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Consumer Preferences for New Fermented Food Products that Mix Animal and Plant Protein Sources

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Abstract: Consumers are being encouraged to increase the proportion of plant protein in their diets to enhance the sustainability of food systems. One approach is to develop plant-protein-rich foods that are acceptable to consumers. This study examined French people's reactions to cheese alternatives—new fermented products that mixed animal and plant protein sources. We conducted experimental sessions with 240 French participants to assess their responses to three fermented products containing different percentages of yellow pea and cow's milk. First, we asked the participants to blind-taste the three products and solicited hedonic scores of products. We then provided the participants with simple information about the products' composition and asked them to taste and score the liking of the products a second time. We also asked consumers to estimate their willingness to pay (WTP) for each product before and after revealing additional information about the nutritional or environmental benefits of consuming pea-based foods. The product with the lowest percentage of pea and the highest percentage of milk received the highest hedonic scores, and WTP was correlated with the hedonic scores. The additional information about the nutritional and environmental benefits of pea-based foods led to significant increases in WTP for two of the fermented products, but not for the least preferred product, namely the one with the highest percentage of pea. This finding suggests that participant reactions to information depended on hedonic preferences.

Highlights:

-We combined hedonic and willingness to pay (WTP) approaches to study consumer behavior

-Information about nutritional and environmental impacts may promote dietary transitions

-Participant preference increased as the product's pea percentage decreased

-WTP increased with participant preference but was differentially affected by nutritional and environmental information

-Developing fermented products that mix animal and plant protein sources is a major challenge

-Partially replacing animal ingredients with plant ingredients could enhance dietary sustainability

Keywords: Plant-based product, consumer behavior, economic approach, sensory analysis

1. Introduction

The global population is predicted to reach 10 billion by 2050, and there is thus increasing concern about how human diets affect human health and the environment (Poore & Nemecek, 2018, Springmann et al., 2018, McClements, 2019). One of the major factors responsible for the negative impacts of modern diets is that they are based on large quantities of animal-based foods (Poore & Nemecek, 2018). Indeed, unbalanced diets are responsible for obesity, diabetes, and/or cardiovascular diseases in many countries (WHO, 2015, and Willett et al., 2019), and food production accounts for 25% of the world's greenhouse gas emissions (Lock et al., 2010 and Tilman and Clark, 2014).

To promote healthier and more sustainable food systems, consumers are being encouraged to explore alternative diets and to switch to more plant-based diets (Floros et al., 2010, Springmann et al., 2017). The EAT-Lancet Commission on Food, Planet, Health (Willett et al., 2019) defined ambitious sustainable diets for different regions of the world and suggested that dietary improvements could result in significant benefits for human health and the environment. In particular, this commission recommended (1) a decrease in the consumption of meat, sugar-based products, and processed industrial dishes and (2) an increase in the consumption of fruits, vegetables, seeds, nuts, and legumes (e.g., peas and lentils). It also advised that the populations of North America, Asia, and Europe (including France) should reduce their consumption of dairy products.

Several other studies have highlighted the substantial benefits that can be obtained by reducing the consumption of animal-based foods. However, developing substitute products that consumers will accept is a significant challenge. To this end, it is important to conduct studies in which researchers present consumers with plant-based alternatives to traditional animal-based products and assess their responses (Hartmann and Siegrist, 2017). Indeed, increasing the desirability of plant-based products is one option for reducing the consumption of animal-based foods. In this context, fermented products are of interest because they can contain mixtures of animal and plant protein sources, allowing for product reformulations that are compatible with greater dietary sustainability.

However, the consumption of legumes is relatively low in many countries belonging to the Organization for Economic Co-operation and Development (OECD) (Tobler et al., 2011; Siegrist et al., 2015; Weinrich, 2019). This trend may be due to consumers perceiving plant-based foods as having multiple unpleasant flavors and tastes (e.g., bitter, vegetal, earthy) or being unfamiliar with plant-based alternatives to meat or dairy products (Schösler et al., 2012; Hartmann and Siegrist, 2017). Consequently, it is challenging to develop plant-based foods that will appeal to consumers. Furthermore, this process involves better understanding the trade-off between consumer preferences and health/environmental benefits and exploring how such dynamics are affected by the relative percentage of different protein sources in food products.

In this study, we developed new fermented products that combined animal and plant protein sources and studied participants' behaviours. We chose to employ this food type because it has been overlooked in previous researches. Our approach is original because we used different percentages of animal and plant protein sources in the products. Our plant protein source was the yellow pea, a legume commonly cultivated in northern Europe, including France. The yellow pea (*Pisum sativum*) is particularly rich in proteins, fiber, and minerals (González et al., 2011). Compared to cow's milk, legumes have a relatively low impact on the environment, which includes a weaker carbon footprint. Legumes such as yellow peas require the use of very few pesticides. Moreover, they can be grown without any nitrogen fertilizers because they fix their own nitrogen. When used in crop rotations, legumes provide a major boost to subsequent crops such as wheat, barley, and corn; for example, a 20% gain in yield has been observed (Knight, 2012).

Consumer acceptance of and willingness to pay for fermented foods containing mixtures of animal and plant protein sources may be driven by both food preferences and awareness of health and environmental impacts. We thus investigated whether participants who were informed of food-related health and environmental issues were more willing to purchase these types of products. Briefly, we first asked participants to provide a hedonic score for the food products before and after being given basic information on the products' composition. Then, the participants were asked to indicate their willingness to pay (WTP) for a given product before and after being given additional information about the product; half the participants were told about the nutritional benefits of consuming pea-based foods, and half were told about the environmental benefits of consuming pea-based foods. The study's goal was to identify the various drivers and barriers involving in consumer preferences and WTP.

2. Materials and methods

This section describes the design and production of the fermented food products used in the study, the experimental sessions with the study participants, and the statistical analyses.

2.1. Design and production of the fermented products used in the study

2.1.1. Ingredients and raw materials

We obtained pea protein isolate (NUTRALYS®S85F) from Roquette Frères (Lestrem, France), skimmed cow's milk powder from Lactalis (Bourgbarré, France), and rapeseed oil (Fleur de Colza, Lesieur, France) from a local supermarket. Glucono delta-lactone (GDL) was used for coagulation (Sigma Aldrich, Steinheim, Germany). Agar (HP700IFG, Kalys, Bernin, France) was used to strengthen the gels.

2.1.2. Microbial strains and inoculation preparation

To ferment the products, we used four cheese strains (CNRZ212, S3, 3550, and ATCC 204307) from the following species (respectively): *Lactobacillus rhamnosus* (a lactic acid bacterium)*, Lactococcus lactis* (a lactic acid bacterium), *Kluyveromyces lactis* (a yeast), and *Geotrichum candidum* (a yeast); all these microorganisms have been granted qualified presumption of safety (QPS) status. These strains were chosen because they can grow on pea protein isolate and change the isolate's initial green off-note (Ben Harb et al., 2019). Strains were cultured separately at 28°C for 48 to 72 h on the following broth media: Man, Rogosa, and Sharpe (MRS) agar for the lactic acid bacteria and potato dextrose broth (PDB, Biokar Diagnostics) for the yeasts. When the stationary phase of growth was reached, cells were harvested by centrifugation (5000×g, 10 min, 4°C), washed in sterile physiological saline (NaCl 9g/l), and resuspended in sterile physiological saline at a cell density of 8.0 log10 CFU/ml.

2.1.3. Preparation of gels

We prepared two types of initial emulsions—100% pea and 100% milk. We then made four further emulsions intended for fermentation: i) a 100% pea emulsion; ii) a mixture containing 75% pea emulsion and 25% milk emulsion; iii) a mixture containing 50% pea emulsion and 50% milk emulsion; and iv) a mixture containing 25% pea emulsion and 75% milk emulsion.

Further details about the preparation, gelation, and fermentation of the food products are given in Appendix A. After 14 days of fermentation, the products were packed and stored at 4°C for 5 days until they were consumed during the experimental sessions. The composition of the four foods is described in Table 1. Fermentation took place at the INRAE

Joint Research Unit for Cheese in Aurillac, France (see https://www6.ara.inrae.fr/umrf/), which respected all necessary food safety procedures.

