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Plant-based Report, Part 2: Next-generation dairy alternatives, from plant-forward to animal-free

Introduction

Demand for plant-based dairy alternatives has soared in recent years. However, using plant-based ingredients to create truly dairy-like milk, yoghurt, ice cream, and more remains a technical and functional challenge for product developers. In this report, we look at how sensory analysis can aid new product development; identify high-potential plant-based ingredients; and explore how precision fermentation could be a game-changer for the category.

The Plant-Based Report 2023 will be published in three parts throughout the year. You are reading part two.

Finding functional equivalents: The food technologist's view

Dairy has a complex composition, and this is one of the reasons that finding suitable alternatives from the plant kingdom is so difficult, according to Els de Hoog, senior project manager for flavour and texture at Netherlands-based food research firm Nizo.

> “Fermentation is a very powerful technology [...] with a lot of opportunities to improve the quality of your product."
>
> Els de Hoog, senior project manager for flavour and texture, Nizo

Milk fat, for instance, melts at body temperature, thus contributing to the creamy sensation of dairy products. Lactose plays a functional role when milk is fermented into other products such as cheese or yoghurt because it provides the source of energy for the microorganisms, while the micellar structure of casein is unique and plays an important role in contributing to many of dairy’s functional and technical qualities.

“We don't have that in plants,” said de Hoog, speaking during a Fi Webinar Series presentation entitled “Dairy and dairy alternatives: How can we close the gap in consumer perception?”.[1]

Dairy products have also been eaten for millennia, setting the gold standard in terms of the taste and texture that people want.

“The main issue we see in plant-based products is the sensory gap. A consumer in the end [...] is used to traditional dairy products and, a lot of time, the dairy alt products are different; they have a different taste and different sensory quality,” said de Hoog.

Dairy alternative developers face the huge task of finding dairy’s characteristics in plants. Pea and oat are common building blocks for plant-based products but their protein fractions have different solubility levels and functionalities compared to dairy.

Nevertheless, the sensory gap can be bridged by using several formulation strategies at once, according to de Hoog.

Use analytical tools to quantify and qualify sensory traits

Brands must begin by carefully analysing the sensory characteristics of both the dairy-based target – creaminess, for example – and the plant-based iteration. This will help identify which attributes need to be improved.

Creaminess can be measured using a tribometer, an instrument that quantifies the friction between moving surfaces such as the palate and the tongue. Tribometry analysis by Nizo shows that skimmed dairy yoghurt has higher friction rates than full-fat dairy yoghurt, which explains its “drier” and less creamy texture. A soy-based yoghurt, on the other hand, has similar friction levels as full-fat dairy.

“We see a yoghurt based on oat and almond are also fairly good; they have a low friction, meaning high creaminess,” said de Hoog. “But if you look in more detail, you see that it is not because of the product itself but because of the additions: there is a huge amount of fat and carbohydrates added to compensate.

“If [...] you have a lot of fat, this forms an oil film on your tongue and that will have a very smooth feeling. [It’s] the same if you have polysaccharides of carbohydrates on your tongue; they will bind to water and also increase the lubrication into a smooth sensation.”

“If you don't have that, you will only have the proteins or even the polyphenols that are very abundant in plant-based products, and that [creates] a more astringent, dry mechanism.”

Product developers can use this analytical data to replicate the effect of fats and carbohydrates in their plant-based products without having to use sugar or fat, thus achieving both desirable sensory attributes and a healthy nutritional profile. It can also be used to achieve clean-label formulations. Using analytical tools to better understand protein viscosity can allow brands to replace stabilisers in clean-label products, for instance.

Fermentation: Low-tech but effective

Fermentation is an example of a “low-tech” processing technique that has been used for millennia to make foods more palatable. It is also a useful tool for dairy alternative brands on many fronts, said de Hoog.

By influencing proteolytic activity, fermentation can improve the texture of plant-based cream cheeses by increasing the creaminess and spreadability, and improving mouthfeel.

It can also improve taste because microbial cultures can remove off-flavours, such as beaniness or grassiness in pea protein, and even form new flavour compounds that have fruity or savoury notes.

In addition to naturally increasing shelf life, fermentation bacteria can also improve the healthiness of the product by removing anti-nutritional factors, which are nondigestible and can also contribute to astringency, and making indigestible carbohydrates more accessible.

“Fermentation is a very powerful technology [...] with a lot of opportunities to improve the quality of your product,” said de Hoog.

