Pasteurised eggs - A food safety solution against *Salmonella* backed by sensorial analysis of dishes traditionally containing raw or undercooked eggs

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ABSTRACT

This study evaluates the potential of pasteurised eggs to be used as a replacement for raw eggs in recipes where eggs remain uncooked or undercooked. Sensory tests were performed by 178 untrained panellists (143 from Portugal and 35 from Romania) using a 9-point hedonic scale. The tested recipes were tiramisu, chocolate mousse, eggnog, hollandaise sauce, and condensed milk mousse (*Baba de camelo*). While in Portugal the colour and texture of the chocolate mousse prepared with pasteurised and unpasteurised eggs differed significantly, no significant differences in regards to the organoleptic attributes were recorded in Romania. Nonetheless, the results revealed comparable distribution scores regarding the overall acceptability for all the recipes indicating an agreement among panellists for both raw and pasteurised eggs dishes in both countries. The regression analysis showed that the main drivers of consumers' acceptance of dishes made with pasteurised eggs are flavour and texture. This research demonstrates that five dishes prepared with liquid pasteurised eggs are accepted by consumers as they cannot clearly be distinguished from their counterparts prepared with raw eggs. As *Salmonella*-contaminated eggs are the most frequent cause of salmonellosis, pasteurised eggs can be used as a safer ingredient to substitute shell eggs in raw egg-based dishes without significant reduction of the sensory quality of the dish. Since liquid pasteurised eggs are already widely used, especially by industry and restaurants, we provide reasons supporting pasteurisation of eggs in shell as a more convenient solution for consumers. Pasteurised eggs, either liquid or in shell, constitute a way to reduce the burden of foodborne diseases by diminishing the number of cases of salmonellosis associated with cooking at home. Researchers and food safety authorities can use our results as a starting point for future studies or intervention strategies.

1. Introduction

Eggs and dishes made with eggs are one of the most frequent sources of foodborne outbreaks being involved in 15.7% of the total foodborne outbreaks in 2020 and causing 44% of strong-evidence *Salmonella* outbreaks in Europe (EFSA and ECDC, 2021). The Rapid Alert System for Food and Feed (RASFF) notifications concerning the presence of *Salmonella* in eggs and products from eggs appear regularly and relate to different European Union Member States (European Commission, Directorate-General for Health and Food Safety, 2017). The most recent RASFF notifications are from March 9 and 23, 2022, when

Salmonella Enteritidis was reported in egg whites in Poland (RASFF Window. 2022a) and Belgium (RASFF Window. 2022b), which lead to the withdrawal of the eggs from the market, and from May 6, 2022 when Lithuania and Poland reported Salmonella Enteritidis in whole egg powder from Bulgaria (RASFF Window. 2022c; RASFF Window. 2022d). On November 1st, in 2021, it was a notification alerting for *Salmonella* Enteritidis in fresh eggs from Denmark, which affected 18 persons and ended with a recall (RASFF Window, 2021a), and two notifications at the beining of the year: one regarding *Salmonella enterica* ser. Mbandaka found in egg yolk powder from Poland that had to be distributed in Sweden (RASFF Window, 2021b), and one regarding

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Salmonella enterica ser. Enteritidis in eggs from Poland that had to be distributed in Belgium, Germany, and the Netherlands (RASFF Window, 2021c). In December 2020, *Salmonella enterica* ser. Coeln was found in eggs from Latvia (RASFF Window, 2020a). In July 2020, a foodborne outbreak was suspected to be caused by *Salmonella enterica* ser. Enteritidis in eggs from France (European Commission, Directorate-General for Health and Food Safety, 2021, RASFF Window, 2020b) and in June 2020 an outbreak was caused by the consumption of British Lion eggs (Whitworth, 2020).

Between the begining of February and the end of November 2017, eight European countries reported 196 confirmed cases and 72 probable cases of salmonellosis caused by *Salmonella enterica* ser. Enteritidis. After the epidemiological investigation which linked the outbreak to Polish eggs, 97 million eggs distributed in 18 European countries and 30 million which have been distributed to 12 third-countries were withdrawn (European Commission, Directorate-General for Health and Food Safety, 2019).

In order to reduce the risk of foodborne illnesses related to eggs consumption, food safety authorities suggest an array of measures to be taken along the entire food chain. CDC include egg pasteurisation among these measures (CDC, 2019a), while EFSA does not, although the salmon ellosis rate in the EU (The EU/EEA notification rate was 13.7 cases per 100,000 population) (EFSA and ECDC, 2021) does not differ much of that declared by the US (16.7 cases per 100,000 population) (https://www.statista.com/statistics/379025/us-salmonella-rate-by-state/).

