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PROSPECÇÃO TECNOLÓGICA DAS TENDÊNCIAS EM PRODUTOS CÁRNEOS REFORMULADOS COM FOCO NA SAÚDE

TECHNOLOGICAL PROSPECTION OF TRENDS IN REFORMULATED MEAT PRODUCTS WITH A FOCUS ON HEALTH

PROSPECCIÓN TECNOLÓGICA DE TENDENCIAS EN PRODUCTOS CÁRNICOS REFORMULADOS CON ENFOQUE EN LA SALUD

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RESUMO
A carne e os produtos cárneos são alimentos amplamente consumidos e bem aceitos pelos consumidores. A presente pesquisa tem como objetivo mapear as tendências na reformulação de produtos cárneos com foco na saúde, a fim de verificar a evolução das pesquisas científicas desenvolvidas no Brasil e no mundo. Dessa forma, o estudo prospectivo analisou o avanço das publicações científicas no período de 2018 a 2022. A base de dados utilizada foi a Scopus para a obtenção dos artigos, e o software VOSviewer para o tratamento e análise das palavras por coocorrência. Foram selecionadas 1.444 publicações relacionadas a produtos cárneos com foco na saúde. Observou-se uma tendência de crescimento acentuado no número de artigos publicados entre 2018 e 2022, com taxa média de crescimento anual de 6,45%. A China destacou-se como o país com o maior número de produções científicas sobre o tema, sendo responsável por 243 dos 1.444 artigos identificados. As subáreas de maior representatividade foram as Ciências Agrárias e Biológicas, com 886 publicações. Conclui-se que as pesquisas sobre produtos cárneos mais saudáveis aumentaram significativamente nos últimos anos, acompanhando a crescente preocupação dos consumidores com os efeitos nocivos do consumo excessivo de gordura, sal e aditivos sintéticos.

Palavras-chave: Produtos Cárneos. Carne. Saúde. Prospecção. Dados.

ABSTRACT
The text Meat and meat products are very popular foods that are widely accepted by consumers. This research aims to map trends in the reformulation of meat products with a focus on health, in order to verify the evolution of scientific research carried out in Brazil and in the world. Thus, the prospective study developed analyzed the progress of research in the publication of scientific articles in the period from 2018 to 2022. The research database was Scopus, for articles, and Vosviewer for the treatment of data from words with co- occurrences. 1,444 publications were selected in the field of meat products with a focus on health. There was a sharp growth trend in the number of articles published from the year 2018 to 2022. The average growth rate was 6.45%. China is the country with the highest number of scientific productions on the subject, accounting for 243 of the 1,444 articles. The most

Revista ARACÊ
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representative subareas are “Agrarian and Biological Sciences” with 886 publications. It is concluded that research on healthier meat products has increased in recent years. This increase has come as consumers are increasingly concerned about the harmful effects of consuming fat, salt or synthetic additives.

Keywords: Meat Products. Meat. Health. Prospection. Data.

RESUMEN
El La carne y los productos cárnicos son alimentos muy populares y ampliamente aceptados por los consumidores. Esta investigación tiene como objetivo mapear las tendencias en la reformulación de productos cárnicos con enfoque en la salud, con el fin de verificar la evolución de las investigaciones científicas realizadas en Brasil y en el mundo. Así, el estudio prospectivo desarrollado analizó el avance de la investigación en la publicación de artículos científicos en el período de 2018 a 2022. La base de datos de la investigación fue Scopus, para artículos, y Vosviewer para el tratamiento de datos de palabras con co-ocurrencias. Se seleccionaron 1.444 publicaciones en el área de productos cárnicos con enfoque en salud. Hubo una fuerte tendencia de crecimiento en la cantidad de artículos publicados desde el año 2018 hasta el 2022. La tasa de crecimiento promedio fue de 6.45%. China es el país con mayor número de producciones científicas sobre el tema, con 243 de los 1.444 artículos. Las subáreas más representativas son “Ciencias Agrarias y Biológicas” con 886 publicaciones. Se concluye que la investigación sobre productos cárnicos más saludables se ha incrementado en los últimos años. Este aumento se ha producido a medida que los consumidores están cada vez más preocupados por los efectos nocivos del consumo de grasas, sal o aditivos sintéticos.

Palabras clave: Productos Cárnicos. Carne. Salud. Prospección. Datos.

Revista ARACÊ
ISSN: 2358-2472

1 INTRODUCTION

Among all the available food sources for humankind, meat stands out as a prominent dietary component that has accompanied human beings throughout their extensive evolutionary journey. Its significant presence in the diet distinguishes it from other food sources. To enhance the value of red meat and its derivatives, the meat industry has made considerable investments in developing strategies aimed at aligning with the current trend of reformulating meat products (NOVELLO; POLLONIO, 2015).

Meat and its derived products hold a position of great popularity among consumers, being widely accepted as staple foods. These products have undergone rapid evolution, driven by changes in lifestyle patterns and nutritional ideologies embraced by a growing segment of the population (RUIZ-CAPILLAS; HERRERO, 2021).

The market for meat products with health-related benefits has experienced significant growth due to the wide range of potential consumers and the increasing social awareness regarding the relationship between food, health, and longevity. This trend has encouraged numerous studies focused on exploring new processing methods and emerging technologies to meet the evolving expectations and preferences of health-conscious consumers (CEGIELKA, 2020).

The increasing demand for sustainable meat production and the prioritization of human health and well-being have fostered technological innovation within the global food industry (RAMACHANDRAIAH et al., 2015). One of the main challenges faced by the sector is to enhance the nutritional profile of meat products by incorporating health-promoting bioactive ingredients while reducing the use of potentially harmful substances, such as excessive fat, cholesterol, sodium chloride, and synthetic additives (LAMRI, 2021; URSACHI et al., 2020).

The reduction of sodium and chloride intake is particularly important, as both are strongly associated with an increased risk of chronic noncommunicable diseases such as stroke, hypertension, and cardiovascular disorders (KIM, 2021a). Although a comprehensive technological solution for improving the sensory and microbiological quality of low-sodium meat products has not yet been achieved, the food industry continues to explore innovative approaches to overcome such challenges, including advanced processing, preservation, and reformulation techniques (KIM, 2021b).

One noteworthy technological strategy to enhance the composition and functionality of meat products is reformulation, which involves the removal, reduction, addition, or substitution of specific ingredients to create healthier, safer, and more sustainable alternatives (RUIZ-CAPILLAS; HERRERO, 2021). Reformulation is not limited to nutritional improvements, it also represents a pathway toward eco-efficient production and responsible innovation, aligned with global goals of

Revista ARACÊ
ISSN: 2358-2472

sustainable development and food security.

Given the growing number of scientific contributions in this field, the present research aims to map and analyze scientific trends related to the reformulation of meat products with a focus on health, highlighting the technological, nutritional, and sustainability aspects addressed in recent publications. To achieve this, a bibliometric analysis was carried out using the Scopus database to identify and interpret international research patterns from 2018 to 2022.

This study seeks to contribute to the expansion of scientific knowledge and social awareness regarding reformulation strategies and emerging technologies applied to the development of healthier meat products, providing insights for innovation, public policy, and industrial advancement in the field of food science and technology.

2 THEORETICAL FRAMEWORKS

Currently, there is a growing market demand for healthier food options, which has led to new trends and innovations in the development of health-focused products, including those derived from meat.