Spotlight on ingredient innovation

Product developers creating plant-based dairy alternatives have a large and growing range of ingredients they can use, from soy, oat, coconut, almond, and pea to rice, spelt, sesame, quinoa, hazelnut, and more.

Recent product launches include Dug's drinking milk alternative made with potato protein in the UK; Planti's plant-based milk made with broad beans in Sweden; and Lavva's vegan yoghurt made with pili nuts in the US.

READ MORE: Introducing the potato bean: High in protein and fibre and good for the planet (click image)

The products found on supermarket shelves today are a huge improvement on the first iterations from several decades ago. However, many of these products are still not like-for-like dairy replacements when it comes to taste, texture, and appearance, spurring industry to continue developing novel ingredients that can replicate the sensory attributes of dairy fat and protein in plant-based applications. We look at some of these novel ingredients.

Esterified propoxylated glycerol (EPG)

US scaleup Epogee has developed a functional, reduced-calorie vegan fat by restructuring the fatty acids in plant oils. The GM-free, modified plant oil is made by separating the fat's glycerol "backbone" from the fatty acids and then inserting a propoxyl "link" between the fatty acids and glycerol, it says.[2]

The alternative structure of the ingredient, esterified propoxylated glycerol (EPG), means the fat receptors on the mouth and tongue detect the flavour and texture of fat but the propoxyl link resists the enzymatic processes that release calories and saturated fats from fat metabolism. The modified fat, which is Generally Recognised as Safe (GRAS) in the US, contains 0.7 calories per gram compared to nine calories per gram in regular fat.

Although Epogee designed the fat for use in plant-based applications, its functional attributes and reduced calorie content mean that some conventional dairy brands are using it. Swedish dairy ice cream brand N!CK's uses the modified plant-based fat in its cow's milk ice creams because it replicates the creaminess of dairy fat while reducing calories, resulting in a healthier ice cream.

"The creaminess we love in ice cream normally comes from calorie-dense dairy fats. We use a plant-based alternative fat, called EPG, which gives our ice creams their irresistible, creamy mouthfeel, but with a dramatic reduction in calories," says N!CK's.[3]

Oleaginous yeast

Swiss startup Cultivated Biosciences uses biomass fermentation to produce an oleaginous yeast in bioreactors. The yeast accumulates fat in the form of “a complex mixture” – in other words, the ingredient is not a single compound – “that is like a cream”, according to CEO Tomas Turner. The GM-free, yeast-based fat is then extracted and can be used as an ingredient.[4]

According to the startup, which must secure novel food approval before commercialising its ingredient in Europe, the creamy fat is cholesterol- and lactose-free but has the same texture and mouthfeel as dairy cream. It also has the same cream colour as dairy ingredients as well as low lipid oxidation and natural emulsification properties.

Cultivated Biosciences is keeping the specific name and strain of the yeast under wraps, but Turner said it is a well-known yeast that was initially researched for biofuel applications.

The ingredient has a slight umami flavour and so the company plans to initially target savoury applications, such as plant-based cream cheese and sour cream alternatives. Cultivated Biosciences also aims to develop solid fat iterations that are suitable for hard and aged cheese alternatives.

Fusarium filamentous fungi

US startup Nature’s Fynd makes dairy-free cream cheese using a fungus-based, high-fibre and high-protein ingredient. The ingredient, grown via a biomass fermentation process, is *Fusarium strain flavolapis* – a natural fungus that was originally discovered in the hot springs of Yellowstone National Park in the US. The name, *flavolapis*, means "yellow stone" in Latin.[5]

The vegan ingredient, which the company has commercialised under the brand name Fy, contains 50% protein with all 20 amino acids – including the nine essential ones – as well as 30% fibre that includes beta-glucans. It is also low in fat and cholesterol-free.

Nature’s Fynd, which is a founding member of the recently formed Fungi Protein Association,[6] uses its own patented technique for biomass

fermentation called liquid air surface interface fermentation, unlike the more typical submerged fermentation. It says this is more efficient and improves the properties of Fy.

Its dairy-free cream cheese is already on sale in the US, with the main ingredient described on the ingredient list as “dairy-free Fy milk (water, nutritional fungi protein)”.[7]

Chlorella vulgaris

Singaporean startup Sophie’s Bionutrients grows *Chlorella vulgaris* microalgae in urban bioreactors. Its microalgae reach the harvest stage in just three days, which reduces energy costs and makes the ingredient more sustainable, it says.

