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Perspective

Alternative Products Selling Sustainability? A Brazilian Case Study on Materials and Processes to Produce Plant-Based Hamburger Patties

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Abstract: Plant-based protein-production and consumption have been booming recently, requiring novel, greener sources and processes that can make a real contribution to sustainability. Alternatives offered as patties can be found all over the world, promising less environmental and health risks compared to animal-based protein. In this context, a case study on soy-based patties from Brazil is presented, pointing out sustainable aspects of this value chain, from farm to fork, whilst presenting a theoretical discussion on consumer behavior. The implications of extensive land use for soy monoculture and aspects of the soy patty industrial processes, such as use of hexane, lack of information on labels, excess ingredients, and inconclusive data on food additives (such as methylcellulose), as well as integration of these concepts to design new undergraduate Chemistry curricula, are analyzed. Heavy processing in plants to achieve the taste, texture and appearance of meat increases the environmental footprint of vegetarian diets containing these items, disrupting the idea of sustainability that these products come with. Although meat production has a significant environmental impact, plant-based patties demonstrate that less impactful meat substitutes can also have environmental, social and health risks.

Keywords: green and sustainable chemistry; protein extraction; soybean processing; soybean production in Brazil; plant-based meat analogs; case study

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1. Introduction

In 2015, the United Nations (UN) launched the 17 Sustainable Development Goals (SDGs) aiming to enable a transition to more sustainable and healthier societies all over the world [1]. Under the 17 SDGs, 169 targets were created to describe how to achieve these goals. In target 3.9 of SDG 3 (Good Health and Well-being) it states: "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination". Moreover, target 12.4 of SDG 12 (Responsible Consumption and Production) says: "By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment".

Although just two targets address the chemical sector so precisely in the SDGs, most of the goals and targets could be indirectly impacted by services and products provided by the chemical sphere. Chemistry plays an important role in the transition to sustainable ways of development, as it can be found in topics, such as food production, reducing use of pesticides and antibiotics in farmed animals and replacing them with biopesticides, offering food in adequate quantities and quality [2,3]. Therefore, Green Chemistry and Sustainable Chemistry play roles that could impact most of the 17 SDGs and their targets.

The COVID-19 pandemic called attention to the urgency of a fast transition to greener and more sustainable ways of living, also encompassing how we produce, process, transport and commercialize food. In the European Union (EU), the pandemic highlighted political discussions that were already happening related to sustainable transition, especially in the food chain. The European Green Deal showed the need for a circular economy which takes into account planetary boundaries [4], while the Farm to Fork strategy aimed to be "moving towards a more healthy and sustainable EU foods system" [5].

These documents call the attention to the way food is produced and reflect on how to ensure healthier, affordable and more sustainable food while tackling climate change. Among other issues, they also approach topics, such as biodiversity preservation, fair economics in the chain and the increase of organic farming. These ambitions are not just exclusive for the EU territory, but apply all over the world. The scientific community together with governments, companies and social-environmental organizations are questioning how to feed a growing population sustainably, and this includes how food is produced, packed, distributed and discharged [2,6].

In Brazil, there is still not a political discussion about a Green Deal or a "Farm to Fork" strategy, but social-environmental movements have been working actively with advocacy campaigns to raise this debate and the need for new public policies focusing on a transition to sustainable food systems connected with a low carbon footprint, zero deforestation, fair working conditions and regenerative production. In this country, this debate has extreme importance, as agriculture is the main economic player in Brazil and a range of aspects related to sustainable food production and distribution are still a challenge.

Considering the growing debate initiated by the international community regarding the sustainable food production chain, some novelties have begun to emerge, including the plant-based meat analog (PBMA), which is marketed as an environmental and climate salvation that can create a product that looks and tastes like meat, which has a similar amount of protein for peoples' diets, but without using livestock and its associated impacts [6]. Small walk-in supermarkets in different countries all over the world already show this new trend. PBMA foods are appearing on shelves as new products and brands are launched every year. Known as meat replacements, these products promise a rich amount of protein whilst avoiding impacts of meat-based problems, especially the ones connected with greenhouse gas (GHG) emissions and their climate change impacts [7,8].