To achieve the goal of producing healthier meat products, strategies can be implemented throughout the entire food chain, from farm to fork, to ensure the production of healthy and high-quality products. The initial step in developing healthy meat products takes place on the farm, where genetic and nutritional strategies are employed during animal breeding and production. These strategies aim to modify and optimize the composition of meat and its derivatives to achieve a healthier profile (RUIZ-CAPILLAS; HERRERO, 2021).

Table 1 below highlights some of the strategies that are notable for their ability to improve the overall composition of meat products. These strategies contribute to the development of healthier meat products.

Table 1. Proposed strategies to improve the quality of meat products.

Nutritional enrichment	**Reduction of harmful components**	**Processing Technologies**
Dietary fiber	Salt	High Pressure Processing
Natural antioxidants	Animal fat content	Cold Plasma
Probiotics and Prebiotics	Nitrate and nitrite	Ultrasonics
Herbal ingredients	Phosphate	Nanotechnology
	Polycyclic aromatic hydrocarbons (PAHs)	Hot-Boning Technology Radiation
	Heterocyclic aromatic amines (HCAs)	Pulsed electric field processing
		Pre-emulsification
		Infrared Spectroscopy

Source: Adapted by Ursachi et. Al (2020)

Revista ARACÊ
ISSN: 2358-2472

2.1 REDUCTION OF HARMFUL SUBSTANCES

2.1.1 Animal Fat

The enhancement of lipid content in meat products has garnered significant scientific interest as a strategy to enhance their composition in response to health guidelines. This approach commonly entails substituting a portion or a substantial amount of fat with alternative lipid sources that offer superior health benefits. Various technological methodologies are employed to achieve this objective, encompassing a range of procedures (RUIZ-CAPILLAS et al., 2021). Table 2 provides a comprehensive overview of these different strategies, which involve the replacement of fat, incorporation of healthier lipid alternatives, selection of lean meat, utilization of emulsion technology, and implementation of modified processing techniques.

Table 2. Main animal fat substitutes for the manufacture of healthy meat products.

Animal fat substitutes	Ingredients	Reference
Flours and fibers	Peas, rice bran, chickpeas	Polizer et al. (2015), Echeverria et al. (2022), Pietrasik e Soladoye (2021),
Hydrocolloids	Alginic acid, Konjac, carrageenan, xanthan, sodium alginate, guar gum, carboxymethyl cellulose, gel gum, pectin and carob gum.	Dinani et al. (2022) Yuan et al. (2022)
Mushrooms	Pleurotus ostreatus, Lentinus edodes, Coprinus comatus	Torres-Martínez et al. (2022) Yuan et al. (2021)
Whey and collagen	Microparticulated milk soro protein, hydrolyzed whey protein, hydrolyzed collagen	Bahrami Feridoni (2020) Ozturk-Kerimoglu (2022) Barrón-Ayala (2020) Souza et al. (2017)
Vegetable oils	Sesame, sunflower, acai, walnut, soy, canola, flaxseed, peanut	Cittadini et al. (2022), Hernández-Jiménez et al. (2022), Mora-Gallego et al. (2016), Cheetangdee (2017), Chen et al. (2020), Bolger et al. (2018), Kÿlÿç & Özer, (2019), Nakab et al. (2021)

Source: O autor (2022)

Cittadini et al. (2022) conducted a study to investigate the impact of partially replacing animal fat with a blend of sesame oil and algae oil emulsion hydrogels on the quality characteristics of dry-fermented sausages. The incorporation of oil emulsion hydrogels led to a significant reduction ($P < 0.001$) in the content of saturated fatty acids, resulting in a decrease from 34.16 g/100 g fat to 30 g/100 g fat. Furthermore, there was a notable increase ($P < 0.001$) in the levels of monounsaturated (T1) and polyunsaturated (T2) fatty acids, with specific outcomes varying depending on the batch. The study

Revista ARACÊ
ISSN: 2358-2472

also demonstrated an overall improvement in health indices such as the omega-6/omega-3 (n-6/n-3) ratio. These findings suggest that the utilization of sesame oil and algae oil blend emulsion hydrogels represents a promising strategy for producing healthier dry-fermented sausages that are well-received by consumers.

In a separate investigation, Hale et al. (2002) utilized a dry whey protein concentrate with a protein content of 80% to develop an ingredient capable of substituting 0% to 50% of beef in hamburger formulations. The samples incorporating up to 40% whey extrusion were found to be equally acceptable to a consumer panel when compared to traditional beef burgers. Notably, these burgers exhibited improved cooking yield, experienced smaller diameter reductions, and demonstrated lower water and fat losses during the cooking process. These outcomes suggest that incorporating dry whey protein concentrate as an ingredient in hamburger preparations has the potential to enhance consumer acceptance, while also improving cooking attributes and minimizing moisture and fat losses.

2.1.2 Sodium chloride

Numerous scientific investigations have underscored the pivotal significance of sodium chloride, commonly referred to as salt, in the realm of food production, particularly in sustaining human life. Salt assumes a critical role in maintaining the body's water equilibrium and actively participates in diverse physiological mechanisms, encompassing the transmission of nerve impulses, regulation of muscular contractions, absorption of nutrients in the gastrointestinal tract, and hormonal control (KIM, 2021a).

In the specific domain of meat processing, salt plays an essential and multifaceted role as an additive. It effectively interacts with the microfibrillar proteins inherent in meat, leading to the formation of a stable emulsion. This interaction facilitates the encapsulation of fat constituents, thereby impeding the release of moisture and conferring the desired attributes to the final meat product (KIM, 2021b). For a comprehensive understanding of salt's involvement in meat processing, pertinent details can be found in Table 3.

Table 3. Role of salt (NaCl) in meat processing to improve quality.

Function of salt	Reference
1 . Increases the service life	Inguglia (2017), Petit (2019), Taormina (2010)
2. Increases microbial safety	Inguglia (2017), Petit (2019), Taormina (2010)
2.1. Decreasing the water activity of the product	
3. Enhances sensory properties	Roper (2015), Tunieva e Gorbunova (2017), Hoppu et al. (2017)

Revista ARACÊ
ISSN: 2358-2472

3.1. Suppressing bacteria growth and improving taste	
3.2. Improving Texture	
4. Increases physical-chemical properties	Desmond (2006)
4.1. Increases physical-chemical properties	
4.2. Decreasing cooking loss	
4.3 Binds salt-soluble protein extracting myosin, actin from myofiber	

Source: Adapted by Kim (2021).

Low-salt meat products exhibit diminished moisture retention capacity during the manufacturing process due to a reduction in the extraction capacity of salt-soluble proteins. Consequently, the introduction of alternative substances becomes necessary to replace the salt-soluble proteins and impart water retention properties that contribute to desirable physical characteristics (KIM, 2021b).

The replacement of sodium chloride (NaCl) with other chloride salts such as potassium chloride (KCl), calcium chloride (CaCl2), and magnesium chloride (MgCl2) poses a significant challenge in the production of meat products. The objective is to minimize alterations in the processing steps and the addition of new ingredients while enhancing flavor and improving texture. This challenge arises within the context of consumer awareness concerning sodium consumption and its health implications (VIDAL et al., 2021). Detailed information on these substitutes is provided in Table 4.

Table 4. Studies on salt substitutes used for salt reduction in meat products.

