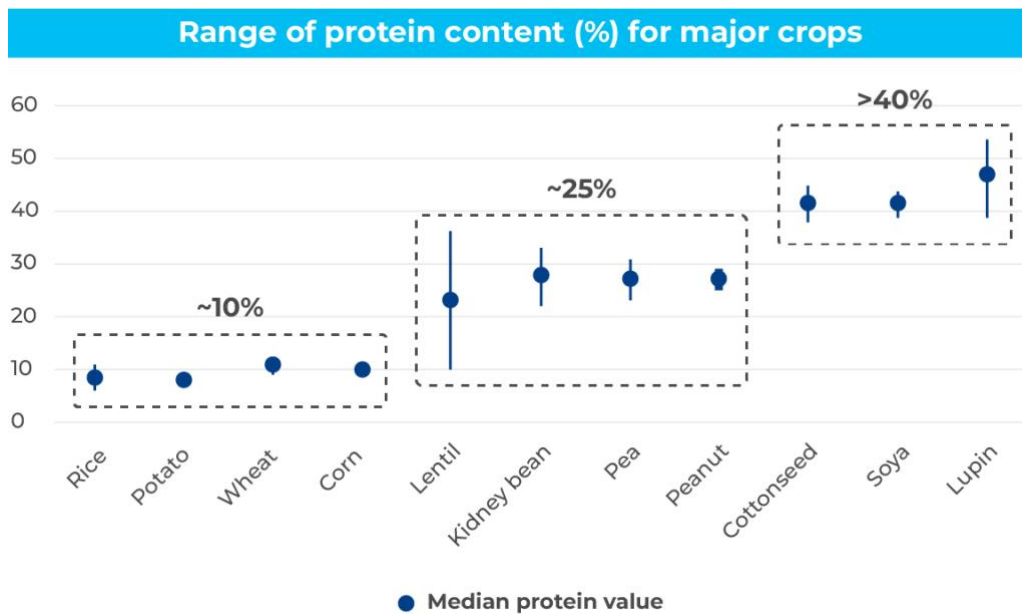
Dairy cheeses are made out of milk from different sources, but milk from cows, goats, and buffalo are fairly similar in protein/carbohydrate and fat composition, while plant-based raw materials differ quite a lot in formats and composition. So a plant-based production process might begin with any of the following, or a mixture:

- Fresh raw **crops**, such as seeds, beans, nuts or fruits
- **Paste**, the main supply method for nuts
- Plant-based liquid **base**, the same raw material base used for plant-based beverages
- Protein **concentrates**, with a protein content of 50-70%
- Protein **isolates**, with a protein content of 80-90%

The different formats and the different crops are often combined so that the final cheese can benefit from many different properties of the raw materials. A fresh crop might be used for labelling reasons, a light product might be used for similarity to cheese colouring, and two different isolates might be combined for the firmest cheese with the best sliceability.

## Protein sources

The variation in crop protein levels is another significant difference. The plant variety, growing conditions and preparation of the crop will affect the availability of proteins in the raw material greatly (*Figure 7*). Note that the protein level shows unrelated crops falling into three major groups defined by median protein levels around 10%, 25% and 40%.



**Figure 7** Examples of protein content in different crops. Graph based on data from Kumar et al. 2022

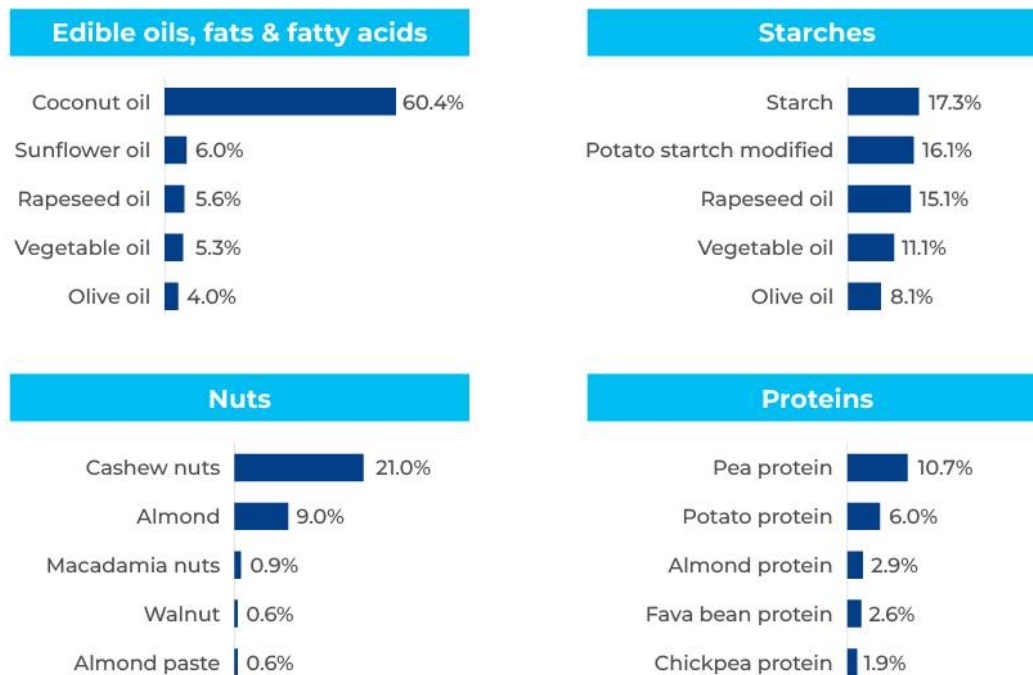
The functionality of these proteins will vary as well, in many cases reflecting their performance with the processing equipment, making it easier to adapt a processing component to produce cheeses with raw materials that have similar protein functionality (such as those in [Table 2](#)).

