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Understanding consumer liking for sustainable products: insights from EsSense25 and the Emotional Index

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ABSTRACT

Rapid population growth and resource depletion necessitate exploring sustainable food solutions, and brewery spent grain (BSG), rich in fiber, presents a promising approach. This study investigated consumer acceptance of BSG-enriched bread, pasta, and chocolate milk combining explicit self-reported and implicit physiological measures of emotional states. For the explicit measures, 100 consumers rated product liking and completed the EsSense25 questionnaire; while for the implicit measures, 30 participants underwent psychophysiological measurements with a Shimmer3 GSR system to record Galvanic Skin Response (GSR) and heart rate (HR) for each product, which were used to calculate the Emotional Index (EI). Results showed BSG's impact on liking was product-dependent. "Satisfied" and "interested" correlated positively with liking, while "disgusted" and "bored" correlated negatively. PCA revealed distinct emotional profiles for BSG-enriched pasta. Regression models identified "disgusted" and "satisfied" as key liking predictors. The EI was higher during tasting, but didn't correlate significantly with liking. This study shows partial value in integrating traditional hedonic and emotional factors into sustainable food product development, demonstrating the feasability of combining conventional sensory methods with techniques like the EI and EsSense25 to deepen understanding of consumer acceptance, although EI showed only weak alignment with liking.

1. Introduction

Rapid population growth, unequal access to nutrients, shifting consumption patterns, and the depletion or underutilization of natural resources are driving unprecedented challenges in global food systems (Benton et al., 2021; Willett et al., 2019; Hajer et al., 2016) The significant volume of food waste not only represents a loss of valuable resources but also contributes to environmental degradation. In 2020 alone, Europe generated nearly 59 million tons of food waste (De Jong et al., 2023) Agro-industrial by-products, often discarded as waste, add to these environmental challenges (Ahmad et al., 2024). A shift toward prioritizing sustainable diets that promote food security and nutrition is essential (Benton et al., 2021; HLPE, 2021). To achieve this, society must critically evaluate how traditional foods can be adapted to meet nutritional needs while respecting cultural practices. A key aspect of this effort is finding ways to add value to agro-industrial by-products currently discarded as waste by incorporating them into other foods and beverages.

One promising avenue is the utilization of brewery spent grain (BSG), a significant by-product of beer production. Beer, a globally popular beverage with over 188 billion liters produced in 2023 (The Kirin Group Vision, 2024), generates substantial BSG waste, constituting approximately 85 % of brewing by-products (Nigam, 2017). The disposal of this waste is costly and environmentally burdensome. However, BSG's high fiber content (exceeding 44 % in dry extract) makes it a valuable functional ingredient for enhancing the nutritional profiles of various foods (Lynch et al., 2016).

While the revalorization of by-products like BSG offers numerous benefits, consumer acceptance remains a key hurdle (Helkar and Sahoo, 2016; Majerska et al., 2019; Oreopoulou and Tzia, 2007; Otles et al., 2015; Sorrenti et al., 2023). Consumer responses are influenced by both sensory attributes (taste, texture, aroma, and appearance) and emotional experiences (Köster et al., 2007). These emotional responses are shaped by extrinsic cues (packaging, labeling, branding) and

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intrinsic cues (sensory experiences), which interact with pre-existing expectations (Acebrón and Dopico, 2000; Cardello, 2007). For example, while packaging claims such as “by-product” may trigger negative associations, “with barley fiber” suggests health benefits, and may generate more positive expectations (Curutchet et al., 2023).

Intrinsic cues, encompassing both exteroceptive (visual and olfactory) and interoceptive (taste and mouthfeel) aspects, further contribute to emotional responses and, ultimately, product acceptance (Ares and Gámbaro, 2007). Although traditional preference assessments rely on liking ratings (e.g., using a 9-point hedonic scale), recent research emphasizes the role of emotional responses in driving loyalty and decision-making (Meiselman et al., 2022). These approaches include explicit emotion measurements, where consumers self-report their feelings, often through questionnaires such as the EsSense Profile® (King and Meiselman, 2010) or its reduced version, EsSense25 (King et al., 2013), and implicit measurements, which capture unconscious emotional reactions through physiological indicators like heart rate, skin conductance and frontal alpha asymmetry (Lagast et al., 2020; Spinelli et al., 2023). Implicit methods, while bypassing verbalization, often exhibit lower sensitivity (Lagast et al., 2020), and inconsistent results in food studies (de Wijk et al., 2012; Samant et al., 2017), likely due to the complexity of multiple physiological measures.