The fermented products were transported to Paris in a refrigerated vehicle a few days before the experimental sessions began and were stored at 4°C. Figure 1 shows the products just before the tasting trials were initiated. The products were all tested for five foodborne pathogens—*Listeria monocytogenes*, *Staphylococcus aureus*, *Salmonella*, *Bacillus cereus*, and *Escherichia coli*—by two COFRAC-accredited testing laboratories (Eurofins Scientific and AGROLAB'S).

Four days before beginning the experimental sessions and after conducting some preliminary tests, we decided not to use the 100% pea product for organoleptic reasons: it was deemed to be too different from the three other products.

2.2. Experimental sessions with the study participants

2.2.1 The experimental conditions

The experiment was carried out over multiple sessions in October 2019 at Eurosyn, a private consumer testing company in Villebon-sur-Yvette (a southern suburb of Paris, France). The company has a tasting room that can accommodate up to 16 people simultaneously. There were 11–16 participants in each experimental session. Each participant was set up in an individual booth lit with a white light and equipped with the Fizz software (Biosystem, Couternon, France); the tasting room was kept at a stable temperature (20°C). Eurosyn has an established policy for protecting personal data, supporting innovation, and preserving individual liberty (n°2072127v0).

At the beginning of the session, all the participants received an informational document describing the conditions related to their informed participation in the study and signed a consent form. At the end of the session, the participants received €15 in compensation for their participation.

2.2.2 The participants

Overall, 241 participants took part in the experiment. They all lived in and around Paris and were recruited about two weeks prior to the experiment using online and phone questionnaires focused on their sociodemographic characteristics and consumption habits. Participants were randomly selected using the quota method so that the composition of the sample was representative of the gender, age, and socioeconomic demographics of the city's population. First, equal percentages of women and men were chosen. Second, one-third of participants were 20–34 years of age, one-third were 35–49 years of age, and one-third were 50–70 years of age. Third, 33% of participants were highly skilled professionals, 48% were professionals in middle or low-ranking occupations, and 20% were not actively employed (namely students or retired people). Moreover, participants were asked to indicate their diet in terms of animal and vegetable consumption habits. During the recruitment process, the participants were informed that the experiment would involve the consumption of fermented food products in association with a tasting procedure. Only individuals who ate cheese, even just occasionally, were selected.

Table 2 shows the socioeconomic composition of the sample based on the participants' responses to the recruitment questionnaire. The data indicate that the participants' gender and level of education were representative of those of the French population. In contrast, younger people (< 40) were overrepresented in the sample.

2.2.3 Description of the experimental procedure

Each session lasted 45 minutes and was organized as follows. At the beginning of the session, we orally provided the participants with some basic information. We told the participants that they would be tasting three food products twice. We underscored that all their responses would be kept anonymous. We also made it clear that there were no “good” or “bad” responses and that they should freely express how they felt about the food products.

At that point, the experiment began and took place in three main stages (Figure 2).

Stage 1: Blind tasting. The products were served on plates (see Figure 3) and labeled with a 3-digit code. A balanced monadic presentation was used to limit carryover effects (see Figure 3).

We gave the participants a plate with a specific product, and we asked them to indicate a hedonic score based on the product’s visual appearance. The 7-point hedonic scale ranged from 1 for “strongly dislike” to 7 for “strongly like.” We then asked the participants to consume at least one mouthful of the product and indicate a hedonic score ranging from 1 for “very bad” to 7 for “very good.” The participants then replied to questions regarding their perception of the food (related to bitterness, flavor intensity, saltiness, stickiness, hardness, fattiness, caloric density, protein richness, and sensation of satiation) employing a 5-point Likert scale, where 1 was equal to “strongly disagree” and 5 was equal to “strongly agree.” This procedure (visual liking, taste liking, and perception liking) was successively repeated for the three foods.

Stage 2: Informed tasting and initial willingness to pay. We gave the participants basic information about the products’ composition. A simple text appeared on a screen within the booth that explained the different percentages of pea and milk in fermented products. Afterwards, the participants took part in a new tasting procedure. When the participants were given the plates, each plate indicated the product’s percentages of pea and milk (Figure 3). We then asked the participants to indicate a hedonic score based exclusively on the tasting.

The scale was the same as above: from 1 for “very bad” to 7 for “very good”. This procedure (hedonic scoring) was successively repeated for the three foods.

We subsequently assessed the participants’ willingness to pay (WTP) for the products. Participants were given sheets with a list of multiple prices for each product. We explained that these products were not currently being sold in France but that they could be put on the market in the near future. We made it clear that none of the products would be sold or given to the participants at the end of the session because they were prototypes and because we could not guarantee that they would remained chilled during transport from the lab to the participants’ homes. We asked the participants to respond to the multiple-price list for each product to estimate their WTP (see below for further details).

There was one price-list sheet for each product. At the top of the page, above the price list, was a picture of the product in a packaged form. The packaging showed the percentage of pea and milk in the product. For the purposes of pictures, we created packaging from Camembert boxes (Figure 4). Camembert is a well-known traditional cheese in France, so using its packaging in the photos provided participants with a standard of reference for the potential size of the products. We named the products *Frompois* (short for *Fromage de Pois* in French), which means *Peacheese* in English. We created this false packaging to lend credibility to the idea that the products would be commercialized.

Stage 3: Willingness to pay after receiving nutritional or environmental information. We communicated additional information to participants before reassessing their WTP. Half the participants received information about the nutritional benefits of consuming pea-based foods; the other half received information about the environmental benefits of consuming pea-based foods. More details on that information are provided below. We then asked the participants to respond to the price list for each product a second time.

In the experiment, we controlled for the order in which the products were served. Although serving order varied across sessions, it was fixed for a given session for all the participants (Table 3). During the sessions, WTP was assessed in accordance with serving order.

2.2.4 Details on assessing willingness to pay during stages 2 and 3

To assess WTP for each product, we provided participants with a multiple-price list. During both assessment rounds, participants were asked to choose whether or not they would buy the product for prices ranging from €1.80 to €3.60 that increased in increments of 10 cents (see Figure 5). We based these prices on a supermarket survey during which we noted the observed prices of Camembert in Paris and the suburbs of Paris. As mentioned above, Camembert represented a good standard of reference against which to compare the new food products. Participants were given a new price-list sheet for each product during each round. Just above the price list was the following question: "Would you purchase the product at the following prices? For each line, check either yes, no, or maybe."

During each round, participants had to supply an answer for each price in the list for each product. The WTP for a given product was determined by identifying the highest price to which a participant responded "yes." If the answer was "no" or "maybe" for all the prices, the WTP was equal to €1.70 (10 cents below the lowest proposed price) (an alternative configuration in which the minimum price was €0 was also studied). If the answer was "yes" for all the prices, the WTP was equal to €3.60 (the highest proposed price).[1] The "maybe" replies will be addressed later in this paper.

[1]Our study defines WTP using the highest "yes" for the 241 participants. For only nineteen participants a lower limit (LL) for "yes" was observed, where LL < WTP. In these cases, LL is the lowest price to which they replied "yes"; they replied "no" or "maybe" to prices strictly lower than the LL (see Marette et al., 2013). These LLs are not considered in this study.

In this experiment, we employed multiple-price lists to simplify the participants' task of independently evaluating the products during the two rounds. The use of multiple-price lists has been criticized for two main reasons (Andersen et al., 2006). First, they elicit interval data rather than point estimates for WTP. In our study, the 10-cent interval helped ensure that the WTP displayed a higher degree of precision. Second, there is a framing effect where participants are psychologically biased toward the mid-range prices.[2] However, despite their shortcomings, multiple-price lists remain useful because they are straightforward when participants are being asked to carry out multiple tasks.

2.2.5 Details on the additional information provided during stage 3

The informational texts shown to participants during stage 3 were written after studying articles in the nutritional and environmental sciences. We kept them relatively short because previous research has underscored that shorter texts are more efficient than longer texts with more complex information (Wansink et al., 2004). One text focused on nutrition/health, and the other focused on the environment. They discussed the nutritional or environmental benefits associated with the cultivation and consumption of peas. Because of time constraints, nutritional information was given during half the sessions (representing a total of 123 participants), and environmental information was given during the other half of the sessions (representing a total of 118 participants). Translations of the informational texts are provided in Appendix B.

2.3. Statistical analyses

Data analyses were performed using R software and XLSTAT software (Addinsoft, Paris, France, 2014, 5.02). First, we looked at the hedonic scores and the WTP scores separately.

