Nanotechnology in the agri-food sector: consumer perceptions

Héctor Gómez-Llorente, Pau Hervás, Édgar Pérez-Esteve, Jose M. Barat, Isabel Fernández-Segovia*

Departamento de Tecnología de Alimentos. Universitat Politècnica de València, Camino de Vera s/n, 46022, Valencia, Spain

* Corresponding author.
E-mail address: isferse1@tal.upv.es (I. Fernández-Segovia).

ABSTRACT

The purpose of this work was to evaluate Spanish consumers' opinions on using nanotechnology in food processing and packaging. For this purpose, a literature review was carried out in the main research database to determine the most widespread uses of nanotechnology in the food industry and the most promising developments. Of all the nanotechnology uses in food, five areas of application were identified: developing new ingredients or additives, formulating new antimicrobial systems, and designing new processing methods, sensors and packaging with nanostructured materials. Subsequently, a consumers' opinion study was carried out by means of a survey, in which the opinions and purchase intention of a representative product of all five categories were evaluated, as well as the neophobia level to new food technologies. All the products obtained positive evaluations, and the applications in which nanotechnology did not form part of food were generally better valued than those in which it did form part. The respondents had a medium neophobia level, with an average score of 4.59 (out of 7 points), being consumers with more knowledge about new technologies the least neophobic and those who gave products higher scores. This study provides relevant information for using nanotechnology in the food processing and packaging sector.

Keywords: nanotechnology; food processing; packaging; consumer opinion; neophobia

1. Introduction

The European Commission has reported that nanotechnology is one of the key enabling technologies (KETs) in the Horizon 2020 framework (European Commission, 2020a). The marked revolution that nanotechnology has brought about is because nanomaterials exhibit different functional properties compared to "conventionally sized" equivalents (Royal Society and Royal Academy of Engineering, 2004) given their dimensions. This implies that they have a high surface to mass ratio, which results in higher reactivity. Similarly, the physico-chemical properties of nanomaterials (solubility, shape, etc.) can differ from those of bulk materials, which may entail changes that should be taken into account (Gallocchio et al., 2015).

The food industry has opted for nanotechnology because it is one of the most promising technologies to emerge in recent years. In the food context, Regulation (EU) No. 2015/2283 of the European Parliament and of the Council of 25 November 2015 on novel foods defines engineered nanomaterial as: *"any intentionally produced material that has one or more dimensions of the order of 100 nm or less or that is composed of discrete functional parts, either internally or at the surface, many of which have one or more dimensions of the order of 100 nm or less, including structures, agglomerates or aggregates, which may have a size above the order of 100 nm but retain properties that are characteristic of the nanoscale"*. This definition can be subject to changes based on future market developments (European Commission, 2020b).

Besides potential benefits, the use of nanomaterials could present potential risks. On these scales, changes in the above-mentioned properties could pose toxicity problems for humans and animals, as well as environmental damage (Coles & Frewer, 2013). For all these reasons, today nanotechnology is widely studied. Numerous research works have focused on developing different applications in many industrial sectors, as well as on the characterization nanomaterials and toxicity studies.

As this is a new technology, it is very important to know consumer perceptions because these technologies are rejected by most people, such as GMOs (genetically modified organisms), whose potential use in the agri-food field is enormous, but social rejection is a problem to market the products obtained by this technology (Faccio & Guiotto Nai Fovino, 2019; Mohorčich & Reese, 2019). In nanotechnology, it is necessary to determine if consumers know this new technology and to know their opinions. It is also important to note that people's perception could differ depending on whether nanotechnology is used as "nano-inside" (the nanomaterial forms part of the product that consumers eat) or "nano-outside" (the nanomaterial is used in processing/packaging, but does not form part of the food product and does not enter the human body).

To date, perception studies related to nanotechnology in the food industry have been carried out in several countries, such as: Australia (Evans et al., 2010), Brazil (Vidigal et al., 2015; Coutinho et al., 2021), Canada (Matin et al., 2012; Roosen et al., 2015), Chile (Schnettler et al., 2013, 2017), Taiwan (Chang et al., 2017) and USA (Zhou & Hu, 2018; Kuang et al., 2020). In Europe, several studies have been carried out in countries such as Austria (Joubert et al., 2020), Germany (Roosen et al., 2015), Italy (Sodano et al., 2016; Viscecchia et al., 2018), Ireland (Handford et al., 2015; Henchion et al., 2019), Switzerland (Siegrist et al., 2007, 2008, 2009) and UK (Gupta et al., 2015; Feindt & Poortvliet, 2020). These studies point out that public perception and knowledge about nanotechnology differ depending on the surveyed region, and that it is also changing over time. Therefore, it is difficult to extrapolate the results from one population to another, and much more, to predict how it will evolve over time.

The aim of this work was to evaluate Spanish consumer perceptions of using nanotechnology in food processing and packaging, in order to predict the acceptation of these technologies in the agri-food sector.

2. Materials and methods

2.1. Preliminary literature review

A review of the main nanotechnology applications under development and those commercialized in the agri-food sector was carried out to select the representative applications of this technology in food products to be included in the consumers' opinion survey. For this purpose, the main research databases (e.g. Scopus, Web of Science, Google Scholar) were consulted by employing the following keywords individually or combined: nanotechnology, nanofood, nanoencapsulation, nanoemulsion, nanoparticles, nanomaterials, nanopackaging, nanosensor, active packaging, intelligent packaging, food sector, food industry, agri-food industry. The "Nanotechnology Products Database", which collects data on distinct nanotechnology products available in different countries (StatNano, 2020), was also consulted. No time restrictions were set.

Of all the different applications found, five products were selected to continue with the second part of the study. This selection was based on the Spanish population's consumer habits, selecting products from different food chain links (production, packaging and quality control), and including both nanotechnology as nano-inside (the nanostructured system is an integral part of food) and nano-outside (those that employ nanotechnology, but it does not form part of ingested food).

2.2. Consumers' opinion study

This part of the study was conducted with an online survey designed in Google-Forms. Call for participants was posted on different social networks (such as LinkedIn, Facebook and WhatsApp) as in other studies (Vujić & Szabo, 2022), and the link to the survey was disseminated through these channels. The survey was carried out on a sample of 658 Spanish participants aged over 18, between May and June 2020. Random simple sampling was conducted. The margin of error was below 3.90% for a 95.5% confidence level ($k = 2$), $p = q = 0.5$ (principle of maximum indetermination) (Table 1).

Table 1

Before the survey began, the participants were informed about the study objective and framework, and that the data provided by them would remain completely anonymous. Then they had to indicate whether they wished to voluntarily participate in the study. The questionnaire was designed as follows:

Part 1 consisted of questions about the participants' demographic and personal data, with two questions on their nanotechnology knowledge and their general opinions of it.

Part 2 included opinion questions on nanotechnology applications in five food products and a question on purchase intention. For this part, first information on nanotechnology and the food industry was provided, as in other similar studies (Siegrist et al., 2008; Roosen et al., 2015; Henchion et al., 2019). Choice of the five food products was based on the criteria defined in section 2.1. In this way, there were selected two products in which nanotechnology formed part of food (nano-inside) and three products in which it did not (nano-outside).

For each product, the respondents had to indicate their degree of agreement on 7-level Likert scales (the value 1 corresponded to "totally disagree" and the value 7 to "totally agree"). The three items were: *"This product seems novel", "This product provides many nutrition or food safety or quality benefits"* and *"This product poses NO health risk"*. In addition, they had to establish the extent to which they would like the product and answer a question about their purchase intention. A 5-point scale was used for this last question (the value 1 corresponded to "I would definitively not buy it" and the value 5 to " I would definitively buy it").

Part 3 of the questionnaire consisted of an abbreviated version of the neophobia survey proposed by Cox and Evans (2008), translated into Spanish according to Schnettler et al. (2016), in which consumers had to indicate their degree of agreement with each question on a 7-level Likert scale. A statement on the degree of knowledge about new food technologies was also included (S0).