The Emotional Index (EI) is a unidimensional composite, first introduced by Vecchiato et al. (2014), derived from the two-dimensional valence–arousal framework of Russell and Barrett (1999), which locates affective states within a continuous 2D “affective plane”. In this framework, valence (pleasure–displeasure) and arousal (activation–deactivation) are indexed physiologically by heart rate (HR) and galvanic skin response (GSR), respectively, reflecting their sympathetic and parasympathetic influences. To operationalize EI, moment-by-moment HR and GSR signals are normalized and combined—often via a weighted-difference or principal-component approach—so that positive EI values correspond to pleasant, low-effort states and negative values to displeasure or stress. This approach has been applied successfully to television advertising, where EI tracked viewers’ implicit emotional engagement with commercial content frame by frame (Vecchiato et al., 2014a, 2014b). Despite its demonstrated sensitivity to fine-grained shifts in affect during dynamic stimuli, the Emotional Index (EI) has seen very limited application overall and—crucially—has never been used to study complex food products; except for a study conducted by Cartocci et al. (2017) on wine tasting and olfaction. In this study, EI score was found to be more positive when consumption involved both taste and smell compared to consumption excluding olfactory experience. Unlike discrete questionnaires (e.g., EsSense25), which capture self-reported or overt expressions of emotion, EI delivers an implicit, continuous readout of consumer affect by integrating heart rate and skin conductance. This allows it to tap into unconscious physiological responses that may diverge from stated liking. In the present study, we apply HR, GSR and – for the first time – EI to compare regular food products with their brewery-spent-grain–enriched reformulations, investigating whether these implicit arousal–valence patterns correspond to explicit liking scores and self-reported emotional profiles.

Studies have shown that labeling and branding significantly impact consumer perception of BSG-enriched products (Curutchet et al., 2023; Varghese et al., 2024). Understanding the interplay of sensory, cognitive, and emotional factors is crucial for developing successful, sustainable products ; (Ares and Gámbaro, 2007; Shepherd, 1994).

Therefore, this study aimed to explore non-traditional methods, specifically the Emotional Index (EI) and the self-reported EsSense25 questionnaire, to evaluate consumer liking of three sustainable products: BSG-enriched bread, pasta, and chocolate milk; and to compare these methods with conventional liking evaluations. Building upon previous work on optimal labeling (Curutchet et al., 2023), this research focuses on measuring consumer emotional responses to these products, considering both extrinsic and intrinsic cues.

Table 1
List of terms and classification described by EsSense25.

Emotion (EN)	Emotion (ES)	Classification
Active	Activo	Positive
Adventurous	Aventurero	Positive
Aggressive	Agresivo	Unclassified
Bored	Aburrido	Negative
Calm	Calmo	Positive
Disgusted	Asqueado	Negative
Enthusiastic	Entusiasmado	Positive
Free	Libre	Positive
Good	Bien	Positive
Good-Natured	Bondadoso	Positive
Guilty	Culpable	Unclassified
Happy	Feliz	Positive
Interested	Interesado	Positive
Joyful	Alegre	Positive
Loving	Amoroso	Positive
Mild	Leve	Unclassified
Nostalgic	Nostálgico	Positive
Pleasant	Agradable	Positive
Satisfied	Satisfecho	Positive
Secure	Seguro	Positive
Tame	Insulso	Unclassified
Understanding	Comprensivo	Positive
Warm	Afectuoso	Positive
Wild	Salvaje	Unclassified
Worried	Preocupado	Negative

2. Methods

2.1. Product formulation

Consumers’ expectations tend to vary by product category; therefore, three distinct items were chosen for this study: bread and pasta, representing utilitarian foods, and chocolate-flavored milk as a hedonic example. A 2 × 3 factorial design was employed, with two independent factors: Enrichment (2 levels: BSG-enriched vs. Control) and Product Category (3 levels: bread, pasta, chocolate-flavored milk). The study incorporated Brewery Spent Grain (BSG) into bread (8.3 % w/w), pasta (2.8 % w/w), and chocolate milk (0.35 % w/w), as described by (Curutchet et al., 2022), to produce fiber-enriched versions of these products. The formulations met the dietary fiber requirements to qualify for a "source of fiber" claim under Uruguayan regulations and the Codex Alimentarius. Regular, non-enriched versions of these products were also developed for comparison.

2.2. Label design and product prototypes

Product label designs for pasta, bread, and chocolate milk were adapted from (Curutchet et al., 2022), which identified the most effective labels for generating favorable consumer perception. Each label featured a sustainability logo, a fiber content claim, and a brief description of the benefits of Brewery Spent Grain (BSG) for both consumers and the environment. The fiber-enriched versions met Uruguayan nutritional claim standards, displaying the statement "Source of Dietary Fiber." In contrast, the non-BSG products were labeled as regular bread, pasta, and chocolate milk without additional fiber or sustainability claims, serving as control comparisons. To ensure real-life conditions, prototypes of the products were created with true packaging designs and labels, providing participants with a complete, authentic product experience. This approach allowed consumers to see, feel, and try the product in a way that closely resembled typical market conditions.

