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RESEARCH ARTICLE

Sensory and consumer science as a valuable tool to the development of quinoa-based food products: More than three decades of scientific evidence

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Abstract

Solutions are needed to address both hunger and the promotion of healthy and sustainable diets. Quinoa, a nutritious and sustainable Andean grain, is a versatile option for creating new foods. Over the years, several technological advancements have been made to include quinoa in various food products. However, there is still a need for solid scientific evidence on the impact of quinoa on the product's acceptance. To address this scientific knowledge gap, this work aims to analyze the scientific literature over the last three decades regarding the sensory and hedonic impact of adding quinoa to food products. To do so, bibliometric methods based on the Scopus and Annual Scientific Production databases were used. After selecting and screening using the PRISMA method, seventy-four articles from 1991 to 2024 were analyzed, identifying relationships between keywords in the analyzed studies, forming a co-occurrence and co-authorship network. Results showed that quinoa has great nutritional potential when added to different food products, but its instrumental and sensory properties are modified. The nine-point hedonic scale was used to measure product acceptability in 47% of the articles. Studies on bakery products have shown that increasing the concentration of quinoa in the product formulation decreases the acceptance of the final product in 67% of cases. It is recommended to include consumer demands from a sensory and hedonic perspective when developing new products. The scientific and industrial community is encouraged to develop new food products catering to a broader consumer range.

Keywords: Sensory acceptance; Bibliometric analysis; *Chenopodium quinoa* Willd; Hedonic Scale.

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1. Introduction

People's eating habits have resulted in chronic non-communicable diseases, malnutrition, and climate change (Swinburn et al., 2019). According to the Food and Agriculture Organization of the United Nations (United Nations, 2019), the world's population will reach 9700 million by 2050. This situation poses a challenge to ensure an adequate food supply that meets the sensory needs of the people and promotes healthier eating habits and sustainable production. To address these challenges, promoting sustainable agricultural practices and cultivating crops resilient to climate change is essential to ensuring a steady food supply. Furthermore, promoting methods to boost the nutritional quality of processed foods by reducing the levels of harmful substances like sugars, saturated fats, and sodium (Deliza et al., 2021; O'Sullivan, 2020; Therdthai, 2022; Wolf, 2020), while incorporating beneficial components such as fiber and nutrients, is crucial in promoting consumer health.

Quinoa (*Chenopodium quinoa* Willd.), a highly nutritious Andean grain (Dakhili et al., 2019; Vidaurre-Ruiz et al., 2023), is an efficient alternative for the formulation of new food products, being both gluten-free and environmentally sustainable (Amiryousefi et al., 2021). Due to this reason, technological efforts have been made to incorporate quinoa into various food matrices, for example in the breads (Coţovanu et al., 2023; El-Sohaimy et al., 2021), cookies (Jan et al., 2018; Meriles et al., 2022), muffins (Özgören & Yapar, 2022), meat products (Bahmanyar et al., 2021; Park et al., 2021; Teixeira et al., 2020), dairy products (Abdelmontaleb et al., 2021; Kef & Arslan, 2021; Sekhavatizadeh et al., 2023), quinoa drinks (Ayub et al., 2021; Jeon et al., 2022; Pineli et al., 2015), etc. However, despite the promise these products hold, challenges persist in

sensory acceptance due to the bitter taste of quinoa (Suárez-Estrella et al., 2018). Further research and conjoint evidence based on several scientific articles over a considerable period is still required to estimate the real impact of quinoa incorporation on the sensory and hedonic traits of quinoa-based food products.

Sensory and consumer science is the convergence of different sciences such as biology, chemistry, statistics, social sciences, gastronomy, food science, and food design, among others, and it, in the words of Worch et al. (2023): "the tastiest of all sciences". An example that shows the interaction of the sciences would be the development of an extruded snack with added quinoa protein to improve its nutritional profile in adequate concentrations so as not to alter the product's sensory characteristics. According to ISO 6658, sensory analysis (the main component of sensory and consumer science) is involved with assessing the sensory attributes of a product by the senses. Sensory methods used to evaluate food products are traditionally classified as discriminant (focused on the sensory difference between products), descriptive (focused on the detailed description of sensory attributes), and affective (focused on the degree of acceptance of a product). Various products made from Andean cereals have undergone sensory characterization using the affective method (El-Said et al., 2021; Özgören & Yapar, 2022; Soliman et al., 2019). As a result, sensory and consumer characterization have become increasingly important in developing Andean cereal-based foods mainly because any modification in the formulation will change its nutritional and, concomitantly, sensory properties.

Although there is research on incorporating quinoa in different food matrices, a noticeable gap exists in comprehensively examining the impact of quinoa addition on consumer acceptance. For this reason, this review aimed to explore the effects of adding quinoa on the acceptance of food products from a systematic perspective.

2. Methodology

2.1. Literature search

The Scopus database was searched in April 2024 for scientific articles published from 1991 to 2024 containing the terms "liking" OR "acceptance" OR "acceptability" OR "hedonic" AND "quinoa" AND "product", obtaining a total of 109 papers.

2.2. Selection process

Two authors performed a blinded evaluation using Rayyan's open-access software to select papers. They focused on documents that discussed food products made with quinoa grain and included sensory evaluation of the product and human studies. The two authors had a concordance of 95%, selecting 97 articles. Afterward, a complete manuscript review was carried out to ensure relevant papers were included and those outside the research objectives were excluded. Papers that mentioned sensory aspects in the introduction but did not evaluate them in the study or used quinoa as part of the base formulation of products but evaluated acceptance based on the concentrations of other ingredients were excluded. Papers that did not mention the type of hedonic scale used were also excluded. In the end, the final bibliometric list included 74 articles, as shown in Figure 1.

2.3. Data Processing

Two freely available tools were used to analyze the articles from 1991 to 2024: the R-package *Bibliometrix* (version 2023.06.1) and the *VOSviewer* software (version 1.6.19). *Bibliometrix* (Aria & Cuccurullo, 2017), was used to analyze scientific production over time. Annual Scientific Production and Average Citations per Year analyses were performed to have a broader view of the productivity and impact of the studies during the last three decades. In addition, the Countries Collaboration World Map function was used to visualize and identify scientific collaboration worldwide. Also, keyword clouds were generated for three periods to show the evolution of the interest topics of the scientific community. Visual graphs were created using *VOSviewer* (Van Eck & Waltman, 2010), identifying relationships between analyzed studies' keywords as a co-occurrence network and co-authorship network.

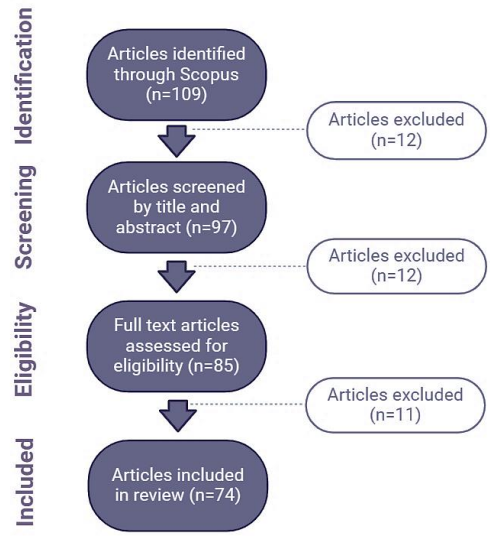

Figure 1. Flowchart used to search and select papers for bibliometric review, adapted from PRISMA (Page et al., 2021).