**Table 2** Classification of common crops by biological origin

High Starch*	Nuts & Stone fruits	Legumes	Oilseeds	Other
Oat	Almond	Pea	Sesame	Potato
Rice	Peanut	Chickpea	Sunflower	Tiger nut
Quinoa	Walnut	Lentils	Flax	Duckweed
Amaranth	Cashew	Lupine	Pumpkin	
Corn	Hazelnut	Fava bean (broad bean)	Chia	
Buckwheat	Chestnut	Mung bean	Hemp	
Millet	Pecan	Soya	Rapeseed / Canola	
Teff	Coconut			
Sorghum	Macadamia			
Rye	Pistachio			
Barley	Brazil nut			

These protein functionalities may involve structure building, textures and taste via foaming, stabilising or emulsifying ability, fat-absorbing capacity, gelling, water-holding ability, viscoelastic and cohesive properties, and ability to form fibrous proteinaceous networks. We'll present some detailed examples after the discussion of processing steps.

## Leading ingredients



**Figure 8** Key ingredient groups for plant-based cheeses. Source Innova Database, 2023-2024 YTD

Coconut oil leads as the top oil ingredient for plant-based cheese bases, being included in about 60% of product launches.

Cashew-based cheeses lead the nut category at about 21% of product launches, with almonds not far behind at 9%. Cashew-based vegan cheese contains vitamins B2 and B12 and is low in fat. This makes it favourable among health-conscious consumers all over the world. Furthermore, gluten-free and cholesterol-free cashew products are gaining traction owing to their health benefits. Pea protein is also surging in use in recent years, and is currently used in about 11% of product launches.

Soy milk is a low-cost substitute for dairy and has a complete balance of desirable fatty acids and amino acids. This makes it a cost-effective solution for large-scale vegan cheese producers. In addition, soy-based cheese is gaining traction among consumers as it is easy to melt.

### Protein concentrates & isolates

Plant-based protein concentrates have a protein content of 50-70%, with dietary fibres and the plant's native starch still present. Plant-based protein isolates have a protein content of 80-90% and have no dietary fibres.

The extraction of the proteins from the plant can be done in several different ways, often by physical separation equipment. This production process may affect the protein molecules, causing denaturation and loss of functionality – for example, a decreased ability to emulsify, absorb fat, or gel properly. Moreover, the production of protein isolates requires both chemicals and energy.

By adding water under heat (hydration) and sometimes with accompanying shear this functionality will be restored to some extent. This hydration of the protein raw material will improve the processing properties as well as solubility, bioavailability and the chemical properties of the proteins in the final product.

Note also that plant-based protein isolates and concentrates aren't just used for protein fortification in the food industry; their properties as stabilisers/emulsifiers and gelling agents are utilised in many different products.

Protein isolates or concentrates do not need to be the main component in the plant-based cheese; they can be used to boost the proteins of a ground vegetable or nut base for a better nutritional content and to add essential amino acids in the final cheese. A producer can make a paste from fresh vegetables, or grind nuts in the mixer and then formulate this paste into a cheese.

The same base that is used to make plant-based beverages or fermented -gurts can be fortified with proteins and fermented into cheese products in the same way.

### **Fat**

It is favourable for the texture of the final cheese to use fats that are solid at ambient temperatures; they melt and act in the mouth in ways similar to dairy fat. The most common source is coconut fat, but shea butter, palm oil and fully hydrated oils are common as well.

A solid fat would most commonly be melted before adding it to the mixer when formulating the product. But if product quality and the recipe allow it, a mixer that can also cut and melt fat creates an advantage.

### **Stabilisers**

The protein networks that are formed within plant-based cheeses are usually not strong enough to give a cheese-like structure; they often need assistance from texturisers or stabilisers, and there are plenty to choose from. The most common method would be to add the stabiliser after fermentation in order to maximise ingredient usage and avoid bacteria culture metabolising from the additive.

### **Cultures**

There are commercially available starter cultures for plant-based fermentation, which can be equally used for yoghurts or cheeses. They can be supplemented by more specific cultures, aimed to enhance flavours or increase fermentation rate, which can be crucial for food safety.

Most of the cultures used for fermentation of plant-based products will improve the taste both by adding a pleasant sourness and also by removing the bitterness associated with proteins. The choice of culture is the most important quality control point to remove the bitterness, and to create the specific taste of gouda or cheddar, for example, in a plant-based cheese.

## **Flavors, colours and spices**

Nutritional yeast and herbs are common sources of flavours in plant-based cheeses. They are often perceived as “natural” and have a high consumer acceptance. There are also many plant-based “dairy flavours” – commercial products that mimic the taste of dairy cheeses. Normally flavours and spices are introduced into the product as late in the process as possible in order to avoid interfering with the desired functionality.

Adding spices or flavours in the form of pieces such as cumin seeds, chives, sundried tomato particles, chili and the like are quite commonly used to enhance the eating experience and create variety in the product family.