2.3. Data collection

2.3.1. Explicit techniques (liking and EsSense25)

Each product (bread, pasta, and chocolate milk) was evaluated by

100 different consumers, following a between-subjects design for product comparisons. Within each product, the same consumers assessed both the regular and BSG-enriched versions in a counter balanced order using a Williams design (Curutchet et al., 2022). Participants first reviewed the product labels, then tasted the product, rated overall liking on a 9-point hedonic scale, and finally completed the EsSense25 questionnaire. The 25 emotions, translated into Spanish and presented in random order, were rated on a 5-point scale and its corresponding emotional valence classification (Table 1) according to the author's original work (King & Mieselman, 2010) Randomization was applied both between and within subjects.

2.3.2. Implicit techniques (GSR, HR and Emotional Index)

Thirty consumers participated in psychophysiological assessments using a Shimmer3 GSR system (Shimmer, Dublin, Ireland) to record Galvanic Skin Response (GSR) and heart rate (HR) for each product. Electrodes were attached to the index and middle fingers of the non-dominant hand, and an optical pulse ear-clip was placed on the earlobe to measure HR. Participants were instructed to keep their non-dominant hand still to ensure accurate measurements. Each session began with a ~30 s calibration period, allowing physiological signals to stabilize while relaxation music played.

The three different products were tested, each in regular and fiber-enriched versions. Each participant evaluated only one product in both versions, and presented in a random order, to prevent carryover effects and ensure unbiased physiological responses. Product evaluations followed a Williams Latin square design. First, participants were presented with the product prototype packaging for free handling for as long as they desired, allowing the collection of data corresponding to intrinsic exteroceptive cues. Once completed, they received a sample of that version for consumption, with taste and mouthfeel corresponding to intrinsic interoceptive cues. A break of approximately 30 s was provided to allow physiological responses to reset, after which the second version of the same product was evaluated in the same manner.

2.4. Data analysis

For explicit emotion data, principal Component Analysis (PCA) using a correlation matrix was conducted to explore the clustering of products based on the mean reported emotions. A Pearson correlation matrix was used to examine the relationships between self-reported emotions and liking. A two-way ANOVA was conducted for overall liking, with enrichment (BSG and regular) and instruction (visualize and taste) as the main factors, for all three products.

Predictive models for liking (y) based on 25 self-reported emotions (x) were developed using multiple linear regression with ANOVA-based model selection and a Generalized Additive Model (GAM) with ANOVA-based model selection to account for potential nonlinear relationships.

For implicit emotional measurements, the average GSR and HR during each stage (Visualize and Taste) was determined, and the Emotional Index (EI) was computed for each individual at each stage, following the method described by (Vecchiato et al., 2014).

First, Z-score transformations were applied to both the GSR and heart rate HR using baseline measurements from the calibration stage to normalize physiological responses,:

$$GSR_Z = \frac{(GSR - \mu_{GSR,calib})}{\sigma_{GSR,calib}} \quad HR_Z = \frac{(HR - \mu_{HR,calib})}{\sigma_{HR,calib}}$$

And the EI was determined as:

$$EI = \begin{cases} -\frac{3}{2} + \frac{atan2(GSR_Z, HR_Z)}{\pi} & if \ GSR_Z \geq 0 \ and \ HR_Z \leq 0 \\ \frac{1}{2} + \frac{atan2(GSR_Z, HR_Z)}{\pi} & otherwise \end{cases}$$

where the atan2 function determines the angle in the *"effect plane"* and the value is adjusted so that it varies between −1 and 1. Positive emotions are correlated with HR above average and result in an EI>0, and negative emotions are correlated with HR lower than average and EI<0. GSR values above average correspond to higher absolute values of EI (|EI|>0.5) and lower than average correspond to low values of EI (|EI|> 0.5) (Vecchiato et al., 2014).

In this way the individual emotional reactions during product evaluation at each stage was obtained for everyone.

During data collection, rare instances were observed where participants' HR was not properly captured, likely due to movement artifacts. These time points were excluded if they accounted for <5 % of the data. Participants with frequent occurrences of this issue (>5 % of the data) were excluded from the analysis.

A two-way ANOVA was performed for GSR_Z, HR_Z, and EI, with enrichment (regular and BSG) and instruction (visualize and taste) as main factors, across all three products. Additionally, the relationship between mean EI and mean liking during the "Visualize" and "Taste" stages was assessed through correlation analysis.

All statistical analyses were performed in RStudio (2024.09.1), while the EI computation was performed using a custom python script.

