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Review

Application of Tomato Byproduct in Food Products-A Review

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Abstract: Tomatoes are one of the most consumed vegetables in the world, and the waste from their processing is mainly discarded. Tomato byproducts can be used in different ways, and the seed, the peel, or both can be incorporated into the process. In most studies, the byproduct is dried, and the powder is incorporated into various products. The powder incorporated concentration varies with the food categories, which for most products is around 10% (w/w). The composition of tomato pomace is rich in fibers and causes a considerable change in technological food aspects, such as hardness, viscosity, cohesiveness, volume, expansion, density, and sensory evaluations. Although the incorporation of the tomatoes byproduct can affect specific characteristics due to the high content of fibers and active compounds, its use has aroused interest. This review aims to assemble studies related to tomatoes byproduct within an industrial context and discuss its effects as an ingredient in physicochemical, rheological, textural, and sensorial parameters in tomato-based foods, meats, bakery products, and snacks, among others.

***Keywords*:** tomato pomace, waste, lycopene, carotenoids, proteins, dietary fiber

1. Introduction

Tomato is one of the most cultivated vegetables [1], reaching a world production of 182 million tons in 2018, with Asia responsible for approximately 59% of this production [2]. Tomatoes are seasonal fruit consumed in fresh or processed forms, such as juice, soup, puree, ketchup, and paste [3]. Processed tomato-based products use only pulp, while the peel and seeds are considered byproducts. Knoblich, Anderson and Latshaw [4] reported that tomato peels and seeds are generally not used for human consumption. During the removal process, other parts are inevitably included, with the byproduct being the combination of these products.

The disposal of tomato byproducts is currently considered an environmental, social, and economic problem [5]. Generally, tomato byproduct is intended for animal feed [6, 7] or is disposed of in landfills [8]. Its storage is difficult mainly due to its high perishability, resulting from high humidity levels (88.5%) [9].

An economical and renewable alternative for tomato byproducts could be studied, providing a higher value-added destination. Italy represents about 5.2 million tons of disposal, which costs, just for its removal, an average value of € 4.00 per ton [10]. Tunisia ranks among the ten largest tomato processors in the world. It generates around 25,000 tons of

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waste annually from processing an average of 800,000 tons of fresh tomatoes [11]. The industrial processors in the USA verified that 14 million tons of tomatoes were produced, and about 75% is processed, which generates an approximate waste discharge of 157,500-525,000 tons [12]. In addition to the large volume of byproduct generated annually, the reuse of this product has generated interest mainly due to its composition, which presents a considerable amount of potentially bioactive compounds that can be used as additives or ingredients in functional foods [13].

According to Del Valle, Cámara, and Torija [14], the tomato byproduct corresponds to a maximum of 4% of the fruit's weight, which is mainly made up of fibers, proteins, fats, and ash, with fibers as its main component (25.4-50%). Studies available in the literature seek to evaluate and quantify the total fibers present in pomace [15] as well as their fractions, although insoluble fiber is present in more significant amounts than soluble fibers, the latter are more extensively studied [16-19]. Other studies reported that seeds have a high percentage of lipids [20, 21]. The interest in the antioxidant potential presented in seeds and peels of tomato byproduct has increased [21-23].

In addition, tomato seeds and peels are considered a good source of lycopene [4, 24], phenolic compounds [25-27], proteins [28, 29] and essential amino acids [30].

In general, the essential use of tomato byproduct is the application of carotenoid compounds, mainly lycopene, as an additive in food preparation. The extraction of the lycopene pigment from the peels is carried out primarily and reincorporated into foods such as olive oil [31], noodles [32], tomato seed oil [24], butter [33], ice cream [22] and mayonnaise [34]. Several studies explore the use of bagasse only as a source of carotenoids, focusing on its characterization [35], method of extraction, and the health benefits of the pigment lycopene [35-40]. Using pomace as an ingredient added directly to the product was reported by Lu et al. [5] and Trombino et al. [40], formulating an animal feed or as a source of bioactive compounds.

