



From underutilized to innovative application: Exploring consumer acceptance of acidified and fermented sea fennel preserves in Italy

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ABSTRACT

Halophytes, salt-tolerant plants that grow naturally or are partially cultivated in coastal ecosystems—especially in the Mediterranean basin—hold significant potential to enhance dietary diversity and promote sustainable food production. Among them, sea fennel (*Crithmum maritimum* L.), a relatively underutilized marine vegetable, is gaining recognition in the scientific community for its nutritional value and functional food properties. However, to date, very few studies have explored consumers' preferences and overall acceptance of this plant. Furthermore, its limited consumption and low consumer awareness hinder the development and diffusion of its potential culinary applications. Therefore, this study aims to explore the acceptance of sea fennel among Italian consumers, particularly by comparing acidified and fermented sea fennel preserves. The findings reveal a clear preference for fermented sea fennel, indicating strong consumer acceptance of the traditional fermentation process when applied to this underutilized plant. However, no significant differences were observed across sociodemographic characteristics. Although the study is based on a local convenience sample, these preliminary insights offer valuable guidance for future research and product development. Promoting fermented sea fennel products could help expand their commercial value and gastronomic appeal. Future research should focus on developing strategies to increase consumer familiarity with fermented sea fennel, emphasizing its health benefits and versatile culinary applications.

1. Introduction

The growing world population faces an urgent need for sustainable food production due to environmental challenges such as climate change, biodiversity loss, and soil degradation (FAO, 2018; Petropoulos et al., 2018). In response, the exploration of underutilized, nutrient-rich crop species that can adapt to adverse conditions has gained significant importance (Basheer et al., 2024; Panta et al., 2014; Petropoulos et al., 2018; Wendin et al., 2024). Recognizing and integrating the underutilized food sources is crucial for enhancing food security and sustainability (Knez et al., 2024). In this context, halophytes – salt-resistant plants such as glasswort, sea aster, and sea fennel - are considered promising alternatives due to their adaptive mechanisms, particularly for the salt-affected agricultural soils in the Mediterranean region (Ben Hamed et al., 2021). However, the cultivation and valorisation of these crops still need to be improved to provide an important addition to Mediterranean agriculture and food biodiversity (Karkanis et al., 2022; Petropoulos et al., 2018).

Among halophytic species, sea fennel (*Crithmum maritimum* L.),

which is also known as samphire, crest marine, marine fennel, or St. Peter's herb, grows spontaneously along the coastlines and is specifically abundant in Mediterranean countries such as France, Italy, Portugal, Spain, and Turkey (Atia et al., 2011; Özcan, 2000). Sea fennel is a perennial halophyte belonging to the *Apiaceae* family, like parsley and celery (Pereira et al., 2017). Its sensory attributes are described as a slightly salty taste accompanied by notes of celery, common fennel, and green citrus peel, followed by a powerful aftertaste (Renna and Gonella, 2012). Although the commerce of this spontaneous plant was quite popular in Europe in the past, it was forgotten for a long time after being lost in several coastal areas due to extensive harvesting (Maoloni et al., 2021). Sea fennel's traditional culinary use is primarily in salads, soups, and sauces as a fresh ingredient, or preserved in vinegar, brine, or olive oil, a practice deeply rooted in Mediterranean culture. Currently, pickled sea fennel, widely used in Mediterranean cuisine, can be found in local shops (Radman et al., 2023). Fresh sea fennel or a few types of sauces are available in the market (Maoloni et al., 2022a; Maoloni et al., 2021; Renna et al., 2017). Other uses of sea fennel are also suggested in the literature. For example, dried sea fennel can be used in several

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gastronomy products as an aromatic herb and a new spice-colourant (Renna and Gonnella, 2012).