Pasteurised eggs are eggs that have been submitted to a mild thermal treatment but sufficiently to kill salmonellae and bird flu viruses that can contaminate them. Pasteurisation can be applied either to eggs in shell or to eggs' content. Although laws do not require worldwide that whole eggs in shell be pasteurised, such eggs are now commercially available in some countries like Belgium (www.cocovite.be), Australia (www.safeeggs.com.au) and the USA (http://www.safeeggs.com/food-service/benefits/regulatory-compliance). On the other hand, egg products like liquid refrigerated and frozen, either as whole eggs or eggs' components (yolks and whites), are commercially available on a larger scale, and they are required by law to be pasteurised. Such products are used in commercial bakeries, restaurants, diners, hospitals, hotels, caterers and food service venues and are also suitable for home use (USDA FSIS, 2013). The use of pasteurised eggs and egg products is recommended in dishes prepared with raw or undercooked eggs, especially for vulnerable groups such as children, elderly, and people with immune-compromised systems (FDA, 2017). Despite a slightly higher price and low availability in some countries (e.g., Romania), pasteurised eggs are advantageous as they are no longer considered hazardous foods as raw eggs. However, to maintain quality and shelf life, proper storage (refrigeration) is still recommended (FDA, 2017). The benefits of liquid pasteurised eggs include smaller space required for storing, increased efficiency in food preparation, saving time to remove shells, and risk elimination of breaking them (https://supereggs.ro/), while the benefit of using pasteurised eggs in shell is that of no need to change consumers' routines. Pasteurisation of eggs in the shell uses other techniques than thermal heating and these are: radio frequency combined with hot water (Yang et al., 2020), hot water immersion, hot water spraying, hot air alone or combined with radio frequency (Yang and Geveke, 2020), far-infrared (IR) heating and continuous IR heating (Alkaya et al., 2021), and ozone and UV irradiation (Mattioli et al., 2020). Pasteurisation of liquid whole eggs up to 10 min at 60 °C improved whole egg functionalities (foaming, emulsifying, gelling), while treatments over 64 °C showed a decrease of whole egg functionalities. Treatments between 62 and 64 °C (up to 10 min) are recommended for safety reasons as well as to prevent detrimental effects on the eggs' functional properties (Lechevalier et al., 2017). Even though eggs are to be stored in refrigeration conditions, Shenga et al. (2010) reported that during storage at the ambient temperature of both raw and pasteurised eggs, the latter were significantly better preserved ($p < 0.05$) in terms of sensory quality aspects, such as colour, flavour, and overall acceptability, as well as in regards to functional properties (foam volume and stability).

The acceptance of pasteurised eggs in shell among consumers is variable as shown in several online blogs. In one blog, the majority of the comments were positive regarding the acceptance of pasteurised eggs (68%), while the rest made erroneous statements and refused to see pasteurised eggs as an alternative to raw eggs (Edwards, 2016). Other blogs revealed that most of the opinions (65%) were about the lack of pasteurised eggs' flavour and that consumers preferred organic eggs over the pasteurised ones (Michaels, 2010).

Future Market Insights (FMI) associated the increasing demand for pasteurised eggs with their health benefits and fitness trends, which lead to an increased interest for protein rich and safe products such as pasteurised egg whites. The US and Europe are majorly involved in the pasteurised eggs market followed by the rest of North America. Even developing countries such as India are also stepping into the market for pasteurised eggs in various food applications (FMI, 2017).

As domestic environment is one of the most common sources of foodborne outbreaks (EFSA and ECDC, 2021; CDC, 2018), the consumption of pasteurised eggs in shell (safe food) could help diminish the rate of outbreaks. Consumers displayed a low prioritisation of food safety regarding egg consumption (Baltzer, 2004), and a higher priority of the sensory qualities of products that may put consumers at risk (i.e., eggs with runny yolk) such as appearance, texture, or taste (Athearn et al., 2004). Thus, the objectives of this study were:

- To investigate if consumers could detect sensorial differences between dishes prepared either with unpasteurised or pasteurised eggs;
- To compare Portuguese and Romanian consumers' acceptance of egg-dishes traditionally containing raw or undercooked eggs when made with pasteurised eggs.

2. Materials and methods

2.1. Tested products

Experiments with products containing raw or undercooked eggs were carried out in Portugal and Romania.

Five products were tested, of which three were deserts (tiramisu, chocolate mousse, and condensed milk mousse), one was a beverage (eggnog) and the fifth was a sauce (Hollandaise sauce). All the three deserts were tested in Portugal, while two desserts (tiramisu and chocolate mousse), the beverage and the sauce were tested in Romania. The Romanian team did not prepare the condensed milk mousse (*Baba de camelo*), which is a traditional Portuguese dessert, but added to tests two more products belonging to different food categories for extending the variety of the tested products.

In Portugal, the pasteurised liquid egg yolks and whites used for the formulations were purchased in a local supermarket (Dovo, Derovo Group, Pombal, Portugal) and used according to the manufacturer recommendation: 1 egg white equals ca. 28.5 g of pasteurised egg whites and 1 egg yolk equals ca. 17 g of pasteurised egg yolks. In Romania, the egg products were obtained from Eurovo Service, S. (Maria in Fabriago, Italy), via Super Eggs SRL (Braila, Romania), and used following the manufacturer declaration: 1000 g product correspond to about 30 eggs. The eggs were pasteurised at 64 °C for 2.5 min.

In both countries, ordinary eggs were purchased in supermarkets.

The products were prepared following the exact same recipe (Supplementary File S1), but using either raw eggs or their equivalent in pasteurised egg yolks and whites. For preparing tiramisu and chocolate mousse, the same recipes were used in both countries.

All dishes were prepared according to good hygiene and manufacturing practices. The same practices have been applied when the dishes were sampled for the sensorial analysis.

2.2. Panellist sample and procedure

Participants were non-probabilistically recruited at site according to their willingness to participate at the tests. No information about the samples was provided, except for safety and hygiene considerations related to their preparation. The participants were informed about the general aim of the study and the procedure for handling personal data, and gave informed consent prior to participation.

The sensory sessions consisted of two phases: initial results, which were obtained in Portugal, and validation of the results from the first tasting panel, which took part in Romania. The validation phase is a recommended process to establish if the sensory data correlate with other data from samples made with the same products (i.e., results from other panels) (ISO 11132, 2012).

2.2.1. Initial testing phase

The initial phase took place in Portugal where a total of 143 untrained panellists (121 female and 22 male), with an average age of 33.0 ± 10.6 years, participated in three independent consumer studies. For each pair of products, consumers were asked to rate the overall acceptability using a nine-point hedonic scale: 1 "dislike extremely", 2 "dislike very much", 3 "dislike moderately", 4 "dislike slightly", 5 "neither like nor dislike", 6 "like slightly", 7 "like moderately", 8 "like very much" and 9 "like extremely" (Delicato et al., 2020) and were asked to rate the magnitude of difference between the product prepared with raw eggs and with pasteurised eggs by a difference-from-control sensory test. In this test each participant received a portion of the product (prepared with unpasteurised eggs labelled as "control sample" and two coded samples: a second portion of the product prepared with unpasteurised eggs (blind control sample) and a sample of the product prepared with pasteurised eggs. Participants were asked to compare the coded samples to the control sample and rate de magnitude of difference for colour, flavour, and texture using a discrete nine-point scale: 0 "no difference", 1 "very slight difference", 2 "slight/moderate difference", 3 "moderate difference", 4 "moderate/large difference", 5 "large difference", 6 "large/very large difference", 7 "very large difference", 8 "extreme difference" (Meilgaard et al., 2007).

