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Consumers' attitudes and change of attitude toward 3D-printed food

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ABSTRACT

3D printing, also known as additive manufacturing, offers a wide range of new possibilities within the food industry. From the realisation of complex food designs to the automated preparation of personalised meals, 3D printers promise many innovations in the food manufacturing, retail and catering sectors. Because the successful launch of foods made using a novel technology needs to be accompanied by targeted communication, a careful assessment of consumers' perception, needs and apprehensions is required. The present study aims to explore consumers' attitude formation and evolution toward this technology and resulting food concepts. Data were collected through a postal survey sent out to a sample of 2047 German-speaking residents from Switzerland, yielding a final sample size of N = 260. Participants' attitudes were assessed at the beginning and end of the survey. Three consecutive multiple regression analyses helped analyse the initial attitude, the final attitude and the attitude change determinants that were assessed. Participants' self-assessment revealed a varied but overall relatively low initial knowledge level of 3D-printed food. Because the first impression has been proven to be decisive in attitude formation, this lack of knowledge allowed us to test the effect of targeted information, and we succeeded in overcoming food neophobia and convincing consumers that this technology can support them in the preparation of healthy and individualised meals while adding a playful dimension to food preparation. The information given, however, failed to overcome food technology neophobia. Avenues for the development and testing of adapted communication concepts are discussed.

1. Introduction

3D printing, or additive manufacturing, is defined as a technology with which computer-aided design (CAD) software instructs a digital fabricating machine to shape 3D objects by the successive addition of material layers (ISO, n.a., Lupton & Turner, 2016). This technology, which originated in the 1980s and was primarily intended for use in the prototyping industry (Savini & Savini, 2015), began to be used in food processing a decade ago. Although many technological challenges related to the use of a food matrix have been tackled, very little research has been conducted on how people perceive food produced with 3D printing and how they form their opinion on this topic. Elsewhere, the food industry, well known for its competitive and innovative nature, is also characterised by a high share of product failure and market withdrawals (Bruhn, 2007; Dijksterhuis, 2016). Although the reasons for the high failure rate are numerous, the lack of importance given to consumer research appears to be one of the most crucial points upon which to work (Dijksterhuis, 2016; Popa & Popa, 2012).

Food innovations can be classified into different categories according to their degree and type of novelty (Grunert et al., 1997); novel foods and their technologies together represent the most disruptive category and are particularly susceptible to instigating mistrust and being rejected by consumers (Cardello, 2003; Cox & Evans, 2008; Ronteltap, van Trijp, Renes, & Frewer, 2007; Ueland et al., 2012). Hence, early investigations about consumers' perceptions, needs and fears are particularly relevant when it comes to marketing these types of innovations (Frewer, 1998; Frewer et al., 2011). By introducing a recent and alien technology for processing food, 3D printing is by essence a novel food technology. In-depth investigations on consumers' attitude regarding the use of this new technology in food processing are therefore recommended prior to the market launch of devices, services or products linked to or derived therefrom. A targeted study on current consumers' opinion toward 3D-printed food and their opinion-formation processes will allow for an evaluation of the potential of new food concepts, help identifying potential early-adopting customers and contribute to the development of an appropriate communication strategy.

1.1. 3D food printing

In 1984, 3D printing technology was invented by Charles Hull, who patented the stereolithography, the first technology to enable the

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creation of 3D objects from digital data. Originally developed for prototyping in the industry, several university-driven initiatives contributed to making this technology accessible to the general public and to democratise its domestic use in the 2000s (Savini & Savini, 2015). In 2001, Nanotek Instruments Inc. patented a 'rapid prototyping and fabrication method for 3D food objects' (US6280785 B1, 2001). This was the very first concept of a 3D food printer; however, further attempts from the appliance specialists Electrolux and Philips suffered from several technical shortfalls, and they found neither industrial nor domestic applications for 3D food printing (Sun et al., 2015). Inspired by the Massachusetts Institute of Technology FabLab project, in 2007, two researchers from Cornell University presented the Fab@Home Model 1, the first functioning and replicable 3D printing system compatible with food (Malone & Lipson, 2007; Sun et al., 2015). Since then, numerous projects have been conducted to refine and adapt this technology to different food matrixes (Godoi, Prakash, & Bhandari, 2016). After a decade of research, scientists have produced a sizeable range of 3D-printed food samples on a laboratory scale, with different technologies and from a variety of raw materials, but have faced several technological challenges along the way (Godoi et al., 2016; Lipton, Cutler, Nigl, Cohen, & Lipson, 2015; Sun et al., 2015). Pizzas, chocolate creations, cookies and dumplings are only a few examples of foods that can be designed by 3D printers.