Its high nutritional value and functional properties make it an excellent candidate for producing health-promoting foods (Alemán et al., 2019; Maoloni et al., 2022b; Pereira et al., 2017). Depending on the parts of the plant studied (e.g., leaves, flowers), sea fennel is rich in vitamin C, fatty acids, phenolics, dietary fibre, and calcium (Generalić Mekinić et al., 2016; Maoloni et al., 2022a; Martins-Noguerol et al., 2022; Nartea et al., 2023; Pereira et al., 2017; Sánchez-Faure et al., 2020). Indeed, numerous studies highlighted the positive effects of sea fennel due to its antioxidant, antibacterial, anti-inflammatory, or anti-parasitic properties (Alemán et al., 2019; Generalić Mekinić et al., 2018; Pereira et al., 2021; Souid et al., 2021; Sousa et al., 2022). Lastly, Maoloni et al. (2022a,b) suggested that sea fennel is a valuable candidate for producing probiotic-enriched foods.

Surprisingly, most research studies have focused only on the chemical composition and properties of sea fennel, overlooking consumer acceptance and market potential. Sea fennel has been the subject of very few sensory analyses (Amoruso et al., 2022; Maoloni et al., 2022b; Maoloni et al., 2021; Radman et al., 2023; Rico et al., 2020), leaving a significant gap in our understanding of its broader consumer appeal.

Understanding consumer acceptance is crucial to realise the potential of sea fennel and fully communicate its benefits (Ben Hamed et al., 2021). More specifically, the attitudinal response of consumers, such as liking, disliking, or perceived pleasantness, can represent a valuable method for studying product acceptance. Therefore, this study explored consumers' acceptance of sea fennel preserves by assessing their product liking through the hedonic scale, which has been the most commonly used tool for measuring food acceptability (Lim, 2011). For this aim, two types of preserves were presented to consumers, one prepared through traditional pickling (acidified in vinegar) and the other using an innovative application of a traditional lactic acid fermentation technique, which had not been previously applied to this plant. A structured tasting protocol was conducted over two days (Napolitano et al., 2010) to evaluate consumer responses. The objective of the study was to assess how different processing techniques, alongside informational cues provided to participants, influenced consumers' liking and acceptance, with particular focus on the effect of information on the innovative fermented product. The results offer valuable insights for the food industry on effective strategies to introduce novel sea fennel products into wider markets.

In this framework, our insights can help to bridge the gap in consumer knowledge and acceptance of innovative sea fennel products - still a niche with limited offerings - addressing the current lack of data on consumer acceptance, which is essential for successfully integrating this marine vegetable into everyday culinary practices and gastronomy. Additionally, previous studies of sea fennel-based products included only a certain number of panellists in their consumer acceptance test. To our knowledge, this is the first study to involve a significant sample size, representing an important step in bridging the gap in consumer research and providing a more accurate understanding of consumer acceptance of sea fennel preserves. The structure of the article is as follows. The next section describes the methodology adopted in this study, detailing the preparation of samples as well as the procedures for data collection and analysis. Subsequently, the "Results and Discussion" section presents and discusses the main findings, highlighting the factors influencing consumer acceptance of acidified and fermented sea fennel preserves. Finally, the "Conclusions" section summarises the key insights, discusses the advantages and limitations of the study, and suggests directions for future research on the valorisation and market potential of sea fennel-based products.

2. Materials and methods

2.1. Sea fennel samples

In Italy, sea fennel is traditionally preserved by acidification with vinegar (Renna et al., 2017). This study compares the traditional acidified preserve with an innovative fermented version (Maoloni et al., 2021). In acidification, acetic acid (an acidifier, usually in the form of vinegar) is directly added, and it is usually followed by heat treatment (pasteurisation) to guarantee food safety (Radman et al., 2023). In the fermentation process, lactic acid is produced by fermentative microorganisms under anaerobic conditions, and due to the lower pH of the medium, the growth of food-poisoning bacteria and other spoilage organisms is prevented. If fermentation is allowed to complete and good manufacturing practices are followed, this ensures the preservation and safety of the product. (Perez-Diaz et al., 2013). The product samples used in the study were supplied by a local company (Rinci S.r.l., Castelfidardo, Ancona, Italy), which produces organic sea fennel destined for the food industry and the manufacture of sea fennel preserves and sauces.