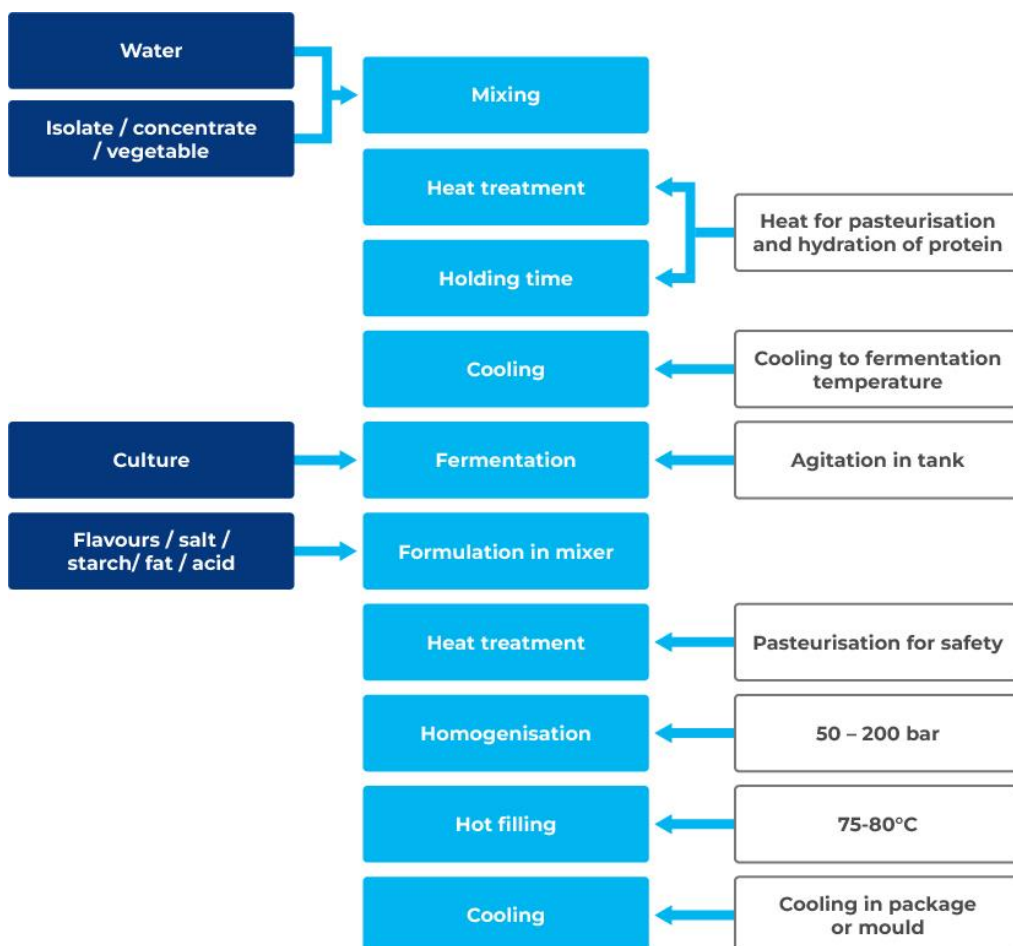
## LINE COMPONENTS

### Process overview

This section explains the step-by-step process of turning plant-based ingredients into a variety of cheeses. We'll cover it at a general level here, and then fine-tune it with additional application know-how and tips in the following section.

If you are unfamiliar with the traditional dairy cheesemaking production process, feel free to download a copy of the Tetra Pak Cheese Technology Guide (2<sup>nd</sup> edition), a 53-page guide to a centuries-old industry. (Available for downloading at <https://www.tetrapak.com/insights/cases-articles/cheese-technology-guide>.) For dairy cheeses, the processes vary based on coagulation method (acidification or rennet), heat treatment, cutting, moisture content, physical handling (e.g. stretching, draining, hooping, pressing), and aging.

The production approach to plant-based cheeses uses much of the same equipment, but in different ways and often using different settings. The following diagram (*Figure 9*) is a generic flow of the inputs and processing steps required to produce plant-based fermented cheeses.



**Figure 9** A generic process for plant-based cheese production

In later sections, we will show how these components can be configured efficiently in several types of line solutions that permit an optimal fit to your desired production capacity.

## Mixing

The word mixing sounds simple, but it is one of the most complex steps in the processing chain, and one that makes some of the most demanding requirements in plant-based cheese processing. One of the reasons is that the mixer technology has to take into account the physical properties of all ingredients, both solid and liquid, maintain their integrity, and avoid degrading their functionality – all under controlled conditions of temperature, shear and viscosity.

Optimal mixing with a high-shear mixer is key, because it enables a base with lower viscosity, making it possible to pasteurise the base in a plate heat exchanger before fermentation.

But mixers can take on additional tasks to increase production efficiency. For example, a high-shear mixer with heating capacity, such as Tetra Pak's (Figure ), lets you use the same component to both mix and pasteurise the base, completely eliminating the need for a separate heat exchanger. In fact, the Tetra Pak High-Shear Mixer can perform many of the essential steps you need: grinding, mixing, emulsifying, heating and cooling.

This resulting mixer versatility and efficiency not only deals well with high viscosity but also utilises the ingredients maximally, to optimise the gelling and structure build-up of any given added ingredient.



**Figure 10** The multifunctional Tetra Pak High-Shear Mixer

### **Moving ahead with the right mixing head**

There are additional requirements – or at least desirable properties – when it comes to the mixing head used for the wide variety of plant-based materials. After all, it may be required to mix everything ranging from a toothpaste viscosity to whole cheese blocks. The mixing head must ensure even particle distribution to maintain high quality. And it should be flexibly configurable with a variety of sizes, materials, knives, and propellers. High shear is the key to optimising performance.

For quality, efficiency and flexibility, it's desirable to have a range of mixing heads, sizes, stators and options. The rotor draws ingredients into the mixing unit and pushes them out through the holes in the perforated stator. During this process, impeller wings at the bottom of the rotor subject the product to high shear. All of the product passes the mixing unit at least once.

### **The problem with air in mixing**

There are other performance requirements on mixers. In general, plant-based protein isolates and concentrates are not hydrophobic or difficult to mix with water. But as powdered protein content is added to water, two things happen: viscosity rapidly increases, as well as the possibility of air incorporation, which would lead to foaming.

You'll want to reduce air in the production process for a number of reasons:

- Loss of micronutrients, colour and taste
- Oxidation that can lead to reducing shelf life
- Increased fouling on heat treatment equipment, which can reduce running time and increase cleaning downtime
- Problems with net volume on filling machines
- Potential product losses.

The solution to the air problem is to add the ingredients under a vacuum system, eliminating any added air. This allows faster addition of ingredients, as well as potentially drawing down consumption of water and energy.

### **Heat Treatment**

Heat treatment prior to fermentation serves two purposes; the heat will kill off unwanted microorganisms and it will facilitate the hydration of the proteins.

For microbial growth, the most common target organism would be *Bacillus Cereus* spores. If the fermentation rate is not rapid enough, there is a risk that the *B. Cereus* spores vegetate and form heat-resistant toxins during fermentation. This can be counteracted by accelerating the fermentation rate by adding fermentation facilitators such as sugar or nutritional yeast.

In addition, since many plant-based proteins are prone to fouling on hot surfaces, you need to choose a heating system that takes this into account. *(You may want to consult our heating technology guide for additional guidance:*

*<https://www.tetrapak.com/insights/cases-articles/heating-technology-guide>.)*

The hydration procedure is very critical for the quality of the final cheese, and depends on the raw material characteristics, as well as the ingredient supplier, as we described in the section on *Protein concentrates & isolates*, and the heat treatment must be adapted to the conditions the supplier recommends. If the hydration is insufficient there will be a loss of protein functionality, as well as poor and inconsistent product quality.