In Germany, one in ten consumers stated that they consume meat alternatives. When the young population (16 to 24 years old) was asked, one in five stated that they consume these products. Furthermore, plant-based drinks, such as soy milk and almond milk, already represent 10% of the dairy market and it is estimated that 30% of millennials are eating meat alternatives every day [8]. Even in Brazil, known for its huge livestock production and meat distribution all over the world and where meat protein is one of the main protein sources in the population's diet, 14% of the those interviewed declared themselves to be vegetarian or vegan [9]. This new market trend has led to even the big meat processing companies investing or acquiring meat alternative brands and products. Moreover, some companies have shifted their focus to protein companies, making it clear that their market is no longer concentrated solely on meat protein [7].

Despite the heroic sentiment and discourse behind these PBMA products, primarily because of the much smaller carbon footprint of plant-based foods compared to meat-based foods [7], these alternatives still reproduce many of the challenges in food chains. For example, hamburgers, which are the symbol of industrialized and ultra-processed food and a non-healthy diet, are also connected with the concept of "eatertainment", intending to grab consumer attention through play, fun and joy, where the experience while eating is more important than the quality of the food itself. Some examples of "eatertainment" are fast food chains and their combinations with toys or other distractions combined with the meal offered [10].

It is important to point out that plant-based does not mean plant or a natural product. A series of processes are followed for plant-based proteins used as meat replacements, including using chemicals and synthetic materials. Moreover, to ensure that a product looks and tastes like meat, many ingredients are added, making it difficult to track, evaluate and calculate the impacts of those products through a Life Cycle Assessment (LCA) [11]. Despite the novelties behind these products, they are still based on the conventional food system chain that reproduces conventional practices of food production and consumption, leading to similar challenges faced by current societies [7]. When these plant-based proteins appeared on the market, most of them were made from soy protein. However, the social-environmental controversies created by soybean production, and considering the profile of the consumers of these products, related to environmental concerns, has resulted in other proteins becoming more popular on the market, such as chickpeas, peas, lentils and other beans. As an example, this work will consider only using soy protein to produce PBMA patties, especially targeting the Brazilian market.

Soybean crops occupy 4% of Brazil's territory. The growth in the period of 1990–2017 was 313% in production and 76% in soybean production, which were found in the six Brazilian biomes. Despite soy production in the Amazon having more visibility in terms of social-environmental controversies, such as deforestation, loss of biodiversity and significant participation in GHG emissions related to land use, most crops are concentrated in the Cerrado biome (Brazilian Savannah), especially in the state of Mato Grosso (MT), where 27% of the soybean production in the country is found. The Cerrado biome is known for its massive deforestation and threats of ongoing species extinction [12,13].

Deforestation by soybean crop production, a form of land-use change, alongside agriculture, is one of the main activities that produces the most GHG emission activities in Brazil [14]. Furthermore, pesticides are largely used for soybean production assurance, which results in water, soil and food contamination, and even acute and chronic human poisoning [15]. Therefore, if, on the one hand, soy protein is the most available in Brazil to meet the growing demand for plant-based protein, then, on the other hand, there are controversies and contamination by chemical products and deforestation [16].

In addition to the current social-environmental issues regarding soy proteins, this study also evaluates the chemical processes and compounds used in the manufacture of the various types of soy proteins that are commercialized, focusing on the impacts of the crucial steps for this, namely, the protein extractions. The aim is to observe the controversies but also the potentialities behind plant-based protein from soybeans to promote greener and more sustainable diets. Starting from a soy-based hamburger as a case in point, it is also questioned whether it can be considered a healthy and sustainable alternative for any type of diet [17]. It is important to point out that the nutritious aspects of soy as a healthy and important protein in many diets is not being debated. Soy is known as a healthy and important protein in many diets [18]. Problematization here is concentrated on the impacts of soy cultivation and industrial soy protein processing steps to transform this product into a meat-like hamburger, and the messages behind these products. Finally, this work aims to initiate debate on how the chemical sector can participate and contribute to accelerating the transition to more sustainable diets and food production.

2. Brazilian Scene

Besides health and food safety for everyone, sustainability also encompasses sustainable food production, coherent with current and future demands, mainly considering that 75% of the world's food comprises only twelve species of plants and five animal species, constituting a complex and highly vulnerable system [19].

In this same perspective, food production represents 26% of GHG, whereas 94% of mammal biomass (except human biomass) corresponds to cattle raising [6]. In contrast, agriculture is responsible for 78% of freshwater eutrophication and half of the planet's habitable soils (disregarding deserts and glaciers) [6,20].

Brazil is one of the biggest food producers, due to its territorial extension (approximately an area of 851 million hectares) and the availability of natural resources. About 58% of its territory is covered by forests and 28% is allocated to agriculture and livestock farming [21]. However, it is estimated that between 60 and 100 million hectares of soil are at different levels of degradation due to agricultural activity [22].