2.2.2. Validation phase

To validate the results from Portugal, a sensory session took place in Romania where 35 untrained panellists (25 females and 10 males) with an average age of 35.1 ± 10 years old participated in both a pairwise preference test and a sensory evaluation of samples. Since the purpose of this tasting session was to validate the results from Portugal, we prepared two of the dishes tested in Portugal (tiramisu and chocolate mousse). Two additional dishes (mentioned at 2.1) have also been prepared and tested. Consumers' overall acceptability and sensorial attributes ranking were based on a nine-point hedonic scale.

The panellists received two coded samples (random three-digit code) simultaneously and were asked to state their preference (forced choice) and rate the odour, colour, texture, flavour and overall acceptability using the same nine-point hedonic scale as the one used by Portuguese consumers. Due to its reliability and discriminability, the nine-point hedonic scale (Peryam and Pilgrim, 1957) is one of the most frequently used scales when carrying out hedonic evaluations of food products (Lim, 2011). This type of scale is easy to apply and even if participants lack experience, they can still make significant assessments (Peryam and Girardot, 1952). The presentation order of samples was balanced across participants.

2.3. Statistical analysis

In Portugal, after the tasting session, data were analysed using XLSTAT 19 (Microsoft, Mountain view, CA, USA). Since we compared different recipes using the same panellists, Wilcoxon Signed-Rank Test was used to investigate if significant differences exist between each pair of samples (prepared with raw eggs and pasteurised eggs) for the overall acceptability of the products. The same statistics was used to investigate and rate the magnitude of difference between the products prepared with pasteurised eggs and raw eggs (blind control). In Romania, Wilcoxon Signed-Rank Test was used to check if significant differences ($p < 0.05$) exist between the same dishes made either with raw or pasteurised eggs in regards to their overall acceptability and sensorial attributes (odour, colour etc.). Man-Whitney tests, which assume group independence, were run to check if there are significant differences in the overall acceptability regarding the same products tested in both countries (chocolate mousse and tiramisu) ($p < 0.05$).

Minitab 19 (Minitab LLC, State College, PA, USA) was used to examine the score distribution of the overall acceptability for the recipes from both countries. Two ordinal regressions were performed using SPSS 26 (IBM Software Group, Chicago, IL, USA) for Romania and Portugal. Based on the calculation of odd ratios and 95% confidence interval the logistic model was selected to model the dependent variable - overall acceptability (like/dislike) as a function of the independent variables (sensorial attributes). The model fit was evaluated for each regression with the Omnibus Test, which showed a significant improvement in the fit of the final models over the null models ($p < 0.01$). The goodness of fit was assessed by the Pearson chi-square and Deviance tests. In this case significant differences are not desired because it would imply a difference between the final mode and a perfect model, thus non-significant results indicate that the model fits the data well (Field, 2018). In our case, both coefficients showed that our model exhibits good fit to the data ($p > 0.05$). The test of parallel lines checks if our model is valid by verifying if the slope coefficients in the model are the same across response categories. This assumption is met as our results are non-significant ($p > 0.05$). Logistic regressions have been previously used in other studies for consumers acceptability and intent of buying foods such as probiotic yoghurt with added glucose oxidase (Cruz et al., 2011), and choosing the most effective technology for the production of whey-grape juice base on consumers sensory choices (Amaral et al., 2018).

3. Results and discussions

3.1. Distribution of consumers' overall acceptability

The distribution of the overall acceptability scores for the five egg-based products prepared with raw and pasteurised egg yolks and whites is shown in Fig. 1 for Portugal (initial testing phase) and Fig. 2 for Romania (validation of results from the initial testing phase).

In Portugal, the largest score spread was for the overall acceptability of the condensed milk made with pasteurised eggs (3–9) with the interquartile (IQR) = 2. For the chocolate mousse made with raw eggs, the scores varied between 5 and 8 with the IQR = 1, while for the variant made with pasteurised eggs the variability was higher with scores between 4 and 9 and the IQR = 2. The tiramisu sample made with raw eggs received scores between 4 and 9 and had an IQR = 2, while the sample prepared with pasteurised eggs had a condensed body data with scores revolving around 7 with an IQR = 0. All the tested samples from Portugal shared the same median (7 – like moderately), except the chocolate mousse variant made with raw eggs (median = 6.5).

In Romania, all of the tested samples had the same median (8 = like very much), except the chocolate mousse made with raw eggs (8.5). The recipes registered comparable score spreads (5–9) with the interquartile (IQR) presenting similar ranges (0–2). The similar score distribution among each pair of products indicated a good degree of acceptability regarding the recipes prepared with pasteurised eggs. The comparable distribution scores of the samples from Romania validated the results from Portugal and indicated an acceptability level for the pasteurised products equivalent to the products made with the traditional raw eggs.