## Fermentation

Fermentation is started by adding the bacteria culture to the product, a process called “inoculation”. The following period of waiting or buffering time is called “incubation”, which is often longer for plant-based cheeses than dairy cheeses. Cultures adapted for plant-based fermentation sometimes need jacket heating at the same temperature as the optimal growth temperature, if they do not produce enough heat to maintain that temperature in an airconditioned room.

Fermentation reaction will produce a (lactic) acid that lowers the product pH.

Fermentation will also result in a very strong and viscous coagulum, as seen in *Figure 11*. This can be hard to break, which will make it difficult to create a homogenous product in the formulation step. So we advise keeping the agitator running throughout the entire fermentation period, to keep the product in a liquid state. The product will demand a larger amount of texturisers or stabilisers when no coagulum is allowed to form, but the mixing and formulation will be simplified.



**Figure 11** To the left a coagulum from laboratory trials without agitation. The image in the middle shows the results of insufficient agitator speed during fermentation. The right image reflects sufficient agitation throughout fermentation

As most cultures are mesophilic, meaning their preferred growth temperature is 35-43°C, the coagulum will be warm. Depending on the culture, there might be a need to cool the coagulum when the correct pH is reached, in order to inhibit further growth and to maintain the same acidity level in all formulation batches. Thus again, it is advantageous to have a fermentation tank that has independent heating and cooling functions.

## **Formulation**

You can typically divide the fermented protein base into several batches and then add stabilisers, texturisers and flavours to create more than one cheese product from the same fermented base. This way of working will increase your production flexibility and keep investment costs down.

The challenge in formulation is to add powders to a high-viscosity product and distribute them evenly in the mixer without breaking too much of the desired structure from the fermentation. Again, a versatile high-shear mixer can be the key to product success.

## **Heat treatment downstream**

A second heat treatment after fermentation and formulation can be motivated for several reasons:

- For safety... killing remaining bacteria and enabling hotfilling
- Stopping fermentation
- Prolonging shelf life
- Creating optimum conditions for homogenisation
- Improving the functionality of additives such as stabilisers

This heat treatment could be carried out in a mixer equipped with heating technology, or in a separate heat exchanger, which might be one of the following four types:

- Plate Heat Exchanger
- Tubular Heat Exchanger
- Coiled Heat Exchanger
- Surface Heat Exchanger

Choosing the right type of heat exchanger would depend on the product viscosity and rheology, as well as heat transfer calculations, in order to optimise energy usage and minimise product losses.

Legally required heat treatment of the product is performed at specific temperature/time combinations. A change in holding time and temperature is likely to influence texture and taste.

## **Homogenisation**

Homogenisation will make the final cheese smoother, lighter and firmer.

Homogenisation pressure should be optimised so it doesn't interfere too much with added texturisers, but still high enough to create the desired structural changes in the fat-protein matrix.

Any added particles must be added after homogenisation, prior to hotfilling, otherwise they will “disappear” or disintegrate in the homogenising step.

## **Filling**

Pasteurised products are hotfilled, primarily for improved shelf life. The type of filler and any need for “sterilising” the cap or lid will determine filling temperature. A pasteurised, acidic product that is hotfilled normally has an expected shelf life of 3-4 months in cold storage.

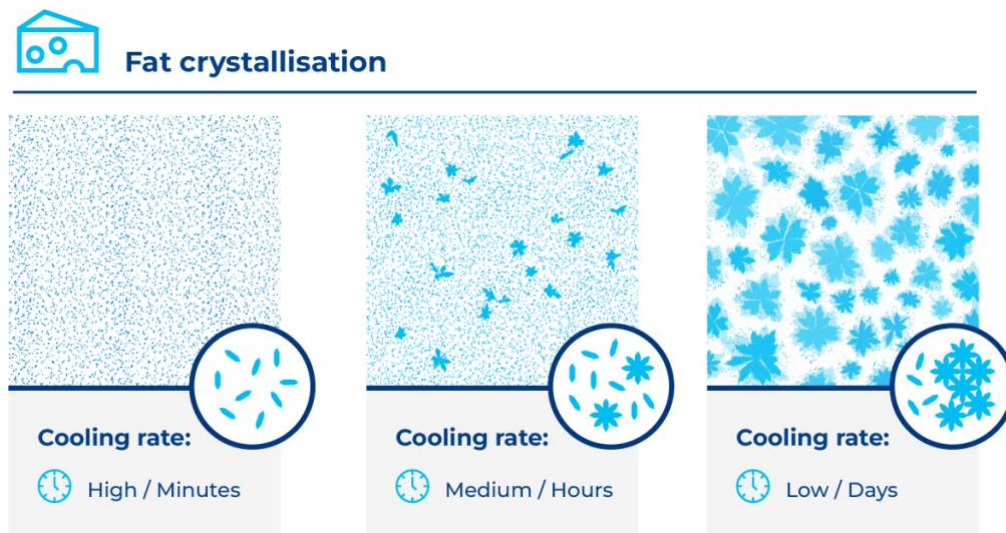
The product is typically 75-85°C at filling; the lower temperature limit is for microbiological safety and the upper depends on the filling nozzles; sudden pressure drops create a risk of boiling at higher temperatures. With this fill temperatures there might be a need for insulation of the pipes, depending on condition in your production plant.

The hotfilling process yields an expected shelf life of 3-4 months under refrigeration. It's appropriate for use with cheese moulds for shreds, slices and blocks, and can also be used with cheese spreads. The filling temperatures will require a package capable of withstanding high temperatures, or moulds for cheesemaking.

## Cooling

After the product has been filled, it is cooled in the package or mould to <8°C. This can be performed in cold rooms, or in a cooling tunnel with spray water or something similar. You can also stack the packages or moulds on a pallet with room for airflow, and then place the pallet in cold storage.

