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# Willingness to try food with the application of nanotechnology

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ABSTRACT

The objective of this paper is to propose a model to evaluate the factors that influence the willingness to try (WTT) food with the application of nanotechnology. The research was conducted with Brazilian consumers who are responsible for the purchase of food (n = 244). The data was analyzed with PLS-SEM. The results showed that the perception of food safety and appropriate nutrition aspects had significant positive effects on the willingness to try food with the application of nanotechnology, while the level of sustainable food consumption was not significant as well as food neophobia and the perception of technology. An additional result demonstrated that there is a difference between the WTT of Millennials and Generation X, indicating more openness of Millennials. Considering the significant variables, policymakers, institutions, and researchers involved in the nanotechnology market must strive to provide the consumer with better information on the benefits of food with the application of nanotechnology, its relationship with the environment, and its nutritional and safety advantages when compared to conventional food. Only with proper information can consumers develop values and perform the most adequate behavior for them.

**Index terms:** innovation, nanotechnology, technology acceptance.

**Ideias centrais**

- Consumers indicate that nanotechnology has appropriate nutritional and safety aspects and are willing to try it.
- Nanotechnology can offer improved taste and smell and benefit the misinterpretation of food with claims of enhanced nutrition, guaranteeing relevant aspects for consumers.
- Consumers may face uncertainty about the relationship between sustainability and nanotechnology.
- Neophobia had no impact on willingness to try, as consumers did not associate nanotechnology with disgust and aversion.
- Millennials are more willing to try nanotechnology than Generation X.

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## A intenção de experimentar alimentos com aplicação de nanotecnologia

RESUMO

O objetivo deste trabalho é propor um modelo para avaliar os fatores que influenciam a disposição de experimentar (WTT) alimentos com a aplicação da nanotecnologia. A pesquisa foi realizada com consumidores brasileiros responsáveis pela compra de alimentos (n = 244). Os dados foram analisados por meio de Modelagem de Equações Estruturais (SEM). Os resultados mostraram que a percepção de segurança do alimento e aspectos de nutrição adequados tiveram efeitos positivos significativos na disposição de experimentar alimentos com a aplicação da nanotecnologia, enquanto o nível de consumo de alimentos sustentáveis não foi significativo, assim como a neofobia alimentar e a percepção de aplicação de tecnologia. Um resultado adicional demonstrou que há diferença entre a disposição de experimentar dos Millennials e a da Geração X, indicando maior abertura dos Millennials. Considerando as variáveis significativas, os formuladores de políticas, instituições e pesquisadores envolvidos no mercado de nanotecnologia devem se esforçar para fornecer ao consumidor melhores informações

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sobre os benefícios dos alimentos com a aplicação da nanotecnologia, sua relação com o meio ambiente e suas vantagens nutricionais e de segurança em relação aos alimentos convencionais. Somente com informações adequadas os consumidores poderão desenvolver valores e efetivar o comportamento mais adequado para eles.

**Termos para indexação:** inovação, nanotecnologia, aceitação de tecnologia.

## INTRODUCTION

The world population is expected to reach 9.7 billion by 2050 (United Nations, 2022), and food consumption is predicted to grow by around 70%. Therefore, it will be essential to implement new technologies to meet the needs of this growing population on a global scale (Padua & Wang, 2012). Nanotechnology has proven to be a possible solution in this regard and provides businesses and investors with a commercial opportunity as a sustainable means of increasing global food production to satisfy the future population (Uldrich & Newberry, 2003; Tolfree, 2006).

Nanotechnology is the manipulation of molecules with a scale of 1-100 nanometers, capable of changing the development of materials and their structure, designing them with properties very different from the original ones (Singh, 2018). The new technology introduced to the market is applied in the fields of medical procedures, computer science, physics, chemistry, industrial production, and food production (Padua & Wang, 2012). Regarding food products, nanotechnology has the potential to increase production in a sustainable way, and can also make food healthier, improving its conservation process and the resistance of packaging materials, making the aroma, texture, and taste more pleasant to the consumer. This increases the bioavailability of nutrients, preventing microbial spoilage, removing contaminants, and even nourishing specific parts of the human body (Sanguansri & Augustin, 2006).

In practice, the application of nanotechnology is capable of changing the smell of food such as fish oil, which is highly nutritious but does not have a very pleasant aroma, allowing the manufacturing of low-fat mayonnaise that is as creamy and tasty as its alternatives and even the growth of peanuts that do not cause allergic reactions (Handford et al., 2014). Nevertheless, besides the benefits presented by food nanotechnology, Siegrist & Hartmann (2020) claimed that it is very likely that it will not be perceived as abnormal or as an interference with nature, therefore, an increase in the risk perceived by the consumer is to be expected. Studies have shown that people feel that there are more risks than benefits associated with this technology and consumers may consider it harmful to their health (Rashidi & Khosravi-Darani, 2011). The risk perception is often associated with a lack of consumer knowledge, which can lead them to misinterpret nanotechnology as a substance, very similar to pesticides, that cannot be manipulated. In this respect, they mainly fear the effects that can occur after the consumption of non-natural ingredients (Siegrist et al., 2008) – this is the case of genetically modified (GM) food, which, despite the benefits, is viewed as unnatural and this elicits a negative affect (Siegrist et al., 2016).