2.3. Data analyses

Cronbach's alpha was used to test the reliability of the scale of neophobia to new food technologies (questionnaire part 3). With the data obtained in this survey a Kruskal-Wallis analysis was performed for each statement to check if there were any significant differences when considering personal data (gender, level of education or relationship with the agri-food sector). Dunn's procedure with Bonferroni correction was used to test for differences at the 5% significance level. A hierarchical cluster analysis was also carried out to check if there were groups of consumers with different degrees of neophobia. Euclidean distances and Ward's aggregation method were used. Next a Kruskal-Wallis analysis was performed for each question in the neophobia survey by considering the identified clusters.

A Chi-square analysis was carried out to evaluate if there were any differences between clusters in the personal data and other data contained in questionnaire part 1.

Finally, in order to check if there were any significant differences between products in opinions and purchase intention (questionnaire part 2), a Kruskal-Wallis analysis was performed following the same above-described procedure.

The employed statistical program was XLSTAT 2020.3.1 (New York, USA) (Addinsoft, 2020).

3. Results and discussion

3.1. Literature review and product selection

After a thorough review of the nanotechnology applications to develop new food products, five application areas were identified. Table 2 summarizes the main categories and some examples of applications in all these areas.

Table 2

As it can be observed, in the food production field, nanotechnology can be applied to reduce the size of an ingredient or additive, which confers it new properties (solubility, bioavailability, etc.), encapsulate an ingredient or additive, improve its stability or release it in a specific place or situation (gastrointestinal tract, in the presence of microorganisms, etc.). For this category, a low-calorie mayonnaise made by the nanoemulsion technology was chosen as an example of a technology already used in manufacturing food products (Sekhon, 2010). This technology allows the droplet size of an emulsion to become smaller, which enables the use of less fat, while maintaining the original food's palatability. This allows products to be developed with fewer calories than their conventional variants, but without compromising their original organoleptic characteristics.

Another important use of nanotechnology is the design and preparation of new antimicrobials, which are based mostly on natural ingredients. This is the case of nanostructured metals, such as silver, or the nanoencapsulation of compounds with antimicrobial activity to improve the compatibility of the bioactive molecule with food. Indeed propolis, with antimicrobial activity, allows the application in some cases of milder heat treatments (Luis-Villaroya et al., 2015), which can be nanoencapsulated to mask its very strong and undesirable taste. Once encapsulated, propolis can be incorporated into apple juice without compromising its taste, which was the second selected application.

Nanotechnology can also be used as part of the production process without becoming part of food. Nanofiltration, for example, is a less aggressive alternative to conventional processing techniques, such as concentration and clarification of juices or wine dealcoholization (Labanda et al., 2009). Given the novelty of this process, the third selected product was an alcohol-free wine obtained by nanofiltration to better preserve the final product's organoleptic characteristics.

Other examples in which nanotechnology does not form an integral part of food is found in packaging. Of all the nanotechnology application possibilities in this field, one in which nanotechnology allows the development of active packaging or packaging able to interact with the medium was selected. Specifically, the selected product was apricots (climacteric fruits whose ripening is very fast, which markedly limits their commercial life), which are packed in a film containing a nanomaterial capable of scavenging ethylene, delaying fruit ripening and, thus, prolonging their shelf life (Gaikwad et al., 2020).

Finally, the inclusion of nanosensors in packaging film allows the creation of smart packaging that can detect changes in food or their environment by transmitting this information in the form of different signals (Pérez-Esteve et al., 2013). Some are capable of detecting gases to provide information on packaging integrity. Other systems provide information on food freshness or the accidental freezing of refrigerated food with a colorimetric indicator (Ranjan et al., 2014). A real application of this technology is packaging for meat products, which contains a nanosensor capable of detecting deviations in storage temperature by indicating a break in the cold chain by the irreversible disappearance of barcodes (Enescu et al., 2019).

In summary, nanotechnology can be applied to different food chain links, from food production to packaging and presentation to the final consumer, and depending on its application, in some cases it will form part of the food ("nano-inside" applications), or does not ("nano-outside") (Henchion et al., 2019).

After identifying different nanotechnology application fields in the food industry and selecting the specific applications to be evaluated by consumers, product sheets were created for each selected application (Fig. 1), on which consumers had to indicate their opinion in the survey.

3.2. Consumers' opinion results

In order to evaluate the opinion of consumers on the use of nanotechnology in food processing and packaging, and their neophobia level as regards new technologies in the food industry, opinion surveys were carried out.

3.2.1. Participants' personal and socio-demographic data

Six hundred and fifty-eight individuals participated in this study. Table 3 shows their socio-demographic and other personal data. Most respondents were women (64.9%). Their ages ranged from 18 to 79 years, and the age of most participants fell within the 30-49 years range. The majority of people had a high level of education, and 37.5% of participants had some kind of relationship with the agri-food sector. Only 3.5% of the participants indicated following vegetarian/vegan diets, which is a low percentage that would not influence the results. Finally, 15.0% of consumers indicated having an allergy or food intolerance.

Table 3

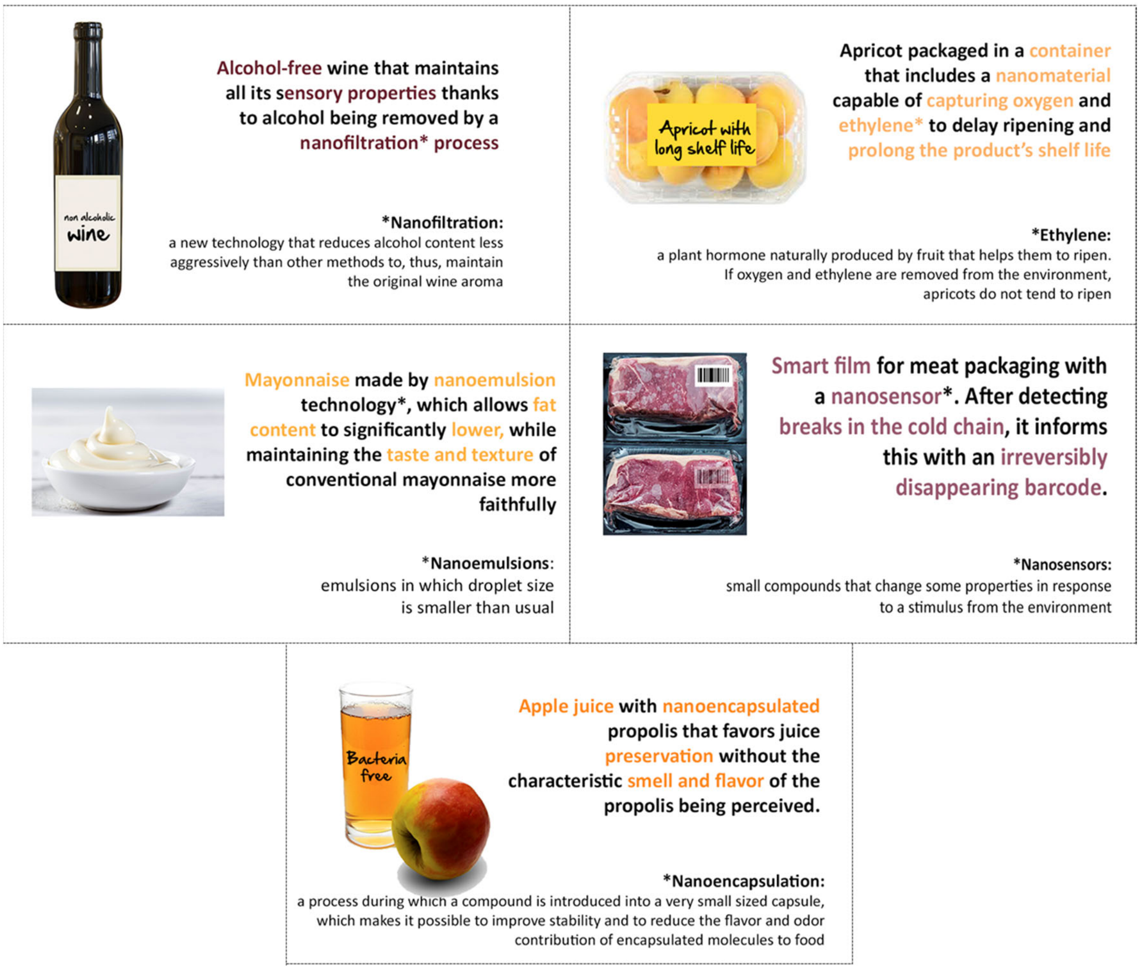

Fig. 1. Nanotechnology application in different products that consumers evaluated in the survey.