[2]Andersen et al. (2006) controlled for this effect by changing the boundaries of the multiple-price list. Here, we chose to use consistent boundaries because we were studying the impact of revealing further information on WTP estimates, which required that the participants receive the same price list. However, it would be possible to test robustness by placing participants in subgroups and giving those subgroups price lists with different intervals and different boundaries (e.g., higher or lower than €0.40 and €2.10).

We tested whether the scores differed significantly between rounds using the Wilcoxon test for paired samples. We examined the correlations between the hedonic scores and the WTP scores with Spearman correlations.

The liking scores reflecting how the participants liked the products (visual liking scores, tasting liking scores after initial consumption, and tasting liking scores after receiving information on product composition) were analyzed using a three-way ANOVA in which product type, consumer identity, and serving order were the main effects. Preference patterns were explored by applying hierarchical cluster analysis (HCA, Euclidean distance, Ward's criteria) to the normalized liking scores. This approach allowed us to define clusters of participants with similar preference patterns. Differences among clusters and the specificities of each cluster were further analyzed using ANOVAs, as described above: cluster was added as an main effect, and the cluster × product type interaction was also included.

We used econometric estimators to analyze the WTP data. We examined the impact of the informational texts by pooling the participants' WTP scores for the three food products during stages 2 and 3. Given that each participant produced two WTP scores, errors related to these variables were potentially correlated for each participant. Therefore, this random effect imposed constraints on the structure of the variance-covariance matrix. Moreover, the WTP scores were real numbers ranging between €1.70 and €3.60. This score could not be negative and was left-censored at €1.70; we therefore used the random effects Tobit estimator, which describes the relationship between a non-negative dependent variable and the independent variables. In our model, product type was represented with dummy variables. More specifically, the variable *25% pea* was equal to 1 for the products containing 25% pea emulsion and 0 otherwise; the variable *50% pea* was equal to 1 for the products containing *50% pea* and 0 otherwise; and the variable *75% pea* was equal to 1 for the products containing *75% pea* and 0 otherwise. We also used dummy variables for the informational text type. The variable *Information about Nutrition* was equal to 1 when participants had been exposed to this text type and 0 otherwise, while the variable *Information about Environment* was equal to 1 when participants were exposed to this text type and 0 otherwise. Regression analyses were also used to explore participants' perceptions and socioeconomic characteristics.

3. Results

3.1. Hedonic scores

Overall, participants moderately liked the products. The mean visual liking score was 3.9; the mean initial liking taste score was 3.1; and the mean liking taste score after participants received compositional information was 3.2 (on a 7-point scale) (Figure 6).

There were significant differences in how the three products were scored over the course of the session (i.e., between the visual liking score, the initial taste liking score, and the post-compositional information taste liking score) ($F_{prod\ (2,\ 478)} = 14.16$; $p<0.0001$) and by different participants ($F_{subj\ (240,\ 478)} = 6.02$; $p<0.0001$). Serving order did not significantly affect the hedonic scores (or the WTP scores). For each subgraph of figure 6, the Newman Keuls tests show that liking scores of different products are statistically different. Regardless of the stage, participants clearly preferred the product with the lowest pea percentage, namely 25% Pea.

Regardless of the stage, participants clearly preferred the product with the lowest pea percentage (Figure 6). After the participants first tasted the products, all the scores decreased by about one point. Providing participants with information about the products' composition had no effect on the scores ($F_{Info\ (1,\ 470)} = 2.02$; $p=0.157$). The differences in scores among products were less pronounced after the products were tasted, as highlighted by the results of the Newman Keuls tests (Figure 6).

When the participants evaluated the products' sensory attributes using the Lickert scale, the products were found to differ in their bitter, salty, sticky, fatty, and flavor notes (Appendix C). The 25% pea product was perceived as less bitter and less fatty than the other two products (50% pea and 75% pea). These results, and notably the greater perceived bitterness, could explain why participants liked the products with greater pea percentages less.

Using the HCA, we identified three different groups of participants with distinct preference patterns (Figure 7). These group differences were confirmed by the significant cluster × product type interaction ($F_{4,\ 478}$=7.36 and 15.12, $p<0.0001$) that emerged for the initial taste liking score and the post-compositional information taste liking score. While this interaction was not significant for the visual score, there was a pronounced effect of product type (Table 4).

The participants in cluster 2 (n=65) gave the products higher scores overall and were more sensitive to the products' pea percentages (Fig. 7). They liked the products with higher pea percentages less. In contrast, the participants in cluster 1 (n=32) clearly rejected all the product types equally. Participants in cluster 3 (n=144) displayed an intermediate response: they gave the products lower scores overall but demonstrated a preference for the 25% pea product. The results of the screening questionnaire found no clear differences in the dietary habits of participants in the different clusters. We did note that there were some slight differences in their consumption of fruit, starchy foods, and tofu. In particular, a portion of cluster 2 participants had a higher level of tofu consumption.

These results can help inform future work to develop plant-based fermented products that are attractive to consumers, regardless of their dietary habits.

3.2 Willingness-to-pay scores

In our analysis of the WTP scores, we distinguished between non-engaged participants and engaged participants. Non-engaged participants never replied “yes” to any price on the six different price-list sheets, while engaged participants replied “yes” at least once.

A total of 239 study participants filled out the price-list sheets; 2 did not. Among these 239 people, 111 were non engaged, and 128 were engaged. Figure 8 shows the average WTP score for the engaged participants. As a reminder, the WTP score indicates the maximum price a participant was willing to pay for the product, which was equal to the highest price associated with a “yes” or to €1.70, if the participant failed to reply “yes” to any price (subsection 2.2). For each product type, we present the mean WTP score for the three different products before and after the participants were shown an informational text about the nutritional or environmental benefits of consuming pea-based foods. Data were pooled including these two treatment groups receiving different informational texts.

In Figure 8, the average pre-information WTP score is the first bar for each product. These mean WTP scores were negatively associated with pea percentage: the 25% pea product had the highest average WTP score, even if these average WTP scores for the three products are relatively close [3]. After the participants were shown the informational texts, the WTP scores significantly increased for the three products. The greatest effect was seen for the 50% pea product (with an increase of 7.4%).

[3] From Wilcoxon tests for comparing paired samples, the study of WTP scores before the revelation of information (corresponding to first bars on figure 8) leads to the following results. The WTP scores for the 25% pea product are statistically different from the WTP scores for the 75% pea product (P=0.010). Conversely, the WTP scores for the 50% pea product are not statistically different from the WTP scores for the 25% pea product (P=0.113) and for the 75% pea product (P=0.329).

The econometric estimates clarified the impact of providing the participants with the nutritional or environmental information. As a reminder, we used dummy variables (1/0) to encode the product types (*25% pea*, *50% pea*, *75% pea*) and the informational types (*Information about Nutrition* and *Information about Environment*).

We also carried out regressions using the data from all the participants (n=239) and the engaged participants (n=128). Both regressions yielded similar results even if their coefficients were different. This difference was explained by the inclusion of non-engaged participants (WTP score of €1.70) in the first regression. The coefficients were higher in the second regression, which only included data for the engaged participants (much higher WTP scores). Table 5 confirms the results shown in Figure 8. In the second regression, before the participants were shown the informational texts, the WTP score for the 25% pea product (coefficient = 2.142) was significantly higher than the WTP score for the 50% pea product (coefficient = 2.071), which was, in turn, higher than the WTP score for the 75% pea product (coefficient = 2.026). These results mean that participants preferred the product with the highest percentage of milk.

After the participants were shown the informational texts, the WTP scores increased significantly, but not across the board. In particular, the WTP score for the 75% pea product was uninfluenced. Both types of information had the strongest impact on the 50% pea product (coefficients = 0.161 and 0.144 in the second regression), although the nutritional information had a greater effect than the environmental information. For the 25% pea product, only the nutritional information had a significant impact, perhaps because the product contained a smaller percentage of pea. These results indicate that the participants internalized what they had been told when it came to the products they liked more (the 25% pea product and the 50% pea product); they did not apply it in the case of the least preferred product (the 75% pea product). In other words, the participants' reactions to the information depended on their preferences.

We also ran alternative regressions using socioeconomic characteristics (taken from the recruitment questionnaires) and the participants' perceptions of food innovations (taken from the end-of-session questionnaire), but these variables had no influence on the WTP scores (results not shown). As previous research has indicated (see Lusk and Shogren, 2009), in laboratory trials, the influence of factors such as income or educational level is limited compared to the influence of dietary habits.

