Alternative Nordic Uses of *Aspergillus oryzae*

The potential of the koji products fava bean shoyu and aged cheese

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Alternativa Nordiska Användningar av Aspergillus oryzae

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Abstract

This study explores the potential of integrating koji (*Aspergillus* spp.), a traditional East-Asian fermentation mould, into novel Nordic produced food items. By examining two Japanese innovations, a fava bean-based shoyu (soy sauce substitute) and a surface-ripened cow cheese using koji, this report evaluates their feasibility and relevance within a Nordic context. Swedish research and consumer behaviour stand example as a Nordic reference. The selection of fava beans addresses regional agricultural suitability and the increasing interest in legumes, while the koji-ripened cheese demonstrates the fungi's potential on dairy-based substrates. Through a review of scientific literature and qualitative interviews with Japanese producers, the report analyses production processes, sensory characteristics, and cultural compatibility. Using the 3F framework (ingredients, process, sensory profile), both products are positioned within the spectrum of food innovation. Results indicate that both products hold promise for Nordic adaptation, particularly in niche markets prioritizing sustainability, local identity, and culinary innovation. The research highlights both the technical feasibility and cultural considerations necessary for integrating koji into Nordic food production, offering insights for producers interested in developing regionally grounded, fermentation-driven products.

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1. Introduction

Koji is the common Japanese name for multiple moulds of the *Aspergillus* genus and has long been used in many East-Asian fermented foods. The aim of this study is to investigate possibilities for using koji in novel Nordic food products. The study will evaluate the potential of two unique food items found on the Japanese market, which presents alternative ways of using koji. One product is a cow cheese, surface ripened with koji, and the other is a fava bean shoyu (soy sauce analogue). The two items are chosen based on their prospects as adequate Nordic counterparts to already established standard products. Either in the sense of the ingredients being of a regionally more suitable sort, or the strengthening of the identity of the item. The processing steps of the cheese and the shoyu will be compared to the standard practice of related products, to possibly pinpoint difficulties in a Nordic adaptation. Furthermore, the taste and perception of the food items will be analysed based on similarity to already known items, both out of a scientific and societal point of view. This study aims at investigating the need of these food items as well as their usefulness and applicability in a Nordic consumer and producer context.

Koji is engrained in many of the East-Asian food cultures because of its signature enzymatically driven flavour development found in miso, soy sauce, sake and mirin. It is traditionally grown through solid-state fermentation on cereals and pulses resulting in a mycelial mass with high levels of hydrolytic enzymes such as amylases and proteases (Narahara et al. 1982). These proteins can when active, break down the substrates' starch and protein into flavour compounds and fermentable components such as amino acids and short-chain carbohydrates. The mycelial substrate base can then, depending on the desired final product, be mixed with more substrate and salt or yeast for further fermentation (Ito & Matsuyama 2021).

All species of *Aspergillus* that fall under the name koji are generally regarded as safe. Domestication of the fungus species derived from or "intended" for the genetical suppression of aflatoxin production, which is found in the wild relatives *A. flavus* and *A. parasiticus* (Barbesgaard et al. 1992; Lee 2019). The natural domestication of fungi stems from generations of cautiously deciding on offspring with desired qualities (Mona 2021). It is suggested that *A. oryzae* comes from an atoxigenic lineage of *A. flavus* which were selected for its cooperation with yeast in sake production (Gibbons et al. 2012). A similar pattern of selection is also found in the history of other food related fungi such as *Penicillium camemberti* (Le Bars 1979).

Different strains of koji mould (*A. oryzae*, *A. sojae*, and wild-type relatives) exhibit distinct enzymatic profiles, directly affecting their suitability for specific substrates and fermentation goals. Three key enzymatic activities, protease, amylase and lipase production, are especially relevant when considering outcomes in flavour development and substrate compatibility (Shih & Umansky 2020).

In modern koji production, inoculation is commonly not done with wild or ambient cultures but with isolated spore strains selected for their enzymatic properties and safety when grown on grains and pulses. This ensures consistent fermentation performance and avoids contamination. It is important to note that koji moulds are not native to the Nordic environment, largely due to the region's colder

climate, which limits spontaneous fungal growth and reduces traditional exposure (Barbesgaard et al. 1992). This lack of historical integration may pose cultural and technical barriers to the fungi's adoption in local food production. Nonetheless, with controlled environments and increasing culinary experimentation, there is a growing opportunity for Nordic producers to also, domesticate the process.

1.1 Shoyu

Shoyu production serves as a representative example of the koji fermentation process. To begin, soybeans are soaked and then steamed, while wheat grains are roasted and cracked. These two components are then combined and inoculated with koji spores. The inoculated mixture is incubated at approximately 30ºC and 90% relative humidity (RH) until the mould reaches full growth, just before it begins to sporulate. At this stage, enzyme production is at its peak. The entire mixture is then transferred into a concentrated salt solution (22–23% NaCl) and left to ferment and mature over time (Ito & Matsuyama 2021).