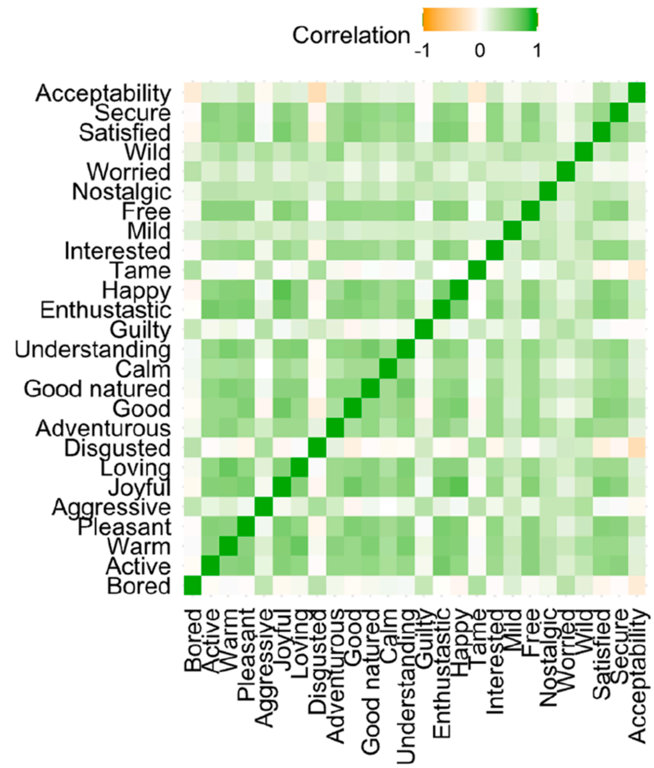

Fig. 1. Correlation Matrix of Consumer self-reported emotions and liking across the three products.

Table 2
Mean liking scores by product.

	Bread	Pasta	Chocolate milk
Regular	6.56 ± 0.15	6.07 ± 0.15b	6.61 ± 0.17
BSG	6.22 ± 0.20	6.78 ± 0.18a	6.09 ± 0.23

3. Results and discussion

A two-way ANOVA (Fig. 1) showed a significant Condition × Product interaction ($p < 0.01$), suggesting that the effect of enrichment (BSG vs. regular) on liking depended on the product. No significant main effect was observed for enrichment alone, but the main effect of product

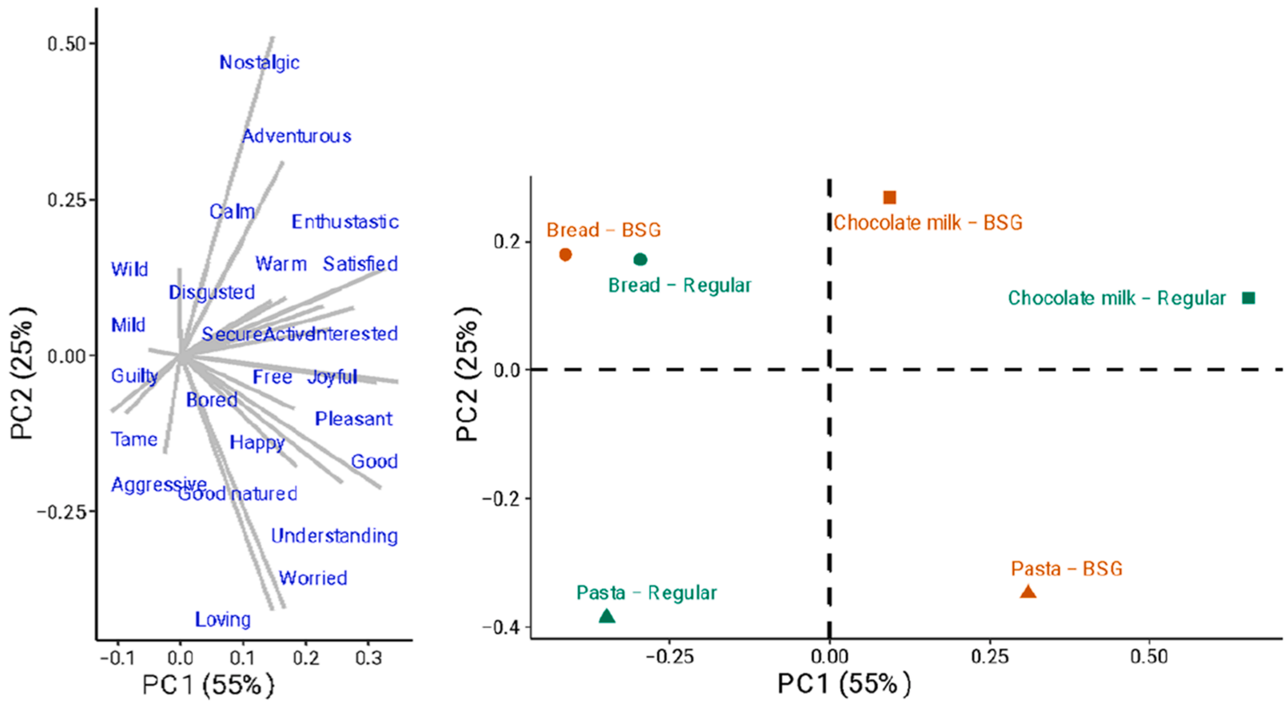

Fig. 2. Principal component analysis (PCA) of products based on reported emotions.