1.2. Consumer perception toward 3D food printing

Although the advantages and numerous possible uses of 3D food printing are already widely discussed (Izdebska & Zolek-Tryznowska, 2016; Sun et al., 2015), very little research has been conducted on consumers' attitudes, perceptions and acceptances toward food produced by 3D printing. To the best of our knowledge, the contribution from Lupton and Turner (2016) is the first and only attempt to understand how consumers might respond to food produced with this technology; the study's online focus group discussion highlights that public knowledge about both the technology and the characteristics of the food produced with it was fairly inexistent and very speculative. Several participants feared that food produced with a printer would be inedible, unsafe or at least nutritionally depleted, and the word printer itself, commonly associated with the non-food industry, seemed to have a negative impact on participants' acceptance. Neither the display of pictures of 3D-printed food and meals, nor the arguments that this technology might contribute to food waste reduction and world hunger alleviation were successful in overcoming most participants' scepticism. Nonetheless, a small minority, describing themselves as adventurous eaters, indicated being open to consuming 3D-printed food.

1.3. Factors influencing consumers' attitude and perception toward novel food and novel food technology

Consumers generally view novel food technologies and their resulting foods with suspicion (Popa & Popa, 2012); however, not all new food technologies and food trigger the same reactions. Both the technology itself (Cardello, 2003; Frewer et al., 2011) and the individual experience and knowledge background play a determining role in the evaluation process (Greehy, McCarthy, Henchion, Dillon, & McCarthy, 2013; Olsen, Grunert, & Sonne, 2010). Some general fostering or stifling factors can nonetheless be drawn from the literature: improved flavour, increased convenience, health-enhancing properties and the proximity to or imitation of natural processes are the arguments most susceptible to enhancing consumers' acceptance of novel foods (Bruhn, 2008; Cox, Evans, & Lease, 2007; Rollin, Kennedy, & Wills, 2011; Siegrist, 2008; Siegrist, Stampfli, & Kastenholz, 2009). Repeated exposure to different types of novel food and visual representations of them (Bruhn, 2007; Cardello, 2003; Cardello, Schutz, & Lesher, 2007; Frewer et al., 2011; Jaeger, Knorr, Szabó, Hámori, & Bánáti, 2015) can also contribute to making new techniques imaginable and new food more familiar to consumers, which in turn positively affects consumers' attitudes (Lyndhurst, 2009). In contrast, suspecting the presence of harmful byproducts and, more generally, any potential health risk associated with the consumption of novel food will undoubtedly pre-empt consumers' acceptance of and interest in consumption (Bruhn, 2008; Cardello et al., 2007; Siegrist, 2008). Chemical transformation (e.g., modification of the food composition) is an additional factor that similarly jeopardises people's acceptance of new foods and new technologies (Cardello et al., 2007; Lyndhurst, 2009; Siegrist, 2008). The literature remains inconclusive and partially contradictory regarding the effect of consumer communication and education (Rollin et al., 2011). Indeed, researchers agree that unilateral and technology-driven information fails to convince consumers of the benefits of novel food (Cox et al., 2007; Scholderer & Frewer, 2003). Yet a segment-specific communication (Rollin et al., 2011) addressing both the top-down and bottom-up attitude-forming pathways (by contributing to the development of consumers' trust and faith in relevant public institutions while providing sufficient information about the risks and benefits of the technology) (Jaeger et al., 2015) using lay terminology, referring to comparable and more familiar technologies (Bruhn, 2007, 2008; Jaeger et al., 2015; Ronteltap et al., 2007; Siegrist, 2008) and addressing the major consumer questions, which are product safety and tangible end-user benefits (Bruhn, 2007, 2008; Cardello, 2003; Lyndhurst, 2009; Siegrist, 2008), has the potential to contribute to the broader acceptance of novel foods and novel food technologies. Consumer trust in the industry, the media, the scientists and the government also plays a decisive role in opinion formation, especially when the opinion-making process follows a top-down pathway, which seems to be the most probable process when it comes to evaluating particularly controversial technologies (Søndergaard, Grunert, & Scholderer, 2005). In Europe, consumer organisations, health professionals and independent scientists belong to the most trusted sources and therefore should be involved in the debate (Rollin et al., 2011; Siegrist, 2008). Taking all this into consideration, the best communication strategy might still fail to change the public's view about a novel food when its content does not match pre-existing knowledge and values (Greehy et al., 2013; Lyndhurst, 2009). Finally, studies on the impact of socio-demographic determinants have yielded contradictory results (Lyndhurst, 2009); moreover, the explanatory power of these factors has been shown to disappear when competing with cognitive and attitudinal determinants (Verbeke, 2005). The consistently more reserved attitude expressed by women toward several novel foods and novel food technologies is a notable exception (Lyndhurst, 2009).