Product Category	**Sodium Chloride Substitutes**	**Reference**
Ground beef	Microbial transglutaminase, fibrimex, alginate.	Atilgan et al. (2017)
Mortadella	$CaCl_2$, $MgCl_2$, KCI.	Horita et al. (2011)
Dried meat	KCl, $CaCl_2$, KCl, soy sauce, fermented flavor enhancer.	Vidal et al. (2019) Sindelar et al. (2018)
Boiled ham	Sal Soda-Lo®	Raybaudi-Massilia et al. (2019)
Turkey breast	Sal Soda-Lo®, Na_2HPO_4, $Na_5P_3O_{10}$, Na_2SO_4, $C_5H_8NNaO_4$.	Raybaudi-Massilia et al. (2019) Pandya et al. (2020)
Bacon	KCl, soy sauce, fermented flavor enhancer.	Sindelar et al. (2018)
Smoked sausage	OF-45LSN, OF-60LSN, Salty powder.	Gaudette, NJ; Pietrasik, Z. (2017)

Source: Autors (2022)

2.1.3 Nitrate and nitrite

Nitrite is utilized in meat products to effectively control the growth of pathogenic bacteria,

Revista ARACÊ
ISSN: 2358-2472

prevent rancidity, and impart the desirable pink color that is favored by consumers (VAN BEDRA et al., 2021). Sodium nitrite (NaNO2) and potassium nitrite (KNO2) are the primary synthetic nitrites employed in the meat industry due to their cost-effectiveness, stability, and ease of preparation and utilization (DELGADO-PANDO, 2021).

The presence of nitrite in meat products is known to contribute significantly to their flavor, although the precise mechanism underlying this effect remains incompletely understood (URSACHI et al., 2020). To replace or reduce the reliance on nitrite in processed meats while maintaining their desirable properties, numerous scientific investigations have demonstrated the promise of employing biologically active compounds (VAN BEDRA et al., 2021).

Researchers have directed their attention toward the utilization of bacteriocins, organic acids, plant extracts possessing robust antimicrobial activity, and various plant components (such as vegetables, fruits, herbs, and spices) as potential alternatives for nitrite elimination or reduction. These alternatives are attractive due to their abundance of phenolic compounds, which are known to benefit human health and exhibit excellent free radical scavenging activity (FERISYUK; WÓJCIAK, 2020). A comprehensive overview of these nitrites scavenging or reduction alternatives can be found in Table 5 below.

Table 5. Effect of nitrate-rich extract on the quality and stability of meat products

Product	Ingredient	Effect
Fermented and cooked meat product	Radish powder	Similar redness to nitrite treatment and similar pigment content.
Cooked sausage	Fermented cabbage and cabbage extract	Lower redness than nitrite treatment; inhibited the growth of Listeria monocytogenes
Emulsified pork sausage	Beet powder	Significant increase in redness and sensory acceptance of color.

Source: Autors (2022)

Phosphates play a crucial role in human health as they are essential for cellular growth, maintenance, and repair, as well as for signaling, energy transfer, and other vital functions. They are involved in numerous metabolic pathways and occur naturally as organic esters in foods such as eggs, meat, potatoes, and cereals (THANGAVELU et al., 2019).

In the meat industry, different types of dietary phosphates (mono-, di-, tri-, and polyphosphates) are commonly used due to their impact on pH, chelation, ionic strength, and antibacterial activity (GOEMAERE et al., 2021). These additives can enhance oxidative and microbiological stability while improving the tenderness and juiciness of meat products.

However, the increased use of phosphates as food additives and preservatives poses an

Revista ARACÊ
ISSN: 2358-2472

avoidable health risk (LONG, 2011). Individuals with kidney disease are particularly vulnerable to phosphate intake, as impaired acid excretion leads to elevated serum phosphate levels, increasing the risk of mortality by up to 40% among patients with chronic kidney disease. Excess phosphate also interferes with calcium absorption, leading to bone diseases even in otherwise healthy individuals (PINTON et al., 2021).

Reducing phosphate levels is of significant industrial importance in the production of meat products to create healthier options. However, the unique characteristics of phosphates make their removal while maintaining product quality a challenge (THANGAVELU et al., 2019). According to European legislation, the permitted level of phosphates in meat and meat products is 5 g/kg expressed as phosphorus peroxide (P2O5) individually or in combination with the final product (LONG, 2011).

Studies addressing phosphate reduction have shown promising strategies. Câmara et al. (2020) concluded that a 2% chia mucilage gel, with its functional properties, is a viable option for replacing 50% of phosphates in low-fat Bologna sausage. Additionally, Wang et al. (2023) investigated the effects of chickpea protein isolate (CPI, 0.5-2%, w/w) on the techno-functional properties of pork patties with 50% reduced phosphate levels. The results demonstrated the potential use of chickpea protein isolates in developing meat products with reduced phosphate content. Table 6 provides a list of commonly used phosphates in meat products.

Table 6. List of phosphates commonly used in meat products

Name	**Formula**
Sodium monophosphate	
Monosodium Phosphate - MSP	NaH_2PO_4
Disodium Phosphate - DSP	Na_2HPO_4
Fosfato trissódico - TSP	Na_3PO_4
Sodium diphosphate -TSPP (Tetrasodium pyrophosphate)	$Na_4P_2O_7$
Disodium Diphosphate - SAPP (Sodium Acid Pyrophosphate)	$Na_2H_2P_2O_7$
Sodium Tripolyphosphate - STPP (Pentasodium Phosphate)	$Na_5P_3O_{10}$
Sodium hexametaphosphate - SHMP (Graham's salt)	$(NaPO_3)_n$
Potassium monophosphate	
Monopotassium phosphate - MKP	KH_2PO_4
Dipotassium phosphate - DKP	K_2HPO_4
Tripotassium phosphate - TKP	K_3PO_4
Potassium diphosphate - TKPP (Tetrapotassium pyrophosphate)	$K_4P_2O_7$
Potassium Tripolyphosphate - KTPP	$K_5P_3O_{10}$

Source: Autors (2022). Adapted by Long et al. (2011).

PAHs are categorized into two groups based on the number of aromatic rings they contain. Heavy PAHs, such as benzo(a)pyrene [BaP] and benzo(b)fluoranthene [BbF], possess five or more

Revista ARACÊ
ISSN: 2358-2472

aromatic rings, while light PAHs, including benzo(a)anthracene [BaA] and chrysene [Chr], consist of two to four aromatic rings (KAFOURIS et al., 2020). The precise mechanism of PAH formation in meat products remains controversial, and there is a wide array of detection methods and influencing factors, posing challenges to food control efforts (ZHU et al., 2022). Meat and meat products are complex food matrices predominantly composed of fat and protein, necessitating thorough cleaning procedures to isolate PAHs and minimize interferences from the matrix (KAFOURIS et al., 2020).

The formation of PAHs in processed meats and meat products is influenced by various cooking processes and techniques, including baking, grilling, smoking, heating, drying, roasting, and ohmic infrared cooking, among others (ADEYEYE; ASHAOLU, 2022). Smoking and grilling are major contributors to the generation of PAHs and can impact the microbiological safety and overall quality of meat and meat products, thereby leading to the production of harmful substances and potential food contamination (ONOPIUK et al., 2022).

Currently, there is significant interest among researchers and meat processors in replacing saturated fats with unsaturated fatty acids. Lu et al. (2017) investigated the effect of substituting different fats (olive oil, sunflower oil, and grape seed oil) for pork bacon on the concentration of PAHs. Additionally, the influence of cooking temperature on the formation of PAHs in pork burgers was examined. Table 7 shows the conditions and technology for treatment the food.

Table 7. Apparatus and treatments used in the reduction and removal of PAHs in processed meat products.