approached significance ($p = 0.069$). In Table 2 are shown liking means by product. Similar findings have been reported in studies where BSG inclusion significantly altered sensory attributes and consumer acceptability, particularly in food matrices like pasta and bread (Naibaho et al., 2024). This variation highlights the importance of context-specific formulations when integrating sustainable ingredients

(a)

Coefficients	Estimate	Std. Error	t value	Pr(>t)
(Intercept)	5.216	0.291	17.94	**<0.001**
Disgusted	-0.642	0.813	-7.90	**<0.001**
Satisfied	0.534	0.897	5.95	**<0.001**
Pleasant	0.255	0.094	2.73	**0.007**
Joyful	-0.221	0.093	-2.38	**0.018**
Nostalgic	0.149	0.065	2.30	**0.022**

F-statistic: 35.78 on 5 and 598 DF, p-value: < 2.2e-16

(b)

Approx. sig. of smooth terms	edf	Ref.df	F	p-value
s(Disgusted)	1.000	1.001	65.51	**<0.001**
s(Satisfied)	1.290	1.518	24.89	**<0.001**
s(Wild)	2.577	2.862	8.79	**<0.001**
s(Pleasant)	1.000	1.001	6.39	**0.0117**

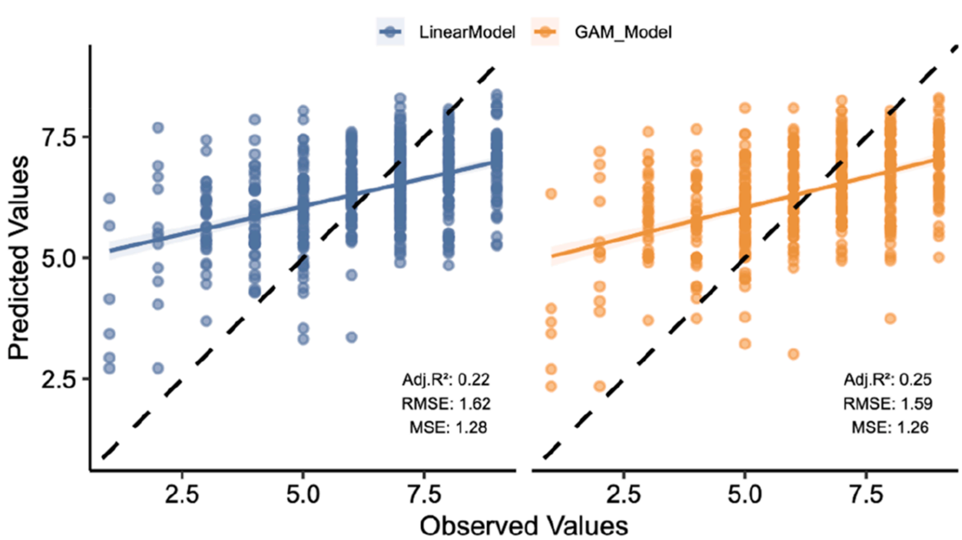

Fig. 3. Results for the two selected models: (a) Linear regression, and (b) Generalized additive model (GAM), with the top panel showing the model summaries for predicting product liking from consumer self-reported emotions, and the bottom panel showing the comparison of predicted vs. observed liking scores.