1.4. The present research

The purpose of the current study is to fill the current knowledge gap by conducting a quantitative study on consumers' attitudes toward 3D-printed food. To this aim and based on the initial insights obtained by Lupton and Turner (2016), we developed a consumer survey and used a drivers analysis. Constructs identified to be related to consumer acceptance toward novel foods and novel food technologies according to the above literature review and that were assessable by means of a paper and pencil survey were included in the questionnaire, including *food neophobia*, *food technology neophobia*, *previous knowledge*, *convenience orientation*, the importance of both a healthy diet (*health*) and *natural* food *content* (see Table 2). Socio-demographic variables were also included. Other insights from the literature review were used to develop the information content delivered to the participants in the questionnaire. Finally, we complemented the survey with a selection of additional factors, which we hypothesised to be involved in the opinion-forming process toward 3D-printed food specifically. *Benefit perception*, the *willingness to consume*, *fun to use*, *cooking creativity*, *food involvement*, a preference for familiar foods (*familiarity*) and an affinity toward digital tools (*digital native*) are in this group of factors (see Table 2). The collected data enabled us (a) to evaluate existing public knowledge on 3D-printed food; (b) capture the determinants of a positive versus negative reaction toward this novel technology; (c) understand how this attitude is susceptible to influences and (d) investigate whether consumers respond similarly to the topic of 3D food printing as to other novel food technologies.

2. Material and methods

2.1. Data collection and sample

A questionnaire-based consumer survey was sent out to a randomly selected German-speaking population sample in Switzerland, whose addresses were taken from the telephone directory. The mailing included a cover letter introducing the study, the questionnaire itself and a postage-paid preaddressed return envelope. The person in the household who had the next birthday and was 19 or older was asked to complete the questionnaire. A total of 274 questionnaires were sent back (13.4% response rate). After deleting one case with more than 40 missing responses and 13 cases that failed a simple consistency test, 260 remained for the analysis.

The participants' recruitment method of relying on telephone entries and the requirement to be 18 or older resulted in an overrepresentation of older age groups. Foreigners, less-educated people and full-time workers perhaps felt little concern over the subject or were too busy to engage in the survey completion and are therefore underrepresented in the sample. Details of the sample characteristics compared to the general Swiss population can be found in Table 1. The data collection was performed between May and June 2017.

Table 1
Demographics of the sample compared with the resident population of Switzerland.

Characteristics	Sample population	Swiss population
Gender		
men	46%	49%
women	54%	51%
Age groups		
0–19	1%	20%
20–39	12%	27%
40–64	54%	35%
65–79	27%	13%
≥80	6%	5%
Nationality		
Swiss	92%	75%
other	8%	25%
Residence area		
urban	56%	76%
rural	43%	24%
Education		
none/compulsory	4%	13%
sec. professional	33%	38%
sec. General	6%	8%
tert. Professional	27%	14%
tert. University	30%	27%
Household size		
1 person	21%	35%
2 persons	45%	33%
3 persons	11%	13%
4 persons	17%	13%
5 persons	4%	4%
≥6 persons	2%	2%
Occupation*		
full time	30%	45%
part time	34%	25%
none	36%	30%

* Resident population ≥20 years; Sources: (Federal Statistical Office, 2013, 2016a, 2016b, 2016c, 2017a, 2017b).