3.2.2. Knowledge and general opinion about nanotechnology

Before giving information about nanotechnology and showing the products in which this had been employed, the participants were asked about their knowledge on this new technology and their general opinion. Table 3 shows their responses. Most participants stated that they knew "something" or "little" (38.8% and 30.4%, respectively) about this technology, while a lower percentage knew "nothing" or "a lot" (16.3% and 12.2%, respectively). Regarding the general opinion on nanotechnology, only three participants had a negative opinion, while 36.2% had a positive opinion and 12.7% a very positive one. The other participants had a neutral attitude ("neither negative nor positive ") and 26.9% were unsure ("I do not know"). No participant perceived this new technology as “very negative”.

3.2.3. Neophobia to new food technologies

In order to determine the level of neophobia of the individuals who participated in this study, they completed a survey, as explained in section 2.2. First of all, they were asked a question about their degree of knowledge on new food technologies, with the statement "I do not know much about new food technologies". The average score given by the respondents was 4.59 (out of 7 points). This value indicates that the participants’ average knowledge on new food production technologies did not excel.

Table 4 shows the results of the neophobia survey on using new technologies in food. Some scores were reversed (S5, S6 and S10) so that a higher score for any statement meant a higher neophobia level. Cronbach’s alpha of the 10 items was 0.799, indicating good internal reliability. It is important to highlight that this value was 0.843 when the S10 was not included in the analysis, showing an improvement in the reliability of the scale.

A score of 4.0 was obtained as the mean value (minimum and maximum value of 3.3 and 4.7, respectively). Taking into account that a score of 4 is a neutral point, it can be considered that the surveyed population would generally be in an intermediate position in terms of phobia to new food technologies.

Table 4

Statements were grouped into four factors according to the meaning of the items, in a similar way to the classification proposed by Cox and Evans (2008), with some modifications. The first factor has to do with the perceived usefulness of the technology, the second one with the perceived risk deriving from applying new technologies, the third with new technologies being beneficial given their possibility of offering balanced and healthy diets and better quality food, and the fourth is related to the media's role in providing information (Cox & Evans, 2008). By calculating the mean of each factor, those with lower values were for Factor 1 (utility) and Factor 3 (quality and health), while the risk perception factor obtained a slightly higher score (above 4). The media-related question obtained the highest score, which indicates that the respondents do not trust the information transmitted by the media on new food technologies being balanced and impartial. Although all these questions are based on a validated survey of neophobia to new technologies, it is noteworthy that this last question does not indicate neophobia to new technologies, but refers to people trusting information about new technologies provided by the media. These results agree with the study carried out by Kuang et al. (2020) in USA, except for Factor 4 in relation to the media. They obtained similar values for Factor 1 and Factor 3 (mean scores of 3.38 and 3.13, respectively) and a higher value (4.27) for Factor 2, which agree with our results. However, their lowest value was for Factor 4, while this factor in our study obtained the highest score, which demonstrates consumers' different credibility of the media between both countries.

The Kruskal-Wallis analysis showed that, in general, there were no significant differences ($p>0.05$) in responses in accordance with gender or level of education. The individuals with a relationship with the agri-food sector exhibited a slightly lower level of neophobia (mean value of 3.7) compared to those not related to the agri-food sector (mean value of 4.1). Age also influenced the responses, with the younger groups generally showing the least neophobia (data not-shown).

Several authors have studied neophobia to new food technologies in different countries like China (Mckenzie et al., 2021), USA (Kuang et al., 2020), Australia (Cox & Evans, 2008; Evans et al., 2010), Canada (Matin et al., 2012), Italy (Verneau et al., 2014), Brazil (Vidigal et al., 2015; Coutinho et al., 2021) or Chile (Schnettler et al., 2017). Based on the results herein obtained, the population of Spain would be more neophobic than the population of China, USA, Brazil or Chile, but less neophobic than those from Australia, Canada and Italy. It should be taken into account that consumer opinions change over time and, with a difference of up to 10 years in some of these studies, the neophobia levels in some of these countries might now be different.

It is also important to note that the standard deviation values were relatively high (Table 4), which reflects considerable variability in the participants' responses. To check if there were consumer groups among the respondents with different neophobia levels, a cluster analysis was performed. Three clusters or groups were identified: cluster 1 = 250 individuals, cluster 2 = 228 individuals, cluster 3 = 180 individuals. Fig. 2 shows the mean scores given by each group. The S5 and S6 values were reversed, as explained above. The responses to question S10 are not included in this figure because, as above-mentioned, it does not directly relate to neophobia, rather to the participants' credibility of the media and can distort the graph. The individuals in the three clusters clearly gave different responses, and cluster 1 had the lowest neophobia level (mean of 2.8), while cluster 3 involved the most skepticism toward new food technologies (mean of 5.1). Cluster 2 presented intermediate values (mean of 4.1). The Kruskal-Wallis analysis demonstrated that the differences between clusters were significant in all cases ($p<0.05$), which indicates segmentation in the surveyed population, with variable neophobia levels (Table S1). In the statement about credibility of the media (S10), cluster 1 showed the least confidence in the media. Regarding the participants' knowledge about new food technologies (S0: I do not know a lot about new food technologies), the obtained values were 4.0, 4.9 and 5.0, for cluster 1, 2 and 3, respectively. These findings demonstrated that the respondents with the least neophobia (cluster 1) stated having more knowledge on new food technologies. This indicates that the more information, the less fear or distrust in these techniques.

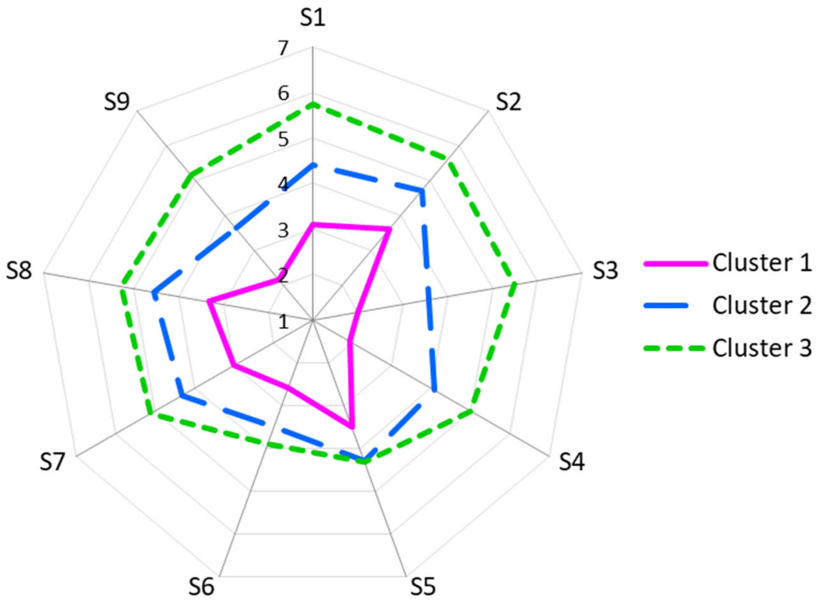

Fig. 2. Mean scores given by respondents in the survey of neophobia to new food technology. S1-S9 correspond to the statements shown in Table 4. Scores in S5 and S6 have been reversed, so higher scores indicate more neophobia.