A. sojae, a relative of *A. oryzae*, is used in some shoyu fermentations and exhibits slower growth but greater tolerance to salinity, making it ideal for long-aged products (Ito & Matsuyama 2021). Advances in genomics and enzyme assays now allow producers to select koji strains based on precise metabolic outputs (Mona 2021), offering potential for tailored fermentation profiles in Nordic food innovation.

Soybeans (*Glycine max*) are by far the most used legume for koji products, being found in both miso and shoyu. The bean originates from East Asia and contain a high amount of protein and fat but relatively low levels of carbohydrates in comparison to other pulses (McGee 2004). The productivity of soybean cultivation has stagnated in many Asian countries (Kobayashi & Kunimitsu 2024), and much like Europe, an increase in imported soybeans and soybean meal from e.g. Brazil can be seen, which have a large environmental impact partially due to the transportation (Prudêncio da Silva et al. 2010). Furthermore, in the context of a Nordic climate there are poor results in growing a suitable soybean cultivar (Fogelberg & Mårtensson 2021), suggesting the inconvenience of producing soybean-based products in the north.

Fava beans (*Vicia faba*), in contrast to soybeans, are better suited to colder climates and a shorter growing season, making them more viable for cultivation in Nordic regions (Jensen et al. 2010). They are also one of the endemic legumes promoted by the EU for increased human consumption (EU 2024). In Sweden, the cultivation of legumes has been steadily increasing, as reflected in recent land-use data[1]. Like soybeans, *V. faba* contain high amounts of protein but differ in its high levels of starch and significantly lower fat content (McGee 2004). Historically, the use of fava beans as a koji substrate is limited, with the primary example being the Chinese fermented paste *doubanjiang*, where the beans are ground into flour, a method distinct from the whole-bean fermentation typical of shoyu (Zhang et al. 2020). However, a notable exception exists on the Japanese island of Shodoshima, where a fava bean–based shoyu is produced using traditional fermentation methods.

[1] The Swedish Board of Agriculture, https://jordbruksverket.se/statistik [Accessed 10 May 2025]

The producer, Takahashi Shoten, is run by the fifth generation of shoyu brewers. Their product serves as the first case study in this investigation.

1.2 Koji cheese

The second product investigated in this thesis is a surface ripened cheese where koji acts as a substitute for the otherwise common moulds (*P. roqueforti* and *P. candidum*). It implies a complete change of substrate for the otherwise plant dependent fungus, which has been showed to proliferate on a dairy based medium despite the lack of expected macronutrients such as starch (Nakanishi & Nakazawa 1959).

In cheesemaking, enzymes are already utilised to a great extent, both as coagulants of milk, and as taste developers over time (McSweeney & Sousa 2000; Shih & Umansky 2020). Previous attempts at developing a cheese ripened with koji have showed how some *Aspergillus* species are enzymatically comparable to the conventional *Penicillium* varieties (Nakanishi & Nakazawa 1959; Kumura et al. 2017). The compositional characteristics of such a cheese have then been investigated in an effort to develop an uniquely "Japanese" type of cheese (Tomita et al. 2022). Cheese consumption is not as well established in Japan as in Europe and there is a supposed preference for white mouldy cheese over the rancid and spicy flavour of blue cheese. It is reported by Nakanishi & Nakazawa (1959) that early koji cheese had the rancid characteristics of blue cheese due to high lipase activity, which was addressed by lowering the fat content of the cheese mass. Contemporary koji cheese has however resorted to using strains with lower lipase production while retaining the elevated protease activity, which proved to be sufficient for cheese ripening (Suzuki et al. 2021).

1.2.1 Products in a food system

The known range of koji usage is however expanding because of an increased search for umami sources and partially as a response to requested flavour development of plant-based foods, sprouting from restaurants (e.g. NOMA, Copenhagen) as well as the spread of fermentation to artisanal food producers. Trailblazers of the new Nordic cuisine, a regional gastronomic ideology, has adopted koji and found ways to incorporate the fungus with Nordic ingredients (Evans & Lorimer 2021). Reflecting the values outlined in the movement's manifesto, their approach emphasizes "cooking based on raw materials whose characteristics are particularly excellent in our climate, landscape, and waters" in combination with "impulses from outside" (Lauterbach et al. u.å.).

For this study, Sweden will make up the foundational example of Nordic conditions and markets, justified by the similarities in food culture, food politics and climate between the countries. However, agricultural differences should be noticed as both geographical and political factors has shaped Nordic farming, with Denmark as an export-focused EU member, and Norway sheltering its agricultural sector as a non-EU member (Rydén 2007).

Regarding the cheese production of Sweden, it has declined during the 21st century, while imports has increased (Figure 1). In 2024 54% of questioned Swedes expressed that they prioritized buying domestic cheese, alongside requesting a national variant of *Brie* (Demoskop 2024).