The present review seeks to summarize the applications of the tomatoes byproduct, the drying beneficial the tomato bagasse incorporation as a functional component, the process, and the concentrations applied in different food products. The main objective was to highlight the challenges in elaborating functional foods to obtain commercially acceptable formulation products, providing sustainability to the tomato production chain. The technological and sensory final characteristics were verified, observing the influence.

The application of tomato byproduct as a food ingredient was related mainly to the partial replacement of wheat flour in the production of cookies [41], bread [42], standard bread, and muffins [43], or incorporation into beef frankfurters and meat-free sausages [44], and in hamburgers as a source of lycopene [45], as well as raw material for ketchup [46], flour for Primosale cheese [47], extruded snacks [48], and jellies [49]. Previtera et al. [50] evaluated tomato puree's chemical and organoleptic characteristics enriched with dried tomato byproduct. They reported that the obtained product is an example of a functional food rich in phytochemicals that promote health, with a significant recovery of a residual fraction that would customarily be disposed of in a landfill, with its associated costs and environmental impact.

Within this context, this bibliographic review aims to present the main applications of tomato byproducts in food products, highlighting primarily how they have been applied and the influence of this addition on the physical-chemical composition and sensory aspects.

2. Application of tomato byproduct in food products

Byproducts from processing fruits and vegetables are a significant problem for the food industry. However, they can be used in food products due to their favorable technological or nutritional properties. There is a growing demand from the food processing industry to reduce the effects of pollution and increase its value with the use of byproducts. Tomato byproduct is a mixture of peels, cores, culls, pulp, crushed seeds, and unprocessed green tomatoes that remain after processing [51]. Generally, the tomato residue is composed mainly of fibers (58.63-68.04 g/100 g dw), proteins (15.08-22.70 g/100 g dw), and total fats (8.37-16.24 g/100 g dw), in addition to antioxidant compounds such as lycopene (9.82-17.21 mg/100 g) [52].

The application of the tomato byproduct in food can occur in different ways, either by using the fresh byproduct, directly in the formulation [43, 53], in dry powder incorporated with other ingredients [46, 54], or replacing part of the flours used in the production process [55, 56]. Most studies use the entirely industrial tomato byproduct, and others separate the husks and seeds manually [41, 43, 45, 57-60], which may interfere in its composition, because the waste did not go through the thermal and mechanical processes applied in the industrial processes.

According to reports in the literature, the main objective of incorporating tomato byproducts into food products is nutritional enrichment, making the product a source of proteins [44], fibers [58] or lycopene [45]. Obtaining carotenoids such as lycopene from tomato peel can be a good solution for reusing it in tomato industries [61]. Some works also seek to increase the shelf life of products through the ability to inhibit the oxidation of lipids [61] or the microbial growth [43] attributed to the presence of antioxidant compounds in the byproduct.

The incorporation of tomato byproducts is carried out to replace artificial additives and improve the functionality of food products such as natural coloring [54] and fat substitutes in meat products [62] or as a source of hydrocolloids in bakery products [63].

The percentage of incorporation varies mainly according to the type of product. The literature reported a maximum of 40% in tomato products such as Ketchup [53], 7% in meat products such as sausages [44], and 40% in bakery products such as muffins [43]. Regardless of the product, the incorporation or replacement percentages improved the functional and/or nutritional properties. The biggest challenge related to tomato byproducts is maintaining sensory characteristics in the foods that may be acceptable to the consumer. Table 1 presents different forms and concentrations of tomato byproduct incorporation in different industrial products.

2.1 *Tomato-based products*

The tomato-based products that use byproducts in their formulation are ketchup and tomato puree, and nutritional enrichment is presented as the main objective. In these products, the assessment of rheological behavior directly reflects consumer acceptability. This important indicator parameter of quality is influenced by the conditions of the process and composition of the raw material [57].