The cooling rate is important for fat crystallisation, which is important for mouthfeel.



**Figure 12** How cooling rate affects fat crystalline structure, with a high rate of cooling (left) and a low rate (right)

The fat crystallisation in the cheese product is highly affected by the cooling rate and will impact the mouthfeel, hardness and stability of the final product. A rapid cooling rate will lead to many small crystals and increased cheese hardness. A slow cooling rate will result in larger flakier crystals and a lower emulsion stability. In Figure you can see the results of a high rate of cooling in the left image and a low rate on the right, and this difference in fat crystalline structure will be noticeable to both the palate and tongue.

The final structure and texture of the cheese will build up during storage for approximately 10-14 days.

## APPLICATION KNOW-HOW

Now that we've covered the general principles of ingredient selection and formulation, as well as individual processing steps and unit operations, we can move on to planning and executing production in an optimal way, drawing on application knowledge and years of testing.

In the section below, we list a number of tips of the trade: interaction effects between certain ingredients and certain formulations and processing steps, and what can be done to assure quality, safety and efficiency.

In the next chapter, we'll show how you can optimise production even further through adaptable line configurations that enable cost reduction in capital equipment and an improved fermentation rate. Moreover, it can provide you with production flexibility and scalability as you grow your business.

### Formulation efficiency

In planning production, we generally suggest producing a white base by mixing protein concentrates or protein isolates and water, adding one or more cultures, and incubating. This fermented base can then be divided into smaller batches that are formulated with different stabilisers, texturisers, flavours, colour, and spices into a variety of cheese products.



**Figure 13** A fermented base can be divided into several different formulated product streams

### Ingredient choices

Ingredients from the high starch group listed in [Table 2](#) are rather low in protein and fat content compared to the other groups. This means that you will use a recipe where you need fewer added texturisers and more added fat. When building a line, the solution for surrounding equipment will look different than for a legume or oil seed, even if the mixer is the same.

### Heating and cooling issues

Many of the plant-based proteins used are prone to protein fouling on hot surfaces. Therefore one cannot heat the product through the mixer jacket, but rather by direct steam injection. A good transport of the heat within the product is necessary to distribute temperature evenly through the batch. There will be a significant contribution to the heat rate if the mixer run with high shear during the steam injection.

Cooling down to fermentation temperature is done with jacket and flash cooling. It is a slow process. There will be a water addition from steam condensate in the heating and a water loss from condensation in the flash cooling. They will normally not balance each other and you'll need to pay attention to the mass balance and dry matter content in the product.

When processing a dairy protein isolate, a generic hydration process of 50°C for 30 min can be applied. There will be **no** generic hydration process for plant-based protein powders, so you will have to calculate the time/temperature needed. There are no ways of measuring the hydration level in a blend.

Another example involves using oil seeds and nuts, or stone fruits. They are high in fat content, and the fats are often the "healthy" ones, the polyunsaturated. But they are heat-sensitive and easy to oxidise (oxidised fat = rancid fat) and therefore you will need to be much more precise when adding heat load to the product. Legumes in general withstand more heat without losing taste or causing fouling, so there is less need for precision.

### **Mixing**

The protein powders can be mixed into water, plant-based beverage base or vegetable puree. It is necessary to have a smooth liquid prior to adding protein, otherwise the final product will be difficult to recognise as cheese. One can cook and grind the vegetable before fortifying with protein powders. There will be a quality balance between smoothness of the puree and the overcooked taste of the vegetable.

### **Stabilisers**

In some cases, it might be desirable to add a part of the stabilisers prior to fermentation to maintain physical stability in the product and then have a second addition post-fermentation for the final structure build-up.

### **Optimising fermentation rate for safety and efficiency**

The fermentation rate is also crucial for food safety. If there are spores present in the raw material, the spores can have favourable conditions to vegetate in the fermentation tank if the fermentation rate isn't high enough. Proteins have a buffering capacity, so the acidification rate might be too low to ensure product safety. This can be adjusted by chemically acidifying the product or using a higher pasteurisation temperature to pacify the spores.

Adding sugar, yeast extract or any other enhancer may improve the living conditions and the digestion rate of the bacteria in the culture.

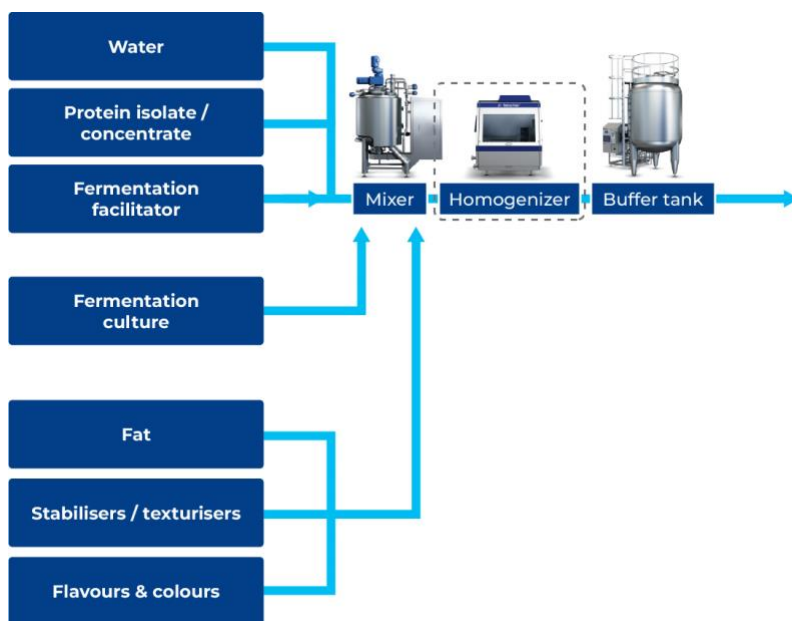
### **Homogenisation and colouration**

Plant-based cheeses are naturally light brown in colour. Homogenising will often make the colour appear lighter, as the smaller fat globules break the light in a different way than the larger droplets do; hence the overall impression is lighter. Colour additives can be used, but some of them are a bit sensitive to heat and oxygen prior to settling in the food matrix.