In order to check whether there were differences among clusters in terms of socio-demographic and other personal data, and also in relation to knowledge and opinion about nanotechnology (collected in part 1 of the questionnaire), a chi-square analysis was carried out by considering the three clusters. The results are shown in Table 3. No significant differences between clusters in terms of gender, level of education, proportion of vegans/vegetarians or allergic/intolerant people were found. The highest proportion of respondents in cluster 1 (less neophobic) were aged between 18 and 29 years old, and 55% stated that they had some kind of relationship with the agri-food sector. The age of the most of the cluster 3 respondents (the most neophobic) ranged from 30 to 49 (similarly to cluster 2) and only 31% stated that they had a relationship with the agri-food sector (Table 3). This demonstrates the correlation between age and neophobia, with young people being less neophobic than old people. In a study carried out in China, the authors found that there was a small significant correlation between age and neophobia in the opposite sense because they stated that food technology neophobia decreased with age (Mckenzie et al., 2021). This evidence differences between Chinese and Spanish populations.

Regarding nanotechnology knowledge in the least neophobic group (cluster 1), most participants (60%) stated that they had some or a lot of nanotechnology knowledge, while the majority in clusters 2 and 3 had little or some nanotechnology knowledge (Table 3). Almost 70% of the cluster 1 respondents stated having a positive or very positive opinion of it, while a lower percentage of respondents in clusters 2 and 3 selected the answer “Very positive”, and many stated that they had not knowledge. Many also opted for the answer "Neither negative nor positive ".

These results show, therefore, that the younger the Spanish population is, the lower the neophobia level to new technologies. It was also confirmed by the finding that the more acquired information, the lower the neophobia level.

3.2.4. Opinion on nanotechnology applications to different food products

Fig. 3 shows the scores given by consumers in the survey on the different products in which nanotechnology has been used. In this part of the study 7-point scales were used, except for purchase intention, which was 5 points, as explained above. However, to better visualize the graph without distortion, the purchase intention score was normalized to a 7-point scale. The higher the score for any question, the better the product valuation. The mean values obtained were higher than 4 points (neutral score) in all cases, which indicates that the respondents had positive opinions of the five food products in which nanotechnology had been employed.

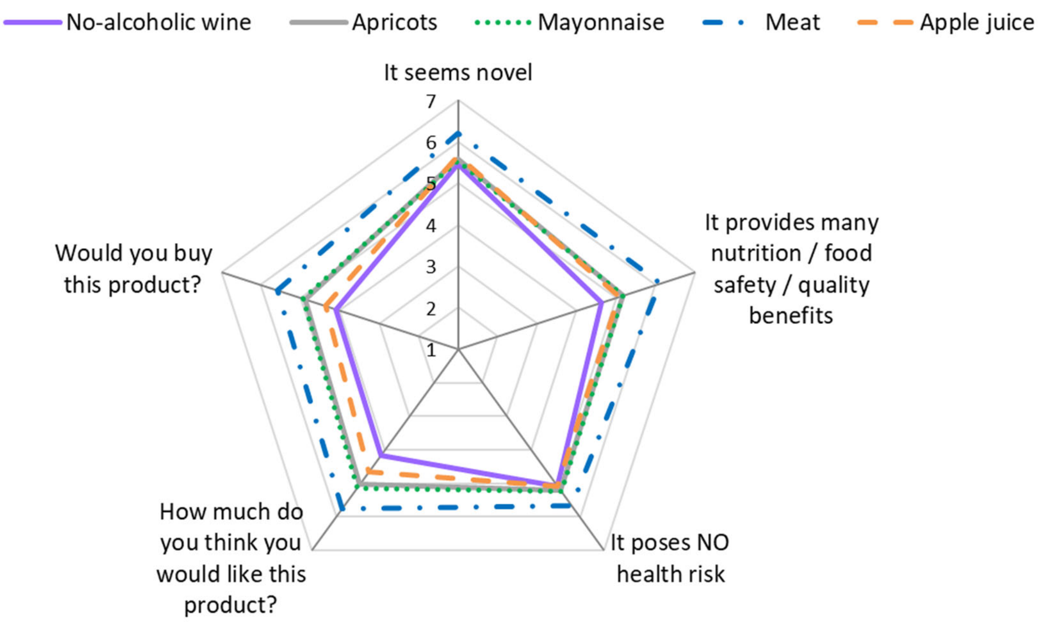

Fig. 3. Mean scores given by respondents in the opinion survey on applications of nanotechnology in five food products.

The best valuated product was meat packed in smart film (mean score of 5.9), with significant differences from the other products ($p<0.05$) for all items. The respondents considered that this product was the newest, that with the most benefits, that with the lowest health risk and that which they would like the most. So they rated it with the highest purchase intention value. This could be due to the fact that nanotechnology in this case only formed part of the packaging and not the product, and was used as an indicator of possible loss of quality, which does not affect product characteristics. This agrees with previous studies in which the perception of products with nanotechnology applied to packaging or “nano-outside” were perceived more positively and purchase intention was higher than when nanotechnology formed part of food products (Siegrist et al., 2007, 2008; Roosen et al., 2015; Schnettler et al., 2017; Henchion et al., 2019).

For the questions about product novelty or health risks, no significant differences were found among the other four products. For the other items, the next highest rated products were low-calorie mayonnaise and apricots packed in active packaging, with no significant differences between them for any item (mean score of 5.2 for both products). Although the nanotechnology applied to apricots did not form part of this product, but its packaging, it could have been evaluated worse than meat because this technology does affect normal product evolution as it delays ripening, while nanotechnology had no technological function in meat.

Nanoencapsulated propolis juice (mean score of 5.0) and, especially non alcoholic wine (mean score of 4.7), were the worst rated products, and mainly for the items related to purchase intention and for the question about how much they thought they would like them.

Of the products in which nanotechnology formed an integral part of the product ("nano-inside"), low-calorie mayonnaise was better evaluated than juice with nanoencapsulated propolis, as above-mentioned. The respondents positively evaluated the incorporation of nanotechnology into mayonnaise because it resulted in a healthier product, a characteristic that is highly valued by consumers, as other studies have shown (Henchion et al., 2019).

As the participants in the survey were grouped into three clusters with different neophobia levels, the opinion of products to which nanotechnology was applied was studied per cluster. Fig. 4 shows the scores given by consumers in the survey on the different products, divided into clusters. Cluster 3 with the highest neophobia level scored all the products with the lowest values, while cluster 1 (the least neophobic) gave the highest scores for all the products, which left cluster 2 between both clusters 1 and 3.

These results agree with those of previous studies that used the neophobia scale to new food technologies. Evans et al. (2010) observed how people with high neophobia levels were more likely to reject food produced by new technologies. Matin et al. (2012) correlated neophobia with positions against nanotechnology in food, packaging and any others. In a study carried out in Brazil, Vidigal et al. (2015) observed how the participants with a higher neophobia level less intended to try food produced by new technologies. Sodano et al. (2016) conducted a purchase intention survey and stated that neophobia, among other factors, led to reluctance to buy products with nanotechnology. In another study carried out in Chile by Schnettler et al. (2017) on the purchase intention of different products subjected to new technologies (including nanotechnology), the authors identified a segment with high neophobia who rejected most products, and another with low neophobia levels who gave higher values to purchase intention. These data suggest that information campaigns could reduce the possible rejection of incoporating nanotechnologies into food products. In this sense Kidd et al. (2020) concluded in a study on the use of nanomaterials for in-home drinking water that if manufacturers provided more information about nanomaterial use, as well as the potential benefits an risks, some consumers concerns over these devices could be addressed.