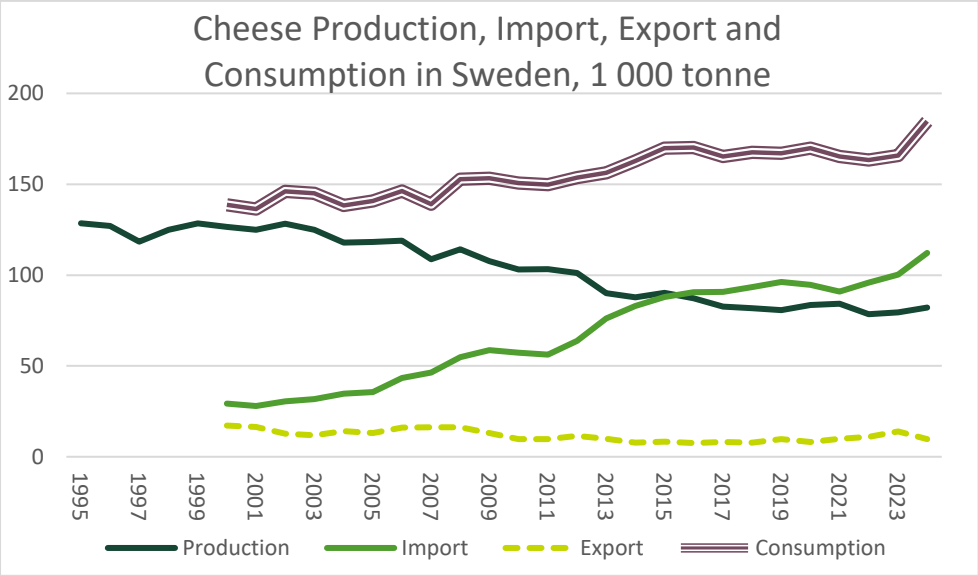

Figure 1. Data from Swedish agencies[2,3] showing the total consumption (not adjusted for waste), importation, exportation and production of cheese for the nation, 2000 (1995)-2024. Presented in 10^3 tonnes.

An increased importation in soy sauce can likewise be seen (Figure 2), alongside the desire to cook more Asian food (Smakbox 2024). Regarding domestic production the industry is almost non-existing with the exception of a larger company manufacturing a soy sauce diluted from imported concentrate and export it to the neighbouring countries[4]. Contrary to the importation trend of both products, is the proposed strengthening of the food chain and self-dependency which the Swedish government has put forth, indicating an encouragement of domestically producing all food items to a greater extent (Ministry of Rural Affairs and Infrastructure 2025). The focus on self-dependency is not only motivated by the fear of disrupted international food chains, but also as an improvement of the Nordics unsustainable food system, where outsourcing of the primary production has great impact on the cropland area and water usage of the whole world (Wood et al. 2019).

1.2.2 Classification framework

To define the products, the analytical framework described by Samson et al. (2024) will be used. The framework aims to illustrate the diversification of food stuffs based on three fundamental factors (3F): sensory profile, ingredients and process. These factors help characterise novel fermented food products in relation to their traditional counterparts. They are embodied as a Venn diagram (Figure 3) consisting of three overlapping circles, one for each factor, where the intersections mark the boundaries for seven categories of different products (‘Traditional’, ‘Analogue’, ‘Experimental’, ‘Faults & Emic Innovations’, ‘Related’, ‘Adjacent’, and ‘Facsimile’). These categories are however not seen as strictly separated, but gradients exist

[2] https://jordbruksverket.se/statistik [Accessed 11 May 2025]
[3] https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/ [Accessed 13 May 2025]
[4] https://www.soy-king.dk/ [Accessed 3 May 2025]

within the fields, as well as across the boundaries. The framework maps novel products in terms of how much they diverge from tradition (Samson et al. 2024). Yoghurt will be made an example standard product applied to this framework. Following is products related to yoghurt (sensory profile, ingredients and process) in the order of the 3F categories (Figure 3): 2. Sour cream, 3. Lemon Posset, 4. Kefir, 5. Cheese, 6. Buttermilk, 7. Plant based yoghurt.

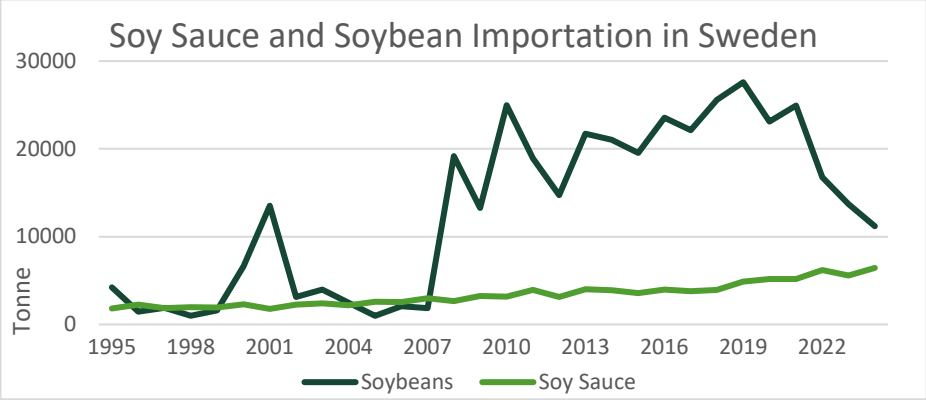

Figure 2. Swedish importation (1995-2024) of two goods, soy sauce and soybeans both for human and animal consumption.