Before the tasting protocol, physico-chemical analyses of the samples were conducted to identify differences and to assess whether these results could affect the tasting outcomes. Aliquots (80 g) of acidified and fermented sea fennel were homogenized with an equal amount of oil to obtain a paste and subjected to pH measurement with a pH-meter pH 7 Vio (XS Instruments, Carpi (MO), Italy) equipped with a solid electrode. Organic acids were quantified as described by Maoloni et al. (2021) with slight modifications. Acetic acid and lactic acid were measured using K-ACETRM 06/18 (Megazyme, USA) and K-DLATE 08/18 kits (Megazyme, USA), following the manufacturer's instructions, with results expressed as g/100 g sea fennel. For titratable acidity, 10 g of chopped sea fennel sprouts were homogenized with 90 mL distilled water for 5 min at 260 rpm using a Stomacher. The suspension was titrated with 0.1 N NaOH to pH 8.3, and % TTA (acetic and lactic acid equivalents) was calculated as described by Rampanti et al. (2023). Data were analysed using one-way ANOVA with the Tukey-Kramer honest significant difference (HSD) test at the level of significance 0.05 with JMP Version 11.0.0 software (SAS Institute Inc., Cary, NC, USA). All analyses were performed in triplicate, with results expressed as mean \pm standard deviation. Acidification with vinegar resulted in a significantly lower pH (3.47 ± 0.04) than acidification through lactic acid fermentation (pH: 4.26 ± 0.01). As far as the organic acid quantification is concerned, acidified samples were characterized by 1.66 ± 0.07 g/100 g acetic acid and 0.04 ± 0.00 g/100 g lactic acid. In contrast, fermented samples contained 0.26 ± 0.03 g/100 g lactic acid and 0.06 ± 0.00 g/100 g acetic acid. The titratable acidity determination agreed with the data for the organic acid. It resulted in equal to 1.63 ± 0.01 % of acetic acid equivalents for the acidified samples and equal to 0.20 ± 0.01 % of lactic acid equivalents for the fermented samples. The data collected for fermented sea fennel agreed well with (Maoloni et al., 2021). Analogously, the authors measured a pH value of 4.24 ± 0.21 in the brines, related to concentrations of 0.29 ± 0.02 g/100 g lactic acid and 0.02 ± 0.01 g/100 g acetic acid after 29 days of fermentation.

2.2. Tasting protocol and data collection

A consumer panel with 100 participants was constituted to test the acceptance of sea fennel preserves. A non-probabilistic convenience sampling method, through volunteer mailing lists, including university staff and student population, was followed for the recruitment. Participants, including professors, researchers, staff, and students, were recruited inside Università Politecnica delle Marche (UNIVPM) in Ancona (Italy); however, additional participants from outside were also included to increase sample variety. The study was conducted following the principles of the Declaration of Helsinki and received approval from the Ethics Committee of the Università Politecnica delle Marche.

Informed consent was obtained from all participants before their involvement in the study. Collected data were anonymized and securely stored to ensure participant confidentiality. Additionally, participants received monetary incentives for their involvement in the study.

All participants were recruited among consumers who had no food allergies and were responsible for household food shopping. They were also aware of sea fennel, as it is a locally consumed plant. The final sample included 100 participants, aged between 20 and 76 years old (mean age 45.9), of whom 59 % were female. Most participants were active workers (56 %) and had a bachelor's or master's degree (63 %) (See Table 1).

The consumer acceptance experiment was split into two subsequent days, with three tests (Napolitano et al., 2010). The detailed experimental design is presented in Fig. 1. This methodology is based on the expectancy-disconfirmation model (Oliver, 1980) and the assimilation/contrast theory (Napolitano et al., 2007; Vitale et al., 2020). The difference between the expected and blind liking, positive or negative, is defined as a 'disconfirmation'. The assimilation occurs when the hedonic ratings change in the same direction as the expectation, while the contrast model takes place if changes are in the opposite direction.