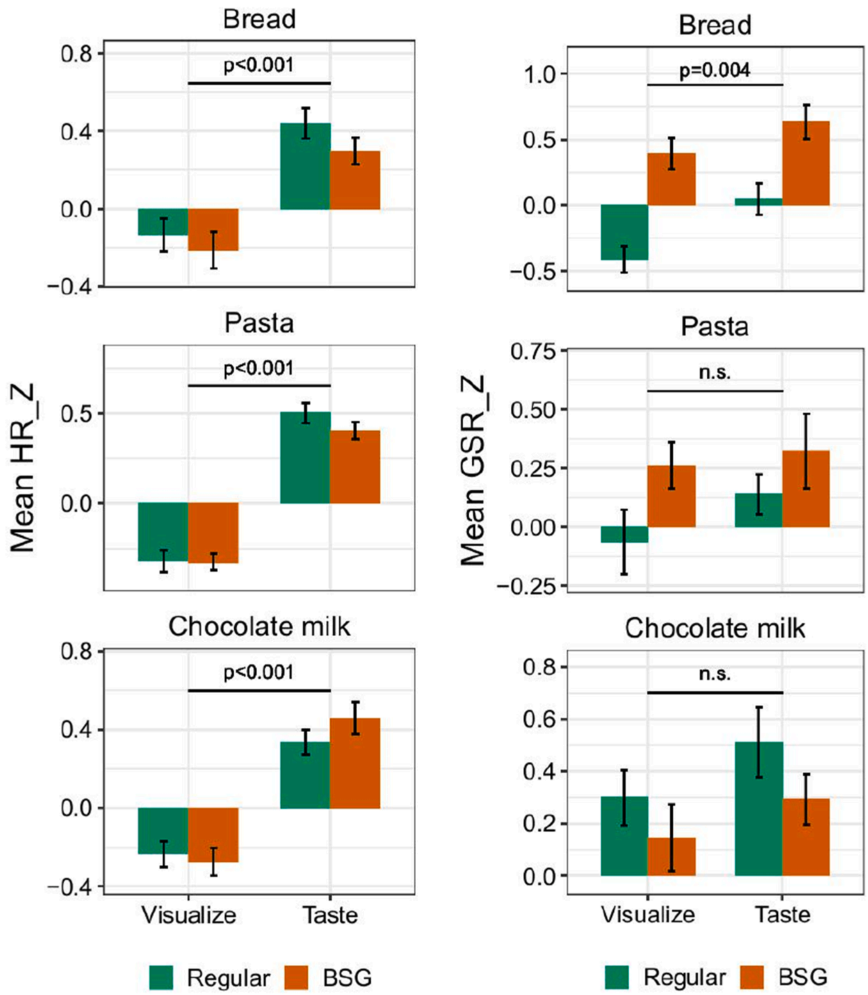

Fig. 4. Left: Mean HR and GSR for bread, pasta, and chocolate milk (regular vs. BSG).

like BSG, as its impact on techno-functional properties can influence product acceptability.

3.1. EsSense25

Correlations between product acceptability and consumer self-reported emotions are highlighted in Fig. 1. Positive emotions, specifically 'satisfied' and 'interested,' show moderate positive correlations with liking, indicating that these feelings are meaningful indicators of product preference. On the contrary, negative emotions such as 'disgusted' and 'bored,' and unclassified emotions like 'tame' are negatively correlated with liking, highlighting the importance of mitigating these perceptions in product development.

Hanmontree et al. (2022) studied emotional and wellness profiles of herbal drinks using different questionnaire designs, it is suggested that the specific inclusion of positive emotional descriptors such as 'satisfied' and 'interested' in product labels can significantly enhance product acceptance. They reported that the application of the EsSense Profile scales effectively captures the breadth of emotional responses associated with the consumption of herbal drinks.

Building on this, Fig. 2 shows emotional responses for regular and fiber-enriched bread, pasta and chocolate milk. The BSG-enriched pasta version evokes emotions such as "good" and "pleasant," indicating positive consumer engagement with this sustainable option. However, the emotion "worried" also emerges, likely due to unfamiliarity with BSG's texture and/or flavor, suggesting a mix of positive and hesitant responses. Previous results showed that BSG enrichment significantly impacts the sensory properties of all three products ($p < 0.05$), affecting both texture and flavor (Curutchet et al., 2022). In contrast, the regular version of pasta is associated with "tame," "aggressive," and "guilty" emotion, highlighting distinct emotional profiles that could underlie consumer choices and acceptance. Among the three BSG-enriched products, pasta had the most marked effect on consumers' perceptions and was the only product to receive higher liking scores ($p < 0.05$) compared to its regular version (Curutchet et al., 2022). No clear differences were observed for the other product pairs evaluated. The emotional response to BSG-enriched products was found to be product-dependent, indicating that the type of product significantly influences how consumers emotionally react to the incorporation of BSG.

Models for predicting product liking based on consumer self-reported emotions for linear regression and generalized additive model (GAM) were constructed (Fig. 3). Both model summaries indicated that "disgusted" and "satisfied" were the primary emotions associated with liking. The multiple linear regression model was statistically significant ($p < 0.001$), with "disgusted" exhibiting the largest negative effect ($\beta = -0.642$) and "satisfied" the largest positive effect ($\beta = 0.534$). These findings align with previous research highlighting disgust as a key determinant of food preferences (Meiselman et al., 2022). The variance inflation factor (VIF) was low, confirming the absence of multicollinearity, and diagnostic plots indicated no violations of regression assumptions.