The ingredient is a natural, high-protein flour that can be used in many applications, but one of the startup’s first iterations was a lactose-free, vegan ice cream that it created in collaboration with the Danish Technological Institute (DTI).[8] The chlorella, when combined with other functional ingredients, mimics the texture of ice cream, according to the company.

It has also made a chlorella-based drinking milk alternative.[9] “Anything dairy can do, microalgae can do in the future,” it says.

Seed oleosomes

Wageningen University spin-off Time-Travelling Milkman is developing a creamy, seed-based fat to replicate the creaminess of milk fat.

Its ingredient uses oleosomes, the naturally occurring fat droplets inside plant seeds that are covered by proteins. The presence of this compact, protein membrane makes oleosome droplets highly creamy in a similar way to milk fat droplets, it says.

Unlike vegetable oils, which are extracted from

oilseeds such as rape and sunflower by pressing the seeds, Time-Travelling Milkman has developed a method to extract fat from the cells in seeds while keeping their natural structure intact.

It also uses a solvent-free, water-based manufacturing process.[10]

“Creaminess comes from fat, not protein,” said Dimitris Karefyllakis, CEO and co-founder. “Alternative protein sources are abundant, but the importance of the fat element has been overlooked. Without this, there will be no protein transition.”

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Plant-based versus animal-free:

Is this the new frontier of alternative dairy?

Precision fermentation has the backing of prominent environmentalists, such as George Monbiot,[11] and also the support of investors. Perfect Day has raised over $700 million[12] to date, while the Every Company (formerly known as Clara Foods) has raised $233 million.

However, its biggest appeal for consumers (and therefore for food manufacturers) is that the ingredients produced using this process are nature-identical and therefore offer the same functionality.

READ MORE: Argentinian startup is using precision fermentation to create plant-based versions of animal ingredients (click image)

A growing number of precision fermentation companies are bringing to market whey, casein, and other nature-identical dairy protein ingredients that are made without animals, and they say the final products are indistinguishable from conventional dairy products.

Plant-based dairy brands offer consumers more sustainable alternatives to dairy with taste and texture profiles that are similar, but not exactly the same. If flexitarian consumers switch en masse to animal-free dairy products, the plant-based category could certainly take a hit.

Although these animal-free ingredients are still very niche and most consumers have not tried them, they have arrived in some countries and a few food companies – including major ones – are embracing them.

In June 2022, confectionery giant Mars launched a vegan chocolate bar made with Perfect Day's animal-free whey protein. The lactose-free chocolate bar, called CO2COA, tells consumers on the front of its packaging that it is "made with animal-free dairy".[13]

Nestlé is also exploring animal-free dairy proteins. It has developed a product using Perfect Day's ingredient that has already been launched in the US in a "test-and-learn" pilot.[14]

The selling point: 'We are changing the process, not the food'

Irina Gerry is chief marketing officer of Change Foods, a US startup whose final product is a precision fermentation-derived casein protein powder. Casein is "the ingredient that is needed to make cheese amazing", she said at Fi Europe 2022.[15]

According to Change Foods, animal-free casein will allow manufacturers to create the melt and stretch of cheese that current plant-based equivalents, made mostly of fats, starches, binders, and emulsifiers, fail to emulate.

"The reason this is exciting and quite revolutionary is because we are no longer limiting ourselves to mimicking dairy with plant-based ingredients," said Gerry. "We are creating the same dairy with a different process; we are changing the process, not changing the food."

Gerry compared this to producing electricity using solar panels instead of oil and gas. For the end-user, the result is the same – you come home, flick the switch, and the lights come on – but that result is achieved at a lower environmental cost.

> “We are creating the same dairy with a different process; we are changing the process, not changing the food.”
>
> Irina Gerry, chief marketing officer, Change Foods

“The way we do this [...] is take microorganisms – you can think of brewer's yeast used in beer-making or bread-making – and insert the part of DNA from a digital database that codes for milk protein production in a cow," she said. "There is no cow involved – this is all digital transformation – but we are able to transfer the gene from this digital database into the microorganism and create these milk-producing cells.

“Then we brew them in a fermentation tank [...] and at the end of the fermentation process, we filter the milk proteins that we want, discarding the actual microorganisms that were used to produce it, that we don't really want. Then we have an ingredient that is identical to the protein that comes from a cow that can be combined with fats, salts, [and] water to create a variety of dairy products."