Technology	Food	Conditions	PAHs	Reduction %	Technology
Gamma Irradiation	Fresh sausage	Fresh sausage was irradiated with γ-rays at doses of 0, 1, 4 and 8 kGy followed by cooking at 220 °C for 20 min	BaP	51.67% less when 8kGy is used than the non-irradiated form.	Gamma Irradiation
Microbial treatment	Smoked Pork Sausages	Lactic acid bacteria with antimicrobial properties	PAH4	Reduction of 30.79% and 12.57% before and after L.sakei treatment than control. 14.11% reduction before and after treatment with P. acidilactici. 21.03% and 20.55% reduction before and after treatment with P. pentosaceus than the control treatment.	Microbial treatment
Fat Replacement	Pork rissoles	Replacing fat with vegetable oils (olive, sunflower,	BaA and BaP	Reduction of 21.70% when the substitution based on sunflower oil followed by cooking	Fat Replacement

Revista ARACÊ
ISSN: 2358-2472

		grape seed) and cooking at 180°C and 220°C.		at 180 °C was done over the control. Reduction of 51.52% over the control when the oil-based substitution was made followed by cooking at 220 °C.	

Source: Autors (2025). Adapted by Singh et al. 2022.

2.1.4 Heterocyclic Aromatic Amines (HAAs)

Meat products play a vital role in our daily diet as they provide essential nutrients, including fat, protein, vitamins, essential amino acids, and trace elements like iron, magnesium, selenium, copper, and zinc. However, excessive heat or improper cooking methods applied to meat can lead to the formation of toxic and harmful substances such as nitrosamines, polycyclic aromatic hydrocarbons, and heterocyclic aromatic amines (HAAs) (TENG, 2023).

HAAs are a group of mutagenic compounds that are formed through the Maillard reaction when muscle meats are cooked at temperatures above 100 °C. Ready-to-eat and processed foods, often subjected to high-temperature cooking methods, can contain significant amounts of HAAs (UR RAHMAN et al., 2014).

The formation of HAAs in meat and meat products can be influenced by various factors, including the type of meat, cooking time and temperature, cooking method, variety and quantity of flavorings, and cooking oil used (LAI et al., 2022). Epidemiological studies have demonstrated that regular consumption of foods high in HAAs may increase the risk of cancer in humans (ZHANG et al., 2022). To mitigate the formation of these carcinogenic compounds, it is recommended to avoid direct contact of meat surfaces with an open flame, employ microwave heating as a pre-treatment, and continuously turn the meat during cooking (UR RAHMAN et al., 2014).

Various compounds with antioxidant activity, as presented in Table 8, can be added to different types of meat to reduce the concentration of HAAs.

Table 8. Inhibition of heterocyclic aromatic amines

Ingredient	Effect
Soy protein or Soybean protein	Reduce the overall mutagenicity and carcinogenicity of cooked meats
Extracts from different fruits and vegetables, including apricot, orange, Brussels sprouts, carrot, red and yellow bell pepper, and tomato	Significantly inhibits the production of HAAs, especially imidazo quinolines (IQ) in beef
Cherry extracts	Relief from HAAs due to the anthocyanin content in its extracts
Blueberries, blackberries, red grapes, kiwi, watermelon, parsley, and spinach	Reduction of HAAs concentrations in beef burgers

Revista ARACÊ
ISSN: 2358-2472

Vitamin E	Addition of 1-10% Vitamin E on the surface of burgers before frying reduced the formation of HAAs from 45 to 75% after cooking
Extracts of green tea, oolong, orange pekoe, decaffeinated orange pekoe, and chamomile	Decreased production of HAAs
Olive oil	Eliminate imidazo quinoline (IQ)-type HAAs from meat products

Source: Autors (2022). Adaptaded by Ur Rahman (2014).

Numerous studies have explored strategies to reduce the formation of heterocyclic aromatic amines (HAAs) during meat processing. Du et al. (2022) conducted a study to investigate the influence of different types of wood chips (beech, oak, pear, and apple) on the levels of HAAs and quality characteristics of smoked bacon. The results demonstrated that beech and oak-smoked bacon exhibited significantly lower levels of total HAAs and non-polar HAAs compared to pear and apple-smoked bacon ($P < 0.05$). The authors concluded that the choice of wood chips had a significant impact on the levels of HAAs and the quality of smoked bacon (DU et al., 2022).

In a study by Kilic et al. (2021), the formation of HAAs in chicken meatballs formulated with varying levels of saffron powder (0.5% and 1%) was investigated at different cooking temperatures (150 °C, 200 °C, and 250 °C). The mean levels of total HAAs were lower in the chicken meatballs formulated with 0.5% and 1% saffron compared to the control group (without saffron). The authors concluded that saffron exhibited a dose-dependent inhibitory effect on the formation of HAAs in chicken meatballs, with the most potent inhibitory effect (72%) observed in meatballs incorporated with 0.5% saffron and cooked at 200 °C (KILIC et al., 2021).

To analyze HAAs, modern extraction methods such as solid-phase extraction and solid-liquid extraction are employed, and techniques like gas chromatography (GC), mass spectrometry (MS), and ultra-performance liquid chromatography (UPLC) are utilized (UR RAHMAN et al., 2014), as outlined in Table 9.

Table 9. Technique for the extraction of heterocyclic aromatic amines.

Technique	Product	Effect	Reference
High performance liquid chromatography	Burger	Determine the level of polar heterocyclic aromatic amines (PHAAs) in hamburger and monitor the parameters important in the formation of PHAAs.	Tajdar-Oranj et al. (2021)
Mass Spectrometry	Minced pork and chicken meat products, such as sausages and hamburgers	Discover unusual patterns in meat that may point to adulteration with (mainly) protein-based bulking agents.	Kosek et al. (2019)

Revista ARACÊ
ISSN: 2358-2472

Gas Chromatography	Pork	Analyze and quantify the volatile organic compounds that confer flavor to the product	Wang et al. (2022)

Source: Autors (2022).

2.2 NUTRITIONALLY ENRICHED MEAT PRODUCTS

Over the centuries, our perception of food has transformed. Initially, food was primarily regarded as a means of acquiring essential nutrients and energy for the body. However, with the advancement of nutrition science, it started to be recognized as a vital component for supporting the proper growth and development of the body (POGORZELSKA-NOWICKA, 2018). It became evident that food carries essential nutrients capable of enhancing an individual's physical and mental health and overall well-being (KAUSAR, 2019).

Animal meat, known for its high biological value, serves as an excellent protein source that fulfills the body's requirements. It also contains beneficial components such as fatty acids, omega-3s, vitamin B12, and significant levels of iron. To enhance the nutritional quality, texture, flavor, color, and shelf life of meat products, the industry has started incorporating functional ingredients to cater to the demands of consumers seeking foods with added functional value and health benefits (KAUSAR, 2019).

Table 10 presents meat products fortified with technologically developed ingredients that possess physiological effects beneficial to health and the body. These products are marketed and consumed due to their value-added properties aimed at improving overall well-being.

Table 10. Nutritionally enriched meat products

	Ingredient	**Product**	**Effect**	**Reference**
Dietary fiber	Pomegranate peel extract	Beef burger	Delay lipid and protein oxidation in meat products, preventing the formation of rancid odor, improving the shelf life of the product Higher scores in terms of color, flavor, odor, texture and overall acceptance. Inhibited oxidation of lipids and myoglobins and retarded color variation.	Turgut et al. (2016) Shahamirian et al. (2019) Bouarab-Chibane et al. (2017)
Natural antioxidants	*Cantharellus cibarius* mushrooms	Sausages	Prevent lipid oxidation and the growth of microorganisms in the final product.	Novakovic et al. (2019)
Probiotics Prebiotics	*Lactobacillus Bifidobacterium*	Salami, Ham	Faster reduction of the pH during processing and preservation of the technological and sensory quality characteristics of the product.	Macedo et al. (2008) Pereira et al. (2018)

Revista ARACÊ
ISSN: 2358-2472

			Decreased water loss and ham weight. No color change and inhibited the detectable growth of Staphylococcus spp., Pseudomonas spp., Enterobacteriaceae and yeast/yeasts for at least 45 days of storage at 4°C.	