## PUTTING IT ALL TOGETHER WITH ADAPTABLE AND EXPANDABLE LINES

In this section, we build on all the previous material and show **how processing components can be configured efficiently in several types of line solutions that permit an optimal fit to the size and desired capacity of your production, as well as your particular ingredients and recipes.** To keep it brief, we'll illustrate two different batch solutions and one continuous solution that can match different stages of production development. In other words, leveraging ingredients and technical processes with application knowledge to increase quality, efficiency and cost-efficiency.

### Batch solution 1 for flexibility and reduced time-to-market (500 litres/day)



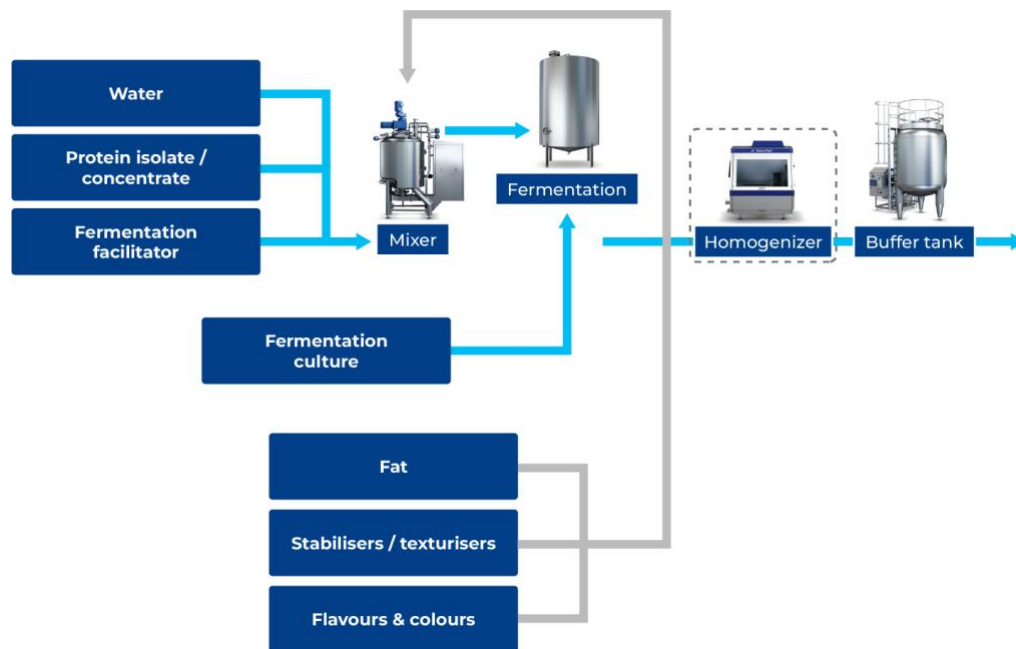
**Figure 14** Batch solution 1

This first batch line solution has most unit operations performed in the high-shear mixer, which, as we previously described, is capable of multiple functions. This includes ingredient mixing, formulation, fermentation, and pasteurisation, achieving a level of both simplicity and efficiency.

This example in [Figure 14](#) shows a 500-litre high-shear mixer. First, a 300-litre base is mixed in the afternoon, cooled and inoculated. In the morning fat, texturisers, colour and flavour are added, heat is applied and 500 litres of one recipe can be hotfilled. Another base is prepared and in five days you can product four different recipes.

The homogeniser unit is optional; homogenisation will increase firmness and make the colour appear brighter but it might or might not be an economical addition, depending on your formulations and quality goals.

**Batch solution 2 for increased capacity to meet market demand  
(4300 litres/day)**

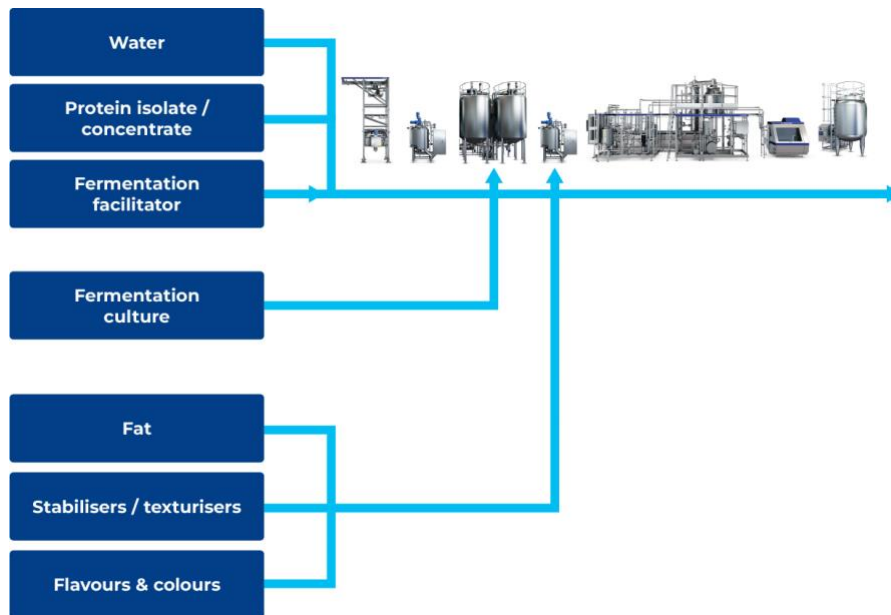


**Figure 15** Batch solution 2

When your initial cheese product is a commercial success, you can easily expand the line with a fermentation tank to increase production capacity, as in [Figure 15](#).

Instead of starting with a single 300-litre base, you could mix 3 x 500-litre base batches into the fermentation tank in the afternoon. The fermentation time is not affected by the volume. In the morning you can withdraw 5 x 300-litre batches back to the mixer to formulate with a variety of fats, stabilisers, colours and flavours, giving you as many as five different recipes to hotfill. But there is room for more expansion...