We examined cases in which participants replied "yes" at least once on the price-list sheets but also sometimes answered "maybe". Indeed, a given participant might reply "yes" to the lowest prices and then "maybe" to some of the mid-range prices. For this analysis, we pooled all the responses for the three product types and the two assessment rounds for each participant. Out of the total of 1,416 observations (including situations in which "yes" was never chosen), there were 548 cases in which participants replied "maybe" at least once above the highest price to which they replied "yes." These cases represented a substantial percentage of the total observations (38.7%). This finding may indicate that many participants felt hesitation in the face of these new fermented products. We noted that the highest "maybe" always occurred above the highest "yes" and that the difference between the two was rather pronounced (Fig. 9), which lends support to this idea. Indeed, the difference was greater or equal to €0.40 in 48% of these cases, suggesting that WTP could increase if efforts were made to persuade individuals to consume these new products.

3.3 Correlations between the hedonic scores and the willingness-to-pay scores

During stage 2, the hedonic scores and the WTP scores were obtained in succession, which allowed us to examine their correlation. Figure 10 shows the relationships between the hedonic scores and the WTP scores, with the hedonic scores on the x-axis, and the average WTP score for each subgroup defined by a specific score on the y-axis. The data for the three product types are pooled, and the numbers of observations associated with each score are indicated at the top of the figure.

The hedonic scores and the WTP scores were correlated (Spearman correlation coefficient = 0.532; Fig. 10). It is clear that when participants gave the products poor hedonic scores (≤ 3), they also showed a low WTP for the products, which averaged between €1.70 and €1.80. When the participants gave neutral or good hedonic scores (≥ 4) to the products, there was a clear positive relationship between the hedonic scores and the WTP scores.

4. Discussion

In general, participants moderately liked the products, with a notable share of individuals demonstrating above-average interest. This interest was reinforced when participants were given additional information about the benefits of pea-based foods, especially when the information conveyed a nutritional message. The large number of "maybe" replies during the WTP assessments suggest that targeted marketing campaigns could help convince consumers of the benefits associated with new fermented products containing a mixture of animal- and plant-based protein sources. We observed marked differences among individual participants, which is common in research on innovative products. We found that participants demonstrated an interest in these fermented foods, which provides support for the products' introduction onto the market. More specifically, there was a clear preference for the product with the highest milk content and lowest pea content (the 25% pea product had the highest WTP scores). Our approach represents an alternative to classical solutions for reducing the consumption of animal products. Indeed, traditionally, efforts have focused entirely on replacing animal-based products with plant-based products. Here, we suggest a partial substitution within the context of a given product.

In our experimental design, we utilized both hedonic scores and WTP to delve more deeply into consumer behavior, an approach that shows great potential. Our results clearly show that a strong correlation exists between how well participants like a product and their WTP (see Roosen et al., 2007). Indeed, both hedonic and WTP scores provide crucial information that should be evaluated before introducing products onto the market.

Although the experiment took place in sensory booths, which do not necessarily replicate real-life conditions, they did allow us to analyze participant behavior under controlled conditions. This approach has clear advantages because certain "field" studies have underscored the problems engendered by information proliferation, imperfect recall, the lack of time before purchasing, the large number of purchased products, and/or confusion about complex information, which many consumers face *in situ* in stores. These issues often make it relatively difficult to interpret results from experiments conducted under real-life conditions (Falk and Heckman, 2009). However, it would be useful to conduct a complementary "field" experiment in which our study food products are made available in supermarkets, although such an experiment would be complicated because of the need to obtain regulatory authorization. However, in such an experiment, consumers would be purchasing real products, which should eliminate the hypothetical nature of the WTP scores obtained in this study (i.e., determined using a multiple-price list). Clearly, two of the key limitations of our research are the artificial conditions under which it was conducted and the estimates of WTP being based on hypothetical purchases.[4]

[4]Even if hypothetical WTP scores are likely to be biased upward, recent research seems to show that the risks of such biases are limited for private goods. By comparing hypothetical and non-hypothetical responses, Lusk and Schroeter (2004) showed that the marginal WTP associated with changes in food quality/characteristics or the revelation of information (as in our study) does not tend to be statistically different between hypothetical and real payment situations.

The results for the participants' perception of the products revealed significant differences in product bitterness. The 75% pea product was perceived as significantly more bitter than the other two products, which could explain why most participants rejected it entirely. Fermentation can help reduce perceived bitterness, but it appeared to be insufficient in this study in the case of the 75% pea product. Indeed, this product presented the sensory characteristics typical of pulses, notably bitterness (Bott and Chambers, 2006; Humiski and Aluko, 2007). The use of other legume species (e.g., faba beans, soybeans) could be another solution for modifying the perceived bitterness of fermented products.

In addition, the culinary role that products have the potential to play can greatly impact their perception and how well they are liked. For example, these fermented products could have different uses than classical cheeses, and they could be cooked, added to salads, or spread on bread. Participant acceptance and WTP could also change if the products were tested under real meal preparation conditions.

Consumer preferences and product composition (subsection 2.1) may also lead to broader industrial options and the possibility of further differentiating the products. The use of products that mix animal- and plant-based protein sources could receive support from policymakers, perhaps via subsidies for low-quality cheeses. The introduction of these new products could also impact supply chains and agricultural systems by lengthening crop rotations and increasing the frequency of legumes in classical rotations, which are often based on wheat, canola, and barley (Knight, 2012).

5. Conclusion

Our study has improved understanding of how consumers may respond to new products incorporating plant-based protein sources. This knowledge may help diversify food protein sources with a view to encouraging behaviors that increase dietary sustainability. We identified different groups of potential consumers who displayed distinct responses to the products. Some were clearly interested in consuming these mixed products; indeed, our results suggest that the products might be accepted by almost half the population. While participants appeared to be largely motivated to consume these products based on their sensory characteristics, desirability was also affected by providing information about the foods' nutritional and environmental benefits. Furthermore, the nutritional information had a stronger overall impact than the environmental information on the participants' appreciation of and willingness to pay for the products. Further research that includes life-cycle assessments of fermented products should be conducted to quantify their environmental benefits.

The results of this study underscore that creating new foods that combine animal- and plant-based ingredients should be promoted as part of the effort to design more sustainable diets. A significant percentage of consumers may actively support the release of these new products, which have significant benefits for human health and the environment.

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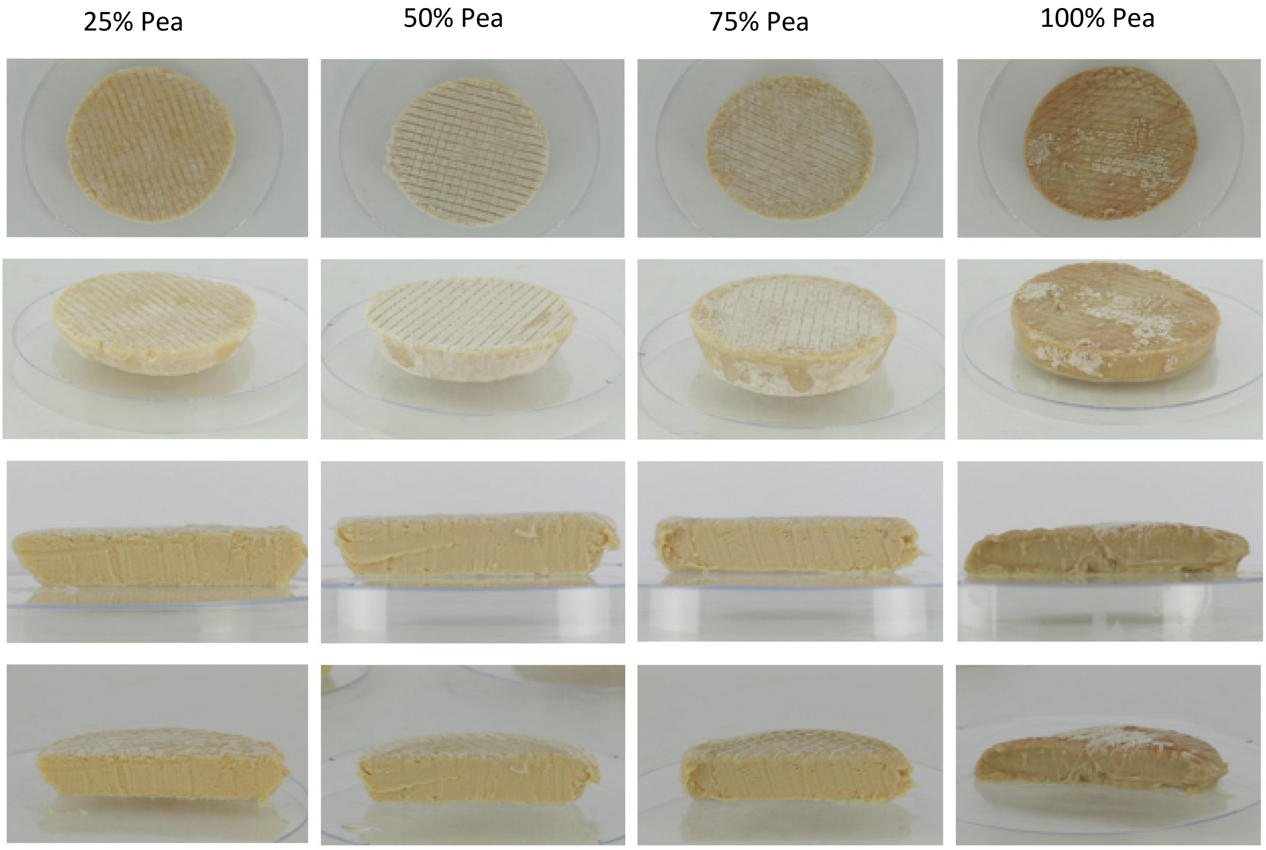