Nanotechnology is viewed as a key technology that can change how companies manufacture their products (Siegrist et al., 2007). Therefore, according to Gómez-Llorente et al. (2022), it is necessary to determine if consumers know this new technology and to know their opinions. Introducing new food technologies to the market is a major challenge (Siegrist & Hartmann, 2020), nevertheless, technological innovations like nanotechnology can increase food safety levels to meet consumers' demands (Morales-de la Peña et al., 2019); in addition, it is able to provide food quality, extend shelf life, and provide better nutrients uptake, and new flavors (Sekhon, 2014), which can enhance health and help overcome some difficulties in consuming untasteful foods. Consequently, the aim of this article is to verify consumers' willingness to try foods with the application of nanotechnology. The following section contains a description of a theoretical conceptual model that proposes five variables (food safety, nutrition, sustainable consumption attitude, neophobia, and perception of the application of nanotechnology). It also contains, based on the literature, five hypotheses regarding the willingness to try foods with any form of applied nanotechnology, which are proposed and tested.


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This study intends to contribute to the expanding of literature and knowledge of consumer behavior regarding new food technologies, by assessing Brazilians' perception of it, which, to the best of our knowledge, was not explored considering the variables assessed by this study. In addition, Coutinho et al. (2021) found that Brazilians are not receptive to new food technologies – the authors found that there are signs of fear, rejection, and sensory changes. Salnikova et al. (2019) demonstrated that the success rate for the inclusion of new products in the market ranges from 59% to 74% for completely new products and products launched with a new formulation. Therefore, understanding how the end consumer operates helps in the further knowledge of what is at play in the variation of the success rate when it comes to putting food products on the market; in addition, it can benefit stakeholders in decision-making and providing suitable policies.

## CONCEPTUAL MODEL

Consumers can perceive the use of new technologies in food production as contradictory in terms of health, nutrition, and flavor. This makes it essential to consider their opinions in the most embryonic stages of product development (Siegrist & Hartmann, 2020). The literature explores several determinants of food purchasing that explain consumers' acceptance of new foods, as they tend to reject foods that cause disgust or a low perception of naturalness. In this respect, Tuorila & Hartmann (2020) noted that to identify barriers to acceptance, it is necessary to measure them properly. It is also necessary to explore the food selection process.

Regarding foods processed by new technologies, individuals are concerned with the nature of food, in addition to the nature of the technology applied, and this becomes a key factor for consumers when the time comes to make the decision to try (Cardello, 2003). The extant literature has been verifying consumer behavior and attitudes regarding nanotechnology application to food products and the majority of them rely on models containing, for instance, knowledge, novelty, perceived advantages (Chang et al., 2017), affect, social trust, health benefits, attitudes to nanotechnology (Siegrist et al., 2007, 2008; Henchion et al., 2019), general acceptance of new food technology and trust in institutions (Zhao et al., 2020), and safety and nutrition (Yang & Hobbs, 2020).

Based on this, our objective is to contribute and measure, in addition to nutrition and safety perception, which needs to be explored for new technologies applied to food (Siegrist & Hartmann, 2020), psychometric properties that may contribute to the consumer behavior, such as the aversion to new and different foods, and the sustainable consumption attitude, in addition to the perception of technology application.

Lastly, our choice of dependent variable relies on the assumption that exploring the willingness to try a food product is suitable for people who never had contact with it (Chang et al., 2017), and by choosing to measure it, as mentioned by Ajzen (1991), we are able to access the effort that individuals are willing to make to perform a determined behavior, i.e., how much they are willing to try. From this perspective, the constructs chosen are proposed to contribute to this behavior and are properly defined in the following subsections based on the studied literature, followed by the respective hypotheses. Figure 1 shows the conceptual model prepared by the authors.

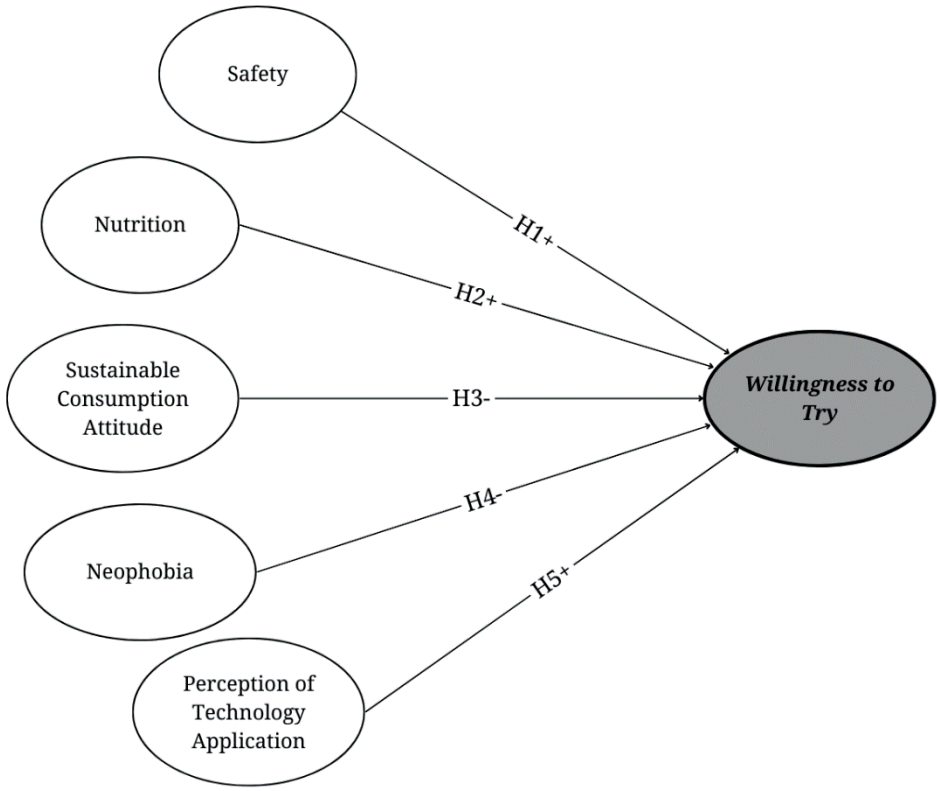


**Figure 1.** Conceptual Model.

## Food Safety

The food safety variable is linked to the application of nanotechnology, considering its usability to detect bacteria, viruses, toxins, and halogens that may be present in food, ensuring safety for the consumer (Brody et al., 2008; Scott et al., 2018). The study by Farkas & Kiss (2021) demonstrated that high food safety levels are considered important by consumers in relation to foods with the application of nanotechnology. In specific terms, the study found that 78.6% of the sample would buy food with the application of nanotechnology if it meant more safety.