Man-Whitney tests were run to see if there are significant differences between the overall acceptability of the raw and pasteurised samples
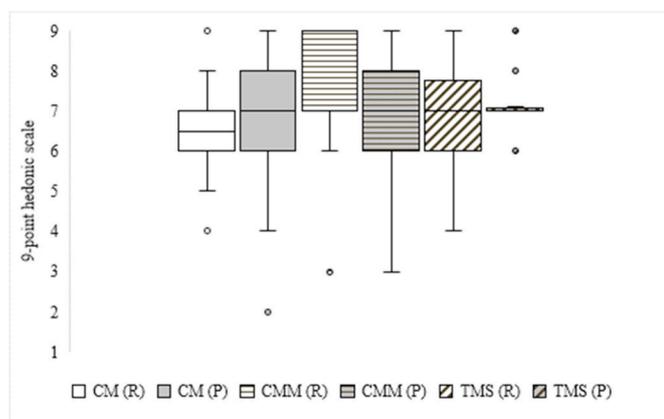
Fig. 1. Distribution of the overall acceptability scores for the products tested in Portugal (CMM = condensed milk mousse; CM = chocolate mousse; TMS = tiramisu; R = raw eggs; P = pasteurised eggs); The hedonic scale used for the overall acceptability was: 1 - "dislike extremely"; 2 - "dislike very much"; 3 - "dislike moderately"; 4 - "dislike slightly"; 5- "neither like nor dislike"; 6 - "like slightly"; 7 - "like moderately"; 8 - "like very much"; and, 9 - "like extremely"; the lower and upper whiskers represent the lowest and highest values. Boxes represent 50% of the values regarding the acceptability of the dishes and their horizontal bar is the median; the dots are the outliers.
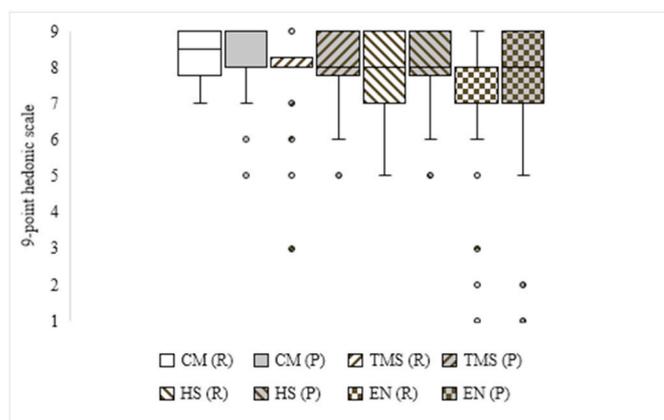
Fig. 2. Distribution of the overall acceptability scores for the products tested in Romania (CM = chocolate mousse; TMS = tiramisu; HS = hollandaise sauce; EN = eggnog; R = raw eggs; P = pasteurised eggs); The hedonic scale used for the overall acceptability was: 1 - "dislike extremely"; 2 - "dislike very much"; 3 - "dislike moderately"; 4 - "dislike slightly"; 5 - "neither like nor dislike"; 6 - "like slightly"; 7 - "like moderately"; 8 - "like very much"; and, 9 - "like extremely"; the lower and upper whiskers represent the lowest and highest values while the boxes represent 50% of the values regarding the acceptability of the dishes and their horizontal bar is the median; the dots are the outliers.

that were tested in both countries (chocolate mousse and tiramisu). We found significant differences for both raw and pasteurised variants of chocolate mousse and tiramisu with higher scores being recorded in Romania ($p < 0.05$).

Overall, these findings indicate that similar scores were attributed to the acceptability of both raw and pasteurised dishes from Portugal and Romania and that recipes prepared with pasteurised eggs can presumably be easily accepted by the lay public as a safer variant of dishes traditionally made with raw eggs.

Tables 1 and 2 show the comparison of the five tested products regarding the mean of the overall acceptability for each pair of samples (i.e., raw versus pasteurised eggs) and the evaluated attributes (i.e., odour, colour etc).

In Portugal, the only significant differences in the mean overall

acceptability were recorded for the tiramisu samples where the variant prepared with pasteurised eggs had a higher mean score ($p < 0.05$; Table 1), indicating that the dessert prepared with pasteurised eggs was better appreciated by consumers.

In Romania, the differences between the mean of the overall acceptability scores were not statistically significant ($p > 0.05$; Table 2) in any of the comparisons among each pair of samples, indicating an acceptance of the products prepared with pasteurised eggs comparable to those made with raw eggs and validating the results obtained in Portugal.

These results show once again that dishes traditionally prepared with raw eggs can be made with pasteurised eggs instead as consumers showed a similar liking for both variants. In order to see if the demographic characteristics play a role in the acceptability of dishes made with pasteurised eggs, we evaluated Romanian and Portuguese participants' scores based on age and gender (Tables S4 and S5). However, no statistically significant differences were found ($p > 0.05$) indicating a similar acceptance among women and men aged between 20 and 60 years old.

Our findings correspond to the results of De Souza and Fernández (2012), where consumers rated the organoleptic properties (colour, flavour, texture etc) of mayonnaise, pudding, and angel cake made with raw, thermally pasteurised, and UV-C treated eggs. After the tasting session, comparable scores were attributed among the tested food products indicating that consumers' acceptance of recipes prepared with treated eggs did not differ from that of recipes prepared with raw eggs ($p > 0.05$).

3.2. Evaluation of difference-from-control tests and organoleptic properties of dishes prepared with raw versus pasteurised eggs

In Portugal, significant differences were found from the difference-from-control test regarding the colour and texture of the chocolate mousse samples prepared with pasteurised eggs ($p < 0.05$) when compared with the control sample (raw eggs), but no differences were expressed for condensed milk mousse and tiramisu ($p > 0.05$). Gender and age did not influence the Portuguese participants perception as no significant differences were observed across gender and age groups regarding the difference-from-control test (Table S4).

In Romania, the participants rated the organoleptic properties (odour, colour, flavour and texture) of the four products similarly with no significant differences between the recipes made with raw and pasteurised eggs, indicating a similar sensorial perception among panellists ($p > 0.05$). The findings indicate that products prepared with pasteurised samples are liked both by women and men and across different age groups varying from 20 to 60 years old (Table S5). Hence, the results from the tasting session conducted in Romania validated the sensory tests from Portugal, with the exception of the differences sensed for the chocolate mousse's colour and texture.

The sensorial ratings indicate that consumers do not find the pasteurised variants to be very different from the raw variants and that they are similar from an organoleptic point of view.