Source: Autors (2023).

2.3 TECHNOLOGICAL PROCEDURES APPLIED TO MEAT PRODUCTS

In recent years, the pursuit of more sustainable approaches in the development of meat and meat products has become increasingly prominent. The demand for sustainable production methods and the focus on human health and well-being have fueled innovation within the food industry (RAMACHANDRAIAH et al., 2015).

Various strategies have been employed to enhance the quality of meat products, primarily centered around improving their composition through the incorporation of bioactive components, reducing the usage of exogenous additives, and minimizing the formation of harmful compounds. Additionally, alternative technologies have been employed to achieve these objectives (URSACHI et al., 2020). Table 11 presents an overview of the alternative technologies utilized to enhance the quality of meat products.

Table 11. Technique for the extraction of heterocyclic aromatic amines.

Reference	**Product**	**Technique**	**Reference**
Claudia Ruiz-Capillas e Ana M. Herrero (2021)	Sausages, Burgers	Vibrational Spectroscopy (Infrared (IR) and Raman Spectroscopy)	Claudia Ruiz-Capillas e Ana M. Herrero (2021)
CHOI, Yun-Sang et al. (2015) SONG, D. H. et al. (2020)	Sausage, Chicken breast	Hot-Boning Technology	CHOI, Yun-Sang et al. (2015) SONG, D. H. et al. (2020)
Tomas Bolumar *et al.* (2021)	Sausage, Ham,	High Pressure Processing	Tomas Bolumar *et al.* (2021)
Corliss A. O'bryan *et al.* (2008)	Sausage, Ham Sausage	Radiation	Corliss A. O'bryan *et al.* (2008)
Tiago Luis Barretto (2018)	Ham	Ultrasonic	Tiago Luis Barretto (2018)
BHAT, Zuhaib F. et al (2020)	Charque,	Pulsed electric field processing	BHAT, Zuhaib F. et al (2020)
Ghaderi-Ghahfarokhi (2016)	Meat patties	Nanotechnology - nanoparticles CEO-CS NP (235.6 nm)	Ghaderi-Ghahfarokhi (2016)

Source: Autors (2022).

Revista ARACÊ
ISSN: 2358-2472

3 METHODOLOGY

Technological Foresight refers to a set of systematic activities aimed at identifying and anticipating technological changes of strategic importance for economic and social development, as well as for guiding future research and innovation efforts (COELHO, 2003). Foresight studies are based on the premise that multiple potential futures coexist. They pursue two main objectives: (i) preparing stakeholders to seize opportunities or mitigate future risks, and (ii) initiating proactive processes to shape a desirable technological and societal future (KUPFER; TIGRE, 2004).

Another crucial dimension of foresight lies in positioning competitors and identifying the most effective means of leveraging technological potential. Researchers, companies, and countries expressing interest in a given technology are also considered valuable sources of information, providing insights that contribute to a better understanding of global market dynamics and innovation capacity (QUINTELLA et al., 2011).

For several decades, technology foresight has been employed as a strategic tool to guide investments in research, development, and innovation (R&D&I) across different sectors. Its initial applications date back to the 1950s, when it was adopted as a means to reduce the time lag between invention and market availability of new products (PIACENTE, 2015). Grupp and Cuhls (2010) highlight the main foresight approaches in public policy contexts, while Meyerhoff (2008) divides the process into four main phases:

(a) Preparatory phase: defining the objectives, scope, approach, and methodological framework;

(b) Pre-prospective phase: developing the research protocol and mapping relevant data sources;

(c) Prospective phase: collecting, processing, and analyzing the data obtained;

(d) Post-prospective phase: disseminating the results, implementing strategic actions, and monitoring progress.

Among foresight methodologies, bibliometric prospecting stands out as a quantitative and replicable approach for mapping scientific and technological developments. It involves retrieving information from bibliographic sources, primarily peer-reviewed journal articles, indexed in recognized databases such as Scielo, Scopus, ScienceDirect, PubMed, Google Scholar, and the Web of Science (WoS), as well as through the CAPES Journal Portal and major publishers such as Elsevier (PARANHOS; RIBEIRO, 2018).

Bibliometric analysis allows for the observation of the state of science and technology by extracting metadata from documented scientific outputs within a defined repository (SOARES et al.,

Revista ARACÊ
ISSN: 2358-2472

2016). This technique enables large-scale analysis of published articles to identify trends in the growth of knowledge, citation behavior, author productivity, institutional output, journal relevance, and emerging areas of research (SACRAMENTO, 2020).

Bibliometrics has been widely used to assess author productivity, citation networks, journal impact, technological maturity, developmental patterns, and emerging competencies (COSTA et al., 2012). Consequently, it serves as a robust methodological tool for understanding the level of scientific development of a specific technology, while structuring the academic and technological knowledge surrounding it.

In this study, a bibliometric analysis was conducted to investigate global research trends in the reformulation of meat products with a focus on health. The search and data collection were carried out using the Scopus database, accessed via the CAPES Journal Portal at the following authenticated institutional link:
"https://www.scopus.ez429.periodicos.capes.gov.br/search/form.uri?display=basic#basic".

The search was conducted on November 25 and 26, 2022, encompassing the fields Title, Abstract, and Keywords (TITLE-ABS-KEY). The query employed a combination of controlled descriptors and Boolean operators. The search terms included *"health," "nutrition," "reformulation," "technologies," "innovation,"* and *"meat products"*. The Boolean operators "AND" and "OR" were utilized to retrieve relevant terms within the search results.

The inclusion criteria for this review comprised scientific articles published within the last five years (2018-2022) that specifically addressed the subject under investigation. Exclusion criteria were established to exclude duplicate publications, theses, dissertations, monographs, and various works that did not pertain to the application of meat products with a focus on health.

The interpretation of results integrated quantitative indicators (publication counts, annual growth rate, and leading contributors by country, author, and institution) with qualitative insights derived from the co-occurrence and clustering analyses. Cross-referencing with prior bibliometric studies in food science and technology ensured methodological consistency, interpretive reliability, and scientific replicability.

4 RESULTS AND DISCUSSION

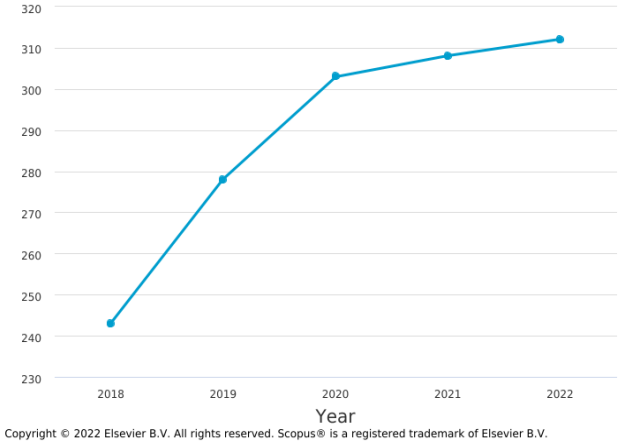
The inclusion criteria for this review comprised scientific articles published within the last five years (2018-2022) that specifically addressed the subject under investigation. Exclusion criteria were established to exclude duplicate publications, theses, dissertations, monographs, and various works that did not pertain to the application of meat products with a focus on health.