However, it is argued in the study that the importance of food safety for the consumer regarding food with the application of nanotechnology needs to be more explored. For instance, Siegrist & Hartmann (2020) found that at least in many developed countries, consumers appreciate natural food, uninfluenced by other factors, such as technology, as they believe that more natural food means guaranteed safety. This was also noted by Siegrist et al. (2009). Bolek (2020) reinforces that consumers are concerned about the safety of new food processing techniques; for instance, the author mentions that this is more important for them than poisoning or hygiene standards, and another view from Siddiqui et al. (2022) proposes that consumers perceive food with the application of nanotechnology as impure.

Food safety is mostly approached from an institutional perspective, regarding the trust in institutions (Zhao et al., 2020), food traceability, and transparency in the food industry, in addition to contamination or poisoning (Zhang et al., 2020). From an anthropological view, some edible food products developed by the industry may make the consumer suspicious, who questions their processing, contents, and provenance (Fischler, 2002, p.144). From this perspective, Fischler (2002, p.144) argues that some foods become unidentified food objects by the consumers, because consumers may say that they “don’t know what they are eating anymore”, characterizing a lack of trust in new foods


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and, in addition, they may ask themselves: “I am what I eat. I no longer know what I eat. Do I still know who I am?”.

Likewise, Bolek (2020) states that food safety is an important aspect for the food consumer and there is a main concern regarding the relationship between what they eat (the overall diet) and their health (consequences for the body). Our proposition is based on the definition that consumers’ trust in the safety of foods can be ensured by not expecting any health harm (De Jonge et al., 2004). Therefore, in addition to nanotechnology being perceived as impure (Siddiqui et al., 2022), or doubtful regarding the technological technique (Bolek, 2020), it is assumed in this study that the consumer is predominantly concerned with poor health consequences.

Based on this, the aim of the first hypothesis is to assess consumers’ perception about how safe foods with the application of nanotechnology are, regarding food diseases, parasites, and chemical residues and, considering the relevance of them being perceived as safe, if they are, a positive relationship with the willingness to try is proposed. Accordingly, five hypotheses are proposed and explained below.

**First hypothesis.** The perception of food safety positively impacts the willingness to try food with the application of nanotechnology.

Nutrition

Regarding consumer preoccupation with their health, nutritional properties are another relevant aspect to be explored, which, as well, produces health consequences. The consumer tends to expect safe food products, and at the same time food products able to provide proper nutrition and health (Lusk, 2019; Tobi et al., 2019; Plasek et al., 2020). According to Klopčič et al. (2020), recent applications have demonstrated that the belief in the healthiness of a food product has become the strongest positive determinant for the consumption of foods with Nutrition and Health Claims, to such an extent that consumers are ready to compromise on taste, which is vastly assumed to be one of the strongest determinants of food choice (Rozin & Vollmecke, 1986).

One of the aims of the industry in the innovation of food products with nanotechnology is to enhance their nutritional value (Handford et al., 2014). The technology is capable of modifying internal structures, with techniques that can make food healthier and even convey nutrients to specific parts of the body (Sanguansri & Augustin, 2006); therefore, foods can become much better, with greater nutritional value, offering more value to users (Weiss et al., 2006). Nutritional modification is done by adding nanoparticles capable of controlling the nutritional content of the food, making it healthier (Siegrist et al., 2007).

Some researchers argue that the presence of Nutrition and Health Claims is bad for taste perception, as these aspects can be often viewed as opposites (Lähteenmäki et al., 2010); therefore, this new food technology may be the next one to provide new claims in order to enhance consumers’ perception, considering its functionality in making the food aroma, texture and taste more pleasant to the consumer, in addition to enhancing nutritional benefits (Sanguansri & Augustin, 2006).

An additional point is that when discussing nutrition and our environment of food choice, according to Rozin (2005), we are still adapted to the ancestral word and, therefore, exposed to risks when choosing a certain food, in addition to having to expend energy (knowing the foods, classifying them as suitable, not harmful, healthy, etc.) to get energy (being able to eat them). Food selection is a basic and a vital need, but even when faced with adequate food, we must make efforts to identify if it is nutritionally complete. Assuming the need to “get energy”, and the need to “spend energy” to characterize a certain food as nutritionally adequate, it is proposed in the study that for a positive willingness to try, the consumer will need to positively evaluate the food’s nutritional aspects. In

addition to this discussion, recent evidence in Farkas & Kiss (2021) demonstrates that 63% of consumers, in their sample, would purchase foods with applied nanotechnology with added value, such as higher levels of omega-3. Likewise, Sodano et al. (2016) referred to a good feeling on the part of consumers regarding the positive effects on health caused by new technologies. Therefore, the following hypothesis is described below.