Despite the several aspects that were perceived by consumers as being different from the control sample (i.e., colour and texture), De Souza and Fernández (2012) reported that the treatments applied to eggs (thermal pasteurisation and UV-C treatment) did not induce the formation of any off-flavours for all of the studied products, and no significant differences were observed regarding their overall quality (cooked egg white, cooked yolk, cooked whole egg, mayonnaise, pudding, and angel cake) ($p > 0.05$).

Additionally, independent taste tests conducted in households resulted in consumers not being able to tell the difference between raw and pasteurised eggs, suggesting the mixed opinions in regards to the acceptance of pasteurised eggs (Flynn, 2009).

In the literature, most consumer acceptance studies focused on analysing the eggs (raw, thermally pasteurised, and ozone treated)

Table 1

Portuguese participants overall acceptance and difference-from-control sensory test for three different products prepared with raw eggs versus pasteurised eggs.

Product	Tiramisu		Chocolate mousse		Condensed milk mousse	
	R	**P**	**R**	**P**	**R**	**P**
Overall acceptability (mean ± stdev)[a]	6.7 ± 1.1^A	7.1 ± 1.3^A	6.4 ± 1.6^A	7 ± 1.3^B	7.5 ± 1.0^A	7.1 ± 1.3^A
Difference from control test [b]						
Colour	2.0 ± 1.0^A	2.1 ± 1.0^A	2.5 ± 0.7^A	4.3 ± 1.3^B	2.5 ± 1.2^A	2.4 ± 1.3^A
Flavour	2.8 ± 1.2^A	2.9 ± 1.2^A	2.7 ± 1.2^A	4.2 ± 1.2^A	2.9 ± 1.2^A	2.6 ± 1.2^A
Texture	2.7 ± 1.3^A	2.6 ± 1.0^A	2.0 ± 1.0^A	4.3 ± 1.3^B	2.2 ± 1.3^A	3.1 ± 1.5^A

R – Raw eggs, P – Pasteurised eggs.

Within each row of the tested samples, means followed by the same capital letter indicate that there are no significant differences between the overall acceptability of the samples and that the pasteurised samples are not significantly different from the control samples at $p > 0.05$.

[a] The hedonic scale used for the overall acceptability was: 1 - "dislike extremely"; 2 - "dislike very much"; 3 - "dislike moderately"; 4 - "dislike slightly"; 5 - "neither like nor dislike"; 6 - "like slightly"; 7 - "like moderately"; 8 - "like very much"; and, 9 - "like extremely".

[b] The scale used for the difference-from-control test was: 0 - "no difference", 1 - "very slight difference", 2 - "slight/moderate difference", 3 - "moderate difference", 4 - "moderate/large difference", 5 - "large difference", 6 - "large/very large difference", 7- "very large difference", 8 - "extreme difference".

without undergoing a cooking process (raw egg white, raw yolk) and simple egg products (scrambled eggs) (Kamotani et al., 2010; Maxkwee et al., 2014). Singh et al. (2019) demonstrated that pasteurised egg whites can be used to make angel food cakes with a similar quality to those made with raw egg whites by adjusting the mixing conditions of the pasteurised egg whites. This evaluation however was only made based on technological parameters as no sensory tests were performed. Then, Maxkwee et al. (2014) conducted consumer taste tests and found no significant differences between scrambled eggs (prepared with raw, thermally pasteurised eggs, and ozone treated eggs) when evaluating visual appearance, flavour, texture and overall liking, implying a consumer acceptance of treated eggs equivalent to that of the traditional raw eggs. Kamotani et al. (2010) also studied consumers' acceptance of scrambled eggs prepared with unpasteurised, ozone-treated, and pasteurised eggs (microwave heating). In their study no significant differences were observed regarding the organoleptic properties of the scrambled eggs prepared with each type of eggs ($p > 0.05$). Although the scrambled eggs' colour prepared with raw eggs was seen as just about right (mean = 3), those prepared with thermally pasteurised eggs (mean = 3.2) and ozone treated (mean = 2.9) were still seen as acceptable by consumers. In the same study, no significant differences were reported regarding the moistness and texture of all three types of eggs ($p > 0.05$).

3.3. Key drivers for assessing the acceptance of the dishes made with pasteurised eggs

An ordinal regression was performed for the sensory tests from Portugal, using the difference-from-control test for the sensorial aspects of the dishes. Thus, every one unit increase on an attribute would translate to the dish being more similar to the control sample leading to

Table 3

Regression analysis of the overall acceptance of the products prepared with pasteurised eggs that were tested in Portugal.

Model 1	*Overall acceptance chocolate mousse*			
	B	**SE**	**OR (95% CI)**	**p**
Colour	0.07	0.19	1 (0.67; 1.49)	0.92
Texture	0.43	0.23	1.55 (0.97; 2.46)	0.00*
Flavour	0.39	0.18	1.48 (1.02; 2.13)	0.03**
Model 2	*Overall acceptance tiramisu*			
Colour	0.14	0.36	1.16 (0.57; 2.35)	0.41
Texture	0.23	0.11	1.23 (0.67; 2.24)	0.03**
Flavour	0.2	0.06	1.22 (0.81; 1.84)	0.04**
Model 3	*Overall acceptance condensed milk mousse*			
Colour	0.01	0.31	1 (0.53; 1.82)	0.85
Texture	0.62	0.23	1.87 (1.26; 2.8)	0.00*
Flavour	0.28	0.22	1.23 (0.85; 1.78)	0.03**

β = regression coefficient; SE = standard error; OR (95 % CI) = odd ratio (95% CI); CI = confidence interval; *$p < 0.01$; **$p < 0.05$.

an increase in the overall acceptability of the pasteurised variant as shown in Table 3. The goodness-of-fit tests for Table 3 are presented in Supplementary file S2.