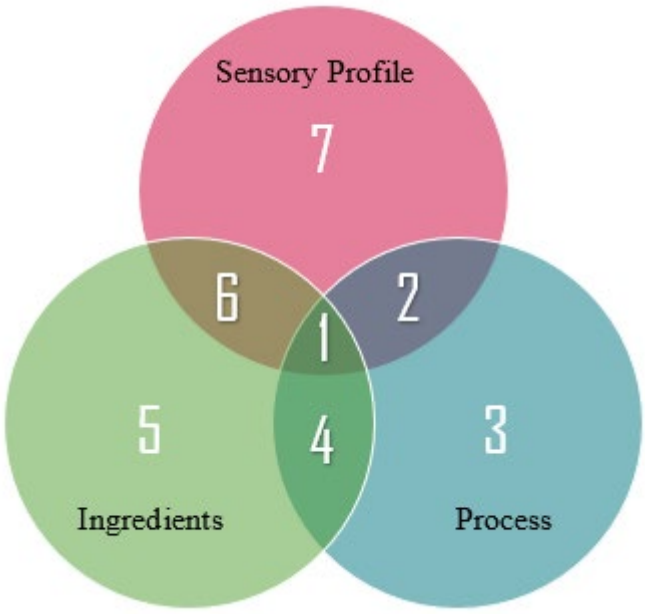

Figure 3. An illustration of the 3F framework where the three key factors – ingredients, process and sensory profile – help categorize a food product through the following numeration: 1. Traditional, 2. Analogue, 3. Experimental, 4. Faults & Emic Innovations, 5. Related, 6. Adjacent and 7. Facsimile.

2. Material & methods

This study reviewed relevant literature and reports covering the potential of the fava bean shoyu and the koji cheese in a Nordic context. Sources included foundational books such as *On Food and Cooking* (McGee 2004) and *Koji Alchemy* (Shih & Umansky 2020), as well as peer-reviewed articles accessed via Google Scholar. Search terms included combinations of "koji", "*Aspergillus oryzae*", "*Vicia faba*", "shoyu" and "dairy". Publications were selected based on if the material contributes to a greater understanding of the fermentation processes and potential for Nordic adaptation. A total of 28 resources have been analysed for this report.

Data on agricultural production and consumption were collected from official statistics provided by Jordbruksverket (the Swedish Board of Agriculture) and Statistiska centralbyrån (Statistics Sweden, SCB).

Additionally, visits to processing sites and qualitative interviews were conducted with two Japanese producers: professor Kauro Sato, developer of koji cheese at Zao Dairy Center[5] (Appendix 2) and Tsutomi Takahashi, producer of fava bean shoyu[6] (Appendix 1). The interviews were complementary to the results gained from the literature and concretized the practical implementation of the products. The interviews were semi-structured, consisting of simple open questions, with the aim of gathering personal reflections and examples to nuance the findings of this review.

The interviews were held in person and aided by Google translate when necessary. Each interview took at an average 30 minutes, and the answers were noted and has been compiled to bring forth relevant insights. There was no formal qualitative analysis since the interviews gave a non-generalized basis for results, instead they assisted in illustrating the reasoning behind the literature analysis. The complete interviews are included in the appendix.

[5] https://www.zao-cheese.or.jp *[Accessed 25 April 2025]*.

[6] *https://www.takahashi-shoten.co.jp [Accessed 2 May 2025]*.

3. Results & discussion

This section presents the results coming from the two interviews alongside relevant literature findings. Simultaneously it discusses the practical implications of introducing koji-based fermentation into Nordic food contexts by examining the case studies: fava bean shoyu and koji-ripened cheese. The findings are analysed through the 3F framework (ingredients, process, sensory profile), allowing comparison to existing products and an assessment of feasibility, cultural compatibility, and potential market adaptation.

3.1 The fava bean shoyu

3.1.1 Details of the product

The field of soy-sauce-like products has expanded due to the wave of modern fermentation (Evans & Lorimer 2021). Unrelated to trends, the fava bean shoyu was developed ca 20 years ago as an allergy-friendly product, according to Tsutomi Takahashi, marketed towards people with wheat as well as soy sensitivity. The brewery reduces potential allergens in the shoyu by completely removing grains. The ingredients only consist of *V. faba*, salt and koji. The specific strain was however not communicated in the interview, conceivably an *A. sojae* or *A. oryzae.* The process is thus simplified to soaking and steaming unhulled beans, excluding wheat, before dusting of koji spores. The inoculated substrate is incubated as per standard practice for ca 2 days at 30ºC and 90%RH, then mixed with the NaCl-solution and left to ferment in traditional wooden vats. The aim of the product is to be synonymous with soy- and wheat-based, umami-rich condiment. The development was led by the previous president of the brewery, but Mr. Takahashi recalled the trial-and-error process in identifying suitable ingredients.

Figure 4. Traditional brewing of shoyu on the island of Shodoshima.