Day 1 consisted of two tests, Test 1 and Test 2, while Day 2 included Test 3:

1. Test 1: Blind liking (*perceived acceptability*). Each participant tasted a sample of each sea fennel, acidified and fermented, without any information (blind condition). They expressed their liking scores over a 9-point Likert scale verbally anchored from 'dislike extremely' to 'like extremely', and at the mid-point with 'neither like nor dislike'.
2. Test 2: Expected liking (*expected acceptability*). Immediately after the blind liking test, a second test was conducted to determine the expected liking of both samples. The aim was to investigate the effect of information on the expected acceptability. To this end, each participant received an information sheet explaining the main characteristics of the acidified and fermented samples. Particularly, the descriptions were specifically neutral and focused on processes, without reporting the origin, brand, or health benefits of these products, to avoid any influence on the expected and actual liking procedure. The descriptions of both processes are reported in Fig. 2. Participants were asked to read the information carefully and to express their acceptability on the same 9-point scale based only on the information and without tasting the products.
3. Test 3: Actual liking (*informed acceptability*). During Day 2, a third test was conducted to evaluate the effect of information on the actual liking of the innovative sea fennel sample. The informed tasting included only the fermented sample, following the methodology used by Napolitano et al. (2010). This choice was made intentionally to assess consumers' reactions to the innovative application of a traditional lactic

acid fermentation technique after receiving product-related information. The incomplete design was chosen for parsimony, since we were not interested in comparing the actual liking of the two products, given that we already had the information regarding blind liking and informed liking. While the acidified product was already marketed, the fermented one is still at the pilot marketing stage. Participants simultaneously received the fermented sea fennel sample for tasting and the same product information sheet used in Test 2. They were asked to taste the sample after reading the information and were invited to score their liking on the same scale as the previous two tests.

Tasting sessions were conducted between November and December 2022 in the university's sensory analysis laboratory. All samples were prepared identically (similar amount, same visual aspects, and inside small paper plates without any seasoning) on the same day of the tests. Each serving plate had a three-digit numerical sample code for traceability. At least two persons were assigned to prepare and distribute all the servings during the tasting evaluation. Besides, participants were provided still water and some bread without salt to rinse/clean their mouths before tasting each sample (Fig. 3).

3. Results and Discussion

Data were analysed using Stata (version 17). Multiple t-tests were performed to evaluate differences between mean scores calculated for each product. To control for potential inflation of Type I error due to multiple comparisons, the results were further verified using a mixed model analysis with Bonferroni correction.

Firstly, consumer acceptance of sea fennel preserves was assessed under blind, expected, and actual tasting conditions for the overall sample. As shown in Fig. 4, blind liking scores were 5.09 ± 0.21 for the acidified (traditional) sample and 5.88 ± 0.22 for the fermented (innovative) sample. Expected liking increased for both products, reaching 5.71 ± 0.20 for acidified and 6.05 ± 0.20 for fermented sea fennel. Actual liking was measured only for the fermented sample (5.96 ± 0.21). Therefore, both traditional (acidified) and innovative (fermented) sea fennel samples have received liking scores above the central point (5 = Neither pleasant nor unpleasant) in all conditions (See Fig. 4, blind, expected, and actual liking). This interesting result may indicate that for sea fennel – a traditional but underutilized ingredient – the taste experience is highly relevant. This finding is consistent with the overall high acceptability of both preserve types, indicating that intrinsic sensory properties of the products were appealing to participants (Napolitano et al., 2010). Sea fennel is one of the local spontaneous plants known as 'paccasassi' (Bianco et al., 2018) in Riviera del Conero of the Marche Region, where the study was conducted. However, the product liking scores reported here were relatively moderate rather than high in both cases, suggesting that consumers typically exhibit lower appeal. Although this preliminary study provides little evidence to explain why sea fennel received moderate liking, this may be partly because it is traditionally consumed as an ingredient within dishes, such as salads, seafood, or meat accompaniments, or as a garnish in various recipes (Bianco et al., 2018; Kraouia et al., 2023). Moreover, consumer responses might have been influenced by food neophobia, the psychological tendency to avoid or feel cautious toward unfamiliar foods (Pliner and Hobden, 1992). As sea fennel is a relatively uncommon plant, particularly in preserved form, neophobic attitudes could have limited consumers' willingness to express a strong liking. In this sense, introducing sea fennel in familiar consumption contexts, such as combined with seafood dishes or cheese, could help enhance overall acceptability. Finding the proper presentation may strongly influence acceptance, and using sea fennel as a substitute for more familiar ingredients can also be an effective strategy to increase consumers' acceptance (Deroy et al., 2015; Tan et al., 2016). Future communication strategies and sensory tests should therefore consider serving conditions and pairing options to better reflect realistic consumption scenarios and improve consumers' perception of this novel product. Besides, the

Table 1
Sociodemographic features of the participants.