In the GAM model, "wild" and "pleasant" were also significant predictors, while the regression model identified "pleasant," "joyful," and

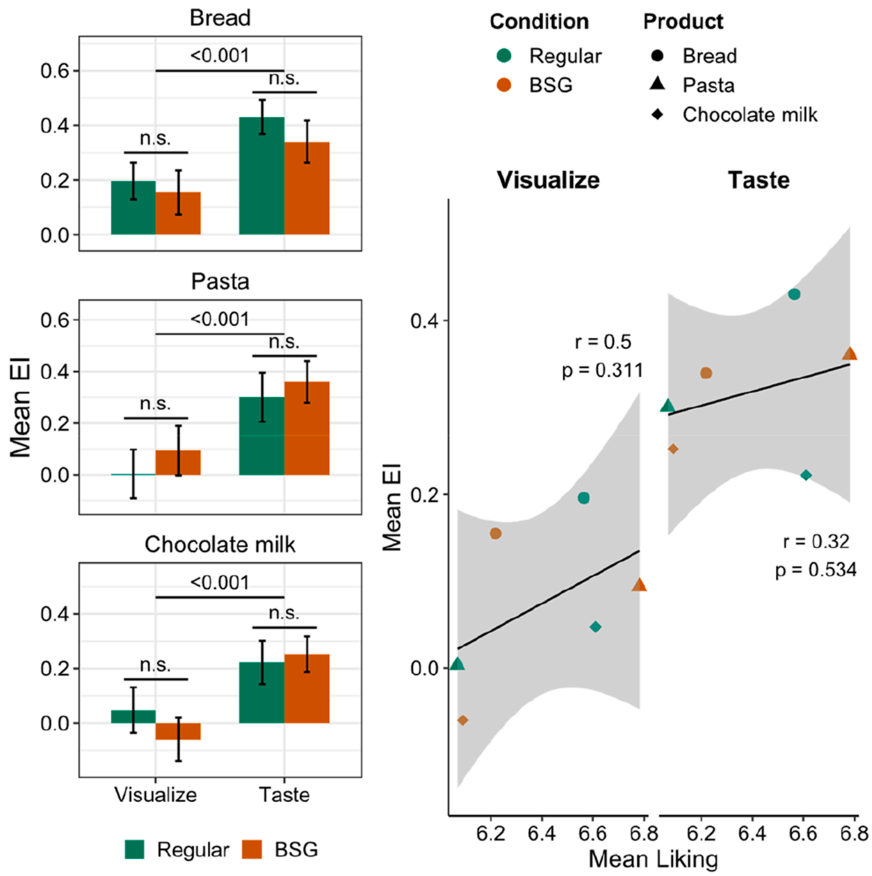

Fig. 5. Left: Mean emotional index (EI) for bread, pasta, and chocolate milk (regular vs. BSG) across the "Visualize" and "Taste" instruction stages, where error bars represent standard deviation (*). Right: Relationship between mean emotional index (EI) and mean liking during the "Visualize" and "Taste" stages for all products. **n.s. and p-values are results from two-way Anova (Instruction*Condition) for each product.*

"nostalgic" as additional significant emotions. For the GAM model, "disgusted" and "pleasant" exhibited a linear relationship (EDF = 1), whereas "satisfied" and "wild" showed varying degrees of nonlinearity (EDF = 1.25–2.58). Notably, "joyful" had a negative coefficient in the multiple regression model, suggesting an inverse association with liking.

Both models exhibited low adjusted R-squared values, high root mean square error (RMSE) and mean square error (MSE), indicating that a substantial portion of the variation in liking remains unexplained. This suggests that the EsSense25 data may provide deeper insights into the emotional drivers that influence liking.

3.2. Emotional Index

Physiological responses differed significantly between traditional and BSG products for bread and pasta ($p < 0.05$). GSR was higher when participants consumed the BSG product compared to the regular version, indicating greater sympathetic arousal (Fig. 4). HR did not show a significant change due to enrichment but increased during the tasting of the

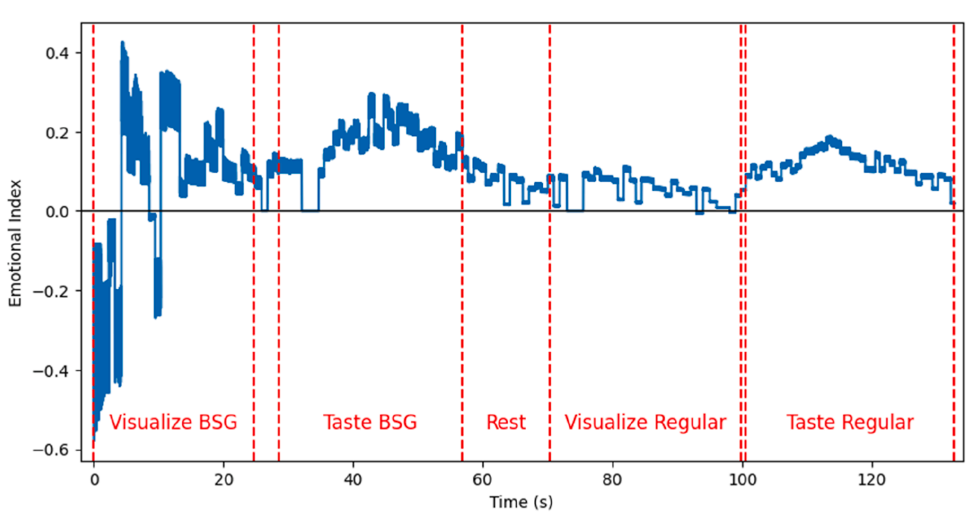

Fig. 6. Emotional index (EI) for a single consumer's bread experiment. The whole experiment lasted approximately 130 s.