Similar products have shown through taste-panel studies that the perceived umami taste is comparable, but sweetness levels are decreased in the fava bean shoyu (Yamana et al. 2020). There is at the same time findings of increased sugar and sugar alcohol compounds such as mannitol, erythritol and arabinose (Ohnishi et al. 2014).

The shoyu is furthermore described in the interview as a interchangeable variant of soy-sauces customary to European kitchens (e.g. *Kikkoman*), and recommended as a cooking ingredient.

In reference to the 3F framework, the Takahashi shoyu ingredients are the singular factor deviating from the standard soy sauce-product, as the sensory profile and process are rather identical. The shoyu can therefore be categorized as an 'Analogue' (category number 2, as seen in Figure 3).

3.1.2 Potential within the industry

The processing required for shoyu remains largely unrealized in the Swedish food industry, suggesting a lack of both technical knowledge and infrastructure. The exception to this is 3 small-scale producers located in Uppsala[7], Värmland[8] and Dalarna[9], whose impressive focus on creating products from local ingredients such as the yellow pea shoyu "Liura" should be noticed in this thesis. However, in conjunction with the raised emphasis on self-sufficiency coming from the Swedish government, motivation is supplied to further explore a local inventory of umami-rich condiments, though it is acknowledged that condiments are not staple foods and therefore are of lesser importance from a preparedness perspective. Nevertheless, local production of condiments such as shoyu could counter the continuing trend of increased import of soy sauce, as seen in Figure 2.

From a technical perspective, fava beans do not present any significant challenges as a substitute for soybeans in producing a shoyu that could meet the expectations of Nordic consumers. Still, the feasibility of large-scale production remains uncertain, as the cultivation of fava beans for human consumption in Sweden is potentially insufficient. The data on occupancy of arable land for pulse cultivation in Sweden shows an increasing expansion, which primarily is driven by the demand for domestic animal protein feed, curiously also as a substitution for the imported soybean (Figure 2). Nonetheless, this trend is parallel to a rising interest in incorporating the legume into multiple industries, including human food production (Karlsson et al. 2015), strengthened by its potential as an environmentally superior crop (Tidåker et al. 2021). In this report, Sweden is mentioned as a template of Nordic conditions, although, it is acknowledged that the agricultural circumstances are different between the countries. This paper does not review the land usage of the remaining Nordic nations which may vary greatly from the Swedish example.

Regardless of the present sufficiency of pulse production, a small-scale production of fava shoyu can feasibly be sustained, especially if the complete national self-sufficiency is de-prioritized and fava beans are imported. Irrespective of the scale of production, the development of fava bean farming could pave the way for a sustainable and locally produced shoyu.

3.1.3 Societal relevance

Shoyu as an ingredient must be considered within the broader context of the cuisine from which it is derived. The Asian cuisine is highly regarded in Nordic household

[7] https://timogarden.wordpress.com/ [Accessed 2 May 2025]
[8] https://njordstorp.se/ [Accessed 2 May 2025]
[9] https://www.liura.se/ [Accessed 2 May 2025]

cooking as seen in the report from Smakbox (2024). Still, the use of many adopted ingredients remains tied to the preparation of distinctly Asian dishes, both in terms of sensory familiarity and cultural acceptance. This raises questions about the relevance of producing one ingredient, such as shoyu, domestically, when many complementary ingredients for Asian cooking are still largely imported. Worth mentioning is the few uses of soy sauce in typically Nordic dishes, such as its presence in gravies. Although it can be seen as an ingredient difficult to incorporate into a majority of the cuisine because of the distinct flavour, regardless of how tasty the condiment is (Zilber & Redzepi 2018). Food culture is however constantly changing and the usage of one ingredient could increasingly be an integral part of fusion cuisines.

As an input to further increase the flavour resemblance and similarity to staple items, a theoretical Nordic fava bean shoyu would not necessarily be created and marketed as an allergy friendly product. Wheat or another grain could be included, with the objective of approaching standard soy sauce ingredients. No such shoyu (fava bean and grain) has been previously compared and analysed in the cited publications (Ohnishi et al. 2014; Yamana et al. 2020). Replacing soy with fava potentially indicated a deviation from the targeted flavour of the product, conceivably reaching too high perceived sweetness as seen in the paper from Yamana et al. (2020). This is hypothesised to arise from greater starch content in fava bean than soy (McGee 2004).

Contradicting the remarks of the fava bean shoyu as an allergy-friendly product in comparison to the standard, the change to *V. faba* implies a risk for individuals with favism, a hemolytic syndrome from the consumption of fava beans (Marquardt 1982). The syndrome is connected to the world's most common enzyme defect, with more than 400 million people having a deficiency in glucose-6-phosphate dehydrogenase (G6PD), a catalyser in the pentose phosphate pathway. The fava bean glycosides divicine and convicine promote the haemolysis in G6PD-deficient patients, making the reaction to consumption acute. The deficiency is more prevalent in Europe compared to East Asia, however more concentrated around the Mediterranean (Cappellini & Fiorelli 2008). The toxic glycosides have however shown to be degraded through enzyme treatment with *A. oryzae* (McKay 1992) possibly proving the reduced harm through fermentation, like that of shoyu production.