Sociodemographic variables	Frequency (%)
Total number of respondents	100
Gender	
Female	59
Male	41
Age groups	
Under or equal to 45	41
Over 45	59
Education	
University or higher	63
Other	37
Occupation	
Active workers	56
Inactive (student/unemployed/retired)	44

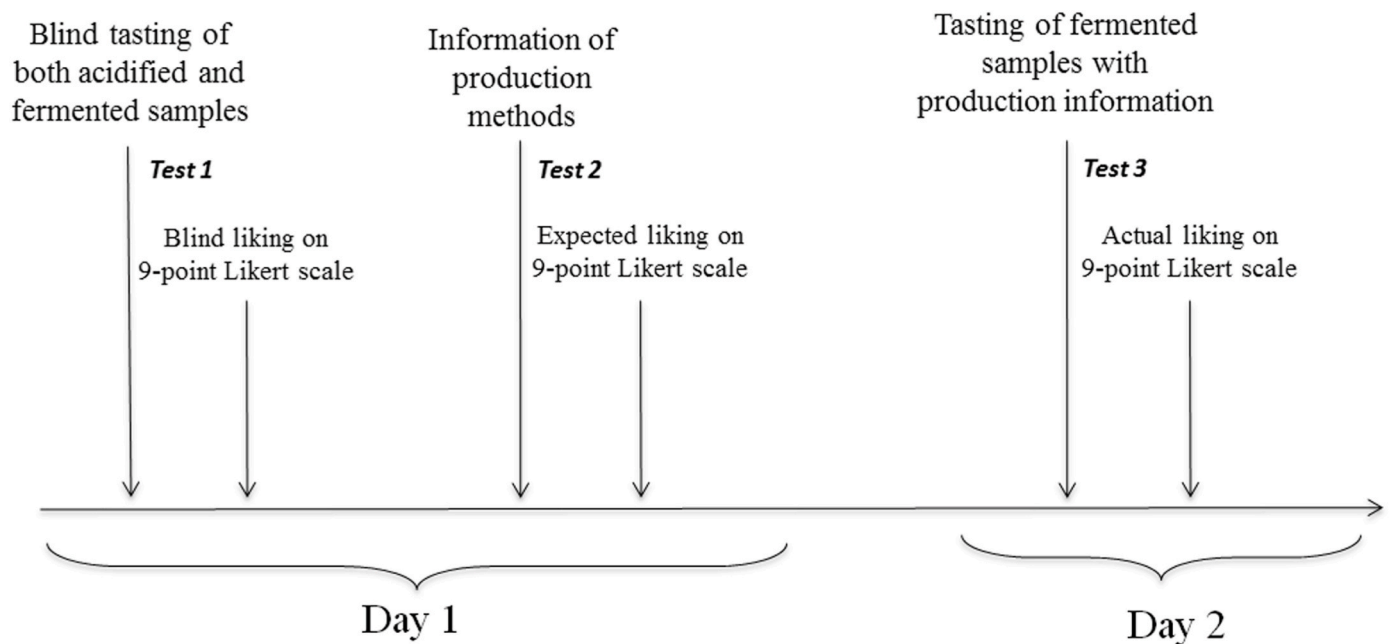


Fig. 1. Experimental design of product tasting.

Fermented sea fennel

- The production of fermented sea fennel involves using preservation techniques through lactic fermentation in brine, i.e., an aqueous solution with a salinity greater than 5%.
- In addition to preserving food safely, this procedure gives the products a sour taste due to lactic acid produced by bacteria.
- This acidification process promotes the preservation of the products that can be stored at room temperature, even without heat treatment (pasteurization), which would affect some of their nutritional properties. For consumption, it is advisable to rinse the product briefly in fresh water to remove excess salt.