In Portugal, texture and flavour were positive significant predictors for the overall acceptance of the dished prepared with pasteurised eggs (Table 3; $p < 0.05$, $p < 0.01$ respectively). Texture had odd ratios of 1.23–1.87, indicating that the higher the similarity between the textures of the control and samples with pasteurised eggs, the higher the odds of according a higher rating on the hedonic scale to the overall acceptability. Likewise, flavour had reported odd ratios of 1.22–1.48, suggesting that the panellists who found the flavour of dishes prepared with pasteurised eggs similar to the control ones were more likely to show an

Table 2

Romanian participants overall acceptability and sensorial rating for four different products prepared with raw eggs versus pasteurised eggs.

Product	Hollandaise sauce		Chocolate mousse		Eggnog		Tiramisu	
	R	**P**	**R**	**P**	**R**	**P**	**R**	**P**
Overall acceptability (mean ± stdev)[a]	7.8 ± 1.3^A	7.9 ± 1^A	8.2 ± 0.8^A	8 ± 0.8^A	7.5 ± 1.5^A	8 ± 0.8^A	7.7 ± 1.3^A	8 ± 1.1^A
Hedonic evaluation (mean ± stdev)[a]								
Colour	8.1 ± 0.9^A	8.5 ± 0.6^A	8 ± 1.3^A	8.2 ± 1^A	7.7 ± 1.1^A	7.9 ± 1.1^A	7.6 ± 1.6^A	8 ± 1.2^A
Odour	7.6 ± 1.4^A	7.5 ± 1.5^A	7.7 ± 1.3^A	8 ± 1.3^A	8 ± 1.1^A	7.6 ± 1.6^A	7.3 ± 1.7^A	7.6 ± 1.5^A
Flavour	7.6 ± 1.1^A	7.7 ± 1^A	8.3 ± 0.8^A	7.9 ± 1^A	7.6 ± 1.6^A	7.5 ± 1.6^A	7.5 ± 1.5^A	7.9 ± 1.1^A
Texture	8.2 ± 0.8^A	8.1 ± 1^A	8.1 ± 0.8^A	8 ± 0.8^A	7.4 ± 1.3^A	7.4 ± 1.4^A	7.7 ± 1.3^A	7.8 ± 1.2^A

R – Raw eggs, P – Pasteurised eggs.

Within each row of the tested samples, means followed by the same capital letter indicate that there are no significant differences between the overall acceptability of the samples and that the pasteurised samples are not significantly different from the control samples at $p > 0.05$.

[a] The hedonic scale used for the overall acceptability and sensorial attributes was: 1 - "dislike extremely"; 2 - "dislike very much"; 3 - "dislike moderately"; 4 - "dislike slightly"; 5 - "neither like nor dislike"; 6 - "like slightly"; 7 - "like moderately"; 8 - "like very much" and 9 - "like extremely".

Table 4

Regression analysis of the overall acceptance of the products prepared with raw eggs that were tested in Romania.

Model 1	Overall acceptance Hollandaise sauce			
	B	SE	OR (95% CI)	p
Odour	0.18	0.29	1.2 (0.68; 2.12)	0.52
Colour	0.05	0.57	1 (0.31; 2.92)	0.93
Texture	1.25	0.75	3.51 (0.8; 15.47)	0.09
Flavour	1	0.51	2.71 (1; 7.4)	0.04**
Model 2	**Overall acceptance chocolate mousse**			
Odour	0.54	0.29	1.71 (0.96; 3.07)	0.07
Colour	1.22	0.61	3.38 (1.01; 11.27)	0.04**
Texture	1.58	0.75	4.87 (1.11; 21.2)	0.03**
Flavour	2.23	0.84	9.91 (1.9; 51.62)	0.00*
Model 3	**Overall acceptance eggnog**			
Odour	1.6	0.78	4.9 (1.95; 12.55)	0.00*
Colour	0.09	0.6	1.09 (0.33; 3.6)	0.87
Texture	0.34	0.68	2.48 (1.19; 5.2)	0.01**
Flavour	2.79	0.82	16.4 (3.98; 67.58)	0.00*
Model 4	**Overall acceptance tiramisu**			
Odour	0.56	0.44	1.74 (0.73; 4.17)	0.2
Colour	0.95	0.28	2.59 (1.47; 4.54)	0.06
Texture	5.15	1.83	18.2 (2.74; 92.2)	0.00*
Flavour	1.96	0.78	7.12 (1.53; 33)	0.01**

β = regression coefficient; SE = standard error; OR (95 % CI) = odd ratio (95% CI); CI = confidence interval; *$p < 0.01$; **$p < 0.05$.

Table 5

Regression analysis of the overall acceptance of the products prepared with pasteurised eggs that were tested in Romania.

Model 1	Overall acceptance Hollandaise sauce			
	B	SE	OR (95% CI)	p
Odour	0.04	0.25	1.05 (0.59; 1.73)	0.47
Colour	0.59	0.64	1.81 (0.55; 4.62)	0.75
Texture	1.08	0.40	2.98 (1.44; 6.2)	0.00*
Flavour	1.21	0.43	3.38 (1.46; 7.82)	0.00*
Model 2	Overall acceptance chocolate mousse			
Odour	0.03	0.3	1.03 (0.46; 2.82)	0.86
Colour	0.34	0.46	1.37 (0.37; 5.06)	0.46
Texture	1.75	0.53	5.79 (1.30; 23.6)	0.00*
Flavour	1.59	0.44	4.92 (1.42; 17.04)	0.00*
Model 3	Overall acceptance eggnog			
Odour	0.38	0.44	1 (0.3; 3)	0.39
Colour	0.38	0.33	1.47 (0.76; 2.81)	0.24
Texture	0.23	0.27	1.26 (0.73; 2.18)	0.38
Flavour	0.52	0.22	1.68 (0.72; 3.94)	0.00*
Model 4	Overall acceptance tiramisu			
Odour	0.43	0.24	1.54 (0.95; 2.49)	0.07
Colour	0.08	0.27	1 (0.63; 1.86)	0.95
Texture	3.16	0.8	23.76 (4.95; 94.07)	0.00*
Flavour	2.23	0.55	9.37 (3.31; 28.01)	0.00*

β = regression coefficient; SE = standard error; OR (95 % CI) = odd ratio (95%); CI = confidence interval; *$p < 0.01$; **$p < 0.05$.

increased level of acceptance. Colour was not found to be a significant predictor of the overall acceptance for the dishes tested in Portugal ($p > 0.05$).