It can besides be discussed to which degree a wheat-containing shoyu already can be classified as a gluten-free product due to proteolysis, further motivating the addition of a grain to the theoretical fava bean shoyu (Li et al. 2018).

Furthermore, the consumer preferences should be considered, as differences are inherent when comparing the Japanese and Nordic prepossessions. At the time of this report, no studies of Nordic people's soy sauce preferences could be found in the literature. It is supposed that the resemblance in solely the shoyu-type between Takahashi's and Swedish market leaders is enough to accept it as an equivalent. However, the interview with Takahashi and the research on similar shoyu's points towards that the existing product is probably well suited for a Nordic palate. Consumer panel tests should however be conducted.

Despite the interest in Asian food, the offering on the umami sauce market barely exceeds the choice between dark Chinese and lighter Japanese types of

sauce. Hence, there is conceivable room in the market for a local competitor opposing the well-known brands. Although the challenge regarding price per volume must be acknowledged, as it is hard to compete with market leaders even if transportation costs would be cut down.

3.1.4 The product as a whole

The fava bean shoyu serves as a compelling example of an alternative to traditional soy sauce, both in its ingredient base and in its sensory output. It retains much of the umami character of conventional shoyu while offering a grain- and soy-free profile that meets the needs of allergy-sensitive consumers. Classified as an *analogue* in the 3F framework, it closely mimics the original in both process and flavour, with ingredients as the primary deviation, which would suggest an easy adaptation for an entrenched manufacturing site. However, the lack of established shoyu production infrastructure in Sweden, combined with the limited cultivation of fava beans for human consumption, presents practical barriers to large-scale domestic production. Moreover, the cultural context of shoyu in the Nordic region is largely tied to imported ingredients and Asian dishes, which may limit its perceived relevance as a standalone product. Its integration would likely require strong positioning within niche markets or fusion cuisines that appeal to food-curious consumers.

3.2 The koji cheese

3.2.1 Details of the product

Presently, the only commercially sold koji cheese was developed by Kauro Sato and Takayuki Miura and is artisanal produced by Zao Dairy Centre in the Miyagi prefecture, following research trials (Suzuki et al. 2021; Hagi et al. 2022; Tomita et al. 2022; Hayashida et al. 2023). This cheese known as *Kura* was introduced as a "Japanese" cheese and made use of the familiar taste profile of sake lees as a flavour enhancer and a regionally changeable variable. Sake lees is the by-product of sake brewing, the residue from filtration or racking, mostly containing yeast and fermented rice (Nishidono et al. 2024). Prof. Sato explained in the interview that the national spread of sake breweries enables other Japanese dairies to collaborate with the breweries to incorporate the by-product as a local flavour element. The cheese is also shaped as a torus, with a hole punched out in the centre of the disk (Figure 5).

Figure 5. The koji cheese Kura exhibited at the Zao Dairy Centre.

Prof. Sato mentioned how well the cheese has been received by consumers and how effective the mould is at producing a flavourful ripening. Technologically, the cheese is processed similarly to a white mould cheese besides a higher ripening temperature required to optimize *Aspergillus* enzyme production. It is highly comparable to industry manufacturing of pasteurized-milk Camembert, where the inoculated coagulated milk is left to ripen at 12-14ºC (Leclercq-Perlat et al. 2004). Prof. Sato states that *Kura* is torus-shaped as a mean to increase surface area for the fungus to grow on, as well as a distinguishing visual characteristic.

Comparative analyses show that, relative to *P. candidum*-ripened cheeses, *Kura* exhibits a faster buildup of amino acids, a quicker pH increase, and elevated levels of flavour-relevant compounds such as methyl ketones, diacetyl, and volatile fatty acids (Tomita et al. 2022), which are compounds known for attributing the flavours of well ripened cheeses (McSweeney & Sousa 2000; Curioni & Bosset 2002). Prof. Kauro commented that prototype cheeses were tested through a trained sensory panel to find a koji strain which achieved the desired profile. They finally chose the *A. oryzae* strain KC46 produced by Higuchi Matsunosuke Shoten Co. Ltd..

According to the 3F analysis, *Kura* is vaguely diverging in all three factors in relation to a conventional white mould cheese. The ripening culture has obviously been changed alongside the addition of sake lees, making the ingredients non-standard. While also demanding the alteration of the process for optimal growth and enzyme production. The flavour of the end-product however, reaches intensities proportionate to a cheese aged far longer. The koji cheese is bordering between the 3F categories of an ‘Analogue’ and a ‘Facsimile’ depending on to which degree the process is deviating (categories 2 and 7 as seen in Figure 3). The process is nonetheless compatible with pre-existing practices within the cheese making industry, with the addition of a warmer incubator than the traditional cheese cave.

3.2.2 Potential within the industry

Importantly, most elements of koji cheese production, including pasteurized milk handling, mould-ripening protocols, and surface treatment, already exist within

Nordic dairy infrastructure, making pilot-scale production feasible with minor modifications.