Previtera et al. [50] used lyophilized tomato byproducts at a concentration of 0.5 to 3% (w/w) to obtain a functional puree with higher micronutrients and bioactive compounds. The physicochemical parameters were similar to the market samples, but it was observed a reduction in the consistency of the puree increasing the pomace concentration. In ketchup, the main objective of using the byproduct was to increase fiber content in relation to the conventionally prepared product. Torbica et al. [53] evaluated a ketchup sample enriched with 40% fresh tomato pomace in six distinct stages of the process and compared rheological, sensory, and color parameters to six commercial ketchup samples. The ketchup prepared from residue showed lower viscosity and consistency than the market samples, presenting a tomato sauce characteristic, which can be improved by increasing the dry matter content of the formulation. Belović et al. [46] developed a ketchup product containing 12.5% tomato pomace powder to increase the nutritional value and verified high values of yield stress and apparent viscosity (at a shear rate of 100 s^{-1}) in relation to values reported by Torbica et al. [53] for ketchup produced with fresh tomato pomace and commercial ketchup. This result was associated with the high surface area of the particles in the ketchup produced with tomato pomace powder and the greater binding capacity of polysaccharides.

Increasing the concentration of tomato pulp (tomato pomace power and water) in ketchup formulas increased the apparent viscosity of ketchup due to the water absorption capacity and an increase in solids in the samples [64].

2.2 *Meat products*

The development of meat products with the incorporation of tomato byproducts has increased, mainly due to the biologically active compounds [61]. Studies in the literature reported the addition of tomato byproducts in products such as ham, sausages, and hamburgers (Table 1), which explored the composition of active compounds and fibers.

Most of the studies that use tomato pomace as an ingredient in sausages of different compositions (chicken meat, beef, pork, and vegan sausage), in addition to nutritional enrichment, aim to obtain a red color related to the presence of lycopene, a natural pigment and becomes an interesting alternative to reducing the level of added nitrite, ensuring an extended shelf life [54]. It was reported that the direct incorporation of the tomato byproduct might reduce costs associated with the extraction of active compounds such as lycopene (the compound of most significant interest in tomato byproduct).

Generally, tomato byproducts are added to meat products after a drying process in concentrations ranging from

0.6 to 9% (Table 1). Calvo et al. [61] evaluated the effect of adding dried tomato skin (concentrations of 6, 9, and 12 g/kg of meat mixture) in sausage. They found differences mainly in the color parameters (a* and b*), indicating a greater intensity of the red color in relation to the control due to the presence of lycopene in dry tomato peel. Additionally, increased lycopene with higher concentrations of dry tomato peel in sausages was verified. However, it was impossible to establish a correlation when evaluating the stability of lycopene due to the extraction difficulty in the matrix. The sausage texture presented significant differences, such as in hardness, cohesiveness, and work of shearing. The hardness and work of shearing increased with the incorporation of dry tomato peel, which can be explained by the fiber in the bagasse.

Also incorporated Tomato peel (60 mesh sieve) was incorporated after the drying process directly into beef sausages, and noted that its addition reduced oxidation during storage (3 months, -18 °C), possibly due to the presence of lycopene. In all treatments, varying the concentration of nitrite, the increase in the tomato peel content increased the hardness of the sausages, which can be attributed to the composition of insoluble fibers, composed primarily of cellulose and lignin, which modifies the sausage texture producing a tougher food [54].

Table 2 shows that texture was one of the main attributes affected by the addition of tomato byproduct, especially in relation to hardness and cohesiveness when only using tomato skin rich in cellulose, lignin, and lycopene. The presence of insoluble fibers in the composition of tomato byproducts is responsible for changes in the texture of meat products since they are composed mainly of cellulose and lignin [61].