Figure 1: Pictures of the four fermented products the day where they were tasted: 25% Pea, 50% Pea, 75% Pea and 100% Pea.

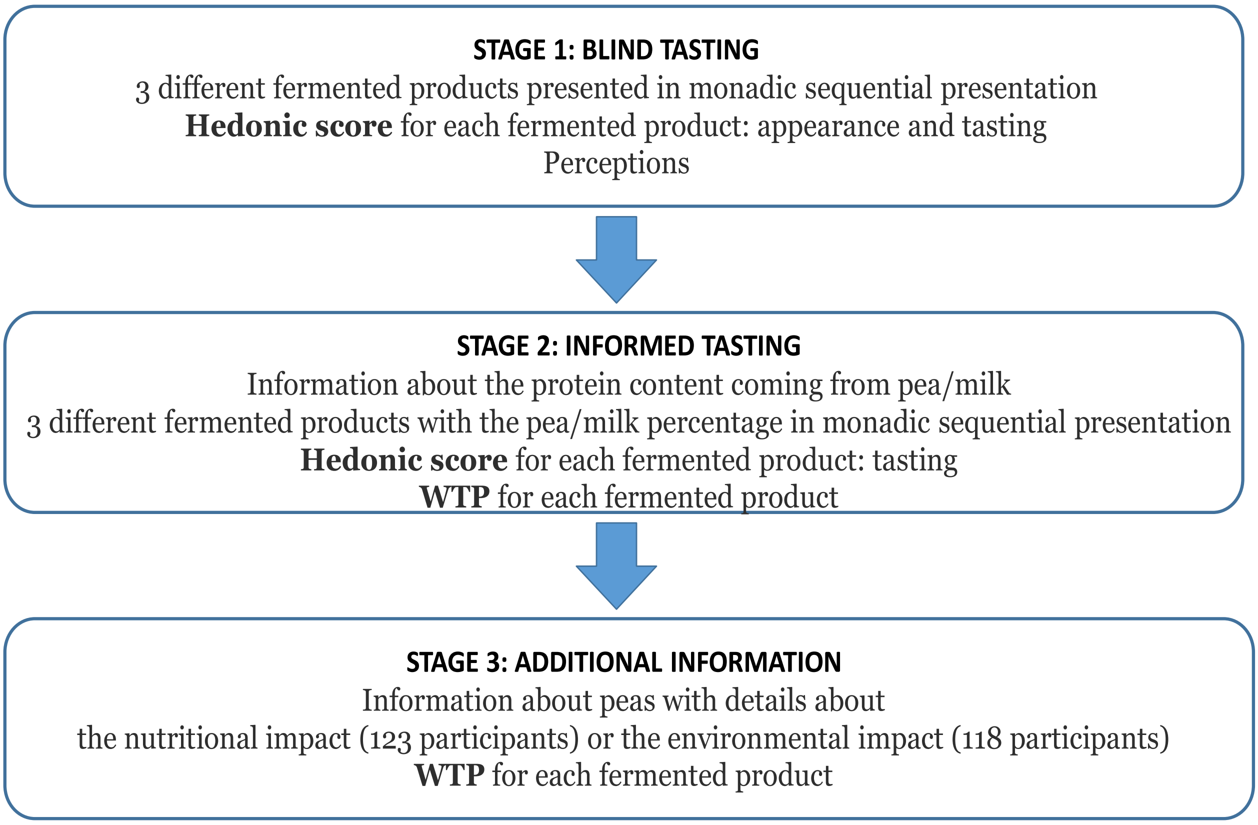


Figure 2. Timeline of the experiment organized in three stages (WTP : willingness to pay)

STAGE 1: Blind Tasting

Figure 3. Plates served at stages 1 and 2 presented with fermented product samples. Note: From French, *lait de vache* means *Cow Milk* and *Pois* means *Pea*.

25% pea, 75% cow milk

50% pea, 50% cow milk

75% pea, 25% cow milk

Figure 4. Pictures of fermented mix products above the multiple-price list for determining the WTP at stages 2 and 3. Note: From French, *Frompois* means *Peacheese*, *lait de vache* means *Cow Milk* and *Pois* means *Pea*.

	YES	NO	Maybe
1.80 Euro	□	□	□
1.90 Euro	□	□	□
2 Euros	□	□	□
2.10 Euros	□	□	□
2.20 Euros	□	□	□
2.30 Euros	□	□	□
2.40 Euros	□	□	□
2.50 Euros	□	□	□
2.60 Euros	□	□	□
2.70 Euros	□	□	□
2.80 Euros	□	□	□
2.90 Euros	□	□	□
3 Euros	□	□	□
3.10 Euros	□	□	□
3.20 Euros	□	□	□
3.30 Euros	□	□	□
3.40 Euros	□	□	□
3.50 Euros	□	□	□
3.60 Euros	□	□	□