In Romania, two ordinal regressions were used to model the dependent variable (overall acceptance of recipes prepared with raw eggs or pasteurised eggs) revealed that some of the sensorial attributes had significant contributions in regards to the products' acceptance level as shown in Table 4 and Table 5. The goodness-of-fit tests for Tables 4 and 5 are presented in Supplementary file S2.

Regarding the regression model that was applied for the recipes made with raw eggs in Romania, all of the sensorial attributes were significant predictors of the overall acceptability ($p < 0.05$, respectively $p < 0.001$; Table 4). Texture had the highest impact on the overall acceptability of the dishes (OR 2.48–18.2; $p < 0.05$) followed by flavour (OR 2.71–6.4; $p < 0.05$), suggesting that these two attributes were

considered by the panellists the most important when evaluating the overall acceptability of the dishes. Colour was a significant predictor of consumers' overall acceptance only for chocolate mousse (OR 3.38; $p < 0.001$), while odour was a significant predictor for the acceptability of eggnog (OR 4.9; $p < 0.001$).

Similar results were revealed by the regression model that was used for dishes prepared with pasteurised eggs, except that in this model colour and odour were not significant predictors of consumers' overall acceptance (Table 5). The most important predictors for the overall acceptance of the dishes made with pasteurised eggs were texture and flavour ($p < 0.01$). Flavour had reported odd ratios (OR) between 1.68 and 9.37, indicating that the odds of having a greater level of acceptance for the pasteurised recipients increase by up to a factor of 9.37 for each one unit increase in flavour. Texture however, had even higher odd ratios from 2.98 for hollandaise sauce to 23.76 for tiramisu. This effectively proved that the participants who liked the flavour of the tiramisu samples prepared with pasteurised eggs were up to 23 times more likely to show an improved overall acceptability.

The regression models from Romania confirmed that texture and flavour are the strongest predictors that influence consumers' overall acceptability of dishes prepared with pasteurised eggs, hence validating the regression model used for Portugal.

Overall, the regression models indicated that among colour, odour, flavour, and texture, the last two are the most important factors that influence consumers' perception of similarity and overall liking of the dishes from this study.

Comparable results were reported by other studies where the intent to buy food products such as probiotic yoghurt and whey-grape juice was predicted by taste, texture, and flavour ($p < 0.05$) (Amaral et al., 2018; Cruz et al., 2011), and the overall acceptance of products like caviar was highly correlated with texture and flavour (Baker et al., 2014).

Flavour and texture are often rated as the most important sensorial aspects and are seen as the key drivers that determine consumers' perceptions of food quality and acceptance (Cardello and Schutz, 2003; Foegeding et al., 2011; Tuorila and Cardello, 2002). Even though the flavour is responsible for consumers' food preferences, texture is often being cited as having an important role in whether they like a food product or not (Foegeding et al., 2011).

Most consumers acknowledge the link between eating and health, however when evaluating the quality of a food product, taste is the first major criterion (Grunert, 2005). Although knowing that there is a trade-off between health, taste, and convenience, some consumers are not willing to make any compromises and prioritise taste and enjoyment (Cowling, 2020). A study from the UK indicated that taste was among the major variables that influenced the food purchase decision of British consumers (Barker et al., 2019). The fact that taste leads to an immediate fulfilment gives it a higher priority when compared with aspects such as food safety or quality.

Eggs are renowned for their functional properties, and they are often used as an ingredient to enhance the texture and flavour of other food products (Guha et al., 2019). Hence, pasteurised eggs are a food product that have advantages such as ensuring the safety of consumers but can also be used as enhancers of flavour and texture, the top two key drivers of food quality and acceptance. This may also be the reason our tested recipes received high values for texture and flavour on the hedonic scale (like moderately, like very much respectively), and the positive reported odd ratios of having a higher level of acceptability due to the increased likeliness showed for these two aspects.

3.4. Reasons to support pasteurisation of eggs in shell

Salmonellosis is the most frequently caused by *Salmonella*-contaminated eggs (up to 90% of salmonellosis cases are associated with the consumption of raw or insufficiently heat-treated eggs) (Smajhel and Shadrova, 2019). Although a very small proportion of

eggshells are infected with salmonella (1 in 20.000 up to 1 in 10.000 eggs are contaminated with *S.* Enteritidis) (Rettner, 2018), the health risk is high due to a high exposure with 700 billion eggs being consumed per year worldwide (Réhault-Godbert et al., 2019; Nys et al., 2011).

The risk of consuming eggs that might be contaminated with *S.* Enteritidis can be reduced if some critical safe handling practices are applied (e.g., eggs or leftover egg dishes are kept refrigerated, then cooked and/or reheated thoroughly prior to eating; contamination from raw egg product to cooked products is avoided). However, an estimated 2 million illnesses occur because of *Salmonella*-contaminated eggs in the US every year, while in Europe 7,400 cases occur annually (Hald, 2013). The number of strong-evidence foodborne outbreaks of salmonellosis has been stable in the last ten years with 52,702 human salmonellosis cases, 6,149 hospitalisations, and seven deaths being reported in 2020 (EFSA and ECDC, 2021). Also, acute salmonellosis kills up to 420 people in the US and 156 people every year in Europe (CDC, 2019b; ECDC, 2020), which means that the above-mentioned practices are not correctly performed or not performed by everyone. Due to the health impact of *Salmonella* in eggs and that most foodborne outbreaks, sporadic cases and hospitalisations are related to the domestic environment, EFSA recommends education regarding the procedures of food handling, preparation, preservation, and consumption of eggs and egg products (EFSA & ECDC, 2021). This is a good idea but what happens in consumers' households is not under the control of food safety authorities.