Savadkoohi et al. [44] evaluated the effect of adding tomato byproduct in beef frankfurter, meat-free, and beef-ham sausages. Increasing tomato byproduct concentration in meat-free sausages promoted an increase in hardness for a concentration range (1-5%) and a reduction in higher concentrations (7%); the same behavior was observed for beef ham. The authors relate that the increase in hardness may be associated with the gelling properties of proteins present in tomato pomace, which may contribute to the chemical water retention in the protein matrix. Additionally, the increase in hardness may be related to the presence of fibers and some hydrocolloids (mainly lignin and cellulose) in tomato pomace. In the case of cohesiveness, the presence of tomato pomace can affect emulsification characteristics.

The effect of incorporation in hamburgers and other products is mainly related to the part of the byproduct which was incorporated. Luisa García et al. [45] found that incorporating dried tomato peel (6%) in hamburgers caused changes in all texture parameters compared to the control sample. The addition of tomato peel did not show significant differences in springiness, cohesiveness, and work of shearing, presenting higher values than the control sample. Hardness and chewiness significantly increased, mainly in the 6% dry tomato peel sample. This effect is attributed to pectin, lignin, and cellulose, which increased the elasticity, influencing hardness and cohesion and resulting in higher chewability.

In general, color changes, economic aspects, and active compounds are the main justifications for adding tomato byproducts to meat products. However, the direct addition of byproducts can provide advantageous changes, especially in relation to the percentage of proteins and fibers.

2.3 *Bakery products*

Among the existing bakery products, studies in the literature reported the incorporation of tomato byproducts in bread, cookies, crackers, and muffins (Table 1). As reported for meat products, or tomato products, the incorporation of tomato byproducts in bakery products has aroused interest mainly due to the high fiber content [15, 16], proteins [21], phenolic compounds [65], carotenoids [66], ascorbic acid [67], flavonoids [67], essential amino acids [30, 35], minerals [35], among others.

There is usually a partial substitution of wheat flour by different types of tomato byproducts such as defatted seed [28], powdered byproduct [41, 63, 68], byproduct containing tomato skin, seed, and pulp [43], and seeds obtained from industrial bagasse [42].

In bread, tomato byproducts are used to replace wheat flour partially. Concentrations may vary from 10 to 35% (w/w), affecting properties such as dough, color, volume, rheology, and texture (Table 2). Sogi et al. [28] evaluated the effect of substituting 0 to 30% (w/w) of wheat flour for tomato seed meal and found an increase in weight and firmness and a reduction in the specific volume of bread, which in turn negatively influenced the sensory characteristics of the crumb.

The partial substitution of wheat flour for tomato seed flour in bread indicated that adding 10% (w/w) of the byproduct had a positive and significant effect on the volume, porosity, and elasticity. However, the addition of higher concentrations of byproduct (> 10%) promoted an increase in bread hardness [42].

The addition of 10% deoiled tomato seed meal in bread significantly affected the volume and weight of bread, with the increase in weight attributed to the greater water absorption capacity of the byproduct [28]. Supplementing wheat flour with tomato powder byproduct (6%, w/w) also promoted a reduction in the specific volume and porosity of the crumb in bread [68].

In the case of pasta, Padalino et al. [69] evaluated the addition of different concentrations of tomato byproduct on durum wheat whole-meal spaghetti, and the most affected characteristics of the product were break resistance, fibrous, and color before and after cooking. Another characteristic attributed to the addition of tomato paste byproduct was the reduction of water absorption and swelling index, attributed to the competition between fiber and starch for water absorption [60]. For muffins and cookies, the main altered properties were hardness [43] and thickness [41], respectively (Table 2).

In general, adding different concentrations of tomato byproduct significantly affects the properties of bakery products. However, the ideal concentration can be found so that the properties are less impacted and provide positive characteristics, mainly related to fiber content and antioxidant properties.

2.4 *Snacks*

Snacks are portions of food usually eaten between main meals (breakfast, lunch, and dinner) and often in smaller quantities than a normal meal [70]. According to Nemś and Pęksa [71], these are popular food products with various flavors, formats, and crunchy textures. Several literature studies reported adding tomato byproducts to snacks (Table 1), aiming for healthier products. This is achieved by providing a higher percentage of fibers and better nutritional properties, with byproduct concentrations ranging from 0 to 30%.