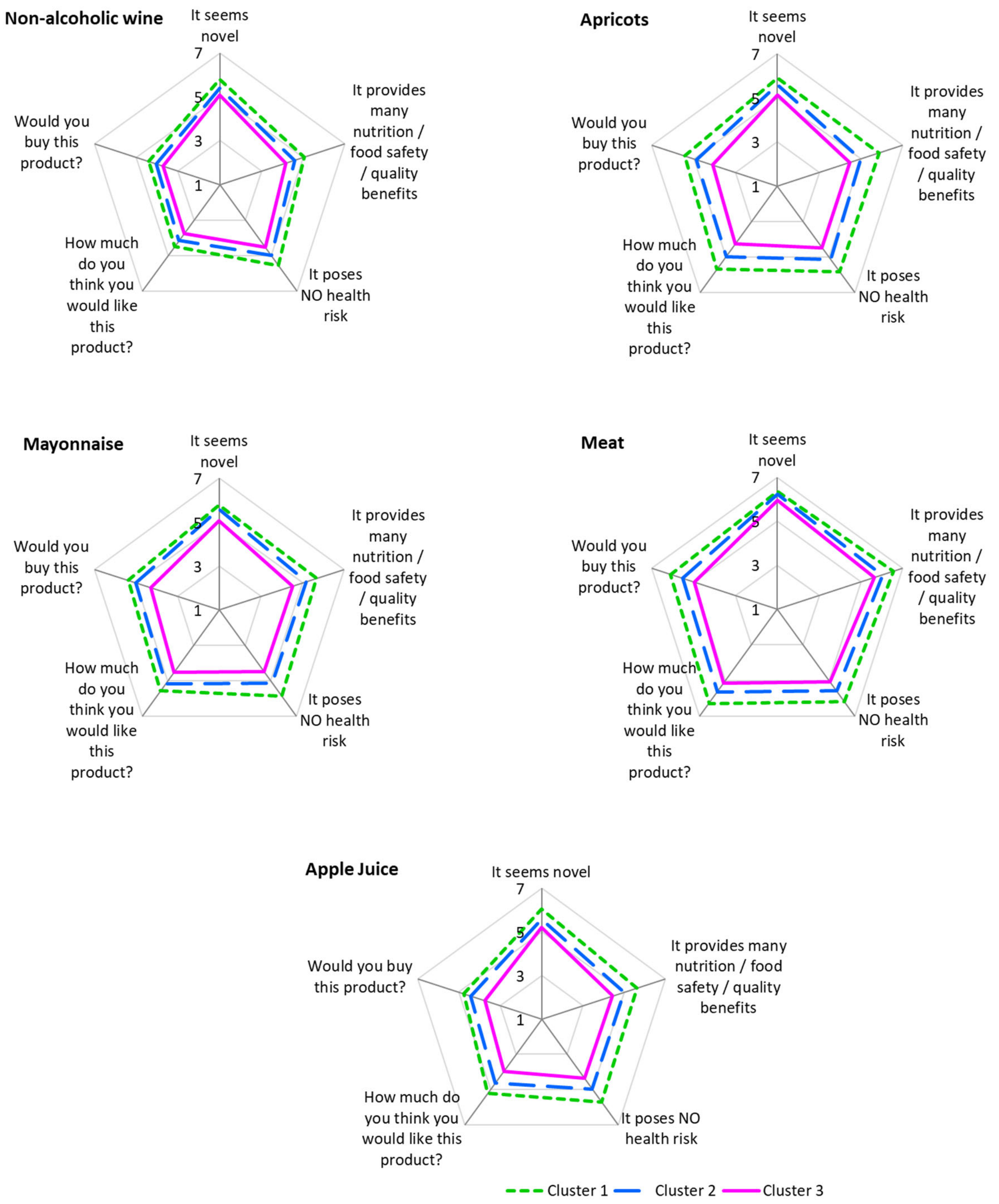

Fig. 4. Mean scores given by respondents in the opinion survey on applications of nanotechnology in five food products, considering the three clusters.

In this study the potential benefits of nanotechnology to the food sector have been shown and that most of the consumers might accept this technology in the formulation, manufacturing, packaging or quality assesment of food products. However, the following limitations of this study should be considered: the sample was relatively homogeneous, especially in terms of age, gender and education, with the majority of participants being young (47.4% were aged 30-49), female (64,9%) and with a high education level (77.5 %). Despite this, the Kruskal-Wallis analysis of the socio-demographic data (see section 3.2.3) showed that no differences were found in the level of neophobia, according to gender or educational level, as did the chi-squared analysis that showed that these factors did not present signifficant differences between clusters. These findings indicate that gender or educational level in this study were not factors biasing responses. However, age influenced the responses. Although in this work the different perception of the population according to age has been discussed, future studies should consider citizens in other stages of life. On the other hand, to evaluate the single impact of nanotechnology in the consumer perceptions, a comparison of these products with the same food products without nanotechnology should be carried out in future works.

4. Conclusions

The findings of the present study show that approximately half the Spanish respondents have some knowledge about nanotechnology, and the same percentage values it positively or very positively as only 0.5% had a negative opinion.

The valuation of five different food types to which nanotechnology had been applied to manufacture or package them is generally positive. Moreover, most participants indicate high acceptability and willingness to buy them. Of all the products, packaged meat with nanotechnology incorporated into packaging to inform consumers of the product's quality/safety has been the best valued, which confirms that consumers prefer products in which nanotechnology forms no part of food (nano-outside).

The good product acceptability falls in line with the observed low neophobia level. In general, the Spanish respondents have an intermediate neophobia level. However, there are segments with significantly different neophobia. The younger age groups and groups with more knowledge about new technologies exhibit less neophobia. As the most informed have been those who best value the use of nanotechnology, information campaigns carried out mainly by sector organizations or official bodies could reduce the possible rejection of incoporating nanotechnologies into food products.

This study shows that, unlike other technologies, the use of nanotechnology in the food field would not negatively impact the food product image for the surveyed Spanish population. This is a good boost for food industries interested in implementing nanotechnologies into their processes and products, although future studies should be performed to include a broader range of products as well as a greater participation of older people, who may have a higher level of neophobia and, therefore, a lower level of acceptation of products with nanotechnology.

Author contributions

Héctor Gómez-Llorente was involved in investigation, formal analysis and writing of original draft. Pau Hervás was involved in methodology, formal analisys and writing of original draft. Édgar Pérez-Esteve was involved in conceptualization, methodology, supervision, review and editing. Jose M. Barat was involved in investigation, resources and project administration. Isabel Fernández-Segovia was involved in investigation, methodology, formal analysis, supervision, review and editing.

Declaration of competing interest

There is not any conflict of interests.

Acknowledgements

The authors gratefully acknowledge the financial support for the experiment reported herein from the Spanish Government (RTI2018-101599-B-C21-AR). Héctor Gómez Llorente wishes to thank the Universitat Politècnica de València for the FPI Grant. The authors also thank Helen Warburton for editing the English style.

Appendix A. Supplementary data

Supplementary data to this article can be found online at xxx.

References

Addinsoft (2020). XLSTAT statistical and data analysis solution. New York, USA. https://www.xlstat.com.

Bumbudsanpharoke, N., & Ko, S. (2019). Nanomaterial-based optical indicators: promise, opportunities, and challenges in the development of colorimetric systems for intelligent packaging. *Nano Research*, *12*(3), 489-500. https://doi.org/10.1007/s12274-018-2237-z.

Cetinkaya, T., Mendes, A. C., Jacobsen, C., Ceylan, Z., Chronakis, I. S., Bean, S. R., & García-Moreno, P. J. (2021). Development of kafirin-based nanocapsules by electrospraying for encapsulation of fish oil. *LWT-Food Science and Technology*, *136*, 110297. https://doi.org/10.1016/j.lwt.2020.110297.

Chang, H. H., Huang, C. Y., Fu, C. S., & Hsu, M. T. (2017). The effects of innovative, consumer and social characteristics on willingness to try nano-foods:Product uncertainty as a moderator. *Information Technology & People, 30*(3), 653-690. https://doi.org/10.1108/ITP-10-2015-0266.

Coles, D., & Frewer, L. J. (2013). Nanotechnology applied to European food production– A review of ethical and regulatory issues. *Trends in Food Science & Technology*, *34*(1), 32-43. https://doi.org/10.1016/j.tifs.2013.08.006.

Coutinho, N. M., Silveira, M. R., Guimarães, J. T., Fernandes, L. M., Pimentel, T. C., Silva, M. C., et al. (2021). Are consumers willing to pay for a product processed by emerging technologies? The case of chocolate milk drink processed by cold plasma. *LWT-Food Science and Technology*, *138*(2), 110772. https://doi.org/10.1016/j.lwt.2020.110772.

Cox, D. N., & Evans, G. (2008). Construction and validation of a psychometric scale to measure consumers' fears of novel food technologies: The food technology neophobia scale. *Food Quality and Preference*, *19*(8), 704-710. https://doi.org/10.1016/j.foodqual.2008.04.005.