**Second hypothesis.** Perceived nutritional value positively affects the willingness to try foods with nanotechnology.

Sustainable Consumption Attitude (SCA)

In addition to the basic need that food is nutritionally adequate and safe for consumption, for food to be suitable for the modern consumer, another aspect that is closely linked to them is that the food is not harmful to the environment (De Jonge et al., 2004). However, regarding nanotechnology, there is a particular discussion about this, which makes it a relevant variable to be explored.

Nanotechnology has made advances in improving the way society produces food, improving the quality of life, and helping to preserve the environment. With the application of nanotechnology, three areas of the environment can benefit, namely: the prevention of direct and indirect pollution of the environment; the treatment and recovery of already affected environments; and the detection and monitoring of pollution and diseases (Quina, 2004). To treat and repair already polluted environments, nanotechnology can facilitate the removal of polluting substances by separating metals from wastewater (Ngomsik et al., 2005; Ye et al., 2006; Siqueira-Batista et al., 2009), and it is also able to manufacture nanosensors to monitor and diagnose diseases in animals and the environment (Ramos, 2006; Vaseashta et al., 2007).

However, although the new technology presents these environmental benefits, there are also disadvantages. Some nanoparticles may be responsible for the transport of toxic materials and heavy metals. Therefore, the large-scale production of nanoparticle-based products runs a great risk of causing toxicity (Dreher, 2004; Siqueira-Batista et al., 2009). In short, when used in food production, nanotechnology can have negative impacts. Cavaliere & Ventura (2018) found that the greater the attention given to sustainable food consumption, the lower the intention to try products with the application of technology. That is because, in general, an aspect related to sustainable foods by consumers is freshness and naturalness (Vermeir & Verbeke, 2006). Coutinho et al. (2021) also found that consumers showed to be mostly against the use of new technologies on food products, and this may be associated with the lack of perceived advantages in environmental impact.

In addition, accordingly to Vermeir & Verbeke (2006), sustainability is a credence attribute; therefore, consumers cannot easily evaluate it, and even if there is a sustainability claim, trust is needed to consider it in the decision. Based on this discussion, it is proposed in this study that nanotechnology is not well seen by a consumer that has a positive sustainable consumption attitude, because of the perceived lack of naturalness, based on the presence of technology and the potential harm of its application in food production. This can be a major obstacle for nanotechnology to be widely accepted by the modern food consumer. Therefore, is the following is expected.

**Hypothesis 3.** The sustainable consumption attitude negatively affects the willingness to try foods with nanotechnology.

Food neophobia

One of the most relevant factors when exploring new food acceptance is the psychological trait neophobia (Faccio & Fovino, 2019; Siddiqui et al., 2022). Food neophobia is the reluctance to


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consume new foods and is considered an adaptive value that serves as a protective function in an environment where food may appear hostile (Pliner & Hobden, 1992). Neophobia is widely used to measure consumer behavior concerning new foods, and assessing the psychometric properties of consumers can help advance knowledge on the determinants of consumption (Siegrist & Hartmann, 2020).

Schnettler et al. (2013) identified, in individuals with a high level of food neophobia, a rejection of food or packaging produced with nanotechnology. Only participants who characterized two groups of non-neophobic individuals and who were satisfied with their food life showed an intention to buy food or packaging containing nanotechnology. The authors discuss the usability of the NFS (Food Neophobia Scale) for approaching new food technologies, however, based on their results, the authors confirm it as a suitable instrument to verify consumer acceptance of new food technologies in developing countries. Therefore, even though recent applications have used Food Technology Neophobia Scale (FTNS) (Cattaneo et al., 2019; Pérez-Esteve et al., 2022), the NFS has always been an effective instrument and has the necessary reliability to properly measure the resistance to new food products. The construct has also been successfully used to approach attitudes toward genetically modified organisms (GMOs) (Faccio & Fovino, 2019).

Neophobia can be also associated with conservatism (Fischler, 1980) when faced with a new food product. In the context of foods with the application of nanotechnology, Chang et al. (2017) approached a slightly different approach of a mechanism that may cause avoidance of new foods, proposing and confirming that the novelty perception was negatively associated with perceived trustworthiness in these foods.

Therefore, based on the psychological trait that reflects consumer conservativism, reluctance, and protective intuition regarding the presence of novelty in foods, the following hypothesis is proposed in this study.

**Hypothesis 4.** Neophobia has a negative impact on the willingness to try foods with nanotechnology.

Perception of technology application

The last psychometric property approach relies on the consumer's positive perception regarding overall technology application. Farias & Borges (2012) found that the way individuals perceive the utility of a new technology influences the acceptance of foods with the application of nanotechnology, therefore, individuals' perceptions of the application of technology in their daily life to solve problems and improve the quality of life is a variable that can affect nanotechnological food consumption (Chen & Yada, 2011; Handford et al., 2014; Dudefoi et al., 2018; Kim et al., 2018; Scott et al., 2018; Zhou & Hu, 2018).

As proposed by Chang et al. (2017), nanotechnology offers many advances, for instance, making food products safer and more nutritious, and such benefits might be intangible in a way that the consumer cannot directly access it if not properly informed. However, if there is a belief that the advances presented by technology are beneficial, the consumer might extend that belief to nanotechnology. Based on the TAM (Technology Acceptance Model) (Davis Jr., 1985), it is proposed in this study that the consumer that perceives the significant usefulness of technology may be more willing to try food with nanotechnology.

Therefore, the following hypothesis is expected.

**Hypothesis 5.** The perceived application of technology positively impacts the willingness to try foods with nanotechnology.