The research of Kumura et al. (2017) emphasized the known potential of koji enzyme production and applied it to a semi-hard cheese to accelerate maturation. This was done with an extracted enzyme solution from koji strains isolated from sake and miso, not through solid-state fermentation directly on the cheese. It was a Gouda-type cheese, and the results showed rancid elements generated by some strains, however no bitterness, which has occurred in previous trials (Fedrick et al. 1986; Hayashida et al. 2023). Kura signifies the arrival of *A. oryzae* strains capable of promoting the ripening of cheese and new flavour development without producing off-flavours. This is simultaneously mentioned by Shih and Umansky (2020) with their experimental koji cheeses, whose flavours likewise were described as something "never tasted before".

This potential is also implied in the research of Prof. Kauro and mentioned in the interview. The enzymes generated by koji grown on the cheese mass reaches such metabolic effects that the production time can be cut down and still produce a flavourful cheese. However, this demands added heat. The energy effectivity of the koji cheese process could be examined, to assess if it is less costly than traditional methods in reaching a certain flavour concentration. Furthermore, it would be of interest to explore the true range of cheese-types on which koji can influence ripening. This enzymatic acceleration offers not only novel flavour development but also potential economic advantages, appealing both for the industry as well for the small-scale, by reduced maturation time. These factors could be especially relevant to revitalizing Swedish cheese production, which Figure 1 shows have declined in recent decades. An aspect to further address would be the shelf-life of koji cheese in Nordic transport and retail chains.

Additionally, as an effort to reduce the existing minor process differences, it can be investigated whether a koji cheese can be sufficiently ripened at temperatures similar to those used for traditional mould cheeses. If at all possible, the cheese would be categorized as an 'Analogue' according to the 3F framework and suggest a simpler adaptation to pre-existing manufacturing practices in the Nordics. However, colder maturation conditions are likely to be hindrance, because the optimal growth temperature for *A. oryzae* is estimated to be 29-35°C with a minimum of 12°C (Ayerst 1969). Thus, the typical maturation temperatures of 12-14°C (Leclercq-Perlat et al. 2004) would likely reduce the enzyme expression of the fungus, resulting in a less developed cheese. A hypothetical outcome could be enzyme activity levels comparable to or less than those found in conventional white mould cheeses, which would lead to extended ripening periods. Hence, the result could theoretically be a cheese that is nearly identical to conventional varieties, differing mainly in the type of mould used and potentially showing some distinct flavour characteristics.

Moreover, the growth stagnation of the mould at low temperatures indicates a potential suitability for long term refrigerated storage. In comparison to *P. camemberti* cheese, which continues to ripen at 4°C storage, the koji cheese could exhibit a prolonged shelf life. This should however be evaluated through further research.

3.2.3 Societal relevance

The purpose and appeal of a Nordic koji cheese may be subject to debate, as the introduction of a novel mould alone may not be enough to generate sustained interest in a locally produced cheese. In the Japanese market, where dairy products traditionally hold a marginal cultural status, the addition of a familiar fungus like *Aspergillus oryzae* and a by-product such as sake lees helps position the product as a distinctive regional specialty. In a Nordic context, however, sake lees would likely be excluded, as they carry little cultural or sensory relevance for consumers unfamiliar with East Asian cuisine. The exclusion of sake lees would affect the flavour profile of the cheese (Hagi et al. 2022).

In Sweden, where koji is relatively unknown, its use might initially be perceived as a novelty. Nevertheless, the role of unique product characteristics in shaping consumer appeal should not be underestimated. This is particularly relevant in light of growing Japanophilia in the West (Koníček 2019), where a cheese branded with Japanese associations could resonate strongly with Nordic consumers. Research suggests that purchasing decisions for dairy products are largely influenced by familiar sensory qualities and the perceived price–quality ratio. At the same time, consumers also value innovation, especially when it comes to novel flavours (Mariusz 2021). In this regard, the distinct flavour complexity introduced by the use of koji could be seen as an attractive feature on the diary market. It may be potentially advantageous for small-scale cheese makers to distinguish a product.

3.2.4 The product as a whole

The koji-ripened cheese shows great potential for Nordic integration. As demonstrated by the Japanese *Kura* cheese, koji can serve as a viable substitute for traditional moulds like *P. camemberti*, producing comparable or even accelerated flavour development. While this approach demands specific temperature and humidity conditions, it aligns closely with existing cheese-making infrastructure in Sweden. Moreover, the integration would contribute to a diversification of the market in regard to the character of the products as well as the fermentation organisms utilised. It is also worth noting that the present strains of koji are developed in the interest of producing the traditional rice and soy products. This leaving room to improve the metabolomic profile of a cheese-intended strain in the future.

Kura was categorized as a product between ‘Analogue’ and ‘Facsimile’, a technical innovation that maintains recognizable qualities yet introduces a distinct process and novel taste profile. However, a version of the cheese which is more adapted to Nordic customaries (sake lees removed), alongside a desirable non-standard sensory profile, would possibly be classified as a ‘Faults & Emic’, as done by Samson et al. (2024) regarding koji cheese overall. Although koji remains unfamiliar to the average Nordic consumer, the broader appeal of artisanal, innovative dairy products could facilitate market entry. Particularly, the growing interest in Japanese culture and culinary aesthetics may help generate initial interest. As such, koji is, firstly, well-positioned to function as both a regional cheese reinterpretation and a value-added specialty product; and secondly, an organism with dairy industry efficiency potential.