Figure 5. The Multiple Price-List

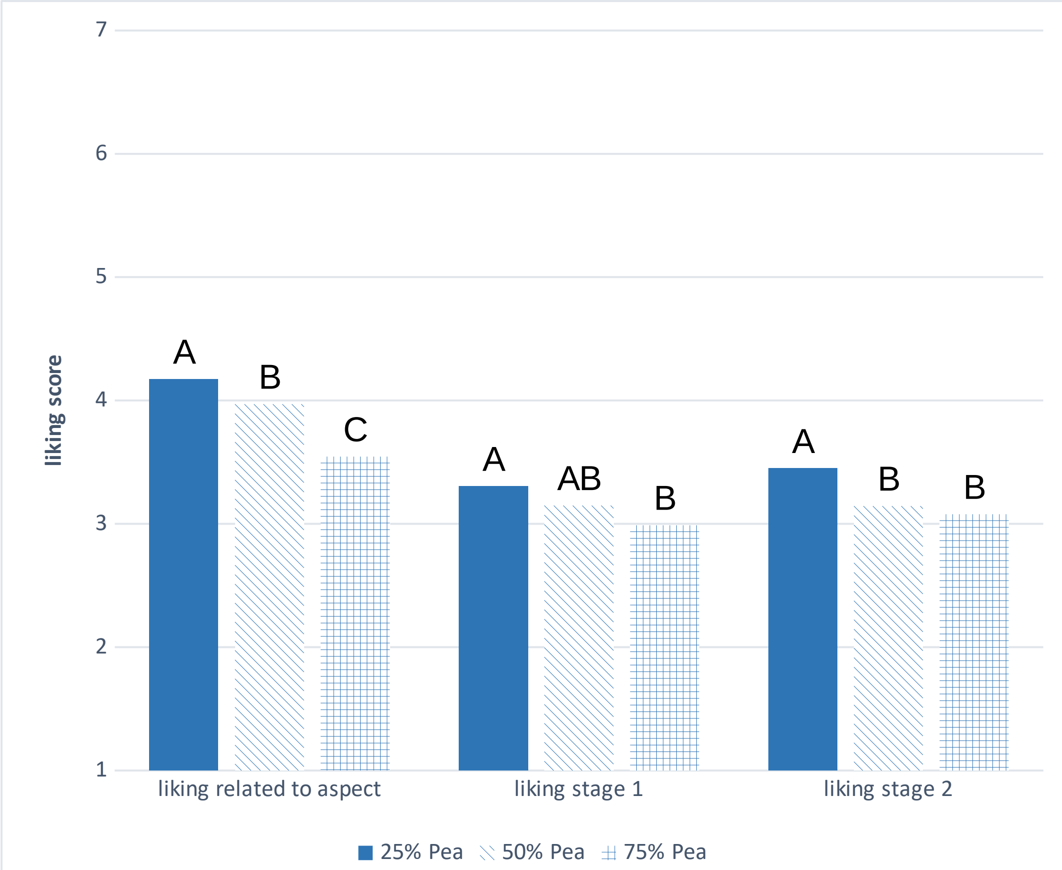
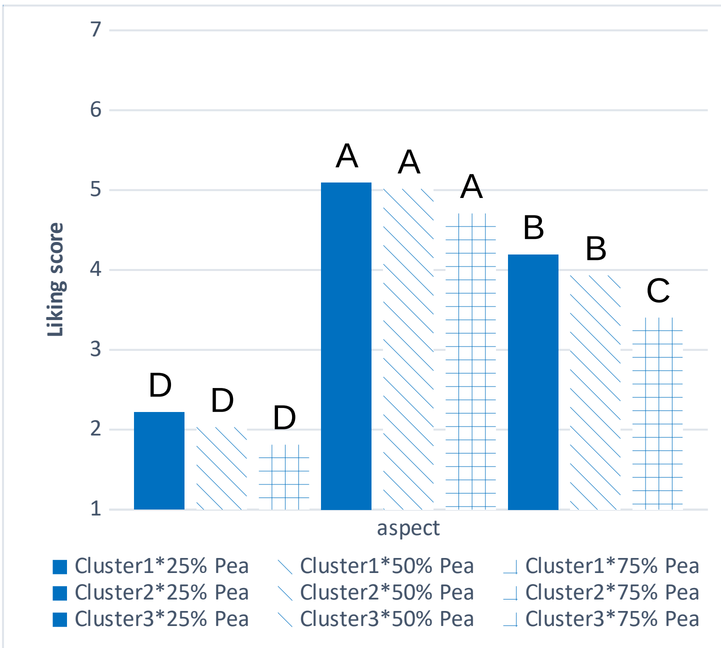
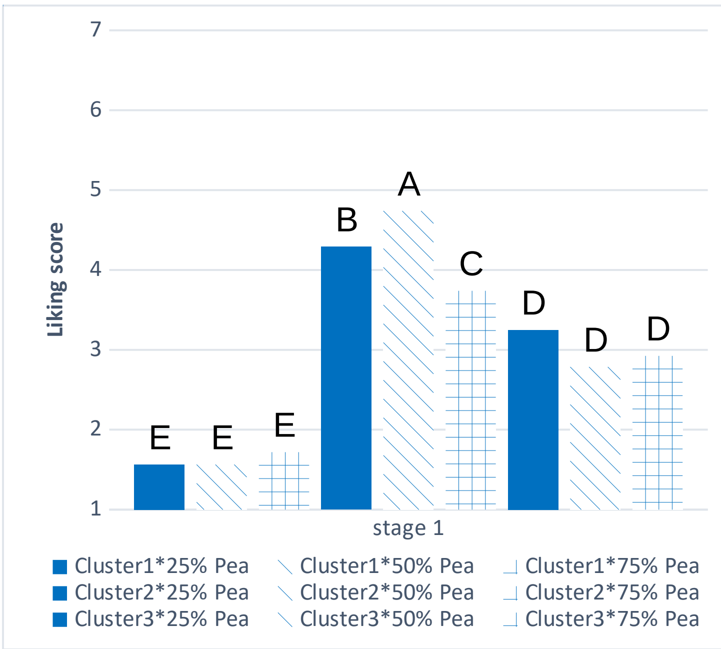


Figure 6. Liking scores of the three fermented products (25% Pea, 50% Pea and 75% Pea) evaluated at the different stages 1 and 2 (mean score of 242 consumers). Note: Post-hoc Newman Keuls tests were conducted to test paired-product differences ($p<0.05$). The letters A to C correspond to the Newman-Keuls group associated and permit to identify sample means that are significantly different from each other.


7
6
5
4
3
2
1
Liking score
D
D
D
A
A
A
B
B
C
aspect
Cluster1*25% Pea
Cluster2*25% Pea
Cluster3*25% Pea
Cluster1*50% Pea
Cluster2*50% Pea
Cluster3*50% Pea
Cluster1*75% Pea
Cluster2*75% Pea
Cluster3*75% Pea


7
6
5
4
3
2
1
Liking score
A
B
C
D
D
D
E
E
E
stage 1
Cluster1*25% Pea
Cluster2*25% Pea
Cluster3*25% Pea
Cluster1*50% Pea
Cluster2*50% Pea
Cluster3*50% Pea
Cluster1*75% Pea
Cluster2*75% Pea
Cluster3*75% Pea

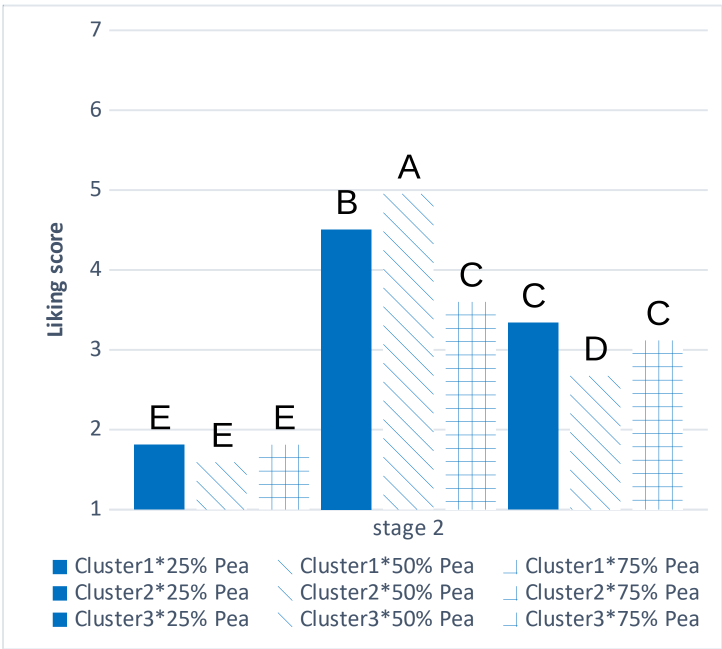


Figure 7. Liking scores related to the appearance (a), the blind tasting at stage 1 (b) and after composition information at stage 2 (c) for the three clusters for each product. Note: Newman Keuls tests were conducted to test paired-product differences ($p<0.05$) and added for cluster*product interaction. The letters A to E correspond to the Newman-Keuls group associated and permit to identify sample means that are significantly different from each other.