2.2. Questionnaire

The questionnaire began with a short paragraph about the purpose of the study—understanding consumers' attitudes toward 3D-printed food—in which the participants were informed that the 3D printing technology, which is mainly applied in the metal and plastic processing sector, can also be used to produce customised food. The participants' initial attitudes toward 3D-printed food were assessed immediately following this statement. A semantic differential scale comprising four items was developed for this purpose. Respondents were asked to state whether they believe food produced with a 3D printer is bad – good, unimportant – important, not to be supported – to be supported and negative – positive on a six-point numeric scale. This construct constitutes the dependent variable in the analysis assessing participants' initial attitudes. Next, 3D food printing was introduced in a short paragraph (see Appendix A) and participants' *previous knowledge* level about 3D-printed food was assessed using four items, to which the respondents had to indicate their agreement on a six-point Likert scale ranging from 1 = 'do not agree at all' to 6 = 'completely agree'. Four possible application fields of 3D printers in food processing were presented: (a) the creation of new optical designs, representing the fun aspect; (b) the facilitation of cooking or improved product handling (e.g., finger food), representing the convenience aspect; (c) the adaptation of food composition to meet specific dietary (e.g., salt reduction), lifestyle needs (e.g., vegetarian) or to increase the acceptance of vegetables and fruits by children (e.g., by means of attractive optical arrangements), representing the health aspect and (d) food composition and sensory individualisation following consumers' individual needs and desires, representing the personalised nutrition aspect. 3D printing has many potential applications within the food sector, the present selection results from the literature review (Lupton & Turner, 2016), the current use in the food processing and catering industries and the authors' personal assumptions regarding the most compelling arguments from an end-user perspective. The complete descriptions of the four application fields used in the questionnaire can be found in Appendix B. Participants were asked to indicate their agreement on the same six-point Likert scale from before. Adherence to each of the four arguments was assessed separately, with the same three items covering three distinct aspects: benefit perception, the willingness to consume and fun to use. A factor analysis revealed that it was not the arguments that mattered, but rather the different aspects across the four arguments combined. Therefore, *benefit perception*, the *willingness to consume* and *fun to use* were introduced as further predictor candidates. The next questionnaire section measured consumer adherence to ten further constructs, which were supposed to be either related to interest, attitude or acceptance toward novel food technologies or associated with the major benefits of 3D printers, according to their advocates. Whenever possible, validated scales were used; some had to be reduced to avoid burdening respondents with a lengthy questionnaire. Participants assessed their agreement to all, but the nutrition knowledge items used the aforementioned six-point Likert scale. Finally, *nutrition knowledge* was assessed by 10 items for which respondents had the choice between three response options: 'true', 'false' and 'don't know'. Table 2 shows the 14 scales and their items, including Cronbach's α and the sources. At the end of the survey, participants' attitudes toward 3D-printed food were assessed a second time using the same construct as at the beginning of the survey, but this time requesting that participants consider the newly gained knowledge. This measure represents the dependent variable in the analysis measuring the attitudes of informed consumers. The questionnaire ended with a series of socio-demographic questions, of which some were also used as predictor variables in the analyses (gender, age, education and working status).

2.3. Data analysis

The internal consistency of the 14 predictors and two outcome

Table 2
Questionnaire items per construct, including internal consistency analysis.

Scales and items	Source
1. Previous Knowledge (Cronbach's α = 0.80)	new
I've already read/heard a lot about 3D-printed food	
I already knew about these facts[°]	
I know roughly how a 3D printer works	
I've already dealt with 3D food printing	
2. Benefit perception (Cronbach's α = 0.90)	new
I see an advantage in this application, also if I do not necessarily intend to make use of it *(argument: fun)*	
I see an advantage in this application… *(argument: convenience)*	
I see an advantage in this application… *(argument: health)*	
I see an advantage in this application… *(argument: nutrition)*	
3. Willingness to consume (Cronbach's α = 0.95)	new
I would have no trouble consuming this product *(argument: fun)*	
I would have no trouble consuming this product *(argument: convenience)*	
I would have no trouble consuming this product *(argument: health)*	
I would have no trouble consuming this product *(argument: nutrition)*	
4. Fun to use (Cronbach's α = 0.96)	
I would have fun producing such a food in my own kitchen *(argument: fun)*	new
I would have fun… *(argument: convenience)*	
I would have fun… *(argument: health)*	
I would have fun… *(argument: nutrition)*	
5. Cooking creativity (Cronbach's α = 0.73)	new
Cooking allows me to express my creativity	
When I cook, I like to try new recipes	
The best of cooking is to develop own recipes or optimise existing ones	
6. Food neophobia (Cronbach's α = 0.77)	(Pliner & Hobden, 1992)
I am constantly sampling new and different foods[R]	
I do not trust new foods	
If I do not know what is in a food, I won't try it	
I like foods from different countries[R]	
Ethnic food looks too weird to eat	
At dinner parties, I will try a new food[R]	
I am afraid to eat things I have never had before	
I am very particular about the foods I will eat	
I will eat almost anything[R]	
I like to try new ethnic restaurants[R]	
7. Food technology neophobia (Cronbach's α = 0.73)	(Cox & Evans, 2008)
There are plenty of tasty foods around, so we don't need to use new food technologies to produce more	
The benefits of new food technologies are often grossly overstated	
New food technologies decrease the natural quality of food	
There is no sense trying out high-tech food products because the ones I eat are already good enough	
8. Convenience orientation (Cronbach's α = 0.72)	(Candel, 2001)
The less physical energy I need to prepare a meal, the better	
The ideal meal can be prepared with little effort	
Preferably, I spend as little time as possible on meal preparation	
I want to spend as little time as possible cooking	
At home, I preferably eat meals that can be prepared quickly	
9. Food involvement (Cronbach's α = 0.68)	(Bell & Marshall, 2003)
I don't think much about food each day[R]	
Cooking or barbequing is not much fun[R]	
Talking about what I ate or am going to eat is something I like to do	
I enjoy cooking for others and myself	
When I eat, I do not wash dishes or clean the table[R]	
I care whether or not a table is nicely set	
10. Health (Cronbach's α = 0.84)	(Steptoe, Pollard, & Wardle, 1995)
It is important to me that the food I eat on a typical day:	
Contains a lot of vitamins and minerals	
Keeps me healthy	
Is nutritious	
Is high in protein	
Is good for my skin, teeth, hair, nails, etc.	
Is high in fibre and roughage	
11. Natural content (Cronbach's α = 0.86)	(Steptoe et al., 1995)
It is important to me that the food I eat on a typical day:	
Contains no additives	
Contains natural ingredients	
Contains no artificial ingredients	
12. Familiarity (Cronbach's α = 0.75)	(Steptoe et al., 1995)
It is important to me that the food I eat on a typical day:	
Is what I usually eat	