## Continuous line solution for optimal production volume and efficiency (8500 litres/day)



**Figure 16** Continuous line solution

To further increase the capacity of your initial line, you could add an external cooler or even a full pasteuriser to speed up the batch time. And you could also add an improved powder handling system to increase efficiency. And with this modular expansion method you could add additional equipment until the line is in fully continuous production, as we illustrate in [Figure 16](#).

And at the end of this modular evolution, we have created a continuous line, with each unit operation being performed in its own piece of equipment.

The ingredient mixer upstream from fermentation or pre-fermentation here can be the same mixer that you started out with in the first batch line, when you started initial production. At that stage, you would be able to produce 500 litres of plant-based cheese four days a week. This upgraded continuous line will produce 8500 litres/day for 7 days a week. The result of combining ingredient knowhow, versatile equipment, application knowledge... leveraged with some advanced production planning.

## SUMMARY

Production of plant-based cheeses, or vegan cheeses, is an exciting growth industry. The global vegan cheese market size was estimated at EUR 1.4 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of around 7.2%, reaching EUR 1.9 billion by 2027. Another marker – the number of product launches – has grown by about 30% per year since 2017. The market is most active in two regions: Europe and North America, which together account for about 80% of product launches.

By “plant-based cheeses”, we mean products that are similar in taste, appearance and texture to traditional dairy-based cheeses. In other words, the same quality markers apply. Nutritional value is also becoming a convergent quality.

One of the strongest consumption drivers for plant-based cheese is perceived health benefits, and their suitability for the growing number of people following vegetarian and vegan lifestyles, especially among millennials. Many consumers are also choosing more sustainable products, even if it means paying a premium. Another factor is lactose intolerance.

Early plant-based cheese production used only oils, starches and flavours. But we are currently in the midst of a second generation, with much higher protein levels, utilising a wide variety of legumes, vegetables, nuts and grains, protein isolates or concentrates; fermentation cultures; and starch and hydrocolloids. The third, emerging, generation will use engineered casein from plant-based raw materials, and more closely match traditional dairy-based cheese production.

Because the chemical and biological processes involved in making plant-based cheeses are currently so different from the dairy world, we described three different perspectives: **ingredients**, **technology** and **application know-how**.

**Ingredients** – Dairy milk is fairly uniform in protein/carbohydrate and fat composition. But plant-based raw materials differ quite a lot in formats and composition, so their production process might use any of the following:

- Fresh raw **crops**, such as seeds, beans, nuts or fruits – which might vary in protein content from ~10% to ~40%.
- **Paste**, the main supply method for nuts
- Plant-based liquid **base**, the same raw material base used for plant-based beverages
- Protein **concentrates**, with a protein content of 50-70%
- Protein **isolates**, with a protein content of 80-90%

These protein sources vary in how they contribute to structure building, texture, taste, foaming, stabilising or emulsifying ability, fat-absorbing capacity, gelling, water-holding ability, and other properties. Thus control of processing parameters is key to product success.

**Technical processes** – Production of plant-based cheeses uses much of the same equipment as dairy cheeses, but in different ways and using different settings – often because viscosity development and heat sensitivity follow different patterns than dairy production.

One of the keys to optimising efficiency is to use a multi-purpose high-shear mixer that is able to perform many essential processing steps: grinding, mixing, emulsifying, heating (pasteurising) and cooling. This eliminates the need for a separate heat exchanger. This mixer versatility and efficiency deals well with the high viscosity of plant-based material and also utilises ingredients maximally, to optimise the functionality of any given ingredient.

Another issue arises when air is incorporated into the mixture when adding ingredients, which can lead to changes in nutrients, colour, taste, shelf life, and increased fouling on heat treatment equipment. Our recommended solution is to add the ingredients under a vacuum system, eliminating any added air and speeding up the process, as well as saving water and energy.

**Application know-how** – Your technical processes must match the chemical and functional properties of your plant-based ingredients, in order to achieve the desired product quality in an efficient manner. Heating and cooling parameters, in particular, have to be carefully calculated. Legumes, for example, are more heat-resistant than oil seeds and nuts.

In planning production, we generally suggest producing a white base by mixing protein/isolates and water, adding one or more cultures, and incubating. This fermented base can then be divided into smaller batches that can be formulated with different stabilisers, texturisers, flavours, colours, and spices into a variety of cheese products.

Other steps that need careful calculation and control are how much heat to apply before adding protein powders; the number of separate steps in which you add stabilisers; maintaining a safe fermentation rate; and managing the homogenisation process to achieve the desired product colouring and viscosity.

**Putting it all together in line solutions** – In the final section, we showed how processing components can be configured efficiently in several line solutions that permit an optimal fit to your desired production capacity, as well as your particular ingredients and recipes.

We illustrated how you could advance from a simple batch solution (500 litres/day) to one with higher capacity (4300 litres/day) and further to a continuous solution (8500 litres/day), matching different stages of demand, by using a modular expansion method. In other words, leveraging ingredients and technical processes with application knowledge to increase quality, efficiency and cost-efficiency.

With more than 100 years of experience in dairy products and cheese production, and more than 40 years in plant-based production, we are ready to share our knowledge with you – and invite you to take advantage of our expertise through our Product Development Centres around the world.

## WHAT TETRA PAK BRINGS TO THE TABLE

### **Expertise and capabilities**

Tetra Pak has a long history with both dairy cheese production and plant-based production that we are now merging into something new – flexible line solutions for plant-based cheeses that are optimised for your production capacities and ambitions.