Revista ARACÊ
ISSN: 2358-2472

Once the database was defined, the identified documents were compiled and analyzed in terms of their frequency. This analysis aimed to assess the progression of scientific publications over five years, and identify the main journals, authors, keywords, institutions, countries, and areas of study related to the specific theme.

As previously mentioned, 1,444 publications were selected in the field of meat products with a focus on health. As shown in Figure 1, there is a marked upward trend in the number of articles published between 2018 and 2022. It can be observed that from 2018 to 2020, the growth in the number of publications was exponential, increasing from 243 to 303 publications. In 2022, the number of articles reached 312. The average annual growth rate during the period from 2018 to 2022 was 6.45%.

Figure 1. Annual evolution of the number of published articles



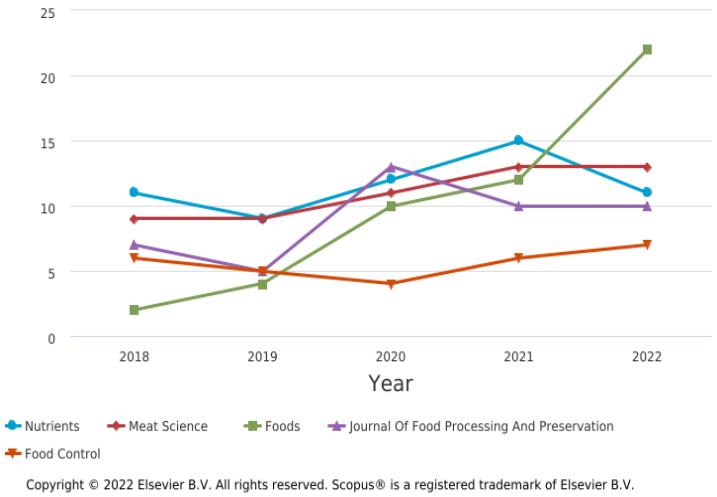
Source: Authors (2023).

Several reasons can be considered for this performance. No matter how detailed and extensive this set of reasons may be, it is worth highlighting the new consumer needs related to nutrition, health concerns, well-being, and natural products. In light of this situation, new research and strategies have been implemented in the development of high-quality meat products that are safe and have beneficial properties for human health.

A total of 158 journals were identified as publishers of articles on meat products with a health focus between 2018 and the end of 2022. Figure 2 illustrates an exponential growth trend in the number of articles published in the journal Food Control during the years 2021 and 2022, increasing from 12 to 22 publications. Conversely, the journals Nutrients, Journal of Food Processing and Preservation, and Food Control experienced a decline in the number of articles during 2018 and 2019.

Revista ARACÊ
ISSN: 2358-2472

Figure 2. Research approach by periodicals



Source: Authors (2023).

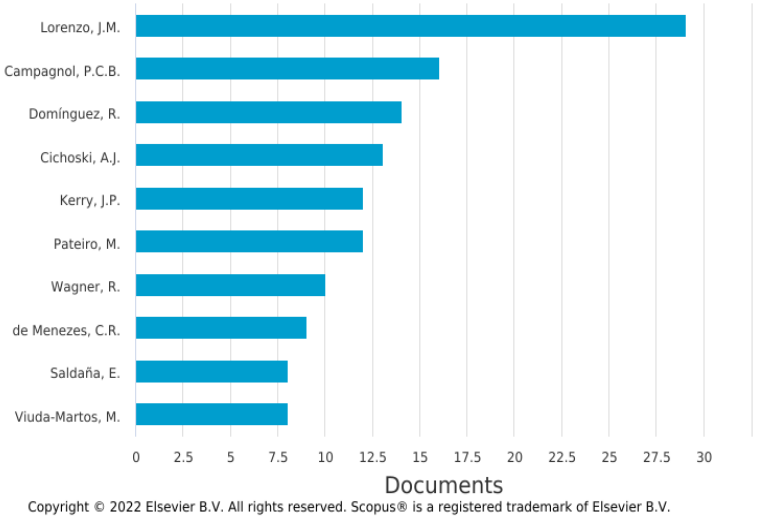
Notably, the Journal of Food Processing and Preservation displayed a change in trajectory from 2020 to 2021, while Nutrients exhibited a similar shift from 2021 to 2022. Throughout the same period, Meat Science and the Journal of Food Processing and Preservation maintained a consistent number of publications at 13 and 10, respectively. Among the analyzed journals, Foods exhibited the highest average annual growth rate during the 2018 to 2022 period, with a rate of 82.12%. On the other hand, Nutrients displayed a growth rate of 0.0% during the same timeframe.

According to Figure 3, José Manuel Lorenzo, affiliated with the University of Vigo in Spain, stands as the researcher with the highest number of published articles on meat products, with a total of 29 works. His expertise lies in the field of Food Science and Technology, particularly in Food Technology. The major topics of his contributions, as indicated by the research analysis, encompass sausage, fat, meat emulsions, pork, rissoles, antioxidants, and meat quality.

Following closely is researcher Paulo Cezar Bastianello Campagnol from the Federal University of Santa Maria in Rio Grande do Sul, Brazil, who has published 16 papers. His specialization lies in the realm of Food Science and Technology, with a focus on Meat Product Technology. His prominent research themes revolve around the preparation of meat products with healthier characteristics. The major contributions based on the research analysis include sausages, fat, meat emulsions, protein, isolated proteins, and pork.

Revista ARACÊ
ISSN: 2358-2472

Figure 3 - The 10 authors with the most publications on meat products with a focus on health.



Source: Authors (2023).

Securing the third position is researcher Rubén Domínguez from the Centro Tecnolóxico de la Carne de Galicia in Spain, with 14 published papers. He also serves as an editor for scientific research journals such as "Foods," "Antioxidants," and "Current Research in Food Science," among others. The main areas of his contributions, according to the research analysis, encompass sausage, fat, meat emulsions, pork, rissoles, antioxidants, and meat quality. His research interests span the development of new healthier and more functional foods, the utilization of agri-food by-products as a source of bioactive compounds, the use of active packaging to preserve food quality, the assessment of carcasses, meats, and by-products, and the application of chromatography and mass spectrometry techniques for food analysis.

Expanding the list of researchers from the Federal University of Santa Maria in Rio Grande do Sul, we find Professor Alexandre José Cichoski in 4th place with 13 published works. His research revolves around the application of clean technologies in food and their impact on food quality and consumer health. The major topics of his contributions, according to the research analysis, include protein, isolated proteins, sausages, fat, meat emulsions, and probiotic agents.

In 5th and 6th place, respectively, we have researchers Joe Patrick Kerry and Mirian Pateiro, both with 12 published papers. Joe Patrick Kerry is a university professor and the head of the food packaging research group at the Department of Food and Nutritional Sciences, University College Cork (UCC) in Cork, Ireland. His notable research topics, as identified in the review, encompass sausages, fat, meat emulsions, sensors, biohydrogenation, fatty acids, and diet. His research interests

Revista ARACÊ
ISSN: 2358-2472

include food packaging, sensor applications in food packaging, and the production of edible and biodegradable packaging, among others.

Mirian Pateiro, a researcher at the Meat Technological Center in Spain, also stands out with contributions in the areas of rissoles, antioxidants, meat quality, pork, sausages, fat, and meat emulsions.