Dehghan-Shoar et al. [55] produced low-density extruded crunchy snacks from corn, wheat, and rice, with or without dried tomato skin or extruded paste powder and found an increase in fiber content (fiber content of 16-18%) in the ingredients after adding 20% of byproduct (tomato skin). This increase was significantly higher than the added ingredients of extruded paste powder (4-6%, w/w). The increase in the percentage of fibers was also reported by Devi et al. [56] in the production of cornmeal rice snacks with added tomato byproducts (shell and seed).

The apparent density, porosity, water absorption, and solubility index (Table 2) in water are other important parameters that must be considered when adding tomato byproducts to produce snacks. Altan, McCarthy, and Maskan [72] produced extruded snacks from barley flour and tomato byproduct and reported density values between 0.370 and 1.111 g/cm^3, while density values increased according to the increase in the concentration of byproduct. Dehghan-Shoar et al. [55] did not observe any significant difference between the density values obtained in the control sample (250.39 g/cm^3) and the sample with added tomato peel powder (240.78 g/cm^3).

Physical properties and expansion characteristics are important in this food category for assessing product acceptability. It is known that the incorporation of tomato byproduct as a raw material directly affects expansion, generating products with less porous structure, more compacted texture, and higher density due to the reduction in the size and quantity of the air bubbles [73]. Altan et al. [72] found that the increase in the level of tomato byproduct, with the increase in temperature, caused a reduction in expansion, with values in the range of 0.893 and 2.014 being observed. The authors attributed this reduction to the dilution of starch after the addition of byproduct.

The pasta containing the highest proportion of tomato peel obtained the lowest expansion values, ranging from 3.806 to 4.779%, as the addition of byproduct reduced the swelling capacity due to the rupture of air bubbles formed during cooking [56]. Dehghan-Shoar et al. [55] reached results of about 25% lower expansion in samples containing 20% tomato skin, compared to the control. This may have occurred due to dough lubrication after adding the byproduct.

The same behavior was observed with an apparent density of 2.19 to 3.55, which is the lowest value attributed to the highest concentration of tomato pomace powder. The expansion rate was inversely proportional to the apparent density, the latter varying between 0.17 and 0.26 g/cm^3; the highest value was relative to the proportion of 20% incorporation of tomato pomace powder. The hardness values also showed the influence of the byproduct addition, increasing gradually with the bagasse addition. Similar to the other studies, this effect was attributed to the increase in fiber content and the dilution of starch with pomace [74].

Several studies have detected a significant impact of adding tomato byproducts on the texture properties of extruded snacks. Although their incorporation directly interferes with the density and expansion of the products, the addition of fibers justifies its use because it adds value to a food category deemed nutritionally poor food.

Table 1. Different forms and concentration of the incorporation of tomato byproduct in different industrial products