(*continued on next page*)

Table 2 (*continued*)

Scales and items	Source
Is familiar	
Is like the food I ate when I was a child	
13. Digital native (Cronbach's α = 0.89)	(Teo, 2013)
I use computers for many things in my daily life	
I use the computer for leisure every day	
I am able to communicate with my friends and do my work at the same time	
I am able to use more than one applications on the computer at the same time	
I use a lot of graphics and icons when I send messages	
I use pictures to express my feelings better	
I expect quick access to information when I need it	
I expect the websites that I visit regularly to be constantly updated	
14. Nutritional knowledge[D] (Cronbach's α = 0.76)	(Dickson-Spillmann, Siegrist, & Keller, 2011)
Lentils contain only a few useful nutrients; therefore, their health benefit is not great[R]	
The health benefit of fruit and vegetables lies only in the supply of vitamins and minerals[R]	
A healthy diet means nothing else than eating vitamins[R]	
Fat is always bad for your health; you should therefore avoid it as much as possible[R]	
A healthy meal should consist of half meat, a quarter vegetables and a quarter side dishes [R]	
If you have eaten high-fat foods, you can reverse the effects by eating apples[R]	
Whole meal foods contain fiber, which is of no use for digestion[R]	
To eat healthily, you should eat less; whatever foods you decrease does not matter[R]	
If chips did not contain so much salt, you could eat more of them without any problem[R]	
All dietary oils have the same ingredients; the oils differ only in taste[R]	

Notes:
[*] Question following a description of the 3D food printing process.
[R] Items reversed for analysis.
[D] Items changed into a response format of 0 (incorrect), 1 (don't know) and 2 (correct).

Table 3
Measure of attitude toward 3D-printed food, including means and standard deviations.

Scales and items	M	SD
1. At the beginning of the questionnaire (Cronbach's α = 0.95)		
I think that foods produced with 3D printers are generally…		
Bad – good	2.42	1.36
Unimportant – important	2.26	1.28
Not to be supported – to be supported	2.30	1.47
Negative – positive	2.29	1.35
2. At the end of the questionnaire (Cronbach's α = 0.95)		
I think that foods produced with 3D printers are generally…		
Bad – good	3.06	1.36
Unimportant – important	2.57	1.35
Not to be supported – to be supported	2.78	1.47
Negative – positive	2.93	1.41

Notes: Measured on a six-point semantic differential.

variables that assessed the participants' attitudes toward 3D-printed food were measured using Cronbach's alpha coefficient; because all constructs yielded satisfactory scores (Cronbach's alpha ≥ 0.68), the means over the corresponding items were calculated and saved for further analysis. Details about items, sources and reliability statistics for predictors and outcome variables' scales are summarised in Tables 2 and 3, respectively.

Multiple linear regression analyses were then run to test the predictors of the respondents' attitudes toward 3D-printed food at the beginning and end of the questionnaire. To capture all relevant predictors, the backward method with a variable removal criterion (POUT) set at > 0.05 was used for these analyses, as suggested by Field (2013, p. 323).