4. Conclusion and future perspectives

This study explored the Nordic adaptation of two traditionally Japanese koji-based fermented products—a fava bean shoyu and a koji-ripened cow cheese—selected for their potential as regionally appropriate counterparts to standard global products. Using the 3F framework (Process, Ingredients, Sensory Profile), the analysis revealed key challenges and opportunities in adapting these items to the Nordic food system.

Sweden's cheese production is well established, especially compared to the country's small-scale umami sauce industry, which includes only 2–3 minor producers. There is therefore feasible room in the market for both investigated food items.

From a processing perspective, both products demonstrate the technical feasibility of applying koji fermentation to local ingredients. However, adaptations are needed to accommodate climatic and infrastructural differences that affect fermentation control and consistency. These steps require further refinement and regional expertise, indicating a learning curve for producers unfamiliar with koji processes.

In terms of ingredients, the substitution of soy with Nordic crops like fava beans represents a shift toward more sustainable and regionally suited raw materials. This supports crop diversification and aligns with broader goals for food security and reduced reliance on imports. The use of familiar Nordic dairy in the cheese case similarly demonstrates how traditional fermentation techniques can be applied without abandoning local resources.

Sensory analysis suggests both products hold promise, though consumer acceptance may hinge on familiarity and taste associations with existing products such as soy sauce and ripened cheese. Strategic positioning that emphasizes similarity to, but improvements over, established items can support market entry.

Beyond processing and taste, the study also examined cultural relevance. The potential to strengthen regional food identity through innovative yet heritage-linked items is notable. Koji-based products tailored to local preferences could meet consumer demands for sustainability, function, and authenticity.

In summary, while koji fermentation offers a viable path toward a more resilient and self-sufficient Nordic food system, its success depends on more than enzymatic performance. It requires integration with local ingredients, adapted processes, alignment with consumer expectations, and a strong value proposition for producers. Koji applications in cheese show promise for both industry and artisan makers, while fava bean shoyu holds potential as a niche product capable of building consumer familiarity over time.

Future research should focus on optimizing koji strains for Nordic substrates, conducting consumer sensory studies, and assessing scalability, including energy use and shelf life. Investigating regulatory pathways and consumer perception will also be key to successful integration into local food systems and is crucial to realizing the full potential of these products in the Nordic context.

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Appendix 1: Interview with Tsutomi Takahashi, on the fava bean shoyu

Interviewee: President Tsutomi Takahashi
Affiliation: Takahashi Shoten, Shodoshima, Japan
Date: April 7, 2025
Format: In-person, semi-structured
Language: Japanese and English translated using Google Translate
Duration: ~15 minutes

1. Purpose of the product

   Mr. Takahashi explained that the fava bean shoyu was developed approximately two decades ago by his predecessor, primarily as an allergy-friendly alternative to traditional soy and wheat-based sauces. The product contains only three ingredients: fava beans (*Vicia faba*), koji spores (*A. oryzae* KC46), and salt. The exclusion of wheat and soy targets consumers with common allergies (gluten, soy).

2. Development of fava bean shoyu

   According to Mr. Takahashi, developing the product required a trial-and-error approach to achieve a satisfactory umami profile and overall flavour. The brewery aimed to replicate the sensory attributes of soy-based shoyu as closely as possible, despite the change in ingredients.

3. Consumer reception

   He reported that the fava bean shoyu is used interchangeably with standard soy sauces in cooking and is appreciated by consumers, especially those with beforementioned allergies. The product has gained broader appeal due to its unique character and traditional fermentation method.

Appendix 2: Interview with Kauro Sato, on the koji cheese

Interviewee: Professor Kauro Sato
Affiliation: Zao Dairy Center, Miyagi, Japan
Date: April 2, 2025
Format: In-person, semi-structured
Language: English
Duration: ~1 hour

1. Purpose of the Product

   Professor Kauro Sato described how the idea behind Kura was to create a distinctly "Japanese" cheese by integrating familiar fermentation agents such as *Aspergillus oryzae* and sake lees—a by-product of sake production. The cheese is surface-ripened and torus-shaped, a design that increases mould coverage and serves as a visual marker of the product's uniqueness.

2. Development of Koji Cheese

   During development, several koji strains were tested through scientific research as well as with sensory panels to identify one that would produce desirable ripening effects without off-flavours. The final strain, KC46, was selected for its balance of protease activity and low lipase activity, optimizing flavour while minimizing rancidity.

3. Consumer Reception

   According to Prof. Sato, *Kura* cheese was well-received, and the production will continue at Zao Dairy Center. It appeals as a local specialty product that blends Western dairy traditions with Japanese fermentation culture.

   Prof. Sato believes the method holds promise for adaptation in other regions, and they have noted interest from other cheese makers to learn the manufacturing of the product.

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