Category	Products	Origin of waste	Form	Amount (%)	References
Baked foods	Bread	Industrial	Seed hot air dried (70 °C/5 h)	10, 20 and 30	Sogi et al. [28]
	Bread	Industrial	Hot air dried (60 °C)	6 and 10	Nour et al. [30]
	Bread	Industrial	Hot air dried (40 °C/24 h)	5, 10, 15 and 20	Mironeasa et al. [42]
	Flat bread	Industrial	Hot air dried (60 °C/8h)	1, 3, 5 and 7	Majzoobi et al. [63]
	Cookie	Manually separated	Hot air dried (60 °C)	5, 10, 15, 20 and 25	Ahmad Bhat and Ahsan [41]
	Cookie	Manually separated	Freeze-dried	15 and 25	Tomic et al. [57]
	Cookie	Manually separated	Hot air dried (60 °C)	2, 4 and 8	Ahmad et al. [59]
	Cracker	Industrial	Hot air dried (60 °C)	4, 8 and 12	Isik & Topkaya [75]
	Pasta	Industrial	Sun and hot air dried (40-50 °C)	15	Padalino et al. [69]
	Pasta	Manually separated	Peel sun and hot air dried (40-50 °C)	10 and 15	Padalino et al. [60]
	Bread and muffin	Manually separated	Fresh	35 (bread) 40 (muffin)	Mehta et al. [43]
Candy	Jam	Industrial	Freeze-dried	13.4, 16.4 and 17.6	Belović et al. [76]
Dairy	Cheese	Industrial	Peel hot air dried (30 °C/48 h)	5 and 10	Costa et al. [47]
Meat products	Sausage	Industrial	Peel freeze-dried	0.6, 0.9 and 1.2	Calvo et al. [61]
	Hamburger	Manually separated	Peel freeze-dried	1.5, 3, 4.5 and 6	García, Calvo and Selgas [77]
	Beef Sausage	Industrial	Peel sun dried	3 and 6	Salem [54]
	Sausage and Ham	Industrial	Hot air dried (55 °C/10h)	1, 3, 5 and 7 (sausage) 1, 2 and 3 (ham)	Savadkoohi et al. [44]
	Chicken Sausage	Manually separated	Hot air dried (58 °C)	3, 6 and 9	Yadav et al. [58]
Snacks	Barley Snack	Industrial	Hot air dried (50° C)	2, 6, 10 and 12.73	Altan et al. [72]
	Corn Snack	Industrial	Sun dried	3, 5, 6 and 7	Yağci and Göğüş [74]
	Rice, corn and wheat Snack	Industrial	Freeze-dried	10	Dehghan-Shoar et al. [78]
	Maize e rice flour	Industrial	Peel and seed electric traydried (50 °C/72 h)	0, 5, 10, 15, 20, 25 and 30 (peel) 0, 2.5, 2.63 and 5 (seed)	Devi et al. [79]
Tomato products	Ketchup	Industrial	Hot air dried (50 °C/8 h)	1, 2, 5, 7 and 10	Farahnaky et al. [64]
	Ketchup	Industrial	Fresh	40	Torbica et al. [53]
	Puree	Industrial	Freeze-dried	0, 5, 1, 2 and 3	Previtera et al. [50]
	Ketchup	Industrial	Freeze-dried	12.47	Belović et al. [80]

Table 2. Effects of tomato byproduct addition on the technological parameters of food

Food	Amount (%)	Effects	References
Bread	30%	Increased Weight (4.5%). Reduced Volume (20%) and Specific volume (24%).	Sogi et al. [28]
Ketchup	10%	Increased Flow Behavior index (7.5%), Yield stress (578%) and Apparent Viscosity (442%).	Farahnaky et al. [64]
Dry fermented sausage	1.2%	Increased Hardness (17.3%) and Work of shearing (24.4%). Springiness, Cohesiveness, Chewiness and Adhesiveness did not show significant ($p > 0.05$) difference.	Calvo et al. [61]
Hamburger	6%	Increased Hardness (33%), Springiness (6.3%), Cohesiveness (18.2%), Chewiness (64.7%) and Work of shearing (100%).	Luisa García et al. [77]
Snack	10%	Reduced Expansion (25%), increased Hardness and Density did not show significant ($p > 0.05$) difference.	Dehghan-Shoar et al. [78]
Beef sausages	6%	Increased Hardness (7%).	Salem [54]
Beef Frankfurter	7%	Increased Hardness (14%), reduced Cohesiveness (28%) and Chewiness (17%). Springiness, and Adhesiveness did not show significant ($p > 0.05$) difference.	Savadkoohi et al. [44]
Meat-free sausage	7%	Increased Adhesiveness (100%) and Chewiness (19.5%). Hardness, Cohesiveness and Springiness did not show significant ($p > 0.05$) difference.	
Beef Ham	3%	Reduced Hardness (7%), Cohesiveness (40%) and Chewiness (26%). Adhesiveness and Springiness did not show significant ($p > 0.05$) difference.	
Bread	10%	Reduced Specific volume (7%) and Crumb porosity (13%). Increased Crumb elasticity (2%).	Nour et al. [30]
Chicken sausage	9%	Reduced Springiness (21%), Cohesiveness (20%), Gumminess (38%) and Chewiness (50%). Hardness and Shear press value did not show significant ($p > 0.05$) difference.	Yadav et al. [58]
Bread	35%	Increased Springiness (14%), Cohesiveness (7%), Gumminess (14%), Chewiness (16%) and Hardness. Adhesiveness did not show significant ($p > 0.05$) difference.	Mehta et al. [43]
Muffin	40%	Increased Adhesiveness (47%), Springiness (65%), Cohesiveness (39%) and Chewiness (92%). Reduced Gumminess (8%), and Hardness (33%).	