3. Results and discussion

3.1. Descriptive analysis

Figure 2(a) displays the evolution of publications on sensory methods for developing quinoa-based products. The graph indicates that publications on this subject started in 1991 but did not see a rise until 2009.

From 2009 onward, the number of articles published increased, despite some fluctuations, indicating the scientific community's interest in researching the importance of acceptance in developing quinoa-based products. As of 2021, the number of publications reached 12. On the other hand, Figure 2(b) illustrates the average number of citations per year, reflecting the increase in the impact of the publications. The graph shows three prominent peaks in 2019, 2021, and 2023.

The number of times a scientific article is cited is an essential measure of its quality and impact. Table 1 presents the top ten articles based on the citations received. Notably, the nine-point hedonic scale was a commonly used tool in the articles that received the highest number of citations.

Based on the findings presented in Figure 3, the top 10 countries with the highest number of publications on the subject are Brazil, Peru, Argentina, Egypt, Spain, Iran, India, Turkey, Romania, and Korea. The collaboration frequency between countries that produce quinoa-based products is as follows: Peru and Spain, Sweden and Bolivia have a frequency of two, while Peru and Finland, Egypt and Saudi Arabia, China and Saudi Arabia, Egypt and China, and Spain and Turkey have a frequency of one. The number of scientific articles published by authors affiliated with institutions in each country where quinoa-based products are used highlights Brazil, Peru, and Argentina with 83, 34, and 24 documents, respectively.

The analysis of 74 research papers on quinoa revealed a dynamic pattern in the word clouds generated from the frequency of keywords. From 1991 to 2001, the studies focused on understanding quinoa's physicochemical properties and general applications, marking the initial research phase on this valuable food resource (Figure 4a). From 2002 to 2012, the focus shifted to developing quinoa-based food products in combination with other Andean cereals, such as amaranth (Figure 4b). Finally, from 2013 to 2024, the research has been centered on formulating food and beverages that consider sensory and nutritional quality. In addition, there is a strong emphasis on developing gluten-free products (Figure 4c). These phases reflect the evolution of research and the scientific community's adaptation to the changing needs and trends in food production and nutrition, considering the sensory quality of the final product.

Table 1
Analysis of the ten articles with the highest number of citations

Authors	Title	Journals	Citations	Hedonic scale
(Alvarez-Jubete et al., 2010)	Baking properties and microstructure of pseudocereal flours in gluten-free bread formulations	European Food Research and Technology	232	6 points
(Iglesias-Puig et al., 2015)	Bread with whole quinoa flour and bifidobacterial phytases increases dietary mineral intake and bioavailability	LWT – Food Science and Technology	90	9 points
(Caperuto et al., 2001)	Performance of quinoa (*Chenopodium quinoa Willd*) flour in the manufacture of gluten-free spaghetti	Journal of the Science of Food and Agriculture	82	9 points
(Pineli et al., 2015)	Low glycemic index and increased protein content in a novel quinoa milk	LWT - Food Science and Technology	64	9 points
(Rosell et al., 2009)	Breadmaking Use of Andean Crops Quinoa, Kañiwa, Kiwicha, and Tarwi	Cereal Chemistry	60	10 points
(Föste et al., 2014)	Impact of quinoa bran on gluten-free dough and bread characteristics	European Food Research and Technology	57	10 points
(Ludena Urquizo et al., 2017)	Development of a fermented quinoa-based beverage	Food Science and Nutrition	54	9 points
(Brito et al., 2015)	Nutritional and sensory characteristics of gluten-free quinoa (Chenopodium quinoa Willd)-based cookies development using an experimental mixture design	Journal of Food Science and Technology	53	9 points
(Jagelaviciute & Cizeikiene, 2021)	The influence of non-traditional sourdough made with quinoa, hemp and chia flour on the characteristics of gluten-free maize/rice bread	LWT – Food Science and Technology	49	7 points
(Bianchi et al., 2014)	Potentially synbiotic fermented beverage with aqueous extracts of quinoa (Chenopodium quinoa Willd) and soy	Food Science and Technology International	45	9 points

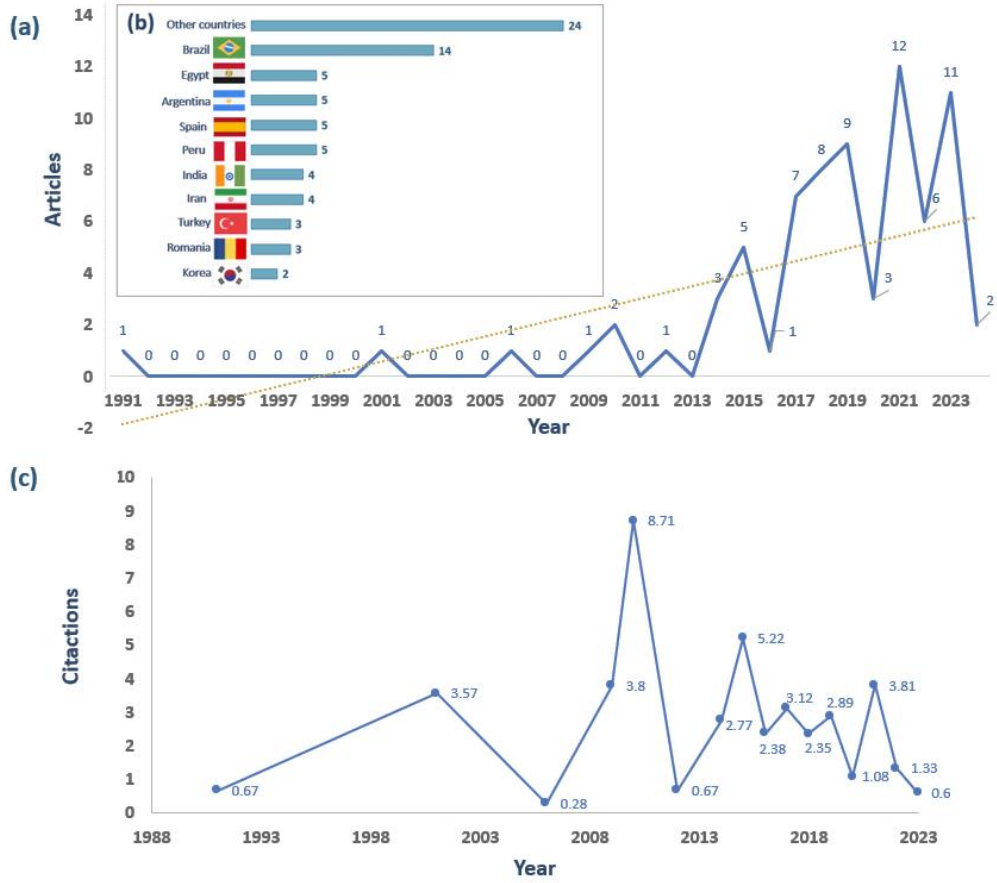

Figure 2. (a) Publications by years (b) countries with the highest number of publications, and (c) citations by years for sensory methods used in quinoa product development.