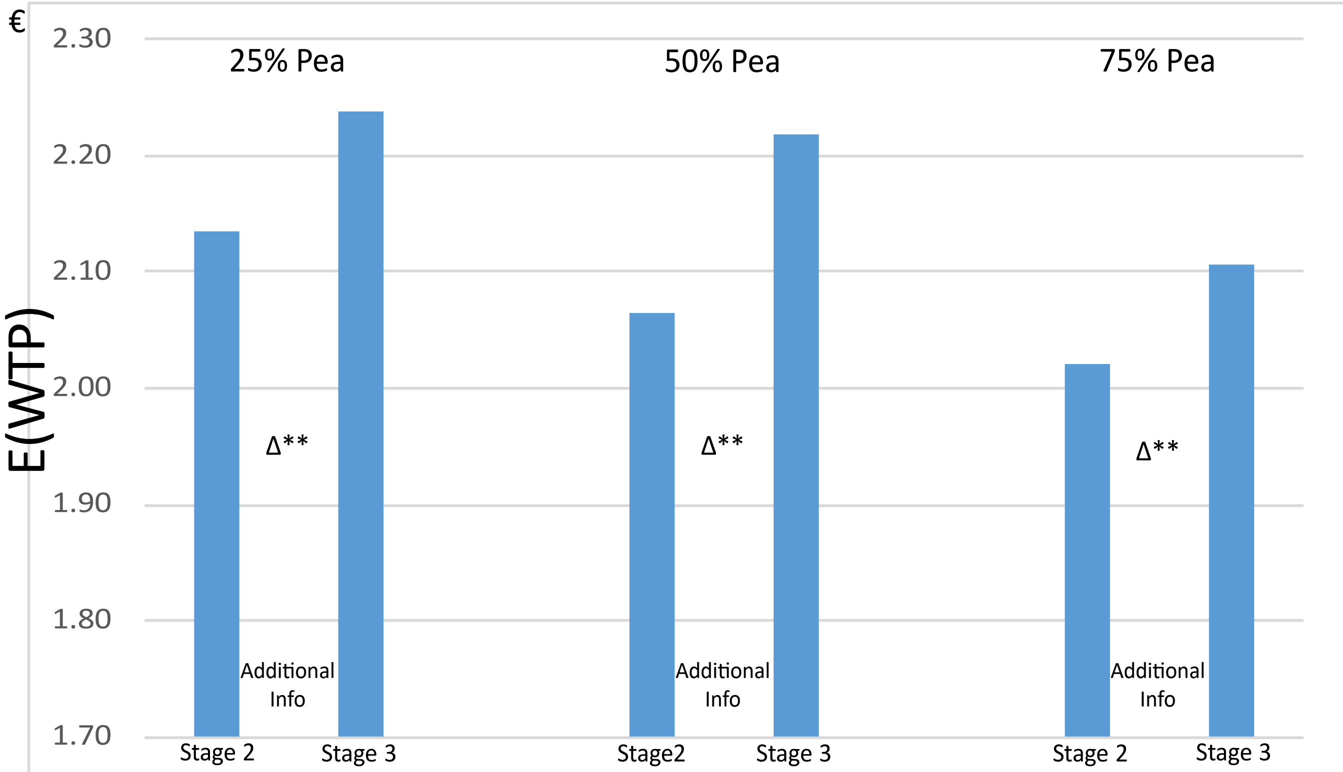


Figure 8. Impact of additional information about nutrition and environment on WTP for 128 engaged participants.

Note: Δ** denotes significant difference at 1% as tested by the Wilcoxon test for comparing paired samples.

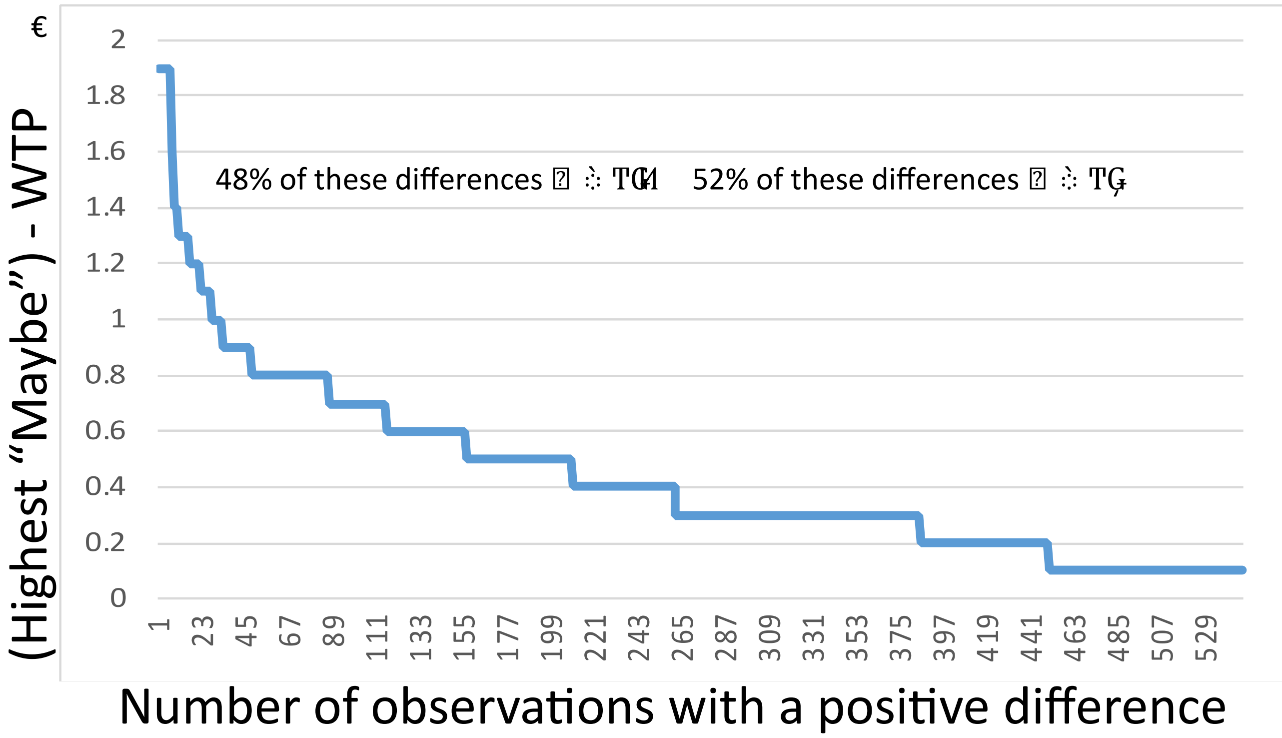


Figure 9. Differences between the highest "Maybe" and the highest "Yes" (WTP) by a same participant. Pooled observations over both stages 2 and 3 and for the three types of fermented products (548 observations with positive differences)

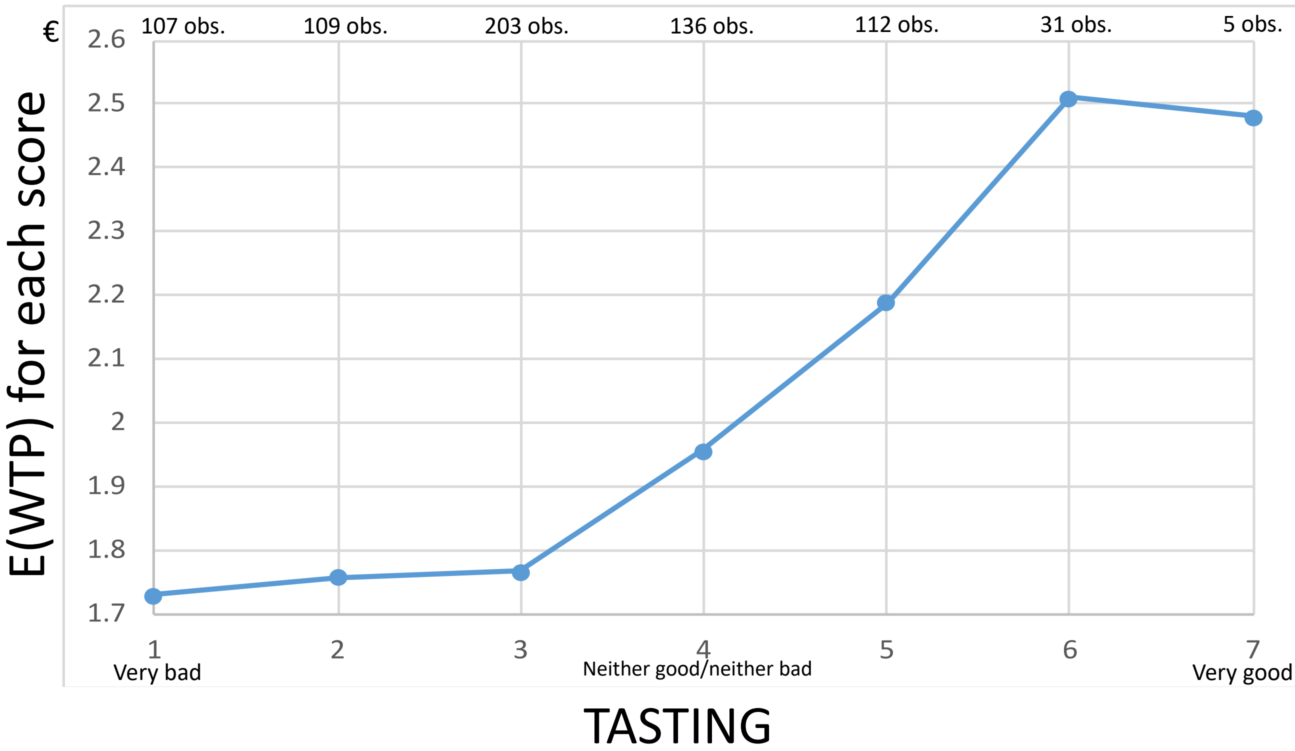


Figure 10. Link between the hedonic score and WTP at stage 2 for the three types of fermented products for which observations are pooled (Spearman correlation coefficient 0.532)