3. The influence of tomato byproduct addition on the sensory properties of food products

Adding byproducts increases the concentration of fibers, proteins, and bioactive compounds replace artificial additives (hydrocolloids and dyes), and prolongs shelf life without significantly altering sensory attributes that influence acceptance. One of the main concerns in developing products supplemented with tomato byproducts is the influence of this ingredient on sensory properties, with sensorial analysis being the tool to evaluate consumer acceptance. In general, tests are performed by comparing the products added with tomato byproducts and control samples (without the addition of byproduct) or by verifying the addition of different byproduct concentrations.

According to reports in the literature, the studies use affective tests of acceptability, using structured hedonic scales and different scores by trained or non-trained tasters. The most used sensory attributes are appearance, structure, aroma, and taste, while global acceptance results in the evaluation of the product. However, according to each product's specificity, some analyses may assign other parameters, such as baked foods, meat products, tomato products, or snacks (Figure 1).

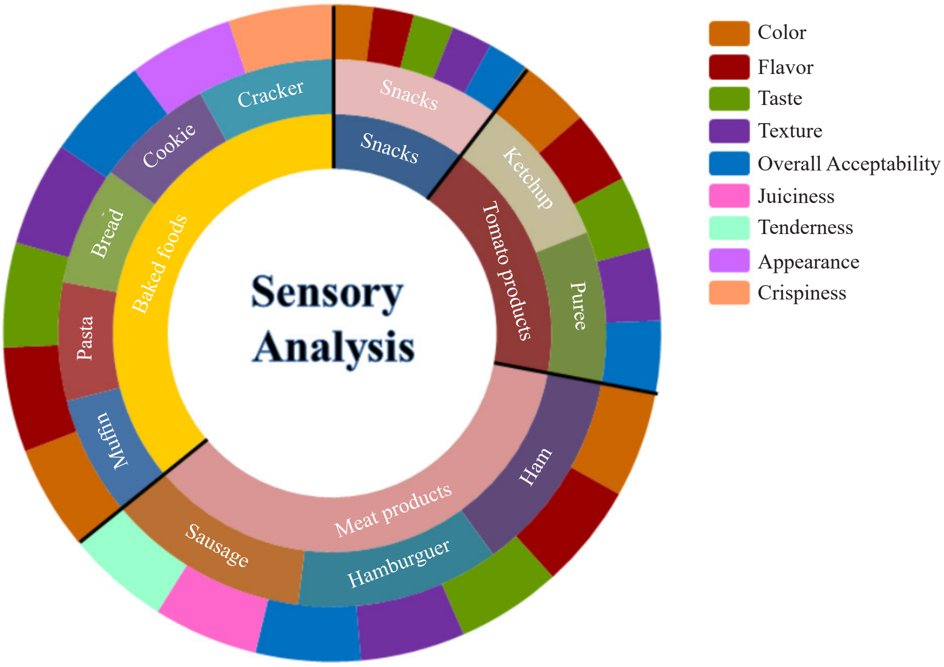

Figure 1. Sensory analysis of food products added by tomato byproducts

In tomato-based products, such as ketchup samples, adding tomato byproducts (45%) greatly influenced the parameters of color, texture, flavor, and aroma compared to the commercial sample [53]. In tomato puree, the addition of different concentrations of byproduct (0.5-3%) provided changes in the sensory quality of the products, increase in the concentration of byproduct, there was a reduction in the scores [50]. Hamburgers enriched with lyophilized tomato peel powder showed a significant decrease in color, flavor, and general acceptability scores, with increases in the percentage of added byproduct. The aroma was the only attribute that did not differ from the control, probably due to the volatile compounds produced during cooking that masked the tomato aroma [45]. The addition of dried tomato byproduct in hams, in concentrations of up to 2%, did not significantly influence the attributes of color, aroma, flavor, texture, and global acceptability, presenting greater acceptance than the control sample without the addition of byproduct [44].

According to Calvo et al. [61], color is one of the parameters of greatest influence after adding tomato byproducts to pork sausage. Incorporating 0.9 and 1.2% of byproducts obtained lower scores than the control. Salem [54] also evaluated the influence of adding tomato peel powder to pork sausages and reported that the scores for softness and juiciness reduced with the increase in the incorporated percentage of byproduct. These attributes were determinant in consumer preference because although the color, flavor, and aroma scores were higher than those obtained in the control sample, the overall acceptability was mainly determined by softness and juiciness. The addition of tomato byproducts in beef sausage with the highest proportion of byproduct (6%) resulted in higher scores compared to the control sample and the samples with the addition of 3% byproduct for the attributes of color, flavor, and aroma [54].