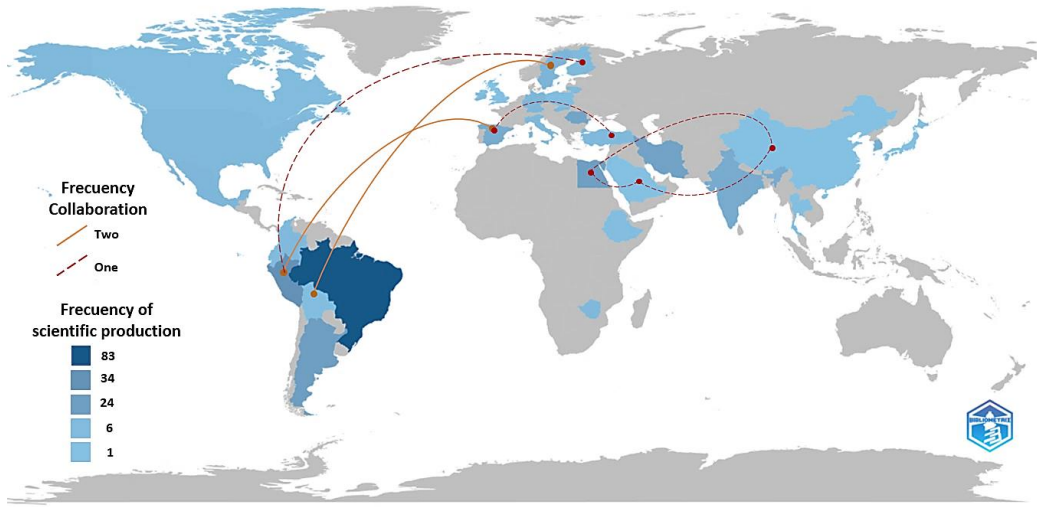

Figure 3. Countries' scientific production and the collaboration of publications.

3.2. Collaboration network

Figure 5 represents 6 clusters of different colors, indicating the authors' collaborations with various researchers regarding the development of quinoa-based products in a color gradient ranging from blue in 2014 to yellow in 2022. This review will cover the six largest clusters of collaboration. Cluster 1, colored blue, focuses on developing quinoa granolas for people with gluten intolerance (de Souza et al., 2014; Pagamunici et al., 2014). Cluster 2, colored green, involves Chiș et al. (2019) and Păucean et al. (2019), who are collaborating on developing quinoa

bakery products. Cluster 3 shows that Ayub et al., 2021 are working together on researching probiotic beverages containing quinoa. Cluster 4 highlights the development of dairy products (Abdelmontaleb et al., 2021). Cluster 5 focuses on developing gluten-free bakery products (Jagelaviciute & Cizeikiene, 2021). Lastly, cluster 6 shows the most recent studies on products developed with quinoa (Chilón-Llico et al., 2022; Jamanca-Gonzales et al., 2022; Silva-Paz et al., 2023).

Based on the results described above, there is an interdisciplinary collaboration among researchers, addressing various issues related to the development of quinoa-based products due to the versatility of this pseudocereal in the development of different food products.

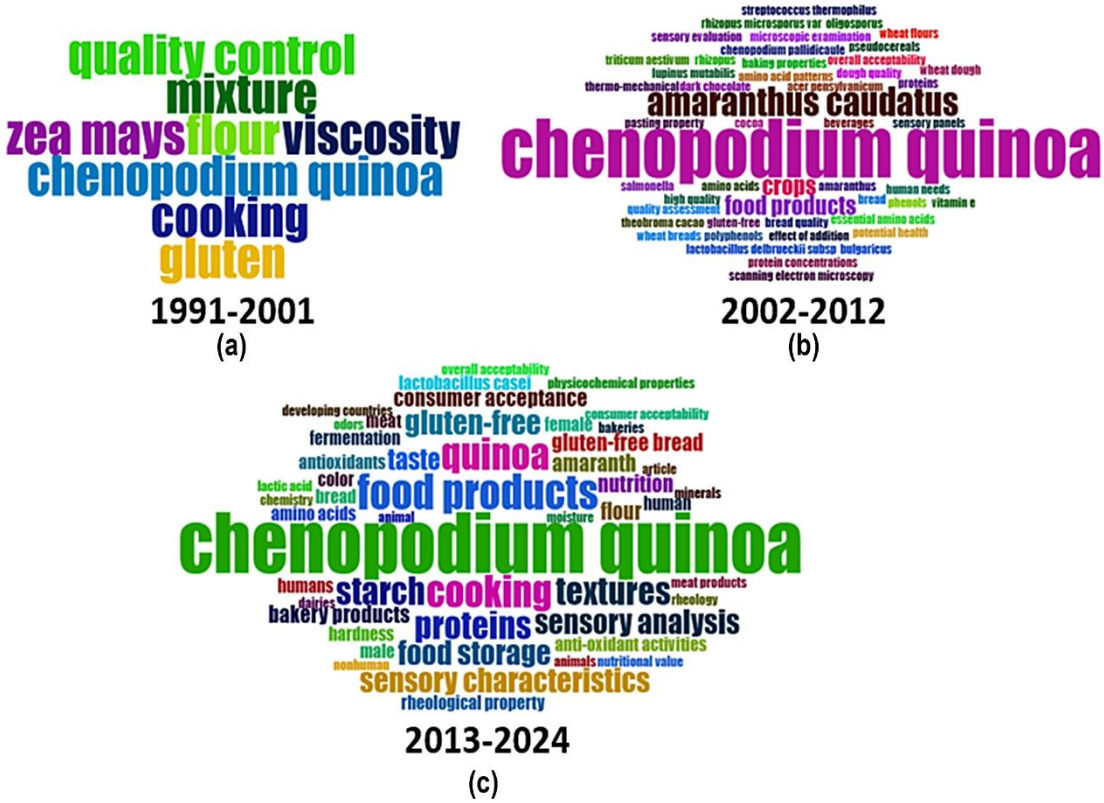

Figure 4. Word-cloud from the titles, abstracts, and keywords of the literature related to quinoa-based products obtained from Scopus between 1991 and 2024.

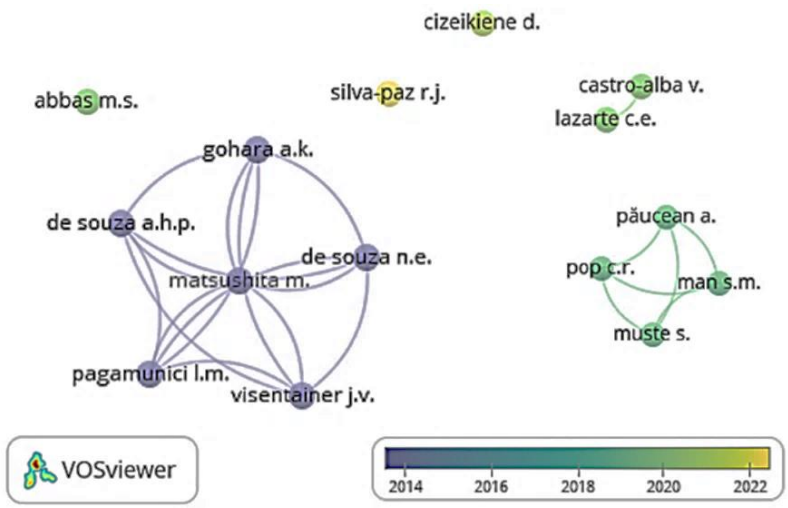

Figure 5. Collaboration Network during 2014-2022, using two documents by the author as the minimum.