Acidified sea fennel

- The production of acidified sea fennel involves using preservation techniques, generally vinegar-based, through acidification by immersion in an acid solution. In addition to preserving food safely, this procedure gives the products a sour taste due to vinegar.
- This preservation process can be combined with a heat treatment (pasteurization) to obtain a product that can be preserved at room temperature. The acidified product can be consumed as it is, without rinsing in water.

Fig. 2. Product information provided to participants during Test 2.

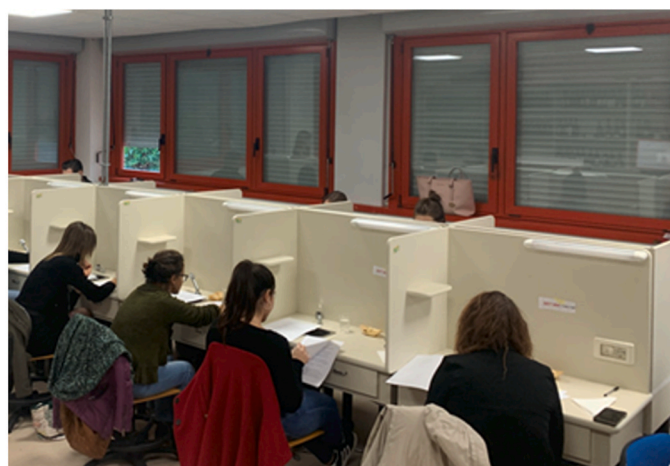
similarity of sea fennel to other familiar halophytes, such as *Salicornia* (e.g., sea asparagus), could enhance favourable associations if effectively communicated and promoted, thereby contributing to increased consumer demand (Tuorila et al., 1994).

Comparing acceptance of two types of preserves (See Fig. 4), results from the blind tasting conditions (perceived acceptance, without information) revealed that fermented sea fennel was liked significantly more than acidified sea fennel ($p < 0.001$) by all participants. This preference may be related to the milder acidity observed in the fermented sample, as confirmed by physico-chemical analyses. The fermented sea fennel demonstrated a significantly higher pH compared to the acidified

sample, which contained higher levels of lactic acid but lower levels of acetic acid. The titratable acidity results supported these findings, showing that acidified samples had higher acetic acid equivalents than the lactic acid equivalents found in the fermented samples. Overall, the lower acidity and less acetic acid notes in the fermented samples may have contributed to their consumer acceptance (Dupas de Matos et al., 2019). Although the present study did not involve the comparison of aromatic profiles of the samples, the observed preference may have also been influenced by the fermentation process itself, which is known to impart complex flavours (van Wyk, 2024). In this regard, Maoloni et al. (2021) had also emphasized that fermentation, as a value-adding



(a)



(b)

Fig. 3. Product liking test a) sample preparation and b) product tasting in the sensory analysis laboratory.