Sausages with different concentrations of tomato byproduct did not present significantly different texture and color parameters compared to commercial sausages. Adding 3 and 5% (w/w) of tomato byproduct can improve sensory properties and consumer acceptance, especially in the case of meat-free sausages [44]. Yadav et al. [58] also reported higher scores in the color attribute of sausages enriched with tomato byproducts than the control. Additionally, the authors observed a smaller difference in the flavor scores of enriched sausages throughout different storage days; this reduction can be related to the presence of bioactive compounds from the byproducts that assist in maintaining flavor.

The addition of tomato byproducts in bakery products can use different sensory attributes, such as dissolving in the mouth, surface roughness, fracturability, tomato flavor, and sweet taste, defined according to the product [57]. Ahmad Bhat and Ahsan [41] produced cookies with the addition of tomato byproduct (5-25%). They reported that the lowest concentration of byproduct obtained higher scores in relation to the attributes of color, texture, appearance, flavor, and global acceptability. In contrast, other concentrations (10 and 15%) showed no significant difference in the evaluated parameters. For bread, the scores were also higher for color and flavor attributes in relation to the control with adding 5 and 7% tomato byproduct [63]. Mehta et al. [43] produced bread and muffins with the addition of 35 and 40% (w/w) tomato byproduct. Compared to the control, these had higher scores for color, flavor, and overall acceptability. In addition, tasters assigned higher values for the bread's texture and the muffins' flavor.

The addition of tomato byproduct contributes significantly to the nutritional properties of food products. If sensory properties are determined from different attributes, it is possible to find the ideal concentration which will win the consumer in different parameters.

4. Conclusion

The byproduct of the tomato processing industry has proven to be a significant source of proteins, fibers, and important antioxidant compounds and an undervalued economic potential. Although the physicochemical, textural, and rheological parameters changed with the addition of byproduct, they offer correction possibilities by improving formulations. The high fiber content in the waste, regardless of the type of application, is one of the main factors that affect the characteristics of the different products.

The great challenge related to using these residues is the definition of a maximum percentage of incorporation aimed at nutritional improvement without affecting sensorial characteristics or reducing acceptability. In this regard, this study provides tools for developing future options for utilizing waste, thus assisting the sustainability of the production chain and guaranteeing the supply of healthier foods.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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