In 7th and 8th place, we have researchers Roger Wagner and Cristiano Ragagnin de Menezes from the Federal University of Santa Maria, with 10 and 9 published works, respectively. Roger Wagner's research focuses on protein, isolated protein, broilers, diet, and carcass characteristics. Cristiano R. de Menezes has conducted research on Bifidobacterium animalis, probiotic agents, protein, and isolated protein. Wagner's expertise lies in food science, specifically in flavor and aroma research, volatile compounds, gas chromatography and mass spectrometry, sample preparation techniques, and the analysis of aroma precursors such as fatty acids and amino acids. He is also involved in the metabolic and metabolomic characterization of fruits and microorganisms.

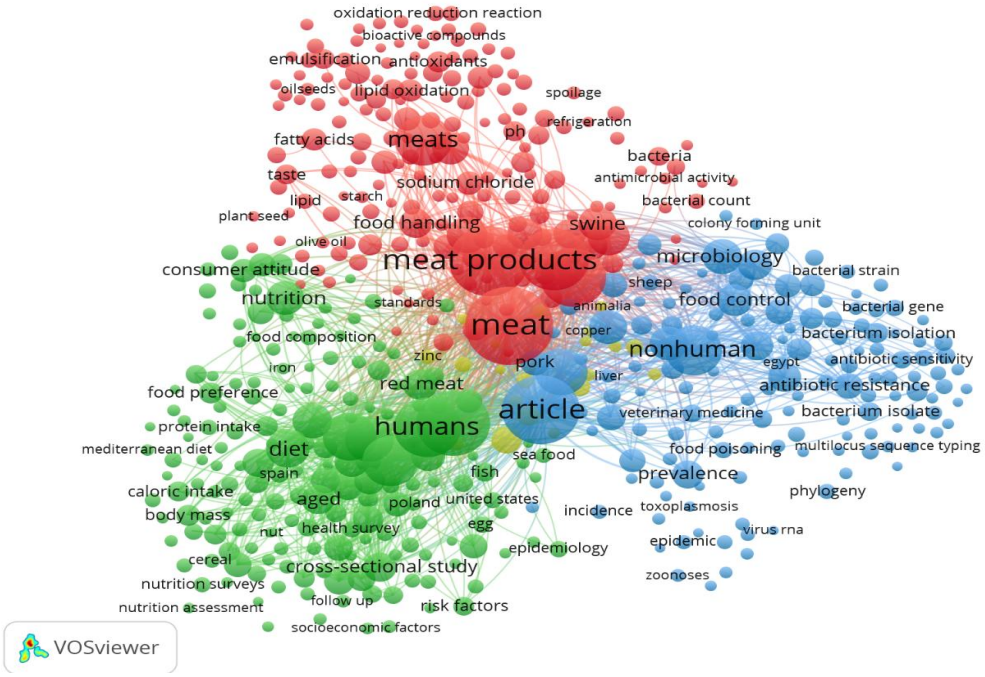
Erick Saldaña and Manuel Viuda-Martos rank 9th and 10th, respectively, with 8 published papers each. Erick Saldaña is a research professor at the National University of Moquegua in Peru. His expertise lies in Food Science and Technology with a focus on the development of new food products using sensory and consumer science. The major topics of his contributions, based on the study cut-off, include sausages, fat, meat emulsions, and pork.

Manuel Viuda-Martos is a distinguished professor and researcher at the Department of Food Technology at Miguel Hernandez University in Spain. He is also a member of the editorial board of esteemed scientific journals such as "Food Research International," "Foods and Industrial Crops," and "Products Journals." The researcher's significant contributions, based on the investigation's cut-off, encompass sausages, fat, meat emulsions, antioxidants, grains, and seeds.

Figure 4 illustrates a graphical representation of the keyword co-occurrence network, generated using the VOSviewer software. The size of the circles corresponds to the frequency of the keywords' occurrence, while the lines depict the connections between the words. The analysis focused on authors' keywords that appeared 10 or more times. In this particular dataset, a total of 10,338 terms were identified, out of which 510 met the specified criterion.

Revista ARACÊ
ISSN: 2358-2472

Figure 4. Co-occurrence of keywords



Source: Authors (2023).

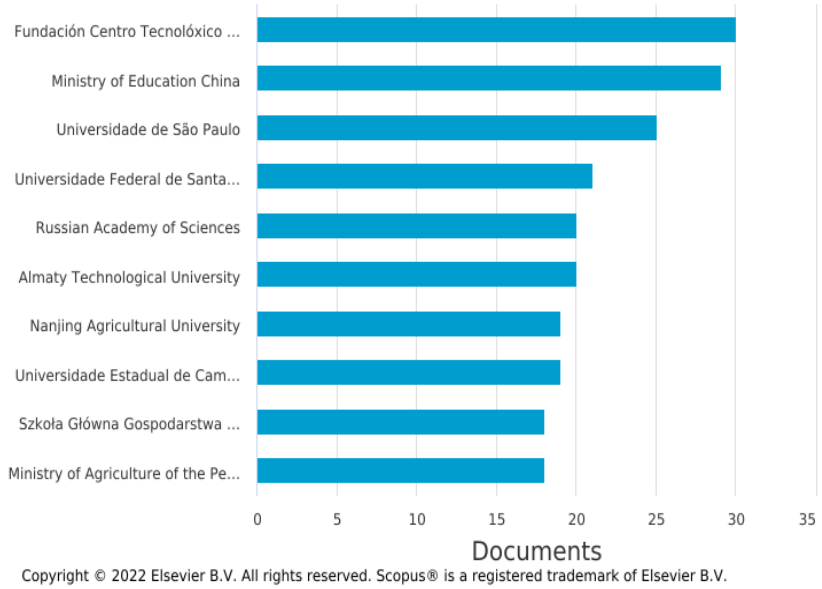
Figure 4 reveals four prominent clusters: cluster 1 (red), cluster 2 (green), cluster 3 (blue), and cluster 4 (yellow). These clusters can be grouped into two thematic subareas, based on their similarity, which revolve around the reformulation of meat products with a health-oriented approach. These subareas are: i) food and ii) health.

Cluster 1 comprises 168 keywords primarily associated with food-related aspects and unhealthy components. Cluster 2 consists of 141 keywords predominantly linked to food and nutrition topics. Cluster 3 encompasses 127 keywords related to food microbiology. Cluster 4 encompasses 74 keywords connected to both food and health concerns. Among all the keywords analyzed through VOSviewer, the term "meat" emerges as the most frequently occurring, with a count of 590. This finding highlights the significance of meat in studies pertaining to novel trends in the reformulation of meat products.

In terms of institutional contributions, publications on the reformulation of meat products with a health focus are widely distributed. The Fundación Centro Tecnolóxico da Carne, located in the Technology Park of Galicia, Spain, occupies the top position in the Top-10 list with the highest number of publications (30 publications), as depicted in Figure 5. It is followed by the Ministry of Education China, the University of São Paulo (USP), and the Federal University of Santa Maria, with 29, 25, and 21 publications, respectively.

Revista ARACÊ
ISSN: 2358-2472

Figure 5. The 10 institutions with most publications on meat products with a focus on health.



Source: Authors (2023).

Notably, seven professors from USP are recognized as some of the most influential researchers globally, according to the evaluation conducted by the British consultancy Clarivate Analytics. This evaluation involved more than 6,938 researchers across 22 knowledge areas. The ranking was based on an analysis of the number of citations received by articles published by each researcher from 2010 to 2020, using the Web of Science platform (YAMAMOTO, 2021).