A revolution... or merely a rebranding?

While Change Foods, Perfect Day, and other precision fermentation companies require regulatory approval for their novel ingredients, precision fermentation has, in fact, been used by food companies for decades to make a crucial ingredient in cheese-making: rennet.

Rennet is a complex set of enzymes produced in the fourth stomachs of ruminant animals, such as cows and sheep, that is used to curdle milk and separate curds from whey. Its main component is chymosin but it also contains other enzymes such as pepsin and lipase.[16]

Traditionally rennet is extracted from the stomachs of calves (it must come from an un-weaned animal), but today around 90% of the rennet used in the US and the majority of that used in the EU is made using precision fermentation.[17]

READ MORE: Can we farm animal proteins in plants? (click image)

Fermentation-produced chymosin, known as FPC, is a common ingredient for modern cheesemakers and can be made using the yeast *Saccharomyces (Kluyveromyces) lactis*. The final ingredient is GM-free.

Josh Kittleson is vice-president of biology at New Culture, a California-headquartered precision fermentation startup that is making casein protein. He said that millions of consumers around the world are already eating foods with ingredients made via precision fermentation, even if they do not realise it.

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Raising awareness of this is an important part of New Culture's mission.

"I would hesitate to call [our ingredients] novel in that, for example, 95% of the cheese in the world today is produced using an enzyme made through precision fermentation. Rennet is not purified from calf intestines; it's made using precision fermentation," he said.

"A lot of the ingredients in products that you find on shelves today say 'natural flavouring' [and] that natural flavouring is made using precision fermentation.

"Fermentation in general is a technology that is as old as civilisation. [Precision fermentation] is a little bit of an evolution of the idea and [...] a rebranding of something that has been going on for a while. So, it's not that we have no history of use and no idea of what this looks like [from a safety perspective]."

Insulin could be 'an instructive example' of uptake and acceptance

According to think tank RethinkX, public acceptance of milk, cheese, chocolate, and other foods made using precision fermentation will follow the same trajectory as that of insulin, the hormone that is crucial to treating diabetes.[18]

Insulin is traditionally produced by extracting it from the pancreases of cows and pigs, and more than 50,000 animals are required to produce just one kilogram. In the 1970s, as rates of type 2 diabetes grew, it was estimated that 56 million animals would have to be slaughtered each year to meet insulin demand in the US alone.[19]

However, the pharmaceutical industry developed insulin made via precision fermentation and the ingredient, which has a more consistent quality than conventional insulin, changed the entire supply chain. In 2000, animal-extracted insulin accounted for less than 1% of the market.

"Insulin is an instructive example of how precision fermentation has created a superior product that led to a rapid disruption of an existing product," said RethinkX.

Global demand for dairy is growing, particularly as more affluent regions begin to adopt Western dietary habits. Asia-Pacific will account for 41% of the dairy market's growth from 2022 to 2027,

according to Technavio.[20] Synthetic biology companies say that producing dairy proteins via precision fermentation to meet this demand is an environmental necessity.

Adopt a 'behind-the-scenes' approach, says Mintel

Although Mars has communicated widely about its CO2COA launch, Emma Schofield, associate director of global food science at Mintel, believes that "behind-the-scenes" applications could also be an important feature of products using animal-free dairy ingredients.

"In many categories like bakery or chocolate, milk is not a key or base ingredient that consumers focus on, but rather a behind-the-scenes ingredient whose properties or selling points are not discussed or promoted on pack as they are with many dairy products," she said.[21]

"In such products, premium attributes linked to cow's milk, such as heritage or tradition, are not important to the product, and precision-fermented proteins that deliver cost-savings may be attractive to producers and end-consumers who seek price as a priority to other more premium attributes."

Is animal-free vegan?

In any case, brands interested in using animal-free dairy ingredients should carefully consider the wording they use to communicate this on pack. The word "vegan" is seen by many to be misleading and could result in a backlash.

One B2C blog, Go Dairy Free, lists all the companies using Perfect Day's ingredients while claiming to be vegan, criticising them for their "deceiving" packaging.[22]

Precision fermentation-derived dairy proteins are allergens, just like conventional dairy proteins, and although companies are required to flag the presence of the allergen on-pack, many dairy-free shoppers scan supermarket shelves for vegan claims, assuming this means dairy-free. For people with a severe milk allergy, eating one of these products could result in a serious or even life-threatening allergic reaction.