3.3. Co-occurrence analysis

A minimum of three occurrences per keyword was required to analyze the correlation between keywords. This resulted in 66 words, which were used to form five clusters (Figure 6). The green cluster, comprised of 15 nodes, focuses on gluten-free foods and their formulation, sensory characteristics, and rheological and textural properties (Jagelaviciute & Cizeikiene, 2021; Peñalver et al., 2023). The yellow cluster, also with 13 nodes, explores using quinoa in meat products, considering factors like color, cooking, moisture, nutritional value, sensory properties, and shelf life (Tafadzwa et al., 2021; Teixeira et al., 2020). The red cluster, consisting of 16 nodes, highlights the protein content of quinoa, its essential amino acids, and its various applications in bakery products (Cizeikiene et al., 2021; Meriles et al., 2022). The blue cluster, also with 13 nodes, examines the sensory characteristics and acceptance of quinoa-based products, as well as consumer satisfaction, storage, and the use of milk additives (Curti et al., 2017; DeBruyne & Hekmat, 2024). Finally, the purple cluster, with 9 nodes, showcases the potential of quinoa in producing fermented foods and beverages (Bendezu-Ccanto et al., 2023; Jeon et al., 2022). All these clusters demonstrate the versatility of quinoa in different food products for nutritional improvement, including bakery and meat products. The following section will explore these products in more detail.

3.4. Quinoa-based food products

Out of the 74 articles that were reviewed, 20 of them presented studies on bakery products, accounting for 27% (as shown in Figure 7). These studies used quinoa flour (or quinoa flakes) to make bread, cookies, brownies, and panettones. These findings demonstrate the potential of quinoa in the baking industry, offering promising new options for creating more nutritious products.

Table 2 presents the bakery products with quinoa, indicating whether their acceptance was maintained, increased, or decreased compared to the control.

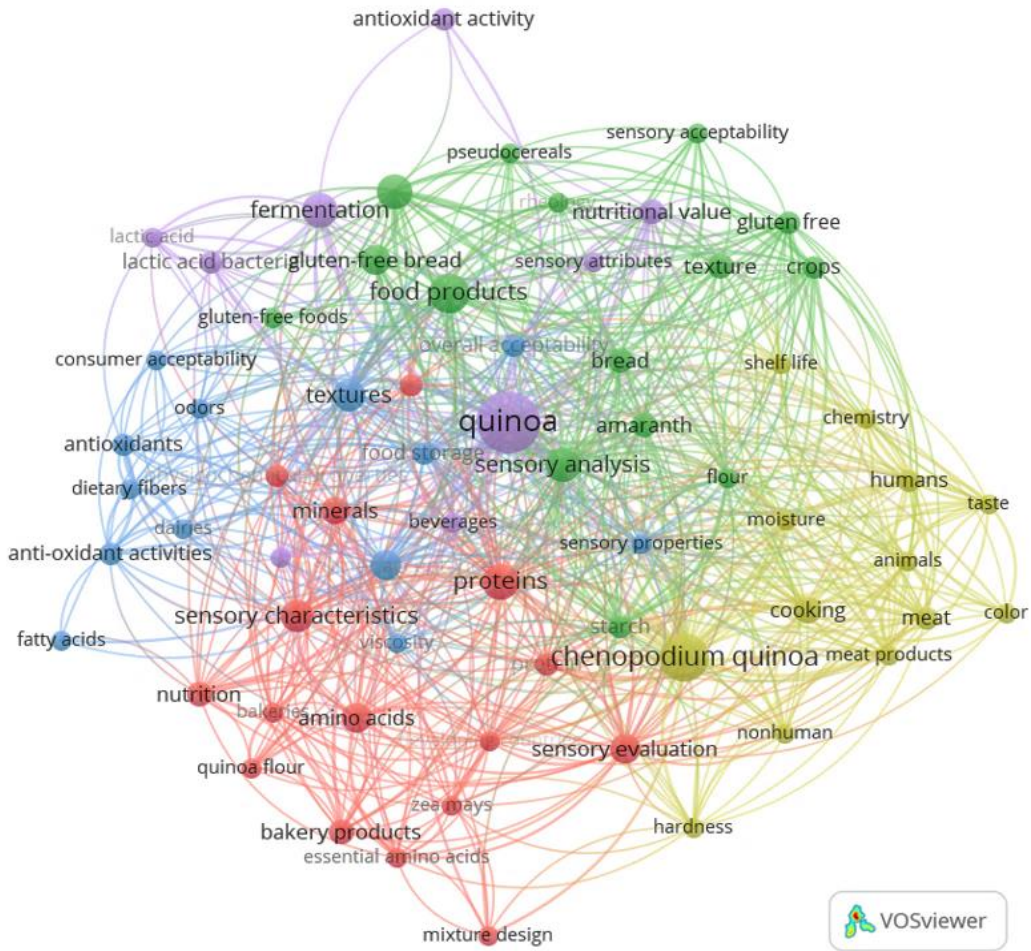

Figure 6. Map of keyword co-occurrence during 1991-2024.

In 67% of the bakery products, it was observed that lower proportions of quinoa-maintained acceptance compared to the control. For example, in the case of bread, it was observed that adding quinoa flour in a range of 5% to 25% maintained acceptance levels similar to the control. In the case of cookies, the concentrations varied from 5% to 20%, in muffins up to 25% and injera up to 30%. Therefore, it can be said that exceeding these percentages resulted in a decrease in acceptance.

According to 22 papers (30%), gluten-free products constitute an essential food category. These products, including meat products, cornbread, cakes, cookies, spaghetti, and granola, are developed specifically for people with celiac disease.

The studies suggest that quinoa can be a promising alternative for producing food products for people with celiac disease.

Of the 22 articles discussing gluten-free products, 17 specifically focus on bakery products, indicating the importance and relevance of this niche. However, some challenges remain to be addressed, such as the pre-treatment of quinoa to remove saponin and phytic acid (Arjmand et al., 2023; Maldonado-Alvarado et al., 2023; Samtiya et al., 2020), which would enhance the availability of nutrients in foods. On the other hand, the scientific community is encouraged to continue exploring new food products incorporating Andean cereals to diversify the applications and benefits of these cereals, increasing food availability.

Table 3 details the incorporation of quinoa in different food matrices to obtain gluten-free products. The main findings suggest that adding low concentrations of quinoa to the food matrix results in either as acceptable as or more than traditional products. However, if quinoa is added in higher proportions or combination with other raw materials, it can decrease the acceptance of the final product. The decrease in acceptance is not necessarily due to the presence of quinoa alone, as it can be affected by other components of the product formulation. Therefore, it is recommended to conduct factorial experiments where the "addition of quinoa" and other blocking factors are identified. It is observed that the 9-point hedonic scale was the most commonly used, which is in line with the findings of the review by Capriles et al. (2023), where it is noted that the 9-point scale is commonly used to measure the acceptability of gluten-free products.