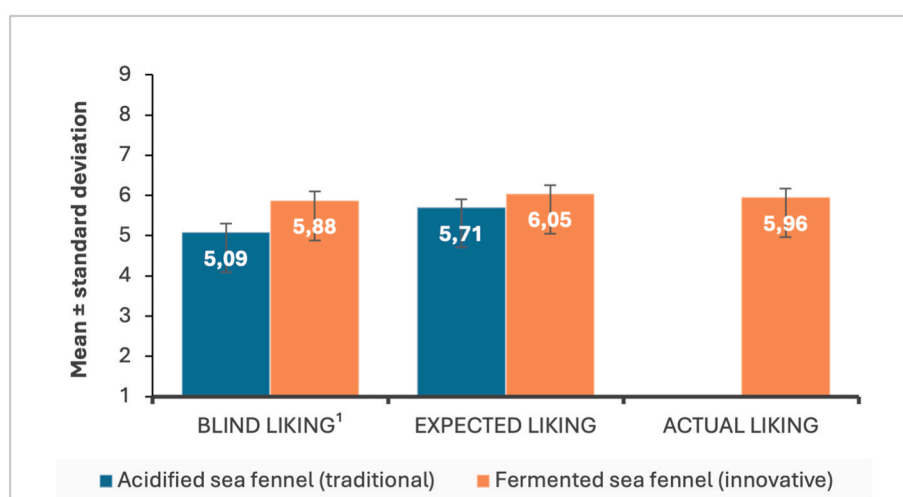


Fig. 4. Comparison of consumer acceptance of sea fennel preserves for the overall sample. ¹indicates a significant difference between the products under blind tasting conditions ($p < 0.001$; Bonferroni adjusted).

process, can improve the acceptability of sea fennel-based preserves. Considering that slight variations in traditional products can stimulate curiosity and acceptance by balancing novelty with recognizable sensory cues (Günden et al., 2024), introducing fermentation as an innovative processing method presents a promising opportunity to promote sea fennel preserves by leveraging both cultural tradition and targeted innovation. Regarding expected liking (expected acceptance), which is based on only information about the processing method, the fermented sea fennel received slightly higher ratings than the acidified sea fennel preserves. However, no statistically significant difference was found.

The differences in liking scores for each preserve across tasting conditions were assessed using the mean values. For acidified sea fennel, expected liking was significantly higher than blind liking (Expected-Blind = 0.62, $p < 0.001$), while actual liking was not assessed. For fermented sea fennel, no significant differences were observed between blind and expected liking (Expected-Blind = 0.17, not significant), blind and actual liking (Actual-Blind = 0.08, not significant), or actual and expected liking (Actual-Expected = -0.09, not significant). These results indicate that providing information on the production method had a significant effect only on the expected liking of the acidified product.

It is important to note that actual liking (informed acceptance)

tasting was performed only on the fermented sample. The reason is that the acidified sea fennel is a commonly marketed product. We did not need this disconfirmation analysis. No significant difference was observed between blind and actual liking for the fermented sea fennel. The absence of a significant difference suggests that providing neutral production information alone was not sufficient to modify sensory perception. Instead, more detailed information and effective labels on the nutritional and health benefits of the fermented product could be a strategy to encourage its consumption (Balco and Gracia, 2022; Barkla et al., 2024). Future studies could explore whether more evocative or value-based information (e.g., healthy, sustainability, or culinary content) might enhance consumer response. For example, like for other specialty foods such as cheese, the consumers' appreciation for sustainable and local productions is often considered a strategic element for more effective communication (Stefani et al., 2006). Lastly, promotion based on tasting events may arouse curiosity among consumers and enhance their hedonic experience.

Secondly, exploratory analyses were performed to examine whether liking scores differed across sociodemographic variables (gender, age, education, and occupation). After applying the Bonferroni correction for multiple comparisons, no significant differences were observed among

demographic groups. These exploratory findings provide a solid basis for more detailed segmentation studies, which could investigate how familiarity, neophobia, and sensory expectations interact in shaping acceptance.

4. Conclusions

Recent scientific studies have highlighted the properties and potential of sea fennel as a novel food ingredient. However, this potential can only be entirely realised if there is sufficient demand. Before fully integrating sea fennel into food production systems, it is essential to assess consumer perceptions of this innovative marine vegetable and gain further insights into how acceptance of both traditional and new preparations shapes overall liking.

According to the results, introducing the fermented sea fennel to the market is likely to appeal broadly to consumers, with no significant differences across sociodemographic characteristics. Nonetheless, understanding consumer segments and their preferences through targeted studies remains important for the successful development and market introduction of new products. In addition, providing information about the processing method can influence consumer evaluation, highlighting the importance of clear communication in shaping perceptions.

While key drivers such as health benefits, environmental sustainability, and cultural background drive the development of sea fennel, barriers such as consumer unfamiliarity and limited product availability present challenges. Initiatives aimed at raising consumer awareness, promoting sustainable production practices, and implementing effective business models can unlock the full potential of sea fennel as a valuable agricultural product, benefiting both producers and consumers.