## MATERIAL AND METHODS

### Data collection and sample

A quantitative and descriptive study was conducted to verify the relationship of the proposed constructs with the willingness to try foods with nanotechnology. The study was carried out online by applying a questionnaire to Brazilian consumers who agreed to participate. The questionnaire was prepared using Google Forms and shared by the authors on social media from June to September 2021, characterizing a snowball sample (Gil, 2017). All told, 244 responses were obtained, of which 56.9% were submitted by women and 58.5% by people aged 18 to 24. 70.8% had completed higher education and 24.3% had a family income ranging from R$ 2,165 to R$ 3,778.50. The sociodemographic characteristics of the collected sample are summarized in Table 1.

**Table 1.** Sociodemographic characteristics (n = 244).

| Characteristics | Participants | Percentage (%) |
|---|---|---|
| Gender | | |
| Male | 104 | 42.7 |
| Female | 139 | 56.9 |
| Other | 1 | 0.4 |
| **Age** | | |
| Under 18 years | 6 | 2.4 |
| 18 to 24 | 141 | 58.5 |
| 25 to 34 | 41 | 16.5 |
| 35 to 44 | 29 | 11.7 |
| 45 to 54 | 17 | 6.9 |
| Over 54 | 10 | 4.0 |
| **Education** | | |
| Elementary | 7 | 2.8 |
| High School | 46 | 18.2 |
| Higher Education | 172 | 70.8 |
| Graduate | 20 | 8.1 |
| **Family income** | | |
| Below R$ 768.00 | 7 | 2.4 |
| From R$ 768.00 to R$ 1,196.50 | 17 | 6.9 |
| From more than R$ 1,196.50 to R$ 2,165.00 | 40 | 15.8 |
| From more than R$ 2,165.00 to R$ 3,778.50 | 56 | 24.3 |
| From more than R$ 3,778.50 to R$ 7,053.00 | 55 | 22.3 |
| From more than R$ 7,053.00 to R$ 15,071.00 | 43 | 17.4 |
| From more than R$ 15,071.00 to R$ 20,888.00 | 13 | 5.3 |
| Over R$ 20,888 | 12 | 4.9 |


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In addition, 31% of the respondents have at least a little knowledge about food with the application of nanotechnology, 34.9% heard about food with the application of nanotechnology and 34.1% claimed that they had never heard of food with the application of nanotechnology. This number was expected since it's a novel technology for most consumers in the country. However, a t-test showed that only 1 item of the 28, considering all scales in the survey, was significantly different between people who had never heard of nanotechnology and people who had. This result indicated that the findings of this research are valid for both groups.

**Measures**

The questionnaire sent to the participants began with a filter question. Therefore, only individuals who were responsible for purchasing food could participate. Participants were not presented with any information about nanotechnology application in food production and were asked, "How much do you think you know about this type of food?", in order to access the sample knowledge about nanotechnology applied to food. First, the applicable respondents demonstrated their perception of the nutrition of foods containing an application of nanotechnology, and for this purpose, four items adapted from Chang et al. (2017) were used (Table 2). The rest of the constructs were evaluated in the following order: food safety was measured using 4 items adapted from Wang & Tsai (2019); willingness to try was measured through 6 items adapted from Chang et al. (2017); food neophobia was measured using 5 items adapted from Pliner & Hobden (1992); sustainable consumption attitude was measured using 5 items adapted from Burnier et al. (2021); and the perception of technology application was measured using 4 items adapted from Chang et al. (2017). All items were measured on a 5-point Likert scale, with response categories ranging from 1 (I strongly disagree) to 5 (I fully agree). The last section consisted of demographic questions.

**Analytical procedures**

The initial analyses were conducted using SPSS software (IBM SPSS Statistics, v. 22.0), and the data did not demonstrate normal distribution (Kolmogorov-Smirnov test, $p<0.05$). Therefore, as a partial least squares SEM shows higher robustness with non-normal data (Hair et al., 2019), a Partial Least Squares (PLS) model was conducted in the SmartPLS version 4.0.9.2 to obtain a better fit (Ringle et al., 2014). PLS is defined by two sets of linear equations: the internal model, which establishes relationships between the latent variables (LVs), and the external model, which relates the LVs and their indicators (Henseler et al., 2009). By using this technique, the causal and hypothetical relationships between the constructs were determined. A measurement model with 5 latent variables was tested.

## RESULTS

**Reliability and validity of measures**

Convergent validity (Table 2) was established by estimating the Average Variance Extracted (AVE), with values above 0.50 considered acceptable (Henseler et al., 2009), acceptable values of Cronbach's Alpha values should be above 0.70 (Hair, 2009), and for Composite Reliability, values above 0.70 (Bido & Silva, 2019). Only the indicators that had factor loads (correlations) with an unacceptable value were selected, to obtain a satisfactory AVE value (> 0.50), therefore, in the final model, Neophobia comprised 5 items. Next, to determine discriminant validity, the Fornell & Larcker (1981) criterion was applied, and all the values of the correlations were lower than the square roots of the AVE values. Therefore, the model has discriminant validity (Table 3).