Likewise, 9% of the articles reviewed included quinoa in sausages, meatballs, and burgers (Table 4), and in these studies, it improved the sensory properties and overall acceptance of the final meat product. Nine articles (12%) focused on quinoa-based beverages (Table 5), including wines, and fermented and vegetable drinks. Some formulations maintained or improved acceptability.

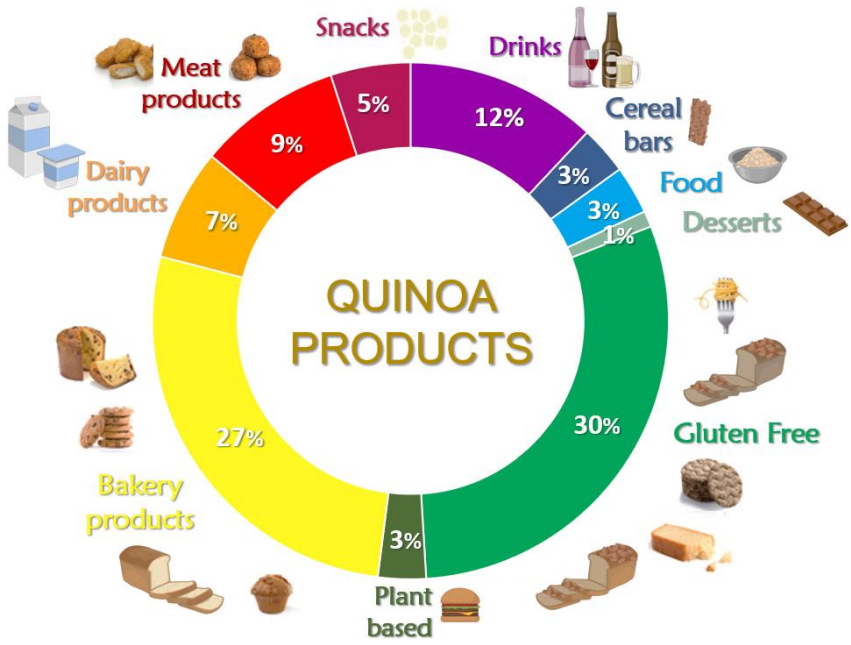

Figure 7. Quinoa-based food products, reported in papers from 1991 to 2024.

Table 2
Quinoa-based bakery products

Product	Country	Number of Consumers	Hedonic Scale	Main findings	References
Sliced bread	Peru	250	10 points	Adding quinoa increased the nutritional properties of breads with Andean grains and resulted in higher acceptability than traditional breads.	(García-Ramón et al., 2023)
Taboun bread	Jordan	20	9 points	The bread was more acceptable with 20% quinoa. However, increasing to 30% resulted in a bitter taste.	(Almaayta et al., 2023)
Bread supplemented with quinoa	Romania	13	9 points	The addition of quinoa to the bread increased the mineral content.	(Coţovanu et al., 2023)
Crackers	Argentina	30 semi-trained	3 points	Crackers made with quinoa contained more protein and lipids and were crunchier in texture.	(Meriles et al., 2022)
Panettone	Peru	80 (19-61 years)	9 points	The addition of quinoa to the formulation increased the acceptance of the panettone.	(Jamanca-Gonzales et al., 2022)
Bread made with fermented seeds	Lithuania	15 (22-35 years)	7 points	Bread made using fermented seeds was more liked than the control bread.	(Cizeikiene et al., 2021)
Bread	Spain	50	9 points	There was no significant difference in bread acceptance when incorporating 20% white, black, and red quinoa flour.	(Ballester-Sánchez et al., 2019)
Cookies	India	27 semi-trained	5 points	Cookies containing 50% quinoa flour were less acceptable than those containing 10% quinoa flour.	(Jan et al., 2018)
Muffin cakes	Turkey	48 (university students and academic staff)	7 points	When 25% quinoa flour was added to the bread, the sensory properties were similar to those of the control group. However, when the proportion of quinoa flour was increased to 50%, it had a negative impact on the flavor, texture, porosity, and bread acceptance.	(Özgören & Yapar, 2022)
Shamy bread	Egypt	10	10 points	Acceptance of the control bread was higher when compared to bread with 5% and 20% substitution of quinoa flour. Breads with 20% quinoa flour substitution were affected in flavor and layer separation.	(El-Said et al., 2021)
Bread	Egypt	15 (25-53 years)	9 points	Bread with 5% and 15% quinoa flour had higher acceptance compared to bread with 20% and 30% quinoa flour	(El-Sohaimy et al., 2021)
Bread	United Kingdom	10 (19-55 years)	10 points	The acceptance and technological properties of the bread remained unchanged in both the control bread and the bread made with 10% quinoa flour. However, there was a decrease in liking observed in the bread made with 100% quinoa flour.	(Gostin, 2019)
Balady bread	Egypt	15	10 points	The acceptance of balady bread with 20% quinoa flour decreased slightly compared to the control, and changes in texture, crumb distribution, and taste after swallowing were observed.	(Soliman et al., 2019)
Injera	Ethiopia	30 (Over 18 years old)	5 points	Injera remained acceptable up to a 30% substitution of quinoa flour. However, when the amount of quinoa flour was increased to 40%, it negatively impacted the flavor, aroma, texture, and liking.	(Agza et al., 2018)
Cookies	India	30 semi-trained (18 - 22 years)	9 points	As the percentage of quinoa flour in cookies increased (from 5% to 15%), a slight decrease in acceptance was observed.	(Goyat et al., 2018)
Quinoa flakes bread	Brazil	50 (15 -60 years)	9 points	The control bread was preferred over the bread that contained 15% quinoa flakes. When 20% quinoa flakes were added to the bread, it became darker in color and had lower values for chewiness and stickiness compared to the control.	(Gewehr et al., 2017)
Bread with whole quinoa flour	Spain	50	9 points	Breads made with 25% quinoa flour showed no significant differences compared to the control sample. However, when 50% quinoa flour was added, the breads had a denser, more compact crumb, and the color and flavor changed compared to the control sample.	(Iglesias-Puig et al., 2015)
Bread	Peru	Not reported (trained panel)	10 points	As the percentages of quinoa increased by 12.5% (25%, 50%, and 100%), the acceptance and hardness of the bread were affected.	(Rosell et al., 2009)