Donsì, F., & Ferrari, G. (2016). Essential oil nanoemulsions as antimicrobial agents in food. *Journal of Biotechnology*, *233*, 106-120. https://doi.org/10.1016/j.jbiotec.2016.07.005.

Enescu, D., Cerqueira, M. A., Fucinos, P., & Pastrana, L. M. (2019). Recent advances and challenges on applications of nanotechnology in food packaging. A literature review. *Food and Chemical Toxicology*, *134*, 110814. https://doi.org/10.1016/j.fct.2019.110814.

European Commission. (2020a). *Key Enabling Technologies*. Retrieved from https://ec.europa.eu/programmes/horizon2020/en/area/key-enabling-technologies#Article. Accessed December 16, 2020.

European Commission. (2020b). *Questions and answers on the Commission recommendation on the definition of nanomaterial*. Retrieved from http://ec.europa.eu/environment/chemicals/nanotech/faq/questions_answers_en.html. Accessed December 18, 2020.

Evans, G., Kermarrec, C., Sable, T., & Cox, D. N. (2010). Reliability and predictive validity of the Food Technology Neophobia Scale. *Appetite*, *54*(2), 390-393. https://doi.org/10.1016/j.appet.2009.11.014.

Faccio, E., & Guiotto Nai Fovino, L. (2019). Food Neophobia or Distrust of Novelties? Exploring consumers' attitudes toward GMOs, insects and cultured meat. *Applied Sciences*, *9*(20), 4440. https://doi.org/10.3390/app9204440

Feher, J. (2012). Methods for preparing probiotic nanoparticles. *WO2012061629.*

Feindt, P. H., & Poortvliet, P. M. (2020). Consumer reactions to unfamiliar technologies: mental and social formation of perceptions and attitudes toward nano and GM products. *Journal of Risk Research*, *23*(4), 475-489. https://doi.org/10.1080/13669877.2019.1591487.

Gaikwad, K. K., Singh, S., & Negi, Y. S. (2020). Ethylene scavengers for active packaging of fresh food produce. *Environmental Chemistry Letters*, *18*(2), 269-284. https://doi.org/10.1007/s10311-019-00938-1.

Gallocchio, F., Belluco, S., & Ricci, A. (2015). Nanotechnology and food: brief overview of the current scenario. *Procedia Food Science*, *5*, 85-88. https://doi.org/10.1016/j.profoo.2015.09.022.

Gupta, N., Fischer, A. R. H., & Frewer, L. J. (2015). Ethics, risk and benefits associated with different applications of nanotechnology: a comparison of expert and consumer perceptions of drivers of societal acceptance. *NanoEthics*, *9*(2), 93-108. https://doi.org/10.1007/s11569-015-0222-5.

Hamad, A. F., Han, J. H., Kim, B. C., & Rather, I. A. (2018). The intertwine of nanotechnology with the food industry. *Saudi Journal of Biological Sciences*, *25*(1), 27-30. https://doi.org/10.1016/j.sjbs.2017.09.004.

Handford, C. E., Dean, M., Spence, M., Henchion, M., Elliott, C. T., & Campbell, K. (2015). Awareness and attitudes towards the emerging use of nanotechnology in the agri-food sector. *Food Control*, *57*, 24-34. https://doi.org/10.1016/j.foodcont.2015.03.033.

Henchion, M., McCarthy, M., Dillon, E. J., Greehy, G., & McCarthy, S. N. (2019). Big issues for a small technology: Consumer trade-offs in acceptance of nanotechnology in food. *Innovative Food Science & Emerging Technologies*, *58*, 102210. https://doi.org/10.1016/j.ifset.2019.102210.

Jeon, J. S., & Lee, H. S. (2009). Nano-particles containing calcium and method for preparing the same. *WO2009011520*.

Joubert, I. A., Geppert, M., Ess, S., Nestelbacher, R., Gadermaier, G., Duschl, A., et al. (2020). Public perception and knowledge on nanotechnology: A study based on a citizen science approach. *NanoImpact*, *17*, 100201. https://doi.org/10.1016/j.impact.2019.100201.

Kidd, J., Westerhoff, P., & Maynard, A. D. (2020). Public perceptions for the use of nanomaterials for in-home drinking water purification devices. *NanoImpact*, *18*, 100220. https://doi.org/10.1016/j.impact.2020.100220.

Kuang, L., Burgess, B., Cuite, C. L., Tepper, B. J., & Hallman, W. K. (2020). Sensory acceptability and willingness to buy foods presented as having benefits achieved through the use of nanotechnology. *Food Quality and Preference*, *83*, 103922. https://doi.org/10.1016/j.foodqual.2020.103922.

Labanda, J., Vichi, S., Llorens, J., & López-Tamames, E. (2009). Membrane separation technology for the reduction of alcoholic degree of a white model wine. *LWT-Food Science and Technology*, *42*(8), 1390-1395. https://doi.org/10.1016/j.lwt.2009.03.008.

Latva-Nirva, E., Dahms, G., Jung, A., & Fiebrig, B. (2009). Ultrafine titanium dioxide nanoparticles and dispersions thereof. *WO2009141499*.

Liu, D. M., & Dong, C. (2020). Recent advances in nano-carrier immobilized enzymes and their applications. *Process Biochemistry*, *92*, 464-475. https://doi.org/10.1016/j.procbio.2020.02.005.

Luis-Villaroya, A., Espina, L., García-Gonzalo, D., Bayarri, S., Pérez, C., & Pagán, R. (2015). Bioactive properties of a propolis-based dietary supplement and its use in combination with mild heat for apple juice preservation. *International Journal of Food Microbiology*, *205*, 90-97. https://doi.org/10.1016/j.ijfoodmicro.2015.03.020.

Matin, A. H., Goddard, E., Vandermoere, F., Blanchemanche, S., Bieberstein, A., Marette, S., & Roosen, J. (2012). Do environmental attitudes and food technology neophobia affect perceptions of the benefits of nanotechnology?. *International Journal of Consumer Studies*, *36*(2), 149-157. https://doi.org/10.1111/j.1470-6431.2011.01090.x.

McKenzie, K., Metcalf, D. A., & Saliba, A. (2021). Validation of the Food Technology Neophobia Scale in a Chinese sample using exploratory and confirmatory factor analysis. *Food Quality and Preference*, *89*, 104148. https://doi.org/10.1016/j.foodqual.2020.104148.

Mesosilver (2020). *Mesosilver Products Database*. Retrieved from www.mesosilver.com. Accessed March 19, 2020.

Mohammadian, M., Waly, M. I., Moghadam, M., Emam-Djomeh, Z., Salami, M., & Moosavi-Movahedi, A. A. (2020). Nanostructured food proteins as efficient systems for the encapsulation of bioactive compounds. *Food Science and Human Wellness*. *9*(3), 199-213. https://doi.org/10.1016/j.fshw.2020.04.009.

Mohorčich, J., & Reese, J. (2019). Cell-cultured meat: Lessons from GMO adoption and resistance. *Appetite, 143*, 104408. https://doi.org/10.1016/j.appet.2019.104408

Moncada, M., Astete, C., Sabliov, C., Olson, D., Boeneke, C., & Aryana, K. J. (2015). Nano spray-dried sodium chloride and its effects on the microbiological and sensory characteristics of surface-salted cheese crackers. *Journal of Dairy Science*, *98*(9), 5946-5954. https://doi.org/10.3168/jds.2015-9658.

Nath, K., Dave, H. K., & Patel, T. M. (2018). Revisiting the recent applications of nanofiltration in food processing industries: Progress and prognosis. *Trends in Food Science & Technology*, *73*, 12-24. https://doi.org/10.1016/j.tifs.2018.01.001.

Pereira, D. I., Bruggraber, S. F., Faria, N., Poots, L. K., Tagmount, M. A., Aslam, M. F., … & Powell, J. J. (2014). Nanoparticulate iron (III) oxo-hydroxide delivers safe iron that is well absorbed and utilised in humans. *Nanomedicine: Nanotechnology, Biology and Medicine*, *10*(8), 1877-1886. https://doi.org/10.1016/j.nano.2014.06.012.