Table 1. Composition of fermented products based on pea protein and milk - biochemical characteristics (pH and dry weight) after the day 0 when the fermented products were created and the day 16 that was the ripening day (% w/w)

		Mix product 25% Pea 75% Milk	Mix product 50% Pea 50% Milk	Mix product 75% Pea 25% Milk	Pea product 100% Pea 0% Milk
Day 0	**Proteins (%)**				
	*** pea**	2.5	5	7.5	10
	*** milk**	7.5	5	2.5	0
	Fat (%)	9.5	9.5	9.5	9.5
	Lactose (%)	12	8	4	0
	Salt (%)	0.2	0.2	0.2	0.2
	pH	5.5	5.6	5.7	5.9
	Dry weight (%)	29.6	27.2	23	20.3
Day 16	**pH**	4.6	4.5	4.5	6.6
	Dry weight (%)	40.3	38.7	34.9	26.3

Table 2: Sociodemographic characteristics of participants

		This experiment 241 participants	French Population[1]
Gender	Women (%)	46	51.6
	Men (%)	54	48.4
Age (year)	20-34 (%)	40	31.2
	35-49 (%)	38	34.4
	59 and over (%)	20	34.4
Level of education[2]	< Baccalaureate (%)	20	28.4
	Bac and bac + 2 (%)	48	40.3
	Higher than bac + 2 (%)	33	31.3

Note: [1] 2018 figures, INSEE (National Institute of Statistics and Economic Studies)
[2] Baccalaureate (bac): French high school diploma

Table 3. Subgroups with specific orders of products appearance

Order of products during sessions	Number of sessions	Overall number of participants
Pea 25%, Pea 50%, Pea 75%	4	43
Pea 25%, Pea 75%, Pea 50%	4	48
Pea 50%, Pea 25%, Pea 50%	4	46
Pea 50%, Pea 75%, Pea 25%	3	36
Pea 75%, Pea 25%, Pea 50%	3	35
Pea 75%, Pea 50%, Pea 25%	3	33
Total	21	241

Table 4: Analyses of variance (ANOVA) on cluster and product with interaction for the liking related to the aspect, the blind tasting at stage 1 and after composition information at stage 2.

	cluster		Product		cluster*Product	
LIKING	*F value*	*P value*	*F value*	*P value*	*F value*	*P value*
aspect - stage 1	230,84	**< 0,0001**	10,16	**< 0,0001**	1,02	**0,395**
stage2	190,27	**< 0,0001**	2,54	**0,080**	7,38	**< 0,0001**
stage3	187,13	**< 0,0001**	4,78	**0,009**	15,12	**< 0,0001**

Table 5. Estimations of pooled WTP with a Tobit random effects estimator
significant at 1%; *: significant at 5%. Standard errors in parentheses.

	239 participants WTP	1 I
25% Pea (1/0)	1.767** (0.020)	
50% Pea (1/0)	1.729** (0.019)	
75% Pea (1/0)	1.704** (0.019)	
25% Pea (1/0) × *Information about Nutrition* (1/0)	0.073* (0.032)	
25% Pea (1/0) × *Information about Environment* (1/0)	0.036 (0.032)	
50% Pea (1/0) × *Information about Nutrition* (1/0)	0.091** (0.032)	
50% Pea (1/0) × *Information about Environment* (1/0)	0.074* (0.033)	
75Pea (1/0) × *Information about Nutrition* (1/0)	0.041 (0.032)	
75% Pea (1/0) × *Information about Environment* (1/0)	0.056 (0.033)	
Stand. devi ε	0.288*** (0.005)	
Stand. dev. μ	0.391*** (0.012)	

Table 5. Estimations of pooled WTP with a Tobit random effects estimator significant at 1%; *: significant at 5%. Standard errors in parentheses.

	239 participants WTP	1 I
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75% Pea (1/0)	1.704** (0.019)	
25% Pea (1/0) × *Information about Nutrition* (1/0)	0.073* (0.032)	
25% Pea (1/0) × *Information about Environment* (1/0)	0.036 (0.032)	
50% Pea (1/0) × *Information about Nutrition* (1/0)	0.091** (0.032)	
50% Pea (1/0) × *Information about Environment* (1/0)	0.074* (0.033)	
75Pea (1/0) × *Information about Nutrition* (1/0)	0.041 (0.032)	
75% Pea (1/0) × *Information about Environment* (1/0)	0.056 (0.033)	
Stand. devi ε	0.288*** (0.005)	
Stand. dev. μ	0.391*** (0.012)	

Appendix A

Details about product preparation, gelation, and fermentation

The pea emulsion was prepared by mixing 64 kg of tap water with 190 g of NaCl in an 80-L stainless steel bioreactor. The solution was heated to 50°C and kept at that temperature for 30 min using the hot water circulation system in the double envelope of the bioreactor. Then, 11.4 kg of pea protein isolate were added. This protein suspension medium was agitated and maintained at 50°C for 20 min before being sterilized. Sterilization was performed via steam injection (110°C for 15 min). The medium was then kept at 60°C for 30 min; 7 kg of rapeseed oil was subsequently added. Lastly, the suspension was heated to 60°C and shaken for 55 min.

The milk emulsion was prepared by mixing 15.48 kg of skimmed cow's milk powder with 32.4 kg of tap water and 132 g of NaCl in a 60-L stainless steel bioreactor. The solution was heated to 50°C and kept at that temperature for 2 h using the hot water circulation system in the double envelope of the bioreactor. The reconstituted milk was then sterilized via steam injection (110°C for 15 minutes). The medium was cooled for 2 h until it dropped to a temperature of 60°C; 4.7 kg of rapeseed oil was then added. The mixture was stirred for 30 min at 60°C.

The two emulsion types were drawn off into sterile cans. The cans were transported to the technology platform, where they were stored overnight in a cold room at 4°C. The two emulsion types were then distributed into four stainless steel manufacturing tanks based on the desired composition: tank 1—100% pea (29 kg); tank 2—75% pea (27.75 kg) and 25% milk (7.25 kg); tank 3—50% pea (14.5 kg) and 50% milk (14.5 kg); and tank 4—25% pea (7.25 kg) and 75% milk (27.75 kg). The four tanks were then heated to 60°C and subject to stirring for 1 h. To initiate gelation, an agar solution (1 L at 1% w/v prepared in boiled water cooled to 50°C) and glucono delta-lactone (GDL; 0.5% w/v) were added to each tank. Tank temperature was then lowered to 40°C and kept there for 30 min before inoculation took place.

The four suspensions were inoculated with a physiological saline solution containing a defined microbial community. Cell density was 6.0 log CFU/g for each bacterial strain and 4.0 log CFU/g for each fungus. The suspensions, which had not yet gelled, were rapidly poured into aluminium moulds (165 mL/type of gel with a mass of 190 g), which were placed in a room kept at 30°C with a relative humidity of 95%. They were left there overnight to allow coagulation to occur.

The products were dried for 24 h under conditions of continuous air circulation; the temperature was lowered by 5°C every 3 h until it reached a stable 10°C. The gels were removed from the moulds, placed on plastic moulds, and incubated in a maturing cellar for 14 days at 9°C with a relative humidity of 92.5%.

Appendix B

Informational texts shown to the participants during stage 3.

Figure B1. Nutritional information about the benefits of pea-based foods shown to 123 participants

Figure B2. Environmental information about the benefits of pea-based foods shown to 118 participants

Appendix C

Specific perceptions of three fermented products

Figure C1 **presents the** perceptions of three fermented products related to 8 criteria namely bitterness, flavor intensity, saltiness, stickiness, hardness, fattiness, protein richness, and sensation of satiation. At the end of stage 1 (blind tasting), we employed a 5-point Likert scale, where 1 was equal to “strongly disagree” and 5 was equal to “strongly agree”. For the three products, the y-axis indicates the percent of participants who agree (including the “strongly agree” replies), who are indifferent, and who disagree (including the “strongly disagree” replies). It shows that the products were found to particularly differ in their bitter, salty, sticky, fatty, and flavor notes.

Figure C1. Specific perceptions of three fermented products