Table 3
Gluten-free quinoa-based products

Product	Country	Number of Consumers	Hedonic Scale	Main findings	References
Sponge cake	Iran	14	9 points	Adding quinoa flour to the sponge cake recipe improved its nutritional value and acceptability	(Madadi et al., 2024)
Mushroom Soup	Egypt	20	10 points	A significant nutritional increase was observed after substituting 10%, 20%, and 30% of mushroom soup with quinoa seed flour. Consumers found the 30% substitution to be more acceptable.	(Saed et al., 2023)
Sourdough Bread	Spain	35	5 points	The bread made with quinoa and moringa was outstanding in the acceptability of texture and aroma.	(Peñalver et al., 2023)
Cookies	Peru	100	9 points	The acceptability of cookies made with quinoa flour was higher than those made with lentil, bean, and broad bean flour but lower than those made with corn, chickpea, pea, and kiwicha flour.	(Silva-Paz et al., 2023)
Bread with quinoa malt	Iran	10 judges	5 points	Breads with quinoa malt concentrations of 0, 2.5, and 5% were more acceptable than 7.5 and 10% breads.	(Yazdi et al., 2023)
Bread	Canada	98	9 points	The addition of quinoa grains to gluten-free breads decreased acceptance.	(Moss & McSweeney, 2022)
Bread	Brazil	50	10 points	The acceptance of bread with added quinoa was moderate but improved with the addition of amaranth and buckwheat.	(Aguiar et al., 2021)
Maize/rice bread	Lithuania	15 (22-35 years old)	7 points	Sourdough bread made with quinoa, chia flour, and hemp had higher freshness and acceptance ratings than the control.	(Jagelaviciute & Cizeikiene, 2021)
Goat meat nuggets	India	15 (trained panel)	8 points	Adding quinoa and amaranth to the nuggets improved juiciness, nutritional profile, and acceptance but impacted the texture and color of the products.	(Verma et al., 2019)
Muffins with quinoa sourdough	Romania	47 (20-63 years)	9 points	Quinoa sourdough incorporated into muffins resulted in high sensory acceptance scores.	(Chiș et al., 2019)
Bread	Poland	100 (18-65 years)	9 points	The addition of quinoa flour in gluten-free bread enhanced not only its nutritional value but also its sensory acceptance.	(Rybicka et al., 2019)
Bread	Italy	12 (20-60 years)	9 points	The quinoa bread had a good nutritional profile and was well-accepted.	(Romano et al., 2018)
Fish patties	Argentina	30 (18-58 years)	5 points	Adding quinoa flour to the patties preparation increased its calcium and iron content, but the control formulation had the highest acceptance.	(Romero et al., 2018)
Cake	Brazil	100	7 points	Creating cakes without gluten using a seed mixture, including quinoa, is possible. This will result in a cake that is high in protein and minerals.	(Ávila et al., 2017)
Bread	Brazil	118 (18 -30 years)	9 points	Breads with 20% quinoa and stevia were moderately accepted when compared to the control group.	(Alencar et al., 2017)
Cookies	Brazil	60	9 points	Incorporating quinoa flour in cookies improves their nutritional value while maintaining moderate acceptance compared to the control.	(Vieira et al., 2015)
Cookies	Brazil	85 (18-65 years)	9 points	The most accepted formulation consisted of 30% quinoa, 25% quinoa flakes, and 45% corn starch. However, it was smaller, harder, and darker than the control.	(Brito et al., 2015)
Bread	Germany	10	10 points	Adding quinoa bran improved the product's nutritional profile, and sensory acceptance was not affected at up to 10% incorporation.	(Föste et al., 2014)
Granola	Brazil	80	9 points	Granolas with a higher content of quinoa and amaranth (22%) have a higher protein, lipid, and mineral content, as well as better acceptance.	(de Souza et al., 2014)
Granola	Brazil	30	9 points	Granolas increased their nutritional level when quinoa was added, and as storage was prolonged, acceptance decreased.	(Pagamunici et al., 2014)
Bread	Ireland	17	6 points	Bread with 10-50% substitution increased nutritional content, while acceptance decreased with storage.	(Alvarez-Jubete et al., 2010)
Spaghetti	Brazil	30 (20 – 51 years)	9 points	Consumers accept the presence of low levels of quinoa flour, up to 10%, in gluten-free spaghetti	(Caperuto et al., 2001)

Table 4
Quinoa-based meat products

Product	Country	Number of Consumers	Hedonic Scale	Main findings	References
Sausages type Frankfurter	Ecuador	Not reported	5 points	The sausages most liked for their flavor and texture contained Sesame + Quinoa, Peanut + Quinoa, and Peanut + Soybean, showing a high protein and fat content.	(Mosquera et al., 2022)
Beef sausages	Zimbabwe	35	9 points	Different binders used in sausages were found to have a significant impact on their texture, flavor, juiciness, and aroma but not on their color. The sausages made with quinoa received the best ratings for texture, flavor, juiciness, and aroma than those made with amaranth. The acceptance was higher for sausages with corn starch and quinoa than for amaranth sausages.	(Tafadzwa et al., 2021)
Chicken meatballs	Korea	35 Semi-trained	9 points	Incorporating quinoa seeds in the meatballs increased antioxidant activity and chewiness while combining quinoa and starch improved taste, texture, and overall liking compared to the control.	(Park et al., 2021)
Beef burger	Iran	30	5 points	Burgers made with quinoa flour were more well-accepted than burgers made with soy protein.	(Bahmanyar et al., 2021)
Tilapia balls	Brazil	100	9 points	Replacing wheat flour with quinoa flour resulted in lower cooking loss, less lipid absorption, and higher acceptance of tilapia balls.	(Teixeira et al., 2020)
Low-fat beef burger	Russia	10 expert panelists	10 points	Increasing the amount of quinoa in the formulation resulted in higher protein, fiber, and ash content and lower fat content. Sensory properties and acceptance improved significantly with the incorporation of 5% or 7.5% quinoa, being similar to the control.	(Baioumy et al., 2018)
Dry-Cured Sausage	Spain	86	5 points	Fat substitution using quinoa resulted in significant changes in protein content, texture, redness, and spiciness. However, the fat reduction did not hurt the sausages' acceptance.	(Fernández-Diez et al., 2016)

Table 5
Quinoa-based beverage products

Product	Country	Number of Consumers	Hedonic Scale	Main findings	References
Wine "Makgeolli"	South Korea	Not declared	7 points	Despite differences in flavor, there were no significant variations in color, odor, appearance, or acceptability between the control and quinoa-added wines.	(Jeon et al., 2022)
Drink Sprouted Quinoa	Peru	60	3 points	Nutritional value increased and acceptance remained unchanged in all treatments.	(Bendezu-Ccanto et al., 2023)
Quinoa-based prebiotic beverage	Sweden	20	9 points	Upon adding 5%, 10%, and 15% fermented quinoa to instant mixtures, the pineapple-orange drink with 5% fermented quinoa was preferred, even surpassing the control commercial.	(Ayub et al., 2021)
Fermented beverages	Slovakia	11	5 points	Quinoa was utilized as a raw material for producing lactic acid fermented beverages. Fermentation resulted in a significant increase in protein content, total phenols, and antioxidant activity. However, the acceptability of the quinoa samples was low, which improved significantly with the addition of raspberry syrup.	(Karovičová et al., 2020)
Kefir fermented beverage flavored with cocoa	Brazil	50	9 points	The fermented quinoa kefir received a high acceptance score of 7.6 due to adding cocoa powder and sugar to counteract its sour taste.	(Tavares et al., 2018)
Fermented quinoa-based beverage	Finland	20	9 points	The acceptance of quinoa-based beverages was improved significantly when blueberry and chocolate flavorings were added to mask the bitter taste.	(Ludena Urquizo et al., 2017)
Quinoa milk	Brazil	160 (18 – 50 years)	9 points	Consumers with lactose intolerance and moderate intake of vegetable milk found quinoa milk acceptable.	(Pineli et al., 2015)
Fermented beverage	Brazil	80	9 points	Viscosity and consistency increased at higher quinoa concentrations. The beverage with 70% soybean extract and 30% quinoa was the best liked.	(Bianchi et al., 2014)
Flavored-peach and grape-fermented quinoa beverages	Brazil	50	9 points	The beverages with peach and grape flavors had significant differences in aroma, color, flavor, and acceptance but not in texture. The peach-flavored drink was the most preferred by consumers.	(Bicudo et al., 2012)