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The dairy-alt dilemma:

Can plant-based products compete with (or beat) dairy's nutritional gold standard?

Can plant-based dairy alternatives compete with dairy in terms of nutrition? Not according to the scientists behind a 2022 Swiss study published in Frontiers in Nutrition, which looked at the quantitative and qualitative nutritional value of 27 plant-based drinks and compared them with cow's milk.[23]

The dairy-alternative products were made from eight different plant species (almond, cashew, coconut, hemp, oat, rice, soy, and spelt) but did not include blends.

The researchers found that cow's milk contained more energy, fat, carbohydrate, biotin, pantothenic acid, calcium, phosphorus, and iodine than most of the plant-based drinks. It also contained more vitamins C, B2, B12, and A.

Milk also won for protein quality, as measured by true ileal amino acid digestibility (TIAAD) and digestible indispensable amino acid scores (DIAAS).

'Not real alternatives to milk'

The soy-based drinks performed well, providing slightly more protein and markedly more vitamins B1 and B6, folic acid, and vitamins E and D2 (with supplemented vitamin D2) and K1, magnesium, manganese, iron, and copper than cow's milk and the other plant-based drinks. The other plant-based milks fell short, however.

The researchers concluded: "Our results show that the analysed plant-based drinks are not real alternatives to milk in terms of nutrient composition, even if the actual fortification is taken into account.

"Complete replacement of milk with plant-based drinks without adjusting the overall diet can lead to deficiencies of certain important nutrients in the long term."

Are dairy health's benefits 'overplayed'?

Some researchers argue that the importance of dairy as a source of certain nutrients such as calcium has been overrated.

Writing in The Guardian, professor of genetic epidemiology at King's College London and microbiome researcher Tim Spector said: "Dairy is a massive cause of global heating, and its health benefits, such as strengthening bones, have been overplayed. There are plenty of better sources of calcium, for example, sesame seeds and tahini, dark-green leafy vegetables, and calcium-set tofu."[24]

Nevertheless, Spector has not given up dairy completely for health reasons. "Personally, the only milk I haven't given up is fermented milk, known as kefir, which I make myself and have a little shot of every day for my gut microbiome," he wrote.

Nutrient trade-offs inevitable – but fortification is key

While the Swiss study determined actual nutrient composition in the products (rather than just comparing information on the nutrient labels), it was limited by the fact the scientists did not analyse blended products, such as rice and soy milk or almond and oat milk. Blending plant proteins is a common formulation strategy to raise the protein quality and amino acid score.

Sandra Einerhand, founder of nutrition consultancy Einerhand Science and Innovation, said there was often a nutritional trade-off when swapping dairy for dairy alternatives.

"[...] plant-based drinks often have a higher [glycaemic index] GI due to the use of sucrose/ glucose or fructose instead of lactose and plant-based drinks also often contain starches," she said. "Cow's milk has a better omega-6/ omega-3 ratio. However, plant-based drink do contain higher amounts of mono- and poly-unsaturated fatty acids compared to cow's milk."

Einerhand said there was "certainly room" to further improve the nutritional profile of plant-based milk drinks, not only focusing on protein quality and micronutrients but also carbohydrates and fatty acids.

"Milk provides micronutrients in a bioavailable from, where some micronutrients added to the plant-based drinks on the Swiss market are not always highly bioavailable," she said. "Therefore, adding rapidly bioavailable sources of such minerals [...] to the levels found in cow's milk is key."

Improving the nutrient profile of plant-based dairy alternatives is becoming a growing priority for many brands, particularly as these products begin to comprise a greater share of people's diet.

In 2022, Danone USA announced a commitment to "increasing the nutrient density" of more than 70% of its plant-based beverages, although it did not say which specific nutrients would be targeted as part of this nutritional overhaul.[25]

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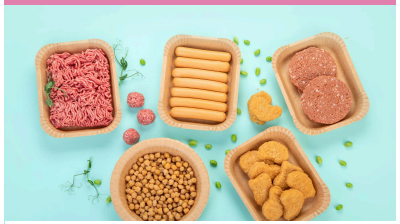