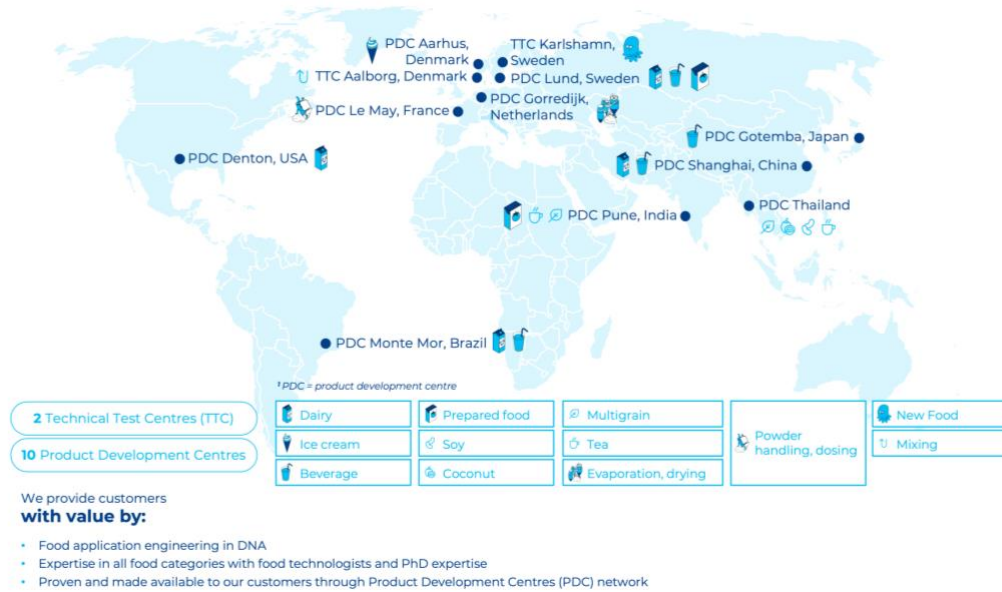
We offer reliable, hygienic and efficient solutions within dairy cheese production. Our best-practice lines make your life easier with state-of-the-art equipment, industry-leading expertise and long experience. Our best-practice lines are available for mozzarella, semi-hard cheese, cheddar, cottage cheese, tvarog, white cheese and string cheese production.

Partnering with us for your plant-based cheese offering gives you access to our global network of ingredient suppliers, state-of-the-art production lines, and packaging options that will elevate your plant-based identity. We can provide expert advice at every decision point along the way – from raw materials to distribution strategies.

We offer more than equipment. We can provide you with decades of plant-based food processing and packaging expertise, combined with automation and maintenance experience based on optimising thousands of plants all over the world. We can match your desired quality with the lowest possible total cost of ownership.

### **Partnerships with ingredient suppliers**

In partnership with suppliers of ingredients and other supplies, we have delivered processing solutions and equipment for several decades to customers expanding their production with ingredients such as oats, rice, nuts, cereals, legumes and seeds. Our network of technology specialists can help you deliver competitive, sustainable and nutritious plant-based products – based on the optimal choice of raw materials and ingredients for a given product and region. In practical terms, if you have a particular processing issue with particular ingredients, we likely have some relevant expertise and test data from our global network on ingredient characteristics and processing parameters.



We have 10 Product Development Centres spread around the globe, 2 Technical Test Centres, and a Manufacturing Hub that specialise in different applications and food categories. They are a great resource for product testing and co-innovation. We encourage customers to get in touch and book some time at a Centre with our experts, in order to consult on ingredients, best practices, and processing parameters. It's also possible to make trial runs of new product formulations, rent equipment and get knowledge support as part of your journey.

### **TTC Aalborg, Denmark (Technical Test Centre)**

Specialising in mixing and water adaptations, crucial for plant-based cheese

### **PDC Monte Mor, Brazil**

Specialising in dairy and beverages

### **PDC Denton, USA**

Specialising in dairy

### **PDC Lund, Sweden**

Specialising in dairy, beverage & prepared food

### **PDC Aarhus, Denmark**

Specialising in ice cream

### **PDC Le May, France**

Specialising in powder handling and dosing

### **PDC Gorredijk, Netherlands**

Specialising in evaporation, spray drying & agglomeration

### **PDC Pune, India**

Specialising in prepared food, tea, multigrain

**PDC Gotemba, Japan**

Specialising in beverages

**PDC Shanghai, China**

Specialising in dairy & beverages

**PDC Thailand**

Specialising in soy, coconut, tea & multigrain

**TTC Karlshamn, Sweden (Technical Test Centre)**

Specialising in New Food

For more information, visit our website:

[www.tetrapak.com/solutions/product-innovation/product-development-centres](http://www.tetrapak.com/solutions/product-innovation/product-development-centres)

## REFERENCES

### Scientific literature

Almena-Aliste M. & Mietton B. 2014. **Cheese Classification, Characterization, and Categorization: A Global Perspective.** *Microbiol Spectr* 2:10.1128/microbiolspec.cm-0003-2012. <https://doi.org/10.1128/microbiolspec.cm-0003-2012>

Manoj Kumar, Maharishi Tomar, Sneha Punia, Jyoti Dhakane-Lad, Sangram Dhumal, Sushil Changan, Marisennayya Senapathy, Mukesh K. Berwal, Vellaikumar Sampathrajan, Ali A.S. Sayed, Deepak Chandran, R. Pandiselvam, Nadeem Rais, Dipendra Kumar Mahato, Shashikant Shiddappa Udikeri, Varsha Satankar, T. Anitha, Reetu, Radha, Surinder Singh, Ryszard Amarowicz, John F. Kennedy, **Plant-based proteins and their multifaceted industrial applications**, *LWT*, Volume 154, 2022, 112620, ISSN 0023-6438, <https://doi.org/10.1016/j.lwt.2021.112620>.  
<https://www.sciencedirect.com/science/article/pii/S0023643821017734>

### Handbooks

**Tetra Pak Dairy Handbook, chapter on Cheese**

<https://dairyprocessinghandbook.tetrapak.com/chapter/cheese>

**Tetra Pak Cheese Technology Guide**

<https://www.tetrapak.com/insights/cases-articles/cheese-technology-guide>

**Heating Technology Guide**

<https://www.tetrapak.com/insights/cases-articles/heating-technology-guide>

### White papers

**Plant-based frozen desserts**

<https://www.tetrapak.com/insights/cases-articles/plant-based-frozen-desserts-future-delight>

**Plant-based yoghurt**

<https://www.tetrapak.com/insights/cases-articles/plant-based-yoghurt-style-products>

**Dairy and plant-based yoghurt production on a single hybrid line**

<https://www.tetrapak.com/insights/cases-articles/dairy-plant-based-yoghurt-single-hybrid-line>