**Table 2.** Validity and reliability of the constructs.

| Items | Mean (SD) | Loadings | AVE | CR | Cronbach's Alpha |
|---|---|---|---|---|---|
| **Safety** | | | | | |
| SFT1 | 3.23 (1.09) | 0.759 | | | |
| SFT2 | 3.34 (1.16) | 0.845 | 0.595 | 0.854 | 0.769 |
| SFT3 | 3.33 (1.19) | 0.808 | | | |
| SFT4 | 2.80 (1.15) | 0.661 | | | |
| **Nutrition** | | | | | |
| NUT1 | 3.04 (1.08) | 0.722 | | | |
| NUT2 | 3.40 (1.11) | 0.816 | 0.649 | 0.881 | 0.819 |
| NUT3 | 3.31 (1.05) | 0.832 | | | |
| NUT4 | 3.41 (1.10) | 0.847 | | | |
| **Willingness to try** | | | | | |
| WTT1 | 2.87 (1.17) | 0.750 | | | |
| WTT2 | 3.21 (1.18) | 0.829 | | | |
| WTT3 | 2.79 (1.14) | 0.707 | 0.583 | 0.893 | 0.859 |
| WTT4 | 3.39 (1.21) | 0.855 | | | |
| WTT5 | 2.56 (1.12) | 0.724 | | | |
| WTT6 | 2.41 (1.06) | 0.704 | | | |
| **Neophobia** | | | | | |
| NFS1 | 2.08 (1.18) | 0.738 | | | |
| NFS2 | 2.10 (1.05) | 0.879 | 0.537 | 0.852 | 0.813 |
| NFS4 | 1.86 (1.10) | 0.647 | | | |
| NFS5 | 2.09 (1.06) | 0.680 | | | |
| NFS6 | 2.35 (1.22) | 0.700 | | | |
| **Sustainable Consumption Attitude** | | | | | |
| SCA1 | 2.86 (1.29) | 0.822 | | | |
| SCA2 | 3.10 (1.24) | 0.836 | 0.709 | 0.924 | 0.898 |
| SCA3 | 3.37 (1.27) | 0.865 | | | |
| SCA4 | 3.09 (1.17) | 0.821 | | | |
| SCA5 | 3.04 (1.22) | 0.865 | | | |
| **Perception of Technology Application** | | | | | |
| PTA1 | 4.01 (1.10) | 0.919 | | | |
| PTA2 | 3.98 (1.09) | 0.911 | 0.837 | 0.954 | 0.935 |
| PTA3 | 3.97 (1.06) | 0.910 | | | |
| PTA4 | 3.95 (1.10) | 0.921 | | | |

SD = Standard Deviation, AVE = Average Variance Extracted, CR = Composite Reliability, NUT = Nutrition, SFT = Safety, WWT = Willingness to Try, NFS = Neophobia Food Scale, SCA = Sustainable Consumption Attitude, PTA = Perception of Technology Application.

**Table 3.** Discriminant validity of the model (Fornell-Larcker criterion).

| | NUT | SCA | WTT | NFS | SFT | PTA |
|---|---|---|---|---|---|---|
| NUT | 0.806 | | | | | |
| SCA | 0.265 | 0.842 | | | | |
| WTT | 0.640 | 0.299 | 0.764 | | | |
| NFS | -0.128 | -0.072 | -0.117 | 0.733 | | |
| SFT | 0.658 | 0.274 | 0.604 | -0.170 | 0.771 | |
| PTA | 0.520 | 0.448 | 0.448 | -0.178 | 0.447 | 0.915 |

NUT = Nutrition, SFT = Safety, WWT = Willingness to Try, NFS = Neophobia Food Scale, SCA = Sustainable Consumption Attitude, and PTA = Perception of Technology Application.


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## Tests of structural models

The model was evaluated by testing the significance of the identified relationships (*t* and *p*-values). Table 4 demonstrates, respectively, the path coefficients, the standard error, t and p-values, and the effect size. The path analysis indicated that the willingness to try (WTT) is positively affected by safety and nutrition, therefore, *H1* ($\beta = 0.290$, $t = 5.518$, $p = 0.000$, $f^2 = 0.089$) and *H2* ($\beta = 0.381$, $t = 5.621$, $p = 0.000$, $f^2 = 0.142$) were supported.

In contrast, *H3* did not obtain support, therefore, the sustainable consumption attitude did not influence WTT ($\beta = 0.086$, $t = 1.491$, $p = 0.136$, $f^2 = 0.012$); as well as the Neophobia level ($\beta = 0.003$, $t = 0.040$, $p = 0.968$, $f^2 = 0.000$) and the perception of technology application ($\beta = 0.088$, $t = 1.310$, $p = 0.190$, $f^2 = 0.010$) did not. Therefore, *H4* and *H5* did not obtain support as well. Figure 2 shows the structural equation model. The WTT foods with the application of nanotechnology presented an adjusted $R^2$ of 47%.

**Table 4.** Path analysis.

| Hypotheses | *β* | SE | *t*-value | *p*-value | Decision | $f^2$ |
|---|---|---|---|---|---|---|
| *H1* + *SFT* → WTT | 0.290*** | 0.053 | 5.518 | 0.000 | Supported | 0.089 |
| *H2* + *NUT* → WTT | 0.381*** | 0.068 | 5.621 | 0.000 | Supported | 0.142 |
| *H3* - *SCA* → WTT | 0.086 | 0.058 | 1.491 | 0.136 | Not Supported | 0.012 |
| *H4* - *NFS* → WTT | 0.003 | 0.068 | 0.040 | 0.968 | Not Supported | 0.000 |
| *H5* + *PTA*→ WTT | 0.088 | 0.067 | 1.310 | 0.190 | Not Supported | 0.010 |

NUT = Nutrition, SFT = Safety, WWT = Willingness to Try, NFS = Neophobia Food Scale, SCA = Sustainable Consumption Attitude, PTA = Perception of Technology Application. ***Significant at p<0.001.