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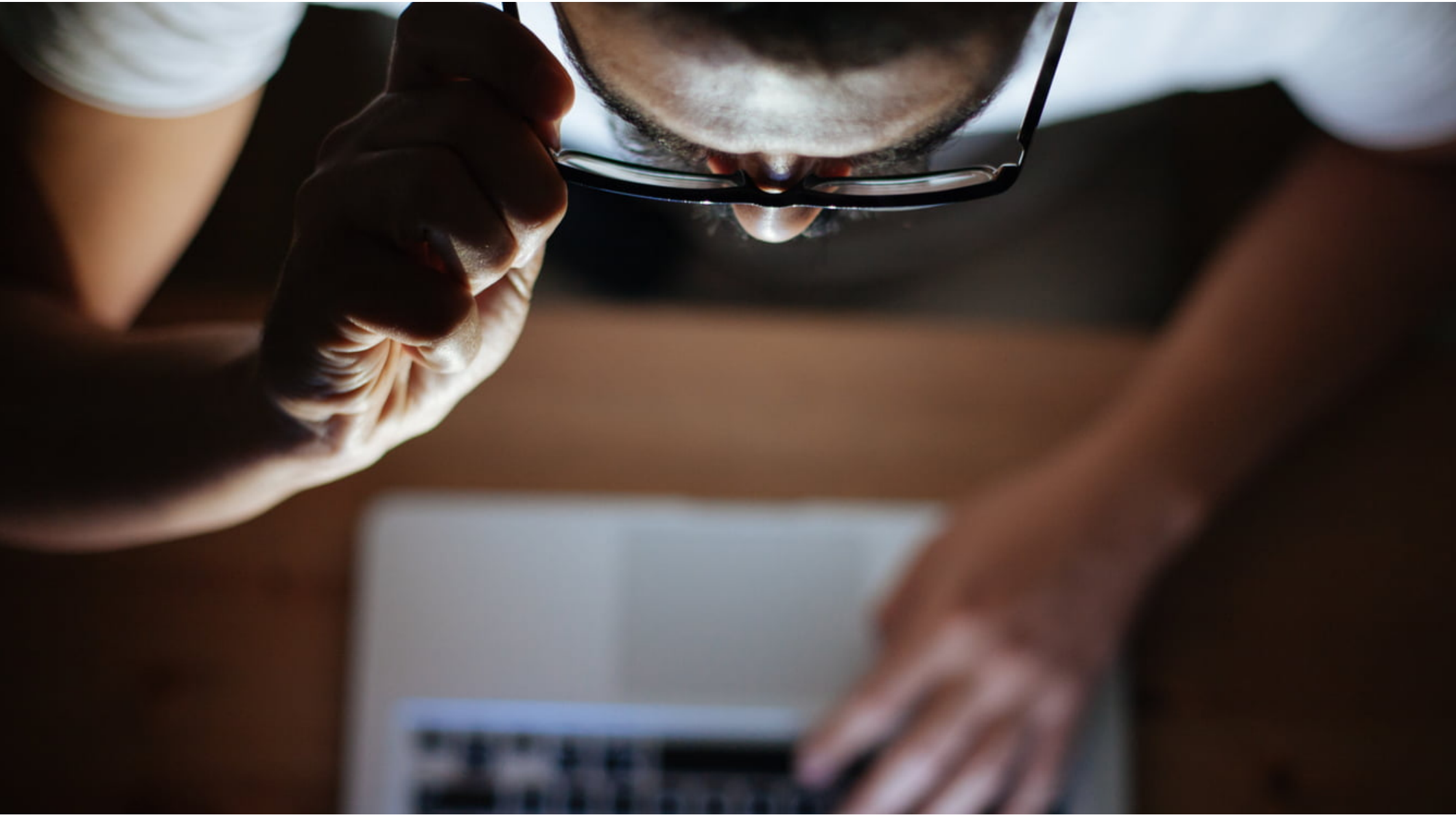
Key takeaways

- Product developers should make use of sensory analysis tools to understand and then replicate the sensory characteristics of dairy using plant-based ingredients.
- Fermentation is an example of a low-tech tool that can improve the taste, texture, shelf life, and nutritional profile of plant-based products.
- Next-generation ingredients that promise to improve the taste and texture of dairy alternatives include seed oleosomes, microalgae, oleaginous yeast, modified oil, and *Fusarium* fungus.
- Precision fermentation is allowing brands to make nature-identical dairy proteins in bioreactors rather than in cows. These ingredients are currently niche but could significantly disrupt the plant-based category in the near future.
- Plant-based brands should fortify their products with rapidly bioavailable sources of nutrients to the same levels as those found in dairy milk, thus allowing consumers to substitute dairy without impacting their nutrient intake.



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