Brazil is currently the largest soy producer, followed by the United States and Argentina [21]. Oilseed has great economic importance to the country and its cultivation is distributed throughout its extension, concentrating on the Central-West and Southern regions (Table 1). Despite this, data from foreign trade, regarding imports and exports, show that soy protein, the main hamburger component, is mostly imported from other countries, mainly China and the United States [23,24], which means higher emissions and economic costs related to transportation.

Table 1. Distribution of soybean production in the Brazilian regions (crop 2020/21). Source: [25].

Region	Area Harvested (ha)	Relative to Region Area (%)	Relative to Brazilian Area (%)
North	2,333,100	0.6	0.3
Northeast	3,544,300	2	0.4
Central-West	17,612,200	11	2
Southeast	3,061,300	3	0.4
South	12,375,300	21	1

We were not able to identify if the soy protein used in a specific hamburger was imported or produced in the country, as this work did not investigate data from industries of the sector. However, considering that the importation flow was higher than the exportation one in most states (except in Rio Grande do Sul-RS), it could be inferred that the product mostly comes from other countries. In Sao Paulo (SP), for instance, exports and imports correspond, respectively, to 0.2% and 36% of the Brazilian total [23].

The first soy cultivations date from the mid-1960s, in Rio Grande do Sul (RS; see Figure 1), due to colder temperatures. Cultivating it in other locations in Brazil was a challenge on account of the hotter climate, which was solved with genetic improvement techniques that could adapt cultivation to drier climate and resistant pesticides, mainly glyphosate, ranking Brazil in the third position regarding the consumption of these products, with 377 kt, behind only the United States (408 kt) and China (1774 kt) [26].

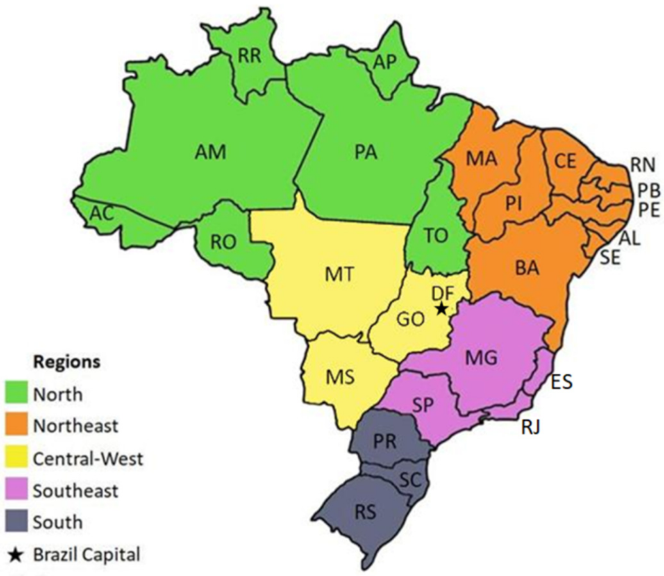

Figure 1. States and regions in Brazil. Brazil is divided into five regions (North, Northeast, Central-West, Southeast, and South) and has 26 states and the Federal District, its capital. The letters stand for the abbreviations of the states.

Data of the Brazilian crop from 2011 showed that 853 million liters of pesticides were pulverized on the farmlands (40% only on soy cultivation), which means 12 L per hectare and an average exposure of 4.5 L per inhabitant [27]. According to the research carried out by the Brazilian Health Regulatory Agency (ANVISA), 51% of the food that makes up the Brazilian everyday diet presents pesticide residues, whereas 23% of this total has active ingredients that are not allowed and/or exceed the acceptable limits, beyond the 0.89% (41 samples) considered as the acute potential risk to the population—according to the Health Regulatory Agency, the consumption of substances that are potentially harmful to health in a short period of time is classified as an acute risk [28].

Mato Grosso (MT) is the largest pesticide consumer and also the only state covered by three biomes: Amazon, Cerrado and Pantanal [27,29]. This rich biodiversity favors food, fibers, and fuel production, while also contributing to deforestation, mining, fires, and other factors associated with the unbalanced expansion of agriculture and livestock farming. Research estimates an increase of 4 billion tons of CO_2-eq in Brazilian emissions due to deforestation, largely related to soy crops [29]. When compared to other protein sources, soy has a lower impact on GHGs [6]. However, the production chain should be considered, regarding industrial and transport processes, especially in countries with high production such as Brazil. Another factor to be considered is that glyphosate alone comprises 15 kg of CO_2-eq per soy kg [30].