Pérez-Esteve, E., Bernardos, A., Martínez-Máñez, R., & M Barat, J. (2013). Nanotechnology in the development of novel functional foods or their package. An overview based in patent analysis. *Recent Patents on Food, Nutrition & Agriculture*, *5*(1), 35-43. https://doi.org/10.2174/2212798411305010006.

Peyravi, M., Jahanshahi, M., & Banafti, S. (2020). Application of membrane technology in beverage production and safety. In *Safety Issues in Beverage Production* (pp. 271-308). Academic Press. https://doi.org/10.1016/B978-0-12-816679-6.00008-5.

Prokisch, J., & Zommara, M.A. (2009). Process for producing elemental selenium nanospheres. *WO2009010922.*

Ranjan, S., Dasgupta, N., Chakraborty, A. R., Samuel, S. M., Ramalingam, C., Shanker, R., & Kumar, A. (2014). Nanoscience and nanotechnologies in food industries: opportunities and research trends. *Journal of Nanoparticle Research*, *16*(6), 1-23. https://doi.org/10.1007/s11051-014-2464-5.

RipeSense®label (2020). Retrieved from http://www.ripesense.com/. Accessed February 19, 2020.

Roosen, J., Bieberstein, A., Blanchemanche, S., Goddard, E., Marette, S., & Vandermoere, F. (2015). Trust and willingness to pay for nanotechnology food. *Food Policy*, *52*, 75-83. https://doi.org/10.1016/j.foodpol.2014.12.004.

Royal Society and Royal Academy of Engineering (2004). Nanoscience and nanotechnologies: opportunities and uncertainties. London: Royal Society.

Schnettler, B., Crisóstomo, G., Sepúlveda, J., Mora, M., Lobos, G., Miranda, H., & Grunert, K. G. (2013). Food neophobia, nanotechnology and satisfaction with life. *Appetite*, *69*, 71-79. https://doi.org/10.1016/j.appet.2013.05.014.

Schnettler, B., Grunert, K. G., Miranda-Zapata, E., Orellana, L., Sepúlveda, J., Lobos, G., … & Höger, Y. (2017). Testing the Abbreviated Food Technology Neophobia Scale and its relation to satisfaction with food-related life in university students. *Food Research International*, *96*, 198-205. https://doi.org/10.1016/j.foodres.2017.04.003.

Schnettler, B., Miranda-Zapata, E., Miranda, H., Velásquez, C., Orellana, L., Sepúlveda, J., ... & Grunert, K. G. (2016). Psychometric analysis of the Food Technology Neophobia Scale in a Chilean sample. *Food Quality and Preference*, *49*, 176-182. https://doi.org/10.1016/j.foodqual.2015.12.008.

Seibert, J. B., Bautista-Silva, J. P., Amparo, T. R., Petit, A., Pervier, P., dos Santos Almeida, J. C., ... & Dos Santos, O. D. H. (2019). Development of propolis nanoemulsion with antioxidant and antimicrobial activity for use as a potential natural preservative. *Food Chemistry*, *287*, 61-67. https://doi.org/10.1016/j.foodchem.2019.02.078.

Sekhon, B. S. (2010). Food nanotechnology–an overview. *Nanotechnology, Science and Applications*, *3*, 1-15. https://doi.org/10.2147/NSA.S8677

Siegrist, M., Cousin, M. E., Kastenholz, H., & Wiek, A. (2007). Public acceptance of nanotechnology foods and food packaging: The influence of affect and trust. *Appetite*, *49*(2), 459-466. https://doi.org/10.1016/j.appet.2007.03.002.

Siegrist, M., Stampfli, N., & Kastenholz, H. (2009). Acceptance of nanotechnology foods: a conjoint study examining consumers' willingness to buy. *British Food Journal*. https://doi.org/10.1108/00070700910972350.

Siegrist, M., Stampfli, N., Kastenholz, H., & Keller, C. (2008). Perceived risks and perceived benefits of different nanotechnology foods and nanotechnology food packaging. *Appetite*, *51*(2), 283-290. https://doi.org/10.1016/j.appet.2008.02.020.

Sodano, V., Gorgitano, M. T., Verneau, F., & Vitale, C. D. (2016). Consumer acceptance of food nanotechnology in Italy. *British Food Journal*, *118*(3), 714. https://doi.org/10.1108/BFJ-06-2015-0226.

Statnano (2020). *Nanotechnology Products Database*. Retrieved from https://product.statnano.com. Accesed March 17, 2020.

Syamsu, K., Warsiki, E., Yuliani, S., & Widayanti, S. M. (2016). Nano zeolite-$KMnO_4$ as ethylene adsorber in active packaging of horticulture products (*Musa paradisiaca*). *International Journal of Sciences: Basic and Applied Research*, *30*(1), 93-103.

Tatli Seven, P., Seven, I., Gul Baykalir, B., Iflazoglu Mutlu, S., & Salem, A. Z. (2018). Nanotechnology and nano-propolis in animal production and health: An overview. *Italian Journal of Animal Science*, *17*(4), 921-930. https://doi.org/10.1080/1828051X.2018.1448726.

Torabizadeh, H., & Montazeri, E. (2020). Nano co-immobilization of α-amylase and maltogenic amylase by nanomagnetic combi-cross-linked enzyme aggregates method for maltose production from corn starch. *Carbohydrate Research*, *488*, 107904. https://doi.org/10.1016/j.carres.2019.107904.

Verneau, F., Caracciolo, F., Coppola, A., & Lombardi, P. (2014). Consumer fears and familiarity of processed food. The value of information provided by the FTNS. *Appetite*, *73*, 140-146. https://doi.org/10.1016/j.appet.2013.11.004.

Vidigal, M. C., Minim, V. P., Simiqueli, A. A., Souza, P. H., Balbino, D. F., & Minim, L. A. (2015). Food technology neophobia and consumer attitudes toward foods produced by new and conventional technologies: A case study in Brazil. *LWT-Food Science and Technology*, *60*(2), 832-840. https://doi.org/10.1016/j.lwt.2014.10.058.

Viscecchia, R., De Devitiis, B., Carlucci, D., Nardone, G., & Santeramo, F. (2018). On consumers' acceptance of nanotechnologies: An Italian case study. *International Journal on Food System Dynamics*, *9*(4), 321-330. https://doi.org/10.18461/ijfsd.v9i4.943.

Vujić, A., & Szabo, A. (2022). Hedonic use, stress, and life satisfaction as predictors of smartphone addiction. *Addictive Behaviors Reports*, 100411. https://doi.org/10.1016/j.abrep.2022.100411.

Wilson, M., Parkin, I.P., & Page, K. (2007). A film consisting of titanium dioxide host matrix comprising silver oxide nanoparticles. *WO2007051996.*

Yu, H. C., Kim, S. B., Kim, S., Oh, M. Y., & Kim, Y. H. (2006). Bactericidal detergent composition. *WO2006071069.*

Yu, H. G., Ji, H. G., Kim, S. D., & Woo, H. K. (2009). Nano-emulsion composition of coenzyme Q10. *WO2009005215*.

Zhang, M., Sun, J., Zhao, J., Wang, W., Li, X., & Chen, L. (2009). An associated sterilization method comprising ozone, ultraviolet and nanosilver coating for quality maintenance of freeze-dried food. *WO2009049450*.

Zhou, G., & Hu, W. (2018). Public acceptance of and willingness-to-pay for nanofoods in the US. *Food Control*, *89*, 219-226. https://doi.org/10.1016/j.foodcont.2018.02.004.

Figure captions

Fig. 1. Nanotechnology application in different products that consumers evaluated in the survey.

Fig. 2. Mean scores given by respondents in the survey of neophobia to new food technology. S1-S9 correspond to the statements shown in Table 4. Scores in S5 and S6 have been reversed, so higher scores indicate more neophobia.

Fig. 3. Mean scores given by respondents in the opinion survey on applications of nanotechnology in five food products.

Fig. 4. Mean scores given by respondents in the opinion survey on applications of nanotechnology in five food products, considering the three clusters.