The significance of the shift in consumers' attitudes after the survey completion was measured using a *t*-test; the difference was then computed and subjected to a further multiple linear regression analysis using the same method and predictor candidates as before to reveal the factors contributing to the change. All statistical analyses were done using IBM SPSS Statistics version 24.

3. Results

3.1. Previous knowledge about 3D-printed food

Participants assessed their previous knowledge of 3D food printing as relatively low; their mean score for this construct reached 2.33 on a six-point Likert scale; details of the single items' scores are shown in Table 4. Interestingly, just over 20% of the respondents reached a mean score of > 3.5, indicating a medium-to-high knowledge level on the topic.

3.2. Consumers' overall attitudes toward 3D-printed food

Respondents' initial attitudes toward 3D-printed food was not unanimous, but overall, their attitudes were rather negative, $M = 2.26$ ($SD = 1.28$). The presentation of several applications of this technology within food processing and the emphasis on end-user benefits during the survey significantly and positively influenced the opinions of the surveyed population, whose general attitude remained still diverse and negative, $M = 2.82$ ($SD = 1.31$, $t(253) = -8.66$, $p < .001$).

3.3. Predicting consumers' initial attitudes

A multiple regression analysis was performed using the respondents' initial attitudes as the dependent variable and the 14 constructs, as well

Table 4
Measure of previous knowledge of 3D-printed food, including means and standard deviations.

Scale and Items	M	SD
Previous knowledge (Cronbach's α = 0.80)	2.33	1.20
I've already read/heard a lot about 3D-printed food	2.03	1.33
I already knew about these facts[*]	2.52	1.72
I know roughly how a 3D printer works	3.27	1.86
I've already dealt with 3D food printing	1.59	1.10

Notes: Measured on a six-point Likert scale.
[*] Question following a description of the 3D food printing process.

Table 5
Summary of multiple linear regression analysis for variables predicting consumers' initial attitude toward food produced with a 3D printer.

	B	CI	SE B	β	p
Constant	2.55	(1.67, 3.43)	0.45		.000***
Fun to use	0.29	(0.18, 0.41)	0.06	0.33	.000***
Willingness to consume	0.17	(0.07, 0.28)	0.05	0.22	.002**
Food technology neophobia	−0.24	(−0.37, −0.10)	0.07	−0.19	.001**
Food neophobia	−0.23	(−0.39, −0.07)	0.08	−0.15	.005**
Gender	0.35	(0.09, 0.62)	0.13	0.14	.010*

Notes: R^2 = 0.42; Coding for gender: male = 1, female = 0.
* p < .05.
** p < .01.
*** p < .001.

as the four socio-demographic variables, as predictors. The results of the normality and homoscedasticity checks and the collinearity diagnostic indicated that the data were suitable for a regression analysis. Five of the 18 entered predictors contributed significantly to the model. *Fun to use* was the strongest predictor of a positive attitude toward food produced with a 3D printer, followed by the *willingness to consume* 3D-printed food. Unsurprisingly both *food technology neophobia* and *food neophobia* were related to a negative attitude toward food produced with this new technology. *Gender* turned out to be the only significant predictor among the socio-demographic variables, with men showing a more positive attitude than women toward 3D-printed food. This model explained 42% of the variance in consumers' initial attitudes. Table 5 shows the results of the regression analysis.

3.4. Predicting the attitudes of informed consumers

The same multiple regression analysis mentioned in 3.3 was conducted using respondents' attitudes at the end of the survey as the dependent variable and the same 18 constructs as predictors. The normality, homoscedasticity and collinearity diagnostics did not show any concern. Table 6 provides a summary of the results of this second regression analysis. The *willingness to consume* and *food technology neophobia* both remained central determinants of informed consumers' attitudes, the former implying a positive outlook and the later a negative one. Besides these two strong predictors, perceiving technology benefits (*benefit perception*), having a marked preference for convenient and short meal preparation (*convenience orientation*) and expecting *fun to use* have also proven to be significantly correlated with a positive attitude toward 3D-printed food. The model explained 66% of the attitude variance in informed consumers.

3.5. Predicting participants' attitude change

Finally, a third multiple regression analysis was conducted to test

Table 6
Summary of the multiple linear regression analysis for the variables predicting consumers' attitudes toward food produced with a 3D printer after the completion of the survey.

	B	CI	SE B	β	p
Constant	2.31	(1.70, 2.91)	0.31		.000***
Willingness to consume	0.27	(0.18, 0.36)	0.05	0.33	.000***
Food technology neophobia	−0.38	(−0.49, −0.28)	0.05	−0.31	.000***
Benefit perception	0.19	(0.08, 0.29)	0.05	0.21	.001**
Convenience	0.16	(0.06, 0.25)	0.05	0.14	.002**
Fun to use	0.10	(0.01, 0.20)	0.05	0.12	.035*

Notes: R^2 = 0.66.
* p < .05.
** p < .01.
*** p < .001.