Table 6
Dairy products manufacturing by adding quinoa

Product	Country	Number of Consumers	Hedonic Scale	Main findings	References
Yogurt	Canada	86	9 points	Yogurt fortified with rice flour obtained higher hedonic scores for appearance, taste, texture, and overall acceptability than yogurt fortified with quinoa.	(DeBruyne & Hekmat, 2024)
Low-fat milk dessert	Iran	30 (22-50 years)	5 points	Adding quinoa protein isolate (1-5%) to low-fat dairy desserts increases protein content but also affects sensory profile.	(Sekhavatizadeh et al., 2023)
Kefir made from cow and goat milk	Turkey	40 (30-50 years)	7 points	The addition of quinoa flour decreased the acceptance of kefirs.	(Kef & Arslan, 2021)
UF-soft cheese	Egypt	24	10 points	Adding 1% and 2% quinoa flour increased protein, fat, dietary fiber content, and acceptance in cheese. However, cheeses with 3% quinoa flour resulted in low acceptance.	(Abdelmontaleb et al., 2021)
Yogurt supplemented with quinoa flour	Argentina	102	9 points	Yogurts supplemented with 1, 3, and 5 g 100 mL^{-1} quinoa flour showed higher levels of protein, carbohydrates, and fat but had low acceptance.	(Curti et al., 2017)

Table 7
Quinoa-based snacks

Product	Country	Number of Consumers	Hedonic Scale	Main findings	References
Snacks	Mexico	50 (17-45 years)	7 points	Cereal bars were developed with expanded quinoa and other ingredients, resulting in a product with a high liking.	(González-Calderón et al., 2021)
Sand puffing of quinoa	India	10 Semi-trained assessors	9 points	The optimal conditions for achieving high expansion and acceptance were: 0.2 mL moisture / 10g quinoa grains, 0.2% salt, 229°C cooking temperature, and 55s of expansion time.	(Subramani et al., 2020)
Sweet snacks	Argentina	Not declared	9 points	Snacks made with chia, quinoa, and amaranth had a good acceptance	(Sciammaro et al., 2018)
Extruded Corn grits quinoa blends	USA	21	7 points	Adding quinoa at 10%, 20%, and 30% to corn snacks showed no significant difference in acceptance, with a slight preference for the 20% option.	(Coulter & Lorenz, 1991)

On the other hand, five articles (7%) focused on manufacturing dairy products such as yogurts, cheese, and desserts (Table 6). The incorporation of quinoa has improved its nutritional quality. However, its low acceptance has been the factor that limits incorporating it in more significant quantities. In addition, four studies focused on developing snacks with quinoa (Table 7), which were generally well-liked. In addition to the products mentioned earlier, research has been conducted on other quinoa-based foods, including cereal bars, quinoa meals, porridge, plant-based products, and chocolates. However, the research on these products is still in its early stages.

All the studies reviewed have shown an increase in the nutritional properties of products when quinoa is included in their formulation. However, the sensory and hedonic characteristics of the products vary depending on the method, scale size, and the product itself. Hence, the sensory techniques used in the studies that involve products made from quinoa are summarized.

To obtain reliable results from a statistical perspective, it is strongly recommended that around 100 consumers be used in acceptance tests (Hough et al., 2006; Mammasse & Schlich, 2014). Additionally, it is recommended that trained or semi-trained assessors should not indicate acceptance since they were not trained to rate product liking but rather the intensity of some product attributes (analytical task) (Ares & Varela, 2017). It is suggested that a 9-point hedonic scale be used, which has been widely used by the scientific community since 1950 (Lim, 2011).

3.5. Sensory methods

Out of the 74 papers that analyzed the degree of acceptance of quinoa-based products through affective methods, 35 studies used the nine-point hedonic scale. This scale has been widely used since its creation by Peryam & Girardot (1952), remaining the most used scale. Fifteen studies used the five-point hedonic scale, eleven used the seven-point hedonic scale, and ten used the 10-point hedonic scale. The remaining three studies used three-, six-, and eight-point scales.

The results of various studies compiled in this systematic review, as shown in Figure 8, indicate heterogeneity in the size of the scales. This heterogeneity can lead to ambiguous conclusions about the effect of adding quinoa to a product on its acceptance. For instance, when adding 10%, 20%, or 30% quinoa to a product, a significant difference between 10% and 20% may be detected depending on the type of scale used. Therefore, it is recommended to use the classic 9-point hedonic scale, which has been widely validated and recognized by the scientific community since its development by Peryam and Girardot in 1952.

A combination of hedonic measures and descriptive measures is recommended to create preference maps. These maps can help identify the attributes that increase or decrease the acceptance of products (drivers of liking). By using this approach, developers of new formulations can have a broader view of product acceptance, allowing for more detailed information to be included. This will ultimately help in the development of better products using quinoa. It is also recommended to use techniques that consider the changes in sensory perception over time. Some such techniques are the Temporal Dominance of Sensations (Pineau et al., 2009), Time-Intensity (Lee & Pangborn, 1986), and the temporal Check-All-That-Apply (Castura et al., 2016). These methods provide a temporal component throughout the tasting process, which is particularly important for quinoa-added products that have altered texture.

3.6. Current and future challenges

Quinoa-based food products face several challenges both now and in the future. One of the main challenges is to overcome the low sensory acceptability due to the bitter taste associated with saponins. In addition, there is a need to standardize sensory evaluation methods to effectively compare studies and educate consumers about the benefits of quinoa to broaden its adoption. Determining optimal quinoa inclusion levels that balance sensory attributes with nutritional benefits without compromising taste and texture is crucial. In this regard, complementing neuroscience (Chen et al., 2023; Izaguirre-Torres et al., 2020) approaches can provide a deeper understanding of how sensory stimuli are perceived by the brain and an understanding of the influence of product presentation (Baranda et al., 2024) is critical to promote the choice of quinoa products.