Table 1

Survey technical specifications.

Target population	Spanish adult people
Sample size	658
Sample error	±3.90
Confidence level	95.5% (k = 2) (p = q = 50)
Sampling procedure	Simple Random Sample
Preliminary questionnaire	Pretest to 20 individuals
Date	May-July 2020

Table 2

Main fields of nanotechnology applications in the food sector.

Goal	Example	Reference
	Ingredients or additives	
Improve the bioavailability of some nutrients	High small-sized bioavailable calcium, iron, selenium or coenzyme Q10	Jeon & Lee, 2009; Pereira et al., 2014; Prokisch & Zommara, 2009; Yu et al., 2009
Reduce the dose of an ingredient without compromising its original organoleptic characteristics	Small-sized sodium chloride to be incorporated into biscuits or peanuts; emulsions with a small droplet size that can be incorporated into fat-reduced **mayonnaise** or ice creams, etc.	Moncada et al,. 2015; Hamad et al., 2018; Henchion et al., 2019
Modify the physico-chemical characteristics of an ingredient or additive	Small-sized titanium oxide which exhibits high visual transparency with good shielding against ultraviolet light	Latva-Nirva et al., 2009
Protect molecules/microorganisms from processing conditions and the gastrointestinal tract by increasing their solubility, bioavailability, etc., masking sensory characteristics, releasing a cargo to a specific gastrointestinal tract region (targeted release)	Encapsulation of vitamins, probiotics, functional molecules, etc, in nano-/microcapsules	Feher, 2012; Henchion et al., 2019; Mohammadian et al., 2020; Cetinkaya et al., 2021
	Antimicrobial systems	

Improve a molecule or substance's antimicrobial power	Silver nanoparticles to be used in the formulation of detergents for washing food, utensils, etc.	Yu et al., 2006; Wilson et al., 2007; Zhang et al., 2009; Mesosilver, 2020; StatNano, 2020
Mask unpleasant sensory characteristics, lower evaporation rates, and improve the compatibility and stability of antimicrobials	Encapsulated antimicrobials, such as essential oils, **propolis, etc.**	Donsì & Ferrari, 2016; Seibert et al., 2019; Tatli Seven et al., 2018
	Processing methods	
Develop processing less aggressive techniques than traditional ones	**Nanofiltration** system for the concentration and clarification of juices or the dealcoholization of beer and wine, etc.	Nath et al., 2018; Peyravi et al., 2020
Provide new supports for enzyme immobilization	Supports for enzyme immobilization	Liu & Dong, 2020; Torabizadeh & Montazeri, 2020
	Packaging	
Create nano-reinforced packaging with improved mechanical or barrier properties	Introduction of nanoparticles (i.e. nanoclays, titanium dioxide) or nanocomposites (nylon resins) into polymeric matrices	StatNano, 2020
Provide food packagers or containers with antimicrobial properties	Introduction of nanometals (i.e. silver, zinc oxide, etc., nanoparticles) into polymeric matrices	StatNano, 2020; Henchion et al., 2019; Pérez-Esteve et al., 2013; Ranjan et al., 2014
Scavenge different compounds (oxygen, ethylene, etc.) from the environment to increase the shelf life of certain foods like fruit, vegetables, meat, etc.	Introduction of nanostructures (i.e. zeolites with potassium permanganate) into polymeric matrices to avoid **fruit ripening**, etc.	Syamsu et al., 2016
	Sensors	

Detect changes in food properties associated with ripening, deterioration, etc.	Nanoparticles of titanium dioxide and methylene blue to indicate the presence of oxygen. Nanosensors that react with volatile compounds in fruit and indicate the degree of ripeness with different colors, etc.	Ranjan et al., 2014; RipeSense ® label
Detect the presence of microorganisms in food	Colorimetric indicators based on noble metal nanoparticles for the detection of foodborne or spoilage microorganisms	Bumbudsanpharoke & Ko, 2019
Detect changes in storage conditions	Colorimetric indicators based on gold nanoparticles to inform about the accidental freezing of refrigerated products. Sensors that indicate if the **meat refrigeration temperature** has been exceeded by a code on the label disappearing	Ranjan et al., 2014; Enescu et al., 2019

Table 3

Participants' personal data and knowledge and opinion about nanotechnology.

		Total		Cluster 1		Cluster 2		Cluster 3		
		n	%	n	%	n	%	n	%	χ^2
		658	100	250	38.0	228	34.7	180	27.4	(p-value)
Gender	Female	427	64.9	164	65.6	143	62.7	120	66.7	ns
	Male	230	35.0	85	34.0	85	37.3	60	33.3	
	Other	1	0.2	1	0.4	0	0	0	0	
Age	18-29	220	33.4	111	44.4	62	27.2	47	26.1	***
	30-49	312	47.4	107	42.8	119	52.2	86	47.8	
	50-65	121	18.4	31	12.4	45	19.7	45	25.0	
	>65	5	0.8	1	0.4	2	0.9	2	1.1	
Educational level	Less than High school	34	5.2	12	4.8	8	3.5	14	7.8	ns
	High school	114	17.3	33	13.2	49	21.5	32	17.8	
	Bachelor degree or higher	510	77.5	205	82.0	171	75.0	134	74.4	
Relationship agri-food sector	Yes	247	37.5	137	54.8	55	24.1	55	30.6	***
	No	411	62.5	113	45.2	173	75.9	125	69.4	
Vegetarians/Vegans	Yes	23	3.5	5	2.0	10	4.4	8	4.4	ns
	No	635	96.5	245	98.0	218	95.6	172	95.6	
Food Allergic/Food Intolerant	Yes	99	15.0	37	14.8	33	14.5	29	16.1	ns
	No	559	85.0	213	85.2	195	85.5	151	83.9	
Knowledge about nanotechnology	I am not sure	16	2.4	7	2.8	4	1.8	5	2.8	***
	Nothing	107	16.3	24	9.6	45	19.7	38	21.1	

	Little	200	30.4	53	21.2	83	36.4	64	35.6	
	Something	255	38.8	116	46.4	79	34.6	60	33.3	
	A lot	80	12.2	50	20.0	17	7.5	13	7.2	
Opinion about nanotechnology	I do not know	176	26.9	35	14.0	73	32.0	68	37.8	***
	Very negative	0	0	0	0	0	0	0	0	
	Negative	3	0.5	0	0	1	0.4	2	1.1	
	Neither negative nor positive	156	23.8	41	16.4	62	27.2	53	29.4	
	Positive	237	36.2	117	46.8	73	32.0	47	26.1	
	Very positive	83	12.7	56	22.4	18	7.9	9	5.0	

*** $p<0.001$ (significant differences between clusters); ns: $p>0.05$ (non-significant differences between clus

Table 4

Mean, standard deviation and median values of the scores given by participants in the survey on neophobia to new food technologies (n=658).

		Mean	**Standard deviation**	**Median**
	Factor 1: New food technologies are unnecessary	**3.8**		
S2	The benefits of new food technologies are often grossly overstated	4.5	1.6	5
S3	There are plenty of tasty foods around, so we do not need to use new food technologies to produce more	3.5	1.9	3
S9	There is no sense trying out high-tech food products because the ones I eat are already good enough	3.5	1.7	3
	Factor 2: Perception of risks	**4.1**		
S5	New food technologies are unlikely to have long term negative health effects (R)	4.0	1.6	4
S7	New food technologies may have long term negative environmental effects	4.0	1.5	4
S8	It can be risky to switch to new food technologies too quickly	4.3	1.6	4
	Factor 3: Quality and healthy choice	**3.7**		
S1	New foods are not healthier than traditional foods	4.3	1.7	4
S4	New food technologies decrease the natural quality of food	3.5	1.8	4
S6	New products produced using new food technologies can help people have a balanced diet (R)	3.3	1.6	3
	Factor 4: Information / Media	**4.7**		
S10	The media usually provides a balanced and unbiased view of new food technologies (R)	4.7	1.6	5

S1-S10: Statements in the order in which they appeared in the survey; (R) The scores in these statements have been reversed, so higher scores indicate more neophobia