This preliminary study presents, of course, limitations. One important limitation is that the study is based on a convenience sample of one hundred consumers, mainly composed of university staff, students, and local residents. Although this approach is acceptable for exploratory sensory studies, it may reduce the representativeness of the results and introduce potential bias due to the relatively high educational level of participants. In general, convenience samples are indeed biased because participants volunteer to take part in studies (Coleman, 2018). Nevertheless, they are widely used in exploratory consumer and marketing research, where student samples are among the most common (Peterson, 2001). Although this may affect external validity and limit generalization to the broader population, it improves internal validity by providing a relatively homogeneous group and reducing confounding factors such as differences in education or food culture (Coleman, 2018). In our case, the inclusion of clerical university staff and local residents aimed to slightly increase sample diversity and mitigate this limitation. Previous research suggests that convenience samples do not necessarily produce qualitatively different conclusions compared to more representative samples (Miller, 2007). Future research should therefore include larger and more diverse samples to confirm and extend these preliminary findings. More specifically, the participant sample could be more targeted to specific characteristics. For example, selecting participants more familiar with similar preserves (like capers) could influence the results. Besides, the replication of sea fennel acceptance studies in other countries, where traditional consumption exists – such as in Turkey and Croatia – as well as in regions where it is a completely novel food, would provide additional insights into consumer knowledge and experience, helping to identify other target groups.

Specific communication strategies designed to improve product familiarity, highlight the nutritional and health benefits of sea fennel, and showcase its culinary uses should be further studied. Moreover, increasing exposure through platforms (e.g., cooking shows) could enhance consumers' intentions to purchase certain less common foods. These exploratory results suggest that consumer acceptance of sea fennel may extend beyond niche markets, highlighting the potential for broader market development.

CRedit authorship contribution statement

Emel Ozturk: Writing – original draft, Investigation, Formal analysis, Data curation. **Serena Mandolesi:** Writing – original draft, Methodology, Formal analysis, Data curation. **Simona Naspetti:** Writing – review & editing, Validation, Conceptualization. **Antonietta Maoloni:** Writing – original draft, Investigation, Formal analysis, Data curation. **Lucia Aquilanti:** Writing – review & editing, Validation, Project administration, Conceptualization. **Raffaele Zanolli:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Implications for gastronomy

The findings of this study have significant implications for the field of gastronomy, particularly for promoting the integration of sea fennel (*Crithmum maritimum L.*), an underutilized halophyte, into mainstream culinary practice. Although sea fennel has traditionally been consumed in certain coastal regions, its presence remains largely limited to local or niche markets. Its nutritional and sustainable qualities, however, highlight its considerable potential as a versatile ingredient within the gastronomic industry.

A comprehensive understanding of consumer preferences is essential for culinary professionals seeking to integrate sea fennel into a diverse array of recipes that respond to the growing demand for sustainable and health-oriented foods. To facilitate broader adoption, chefs and other culinary professionals could incorporate sea fennel in practical applications, such as: pairing it with seafood dishes, or artisan food products (e.g., cheeses) to enhance flavour and texture; using it in salads, sauces, or marinades as a ready-to-use preserved ingredient; and, experimenting with blends in vegetable side dishes or garnishes to maintain familiar flavour profiles while introducing novelty. In addition, marketing and promotion strategies could include: emphasizing local and sustainable sourcing; highlighting nutritional and functional benefits on menus and labels; offering tasting events or cooking demonstrations, and strategic collaborations with social media. Such initiatives are likely to enhance consumer awareness and foster the normalization of sea fennel into everyday meals.

Furthermore, ensuring reliable access to high-quality sea fennel that meets culinary standards is crucial for its consistent application in food service contexts. These actions, combined with coordinated efforts within the food industry to scale production and adhere to stringent quality regulations, have the potential to elevate sea fennel from a niche novelty to a valued ingredient in contemporary cuisine. Ultimately, sea fennel presents a promising avenue for chefs and food entrepreneurs to lead in culinary innovation while simultaneously contributing to the advancement of more sustainable, diverse, and nutritionally rich diets.

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Declaration of competing interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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