The number of recalls and alerts referring to raw eggs and dishes prepared with raw eggs is high with up to 206 million eggs being recalled due to a multistate outbreak of *Salmonella* in the U.S. in 2018 (CDC, 2018), while RASFF reported 13 food safety alerts in the 2019 annual report, and 20 in the latest report from 2020 (European Commission, Directorate-General for Health and Food Safety, 2020; European Commission, Directorate-General for Health and Food Safety, 2021). The RASFF annual reports indicate that between 2016 and 2020 the number of alerts reported for eggs and egg products contaminated with *Salmonella* was 0.95–1.4% of the total number of alerts (European Commission, Directorate-General for Health and Food Safety, 2017; European Commission, Directorate-General for Health and Food Safety, 2019; European Commission, Directorate-General for Health and Food Safety, 2019; European Commission, Directorate-General for Health and Food Safety, 2020; European Commission, Directorate-General for Health and Food Safety, 2021).

Pasteurised eggs are a good choice for vulnerable populations. Pasteurised eggs can be used in the preparation of all products but should specifically be used when preparing dishes that require raw or undercooked eggs (mayonnaise, salad dressings, Hollandaise sauce, Caesar salad dressing, tiramisu, chocolate mousse, etc.).

Switching to pasteurised eggs is a common-sense precautionary measure for those who like runny poached, sunny-side-up, or soft-boiled eggs. In the raw-egg dishes from our sensorial study (e.g., tiramisu, chocolate mousse) no major *Salmonella* inactivation is expected and using pasteurised eggs is the only way to minimise the risk of contracting salmonellosis (Cardoso et al., 2021).

Our demonstration that ordinary consumers do not perceive differences between the sensorial characteristics of dishes made with raw eggs and pasteurised eggs can be used by other researchers and food safety authorities for future research and even an intervention for the pasteurisation of eggs in shell. While liquid egg products (whites and yolks) are matching better the need of those working in bakeries, restaurants, and canteens, places where large quantities of food are prepared, pasteurisation of eggs in shell is appropriate for ordinary consumers. Being pasteurised in shell, eggs will better resemble the unpasteurised form of eggs that consumers are familiar with.

3.5. Study limitations

Although this study used data from two different countries and had both an initial and validation phase, we acknowledge the fact that the number of untrained panelists from Romania was relatively low (35 persons) and that the analysis may be underpowered. On the other hand, technical literature demonstrates that reliable results are obtained for sensory descriptive analysis even with 8–12 panelists (Heymann et al., 2012). Other limitations involve the lack of analyses such as the penalty test, consumers' willingness to pay for the tested recipes, and the temporal dominance of sensations.

4. Conclusions

This study demonstrated that five dishes prepared with pasteurised eggs as replacer of raw eggs are accepted by consumers as they cannot be clearly differentiated from their counterpart. Thus, pasteurised eggs can be used as a safer ingredient to substitute shell eggs in raw/undercooked egg-based dishes without significant reduction of the sensory quality of the food, a characteristic which is much appreciated by consumers. Using pasteurised eggs in in recipes with raw or undercooked eggs could be a feasible solution to minimise the occurrence of salmonellosis, so, food safety authorities should direct educational campaigns emphasizing on consumers to use pasteurised eggs instead of raw eggs, to encourage food processors to produce pasteurised eggs and to persuade distributors to make such products available to consumers, while raising awareness among the general population towards pasteurised eggs' benefits for food safety.

Having in view the frequency of notifications regarding eggs contaminated with salmonellae in the RASFF system, food safety authorities may consider pasteurised eggs a solution that can significantly contribute to decrease the burden of foodborne diseases as result of diminishing the number of cases and outbreaks of salmonellosis. Although the price for pasteurised eggs will be higher than for non-pasteurised eggs, the benefits of egg pasteurisation over the societal burden of salmonellosis are expected to be similar to those obtained for pasteurised milk when it had to replace raw milk, if such an intervention is going to be put into practice.

Moreover, our results can be used as a starting point for future studies regarding consumers' overall acceptability of egg-based dishes made with pasteurised eggs that are traditionally prepared with raw or undercooked eggs.

5. Implications for gastronomy

The technology to produce pasteurised eggs in shell is now available and using such eggs is more convenient for consumers as it does not imply changing any habits related to egg storage or consumption. This paper indicates that from a sensorial point of view consumers were not able to distinguish between raw and/or undercooked egg-based dishes prepared either with raw or pasteurised eggs. The overall acceptability of the dishes prepared with pasteurised eggs is similar to the one for the dishes made with raw eggs. Nonetheless, the only significant difference between raw and pasteurised eggs is that the latter represent a safe alternative for consumers. The ingredients and preparation steps of the recipes tested in this study with pasteurised eggs instead of raw eggs are provided in Supplementary File S1.

The incorporation of these recipes (and others that originally use raw and/or undercooked eggs) in the gastronomic sector contributes to the consumers' on-going demand for safe and healthy products.

CRediT authorship contribution statement

Octavian Augustin Mihalache: Methodology, Software, Validation, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Maria Joao Monteiro:** Investigation, Formal analysis, Writing – review & editing. **Loredana Dumitrascu:** Investigation, Writing – review & editing. **Corina Neagu:** Investigation, Writing – review & editing. **Vânia Ferreira:** Investigation, Formal analysis, Writing – review & editing. **Marta Guimarães:** Investigation.

Daniela Borda: Investigation, Writing – review & editing. **Paula Teixeira:** Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Anca Ioana Nicolau:** Conceptualization, Investigation, Formal analysis, Resources, Supervision, Writing – original draft, Writing – review & editing.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijgfs.2022.100547.

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