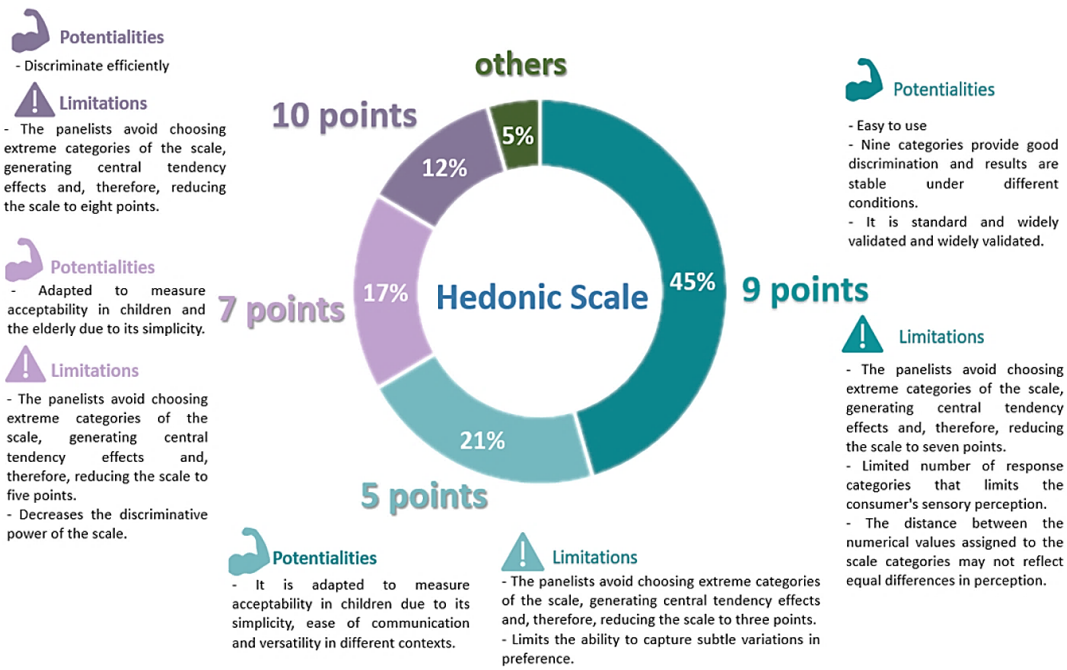

Figure 8. Potentialities and limitations of hedonic scales used. The works of Curia et al., 2001; Giovanni & Pangborn, 1983; McPherson & Randall, 1985; Peryam & Girardot, 1952; and Villanueva & Da Silva, 2009, provided an overview of the scales' potential and limitations.

In the temporal evolution of research topics over the years (Figure 9), it stands out that the most recent topics focus on improving the quality and acceptability of quinoa products by also addressing nutritional and sensory concerns. Therefore, looking ahead challenges will include product innovation, improving sensory profiles through biotechnological methods, establishing sustainable supply chains, and scaling up production without compromising environmental sustainability.

In order to address these challenges, a multidisciplinary approach and strategic collaborations will be required to maximize quinoa's potential as a nutritious and sustainable food source. Furthermore, navigating regulatory requirements for global market access, developing marketing strategies to educate consumers, and leveraging advanced technologies to enhance processing efficiency and product quality are also essential.

4. Conclusions

The scientific community has shown increasing interest in assessing quinoa-based products' sensory and hedonic acceptance. As a result, there has been a rise in publications regarding sensory methods. Although some studies have identified some challenges, there have been significant improvements in the nutritional properties of the final products, which supports the potential of quinoa as a nutritious and versatile ingredient. Quinoa can be adapted to various formulations to develop innovative, more nutritious, healthier, and sustainable foods. It is vital to continue research and determine the optimal concentrations of quinoa to be added to different foods, considering the sensory and hedonic profile to ensure consumer acceptance and satisfaction. This will benefit the industry by offering consumers healthier, sustainable, and sensorially pleasing food options. Based on research, the most widely used method to evaluate the acceptance of quinoa-based products has been affective sensory methods like the nine-point hedonic scale. Also, it was observed that 67% of the bakery products with minor (5-30%) proportions of quinoa, maintained acceptance compared to the control. Furthermore, it has been observed that quinoa is widely used to develop gluten-free products.

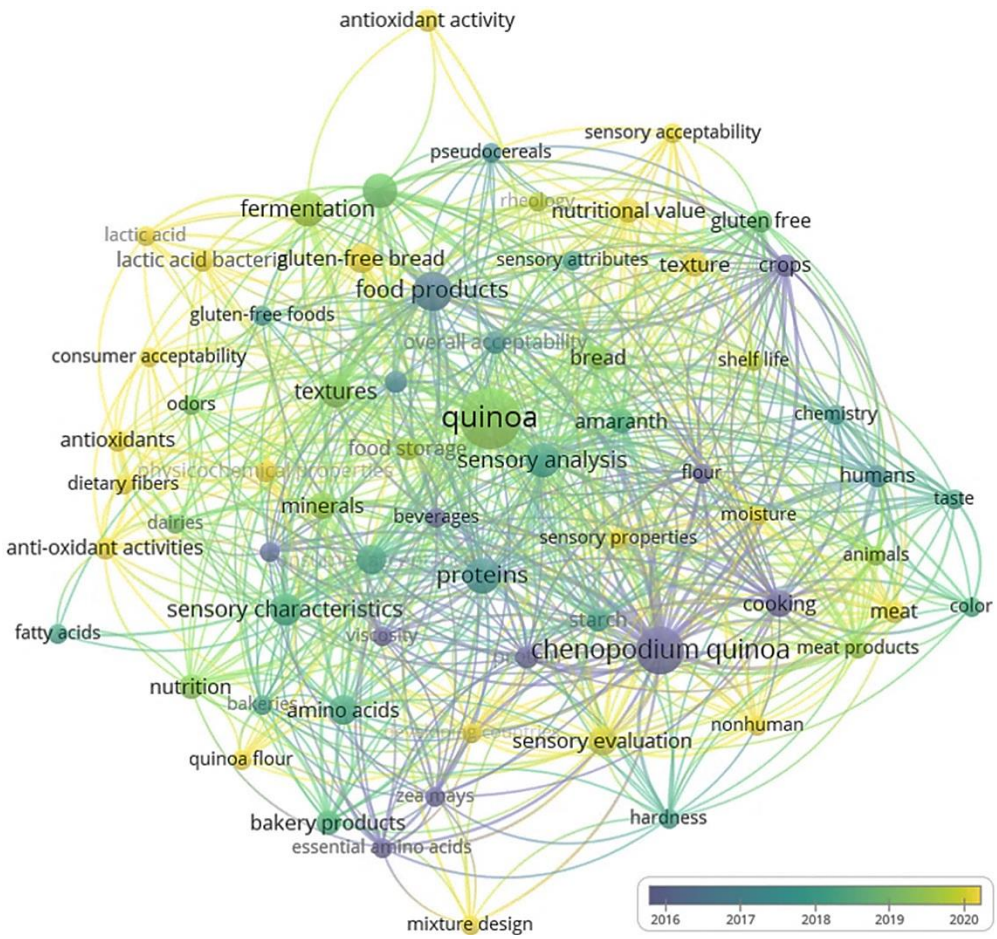

Figure 9. Temporal co-occurrence map.

It is recommended to use technological strategies to improve the bioavailability of nutrients in final products to reduce unpleasant sensory traits. Additionally, it is crucial to conduct comprehensive sensory analyses involving more than 100 consumers to obtain reliable and accurate results. It is also suggested that the 9-point hedonic scale be used to measure acceptance and consumer-based sensory methods, including dynamic sensory methods, to provide a more realistic view throughout the tasting.

Finally, when creating new products, it's essential to consider their nutritional, sensory, and hedonic profile and stay updated on current research trends. To achieve this, it's recommended that specific studies be conducted with children since it's easier to shape their eating habits from an early age, which can have a lasting impact on their food preferences throughout their lives.

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