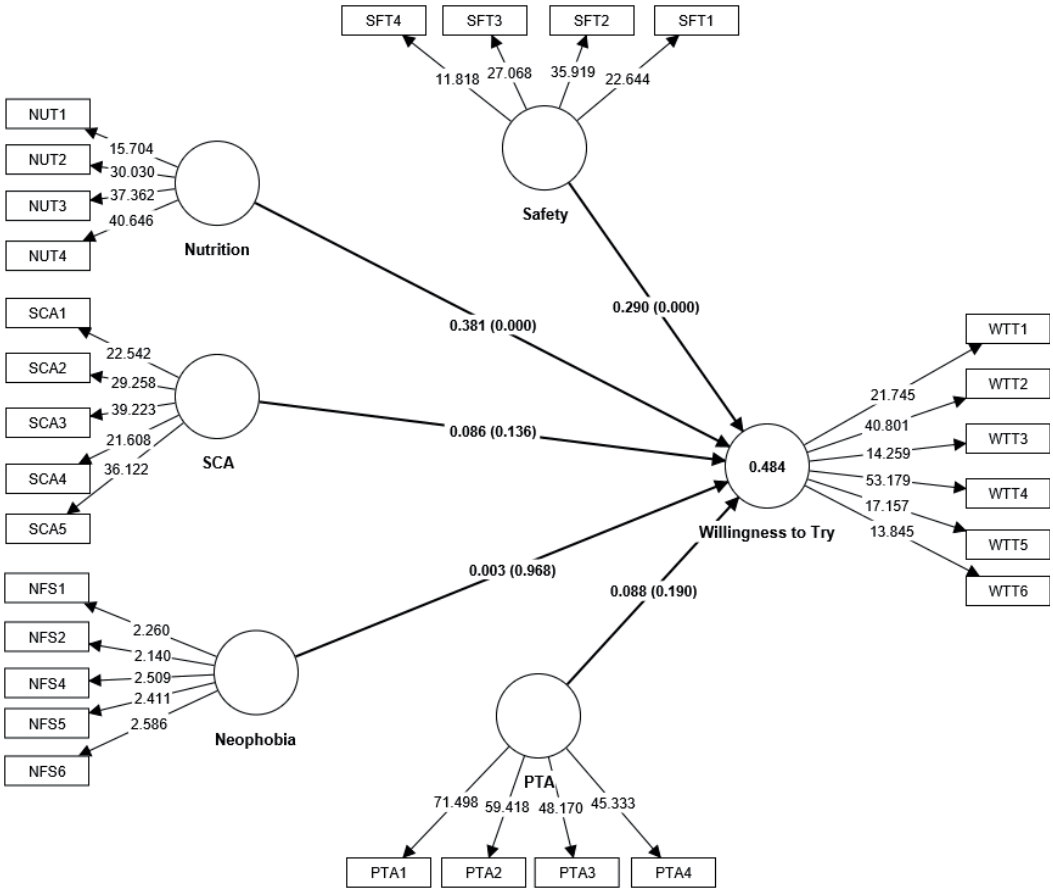


**Figure 2.** Structural Equation Model.

Source: Ringle et al. (2022).

**Independent-Samples T-test**

To further explore the data, an additional independent sample t-test was conducted, as the literature demonstrates differences in the acceptance of technology between genders (Table 5) (Marangunić & Granić, 2015), and between generations (Z, millennials, and X) (Calvo-Porral & Pesqueira-Sanchez, 2020; Szymkowiak et al., 2021; Vitezić & Perić, 2021) (Table 6); therefore, the study tested these differences on the WTT food with the application of nanotechnology, by properly dividing the study's sample into: Generation Z, considering the participants born from 1997 to 2012; Millenials, born from 1981 to 1996; and Generation X, born from 1965 to 1980.

**Table 5.** WTT between genders.

| Variable | N | Mean | SD | *p*-value |
|---|---|---|---|---|
| **WTT** | | | | 0.282 |
| Male | 104 | 2.94 | 0.876 | |
| Female | 139 | 2.82 | 0.871 | |

While there was no significant difference in the WTT between males ($M = 2.94$; $t(233) = 1.079$, $p>0.05$) and females ($M = 2.82$), and there was also no difference between Generation Z's ($M = 2.95$; $t(213) = 0.393$, $p>0.05$) and Millenials' WTT ($M = 2.90$), the study found a significant statistical difference on WTT between Millenials ($M = 2.90$; $t(84) = 2.754$, $p<0.05$) and Generation X ($M = 2.29$).

**Table 6.** WTT between Generation Z and Millennials, and between Millennials and Generation X.

| Variable | N | Mean | SD | *p*-value |
|---|---|---|---|---|
| **WTT** | | | | 0.695 |
| Generation Z | 158 | 2.95 | 0.797 | |
| Millennials | 57 | 2.90 | 0.958 | |
| WTT | | | | 0.007 |
| Millennials | 57 | 2.90 | 0.958 | |
| Generation X | 29 | 2.29 | 0.971 | |

## DISCUSSION

This study aimed to verify the relationship of five variables with the willingness to try food with any form of application of nanotechnology among Brazilian consumers who are responsible, albeit rarely, for food purchases. The impact of food safety, nutrition, sustainable consumption attitude, neophobia, and perceived technology application was measured. Two out of five hypotheses were confirmed and a difference in the WTT was found between Millenials and Generation X consumers.

According to the results, food safety and nutrition had a positive association with WTT food with nanotechnology. Thus, hypotheses 1 and 2 were not rejected. Farkas & Kiss (2021) also found a positive relationship between food safety and WTT, and Sodano et al. (2016) addressed a good feeling about the positive health effects of new technologies. The other results showed that the relationship between sustainable consumption attitude and WTT was not significant (hypothesis 3), and the relationship between the level of food neophobia (hypothesis 4) and perception of technology application (hypothesis 5) with WTT was not statistically significant. Consequently, those three hypotheses were rejected.