Table 7
Summary of the multiple linear regression analysis for the variables predicting consumers' attitude change following the completion of the questionnaire.

	B	CI	SE B	β	p
Constant	−1.08	(−2.27, 0.10)	0.60		.073*
Food neophobia	0.27	(0.10, 0.43)	0.08	0.22	.002**
Benefit perception	0.15	(0.05, 0.25)	0.05	0.21	.003**
Nutrition knowledge	0.05	(0.02, 0.09)	0.02	0.20	.003**
Convenience	0.17	(0.05, 0.29)	0.06	0.18	.007**
Previous knowledge	−0.15	(−0.26, −0.04)	0.06	−0.17	.008**
Food technology neophobia	−0.14	(−0.26, −0.01)	0.06	−0.14	.035*

Notes: ***p < .001; R^2 = 0.21.
* p < .05.
** p < .01.

the 18 predictor candidates of the change in attitude that occurred between the first and second opinion assessments. This analysis revealed that the more the consumers became nutrition conscious (*nutrition knowledge*), *convenience* oriented and agreed with the presented benefits (*benefit perception*), the more their attitudes changed. *Food-neophobic* participants also demonstrated greater opinion improvement. In contrast, the attitude change was smaller among people who reject the use of novel technologies in food production (*food technology neophobia*) and those reporting higher *previous knowledge* of 3D food printing. Details on the factors that significantly affected the attitude change are summarised in Table 7. Twenty-one percent of the consumers' attitude change can be explained by the hereby tested model.

4. Discussion

4.1. Major drivers of consumers' attitudes toward 3D-printed food

The surveyed consumers reported rather limited knowledge and very few experiences related to 3D printing and 3D-printed food. This unsurprisingly and easily explainable result (both 3D printers and 3D-printed food objects being currently nearly unavailable to end consumers) confirms the initial findings of Lupton and Turner (2016). Overall, lay consumers give little credit to 3D-printed foods; our results highlight that this a priori negative attitude is linked to the fear of eating alien food and a certain aversion to highly processed food. The willingness to consume and the expected fun to use were two strong attitude determinants; the superior explanatory power of these predictors, both before and after the provision of information concerning the applications of 3D printing in food production, indicates that the selected arguments – fun, convenience, health and personalised nutrition – are relevant in the promotion of the technology to the target public, namely the early adopters. The information provided throughout the questionnaire also succeeded in convincing nutrition-conscious and convenience-oriented participants of the technology's usefulness and in demonstrating the added value that 3D printers might provide to them.

4.2. The pivotal role of consumer education

The participation in the survey itself and the knowledge gained from it significantly impacted consumers' attitudes and improved their overall opinion of 3D-printed food. The analysis of the attitude change determinants revealed that the information succeeded in one of its aims: clarifying that 3D printing does not necessarily affect food composition. Thus, the information provided in the survey overcame participants' initial food neophobia but failed in its attempt to depict the device as harmless kitchen equipment, even reinforcing the negative high-processed image of 3D-printed food, as highlighted by the negative impact from food technology neophobia on attitude change. In contrast, the descriptions of the possible application fields were compelling and succeed in convincing participants of the usefulness of the technology. Interestingly, the attitude improvement was significantly smaller for participants who indicated a higher level of previous knowledge of 3D food printing. The reaction of this group of participants, which stuck to their rather negative first impression, could indicate that the information delivered through the questionnaire did not fit with their pre-existing beliefs and was thus disregarded in their opinion-formation process, as suggested by Greehy et al. (2013) and Lyndhurst (2009), who examined the effect of information on attitude formation toward several novel food technologies. This observation highlights how important it is to control and anticipate the communication about this new technology, supporting the need for an early and well-designed information campaign.