BSG food compared to the visualize stage ($p < 0.05$), suggesting enhanced emotional engagement (Fig. 4). These effects were product-dependent and varied between hedonic and non-hedonic items, with stronger physiological responses observed particularly for no hedonic products such as bread and pasta. These findings align with previous research demonstrating that foods associated with stronger emotional reactions—either positive or negative—elicit heightened autonomic nervous system activity, such as increased skin conductance and heart rate (de Wijk et al., 2012). For bread the higher GSR values during tasting, compared to visual exposure, reinforces the idea that direct oral consumption elicits stronger emotional arousal—an effect previously documented in studies employing skin conductance as an index of affective response to food witch also found differences in the Autonomic Nervous System (ANS) between look and smell test instructions. (de Wijk et al., 2012).

Results of the three-way ANOVA on the EI showed a significant main effect of product, $F(2, 328) = 6.17$, $p = 0.0023$, and instruction, $F(1, 328) = 138.44$, $p < 0.0001$, but not enrichment, (Fig. 5). EI was higher during the 'Taste' stage, where positive values were consistently observed. In contrast, the 'Visualize' stage showed a lower average EI with greater within-subject variability. As illustrated in Fig. 6, where a single consumer's EI values are plotted over time, EI fluctuated between negative and positive values, likely depending on the specific label area the consumer focused on. Previous studies using the IE by (Cartocci et al., 2017) showed similar patterns, with higher EI results observed during multisensory wine-drinking experiences when the olfactory component was present compared to when it was absent.

The correlation between mean EI (from 30 consumers per product) and overall liking (from 100 consumers) was non-significant, though a positive trend was observed for both instructions. These results suggest a potential relationship, but further research is needed to confirm this, particularly by focusing on products with strong like or dislike ratings (Lagast et al., 2020) and directly measuring consumer liking alongside physiological responses. Although no significant correlations were found between EI and liking, this discrepancy highlights the importance of considering the hole consumer experience, as suggested by (de Wijk et al., 2025). Their findings emphasize that emotional responses unfold across multiple stages—from anticipation to consumption—and that implicit physiological measures can provide critical insights into subconscious reactions that may not align with rational evaluations. In this context, EI serves as a valuable complement to self-reported data, especially for products that challenge expectations or signal sustainability attributes.

The study's limitations include a small sample size for physiological measurements and different moments of evaluation between explicit and implicit emotional measurements, which may affect the generalizability of the results. Only one product was tested per category, which constrains the extent to which the results can be generalized across broader product ranges. Additionally, the controlled environment may not fully replicate the conditions under which consumers typically interact with products, potentially limiting the ecological validity of the findings. Future research should address these limitations by including larger and more diverse samples, testing multiple items per category, and assessing consumer responses under more natural conditions. Even though studies show that skin conductance can be interpretated as arousal (de Wijk et al., 2012), others also propose different interpretations (Quigley et al., 2014), that could be incorporated in the analysis.

Despite the limitations outlined, this study significantly advances our understanding of the complex interplay between emotional responses, and consumer acceptance of sustainable food products enriched with brewery spent grain. Highlighting the innovative and evolving use of emotion measurement in product development.

4. Conclusion

This study offers valuable insights into the effects of emotional evaluations on consumer acceptance of sustainable food products. It was found that the presence of BSG does not significantly impact acceptability but rather interacts with product type to influence consumer hedonic response. Emotional responses, particularly positive emotions such as satisfaction and interest, were closely linked to higher product liking, underscoring the importance of aligning product attributes with positive emotional triggers.

The application of the Emotional Index (EI) demonstrated more pronounced physiological responses during the tasting phase than during the visualization phase. However, these responses did not show a significant correlation with acceptability. Although this study did not find a significant effect of the EI, the use of emotional measures remains a valuable complement to traditional sensory evaluation methods. The findings highlight the need for further research to optimize the application of this techniques in order to capture consumer responses and guide the development of sustainable and nutritionally improved food products.

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Ethic statement

The studies involving human participants were reviewed and approved by ethical committee, Universidad Católica del Uruguay in June 2021. Participants provided their written informed consent to participate in this study

CRediT authorship contribution statement

Maite Serantes Laforgue: Writing – original draft, Visualization, Software, Data curation, Conceptualization. **Patricia Arcia:** Writing – original draft, Visualization, Funding acquisition, Formal analysis, Conceptualization. **Matías Miguez:** Validation, Software, Data curation. **Juan Menéndez:** Writing – original draft, Data curation. **Ana Curutchet:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

All authors declare no conflicts of interest.

Data availability

Data will be made available on request.

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