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It is reasonable to assume that the relationship between food safety, nutrition, and WTT is based on the principle of not viewing food with the application of nanotechnology as inappropriate regarding the basic nutritional needs and the basic hygienic and not harmful to health characteristics. Viewing food as adequate for consumption requires effort from individuals, and if they can make this kind of evaluation regarding nanotechnology, it is a promising advance. Since the beginning of the exploration of new foods, individuals have sought and valued items that are more nutritious and perceived as safe (Rozin & Fallon, 1987), therefore, this is a consistent result.

Another application that must be taken into consideration for this result is the frequent opposition between taste claims and health and nutrition claims, which may lead to misinterpretation of the taste of a food product (Lähteenmäki et al., 2010). It is argued in this study that nanotechnology can benefit this discussion, as in addition to being able to provide assertive health and nutrition claims, it can also guarantee improved taste and smell, through enhancements in the production process and packaging (Sekhon, 2014). This is in line with what is required to make a food acceptable, as it does not only fulfill the role of proper nutrition, but can also have a social function (Fischler, 1980), in addition to providing pleasure and satisfaction, as mentioned by Rozin & Vollmecke (1986): both taste and smell should be closely linked to the nutritional properties of food, considering their particular relevance to the consumer.

In contrast, the sustainable consumption attitude was not relevant for WTT in this study. It was a relevant psychometric property tested, which was expected to contribute to the model. The existing paradox mentioned by Cavaliere & Ventura (2018) regarding sustainable production and nanotechnology is still an important path to be explored, to understand the real implications of this controversy for the consumer WTT. Siegrist & Hartmann (2020) highlight that technology application is often perceived as having a lack of naturalness, which is considered negative, and this rejection hypothesis can be associated with consumers' subjective knowledge, considering that their understanding of the full implications of the new technology may be limited. Another possible discussion is that if there is poor or no information available about the food, consumers will distrust it and face uncertainty, which can even lead them to use another source of information to make a decision (Vermeir & Verbeke, 2006), which, in this case, was the overall nutrition and safety perceptions.

Food neophobia also had no impact on WTT in a sample characterized by low levels of neophobia. It was noted that the prevalence of basic nutrition and safety precepts in the sample corroborates these other results because if the individuals indicated that they mostly perceive food with the application of nanotechnology as "free from infectious diseases" and "without parasites or insects", it is reasonable to suppose that they did not associate them with disgust and aversion. These are determining factors in the rejection of novelty foods (Rozin & Fallon, 1987).

Similarly, the perception of technology application was not relevant for the model; therefore, based on this, it was decided to explore the data regarding genders and generations differences in the WTT this technology, and the study found an interesting result regarding millennials (born from 1981 to 1996) and the generation X (1965–1980). According to Calvo-Porral & Pesqueira-Sanchez (2020), the individual's generation influences the engagement with technology – particularly, the millennials tend to use technology mostly for hedonic purposes, however, as they are more prone to be engaged with it, they may be exposed to a higher volume of daily information. They presented the highest WTT nanotechnology. In contrast, Calvo-Porral & Pesqueira-Sanchez (2020) discuss that Generation X strongly uses technology mostly for information search, but they also have distinct values, attitudes, and behaviors, and distrust in technology is what is most expected from these consumers (Asoba & Mefi, 2022), which resulted in a lower WTT.

In conclusion, it is proposed that manufacturers who use nanotechnology should be more attentive to how they demonstrate the various aspects of their products, by cooperating with institutions, nanotechnology researchers, and government agencies to help spread educational information about the technology and the possible benefits of its application (Chang et al., 2017), while keeping the harmful aspects on the agenda.

Erdem (2018) mentions the uncertainties consumers face with nanotechnology, and that the doubts come from a lack of information and can lead to mistrust in the organizations involved in the supply chain. Rollin et al. (2011) warned that without a serious effort to this end, this kind of innovation could face a negative reception from consumers. Plausibly, accurate and balanced information must be provided to consumers by sources they trust the most, which can be the government, scientists, and consumer organizations (Erdem, 2018). These scientific results contribute by providing policymakers with insight into communication strategies.

## CONCLUSION

Nanotechnology alters some goods that are already consumed on a daily basis worldwide. For its expansion on the supermarket shelf, greater acceptance of this type of food by consumers is required. The aim of this study was to verify the level of acceptance through variables that can positively or negatively affect the willingness to try food with the application of nanotechnology. The path traced allowed us to verify that, of the five variables, only nutritional issues and food safety were indicated as relevant principles by the sample of Brazilian consumers who are, even if only rarely, responsible for the purchase of food. These issues can be observed by companies when presenting their nanoproducts to the consumer to achieve greater acceptance.

First, the low knowledge level of food with the application of nanotechnology is a limitation, although the difference between consumers' knowledge levels was not statistically significant. Nevertheless, this procedure provides a more accurate discussion on the relationships between certain variables in the model. Secondly, another limitation of the study is the lack of representativeness of the sample, which does not allow generalizing the results. Thirdly, the lack of studies regarding the analysis of consumer intention to purchase, intention to consume, or willingness to pay for food with the application of nanotechnology did not allow the study to provide a wide literature review to formulate the proposed hypotheses; therefore, future studies that explore this scenario may rely on a less narrow literature review. The study proposes that the impact of information can also be explored in future studies, as well as the inclusion of hedonic properties such as taste and smell perception in future studies.

In general, a suggestion for the stakeholders involved in the nanotechnology market is that they provide their target audience with better information on the benefits of foods with the application of nanotechnology, their relationship with the environment, and their nutritional and safety advantages over conventional foods. This provides consumers with transparency, making them more aware of what they are consuming and presenting them with readily available information so that they can consume food with the application of nanotechnology in accordance with the factors that are most important to them.

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