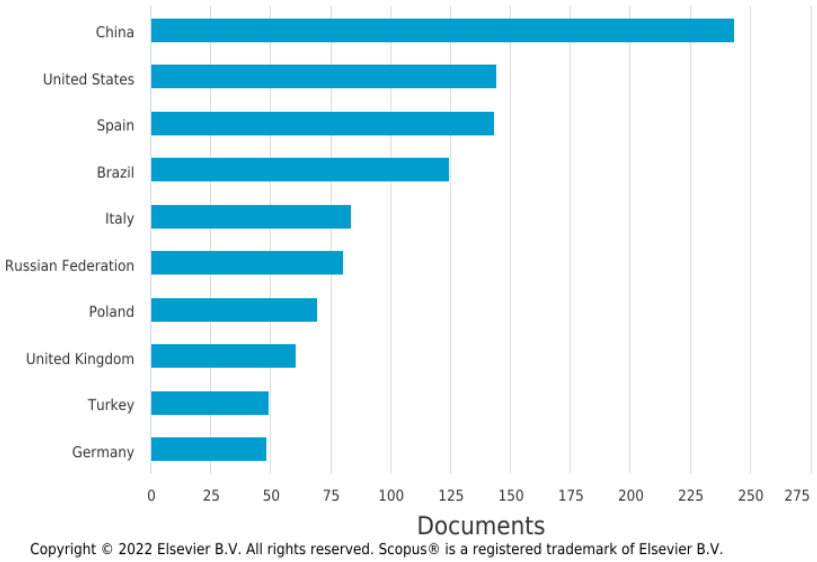
Brazil's presence is significant in the list of the world's most influential researchers, with 21 selected professors. The Federal University of Santa Maria is among the twelve Brazilian universities represented, securing the 4th position in the Top-10 institutions with the highest number of publications (21 publications) on the reformulation of meat products with a focus on health (Chart 4).

Following closely are the Russian Academy of Sciences and the Almaty University of Technology, both responsible for 20 publications. Nanjing Agricultural University and Campinas State University contributed 19 publications each. The Warsaw University of Life Sciences and the Ministry of Agriculture of the People's Republic of China occupy the 9th and 10th positions, both with 18 publications.

Figure 6 illustrates the distribution of scientific productions on trends in meat product reformulation from 2018 to 2022. It indicates that authors from 10 countries have made significant contributions to research in this field.

Revista ARACÊ
ISSN: 2358-2472

Figure 6. Country of origin of scientific productions on meat products



Source: Authors (2023).

One of the leading countries in terms of scientific production about meat products with a focus on health is China, responsible for 243 out of the 1,444 articles in the corpus. The United States follows closely with 144 studies, and Spain with 143 studies. Brazil also demonstrates a significant presence in scientific production on this topic, contributing 125 studies.

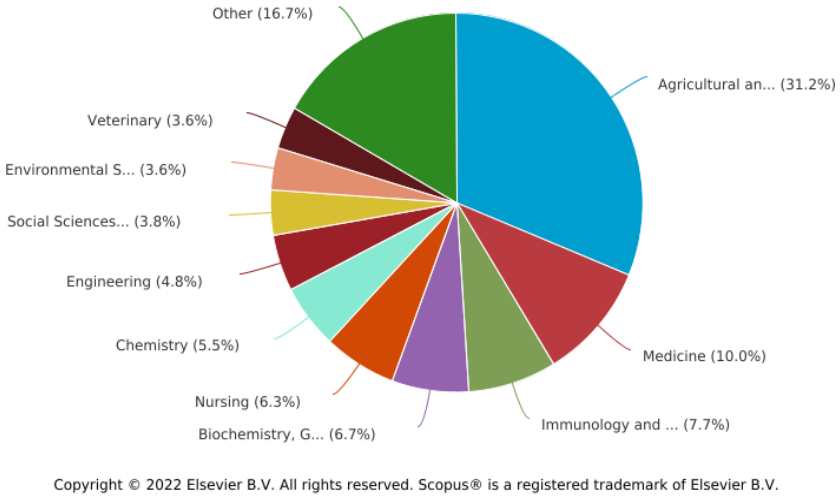
These numbers highlight that despite the reduction in budgets allocated to science and technology in Brazil, the country's scientific production has continued to grow. Hernan Chaimovich, a professor at USP and coauthor of a science report for UNESCO, emphasized this point in an interview with the USP Journal (ESCOBAR, 2021).

Italy, the Russian Federation, Poland, the United Kingdom, Peru, and Germany also stand out in terms of the number of studies they have contributed, with 83, 80, 69, 60, 49, and 48 studies, respectively. Italy currently ranks as the sixth-largest producer of scientific articles worldwide, surpassing Japan and trailing behind Germany. In 2019 alone, Italy generated over 155,000 documents, and between 1996 and 2020, it produced more than 2 million documents. The COVID-19 pandemic has had a significant impact on knowledge production systems. By early April 2020, the innovation agencies of Argentina, Brazil, and Uruguay had already issued calls for research with accelerated approval processes (CHAIMOVICH; PEDROSA, 2021).

In 2019, the European Union accounted for 28.6% of the world's scientific production, followed by China with 24.5% and the United States of America with 20.5%. Together, these three entities represented three-quarters of global scientific publications. Additionally, 13 other countries, including Brazil with 2.8%, contributed 1% or more of scientific publications in the same year (SCHNEEGANS; LEWIS; STRAZA, 2021).

Revista ARACÊ
ISSN: 2358-2472

Figure 7. Main areas of studies on meat products



Source: Authors (2023).

The analysis of sub-areas within the field of meat products with a focus on health reveals the distribution of publications in absolute and relative terms. The sub-area with the highest representation is "Agricultural and Biological Sciences," accounting for 31.2% of the total publications, which corresponds to 886 articles. Following that, the sub-area of "Medicine" contributes 10% of the publications, with a total of 285 articles.

On the other hand, the sub-areas with fewer publications in this field are "Veterinary" and "Environmental Science," each representing 3.6% of the total publications, which corresponds to 102 and 103 articles, respectively. The sub-area of "Social Sciences" contributes 3.8% of the publications, with a total of 107 articles. These findings are visually presented in Figure 7, providing a comprehensive overview of the distribution of publications across sub-areas in the field of meat products with a focus on health.

5 CONCLUSIONS

Based on the data collected through the systematic search of scientific article databases, it can be deduced that research focused on developing healthier meat products has witnessed a significant increase in recent years. This surge in research activity can be attributed to the growing concerns among consumers regarding the potential adverse effects associated with the consumption of high levels of fat, salt, and synthetic additives. In response to these concerns, several researchers have actively collaborated with the meat industry to explore alternative strategies aimed at reducing the presence of these controversial ingredients in meat products.

Driven by the rising demand for novel meat products that offer improved safety, nutritional value, and health benefits, the meat industry is compelled to produce high-quality products that meet

Revista ARACÊ
ISSN: 2358-2472

these evolving consumer needs. The findings of scientific articles indicate that various technologies are being employed in the development of meat products to fulfill the consumer demand for health-conscious and sustainable options.

In conclusion, this study provides an informative overview of the technological and scientific potential within the field of meat products, which is currently being explored by the industry. It significantly highlights the industry's capability to address emerging consumer needs related to nutrition, health concerns, overall well-being, and natural product preferences. The information presented in this study can be valuable for managers, aiding them in making informed decisions and developing appropriate strategies, including potential changes, based on the research insights.

It is worth mentioning that the exploration of patent databases was not included in this study. Hence, it is proposed that future research continues implementing the methodology to examine innovations and technologies, and the obtained results be disseminated both internally and through patent applications related to meat product research. This would contribute to further advancements in the field and facilitate the dissemination of knowledge and technological advancements within the industry.

Revista ARACÊ
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