The combination of a lack of common knowledge and the presumably unfortunate name of the technology, which is a reminder that the device originates from the non-food industry, prevent most consumers from quickly obtaining an idea of the general properties, appearance and potential benefits of food products prepared with 3D-printing techniques; to the contrary, these consumers are likely to adopt very cautious attitudes of the technology. This phenomenon is reflected in the overall low support assigned to the food produced with 3D printing technology prior to the study and was particularly found in food neophobic consumers. The details provided within the questionnaire aimed to address some major consumer concerns regarding novel food technologies: the descriptions were provided in laymen's terms, the 3D printer was compared with other common kitchen equipment, and a special emphasis was placed on the purely mechanical nature of the process and on the use of well-known ingredients and food preparations in the process. This information was successful in assuaging some of the participants' fears, especially those related to the consumption of unfamiliar food but failed to convince consumers opposed to the use of novel technologies or adjuvants in food processing. The examples of applications of 3D printing successfully demonstrated the usefulness and playfulness of the technology while convincing participants to try the resulting food products. The relevance of the aforementioned fears and proposed application fields in the attitude change confirms that consumers' reactions toward 3D-printed food is similar to their responses to other novel food technologies that have added convenience, health-enhancing properties and a natural process as their most compelling arguments (Rollin et al., 2011).

At the beginning of the questionnaire, participants were asked to give their opinions on a food-processing technology about which most had no fact-based and objective knowledge and probably no fixed beliefs. Most respondents thus had no other choice but to build up a relation to this technology by deriving their position from the appellation '3D food printing', a process which resulted in a very individual and non-guided conception of the production situation and the product's properties. Throughout the study, the participants were supplied with concrete examples of the application and target information of 3D food printing, intending to ease some of their expected fears, giving them the opportunity to readjust and objectify their individual positions before being asked to reassess their opinions when taking the gained knowledge into account. The difference between the initial, rather speculative and poorly founded opinion and the second assessment in light of the communicated information throughout the survey is well reflected in our models' explanatory power, which rose from 42% to 66% at the end of the study. Participants moved from their conservative initial attitudes, mainly driven by fears and uncertainties, to more objective and tempered positions by the end of the study.

Our study confirms that socio-demographic predictors have limited explanatory power compared to determinants related to consumers' knowledge and behaviour. Neither age, education level nor working status were significant in the three regression analyses. Although women initially expressed more reservations toward 3D food printing, the gender factor lost its significance in the model explaining attitude changes. This indicates that the study completion allowed to reduce the attitude gap between men and women, which fell short below the significance threshold in the second analysis. Overall, these results are in line with the conclusions of previous studies (Lyndhurst, 2009; Verbeke, 2005).

4.3. Limitations and recommendations for future researches

The difficulty of reproducing images of 3D-printed food in sufficient quality on paper led us to prefer the use of clear descriptions to blurred pictures. Appearance is nonetheless a major determinant in the opinion-formation process, especially when it comes to appraising new food concepts; thus, the absence of visual representations limited the external validity of our results to some extent. A written survey also sometimes falls short of translating real-life situations, which, combined with the rather rational instead of emotional approach chosen in the questionnaire—also possibly too technology oriented—could be partially responsible of the persistence of food technology neophobia. Finally, the two consecutive attitude measurements in the same questionnaire are another potential source of concern. We asked participants to take the information content of the questionnaire into account in their second judgement to minimise the respondents' tendency to avoid giving inconsistent responses; despite this measure, the persistence of a cognitive dissonance mitigation strategy cannot be excluded.

Taken these observations into account and on the grounds of our findings related to the major factors fostering and preventing consumer acceptance toward 3D-printed food, further studies should focus on investigating consumers' responses when confronted with real product samples without any introduction about the processing technology and devices used to make the food. Furthermore, the samples presented to consumers should include common food preparations (e.g., chocolate) and minimal processed foods (e.g., vegetable puree). The impact of food technology neophobia should then be reassessed within this new context. Experiments including product tasting and name variations should also be conducted to determine how the products must be introduced and on what details the communication must focus to gain consumers' approval.

5. Conclusion

Two important conclusions emerged from this study: on the one hand, the first impression consumers receive, and thus the role the first information provider plays, is important in opinion forming; on the other hand, well-designed communication has the potential to positively shape consumers' attitudes toward 3D-printed food. The currently very limited consumer knowledge level allowed us to test the impact of information provision. Our attempt, which included fundamental, factual information concerning the technology and a description of application scenarios, succeeded in positively influencing consumers' attitudes, especially among those who had no or very limited previous knowledge; on the other hand, skilled participants were swayed very little by the provided argumentation. Our results also highlight that some of the fears and reluctances that shaped consumers' initial attitudes were particularly difficult to remove, notwithstanding a target communication that aimed to overcome this presumption. Food technology neophobia persisted and was even reinforced among informed consumers, despite our attempt to compare it to similar well-known kitchen equipment. Because the possibly too rational approach and the written questionnaire form might have played a role in this outcome, alternative communication forms should be considered in future research and marketing studies.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodqual.2017.12.010.

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