The pesticide issue is aggravated by social problems that reflect the inequalities of properties. The last agriculture and livestock farming census, conducted in 2017 by the Brazilian Institute of Geography and Statistics (IBGE), attested that 89% of the producers who use pesticides did not receive technical guidance and 16% were illiterate, which meant more health risks, due to a lack of information and knowledge, and it reflected one of the inequalities that permeate agriculture and livestock in Brazil [31].

The percentage of illiterate people was even higher when considering the number of establishments (not only the people who made use of these products). Nearly 23% of the owners were illiterate and 15% had never attended school [31]. Furthermore, 70% of the properties had an area between 1 and 50 hectares, also revealing the concentration of land and income. Indeed, the previous agriculture and livestock farming census, conducted in 2006, showed that 85% of the value produced in the countryside proceeded from 8% of the commercial establishments and, although the more recent census conducted in 2017 does not approach such analyses, it can be assumed that the situation is not different, principally considering the permanence of low education, machinery resources, and other technologies, as well as the lack of governmental incentives and credit, which stimulate the growth of small producers [31,32].

To conclude the inconsistencies of the Brazilian agricultural system, but not intending to put a stop to the dialogue, as this work addresses only some of the controversies, water use in rural areas should be considered. Besides the large natural freshwater reserves, the country has unequal annual rainfall distribution, resulting in insufficient water in some regions. In addition, 81% of Brazilian water consumption is for agriculture and livestock farming. From this total, 67% is used in irrigation, whereas 40% is wasted by the inadequacy of the systems [22]. Taking into account the predominance of water springs near the crops, the pollution effects of the use of pesticides and fertilizers and the soil erosion directly impact the water bodies.

3. Soybean Protein Products and Their Industrial Processing Steps

For PBMA production, such as patties, some processing is required. In the specific case of soy PBMA, three ingredients can be utilized for its production: the soy textured protein (STP), soy protein concentrate (SPC) and soy protein isolate (SPI) [33]. All of these ingredients are generated from defatted soy meal (DSM), a byproduct of soy oil production. The steps for DSM obtention are shown in Figure 2.

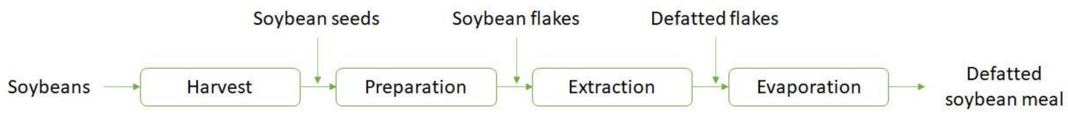

Figure 2. Soybean processing steps for defatted soybean meal production. Adapted from [34].

The mass ratio of the residues is around 2 compared to grain obtained from the soy harvesting step. These residues are commonly left in the harvesting field or employed in animal feed [35]. In the preparation processes, the hulls are removed, which increases the protein percentages in all subsequent products. The extraction step is based on solid–liquid extraction and aims at obtaining soy oil. Organic solvents are used for this extraction process. Hexane is the most used, which represents a safety issue for workers, due to hexane properties (which will be discussed later). The solid phase of the oil extraction is a byproduct that, after undergoing evaporation and grounding, is turned into DSM [34].

DSM soluble carbohydrates are normally removed before thermoplastic extraction for STP generation [36]. Thermoplastic extrusion is considered a high-temperature and short-time process. The meal is inserted into an extruder and goes through it, while transforming chemically and physically due to high temperature, shear force and the pressure generated mechanically. These conditions denature the proteins, making them insoluble, whilst their volatile compounds are separated. As a result of rapid expansion and cooling when leaving the extruder, the STP is foam-like and has a fibrous texture. The thermoplastic extrusion procedure is adopted for soy protein to acquire taste, appearance and texture similar to meat and seafood while preserving high nutritional value. The extrusion step also inactivates antinutritional factors, such as antitrypsin factor, lectins, etc. [37].

For protein levels to increase in final products, DSM can also be subjected to other processing to obtain SPC and SPI [38]. The SPC and SPI can be mixed with DSM and undergo the thermoplastic extrusion process, increasing the protein content of STP. For the sake of comparison, DSM protein content is around 50% (dry mass), SPC ranges from 65–70% of this nutrient, and SPI contains 85–90% of proteins in its composition [33,34].

For SPC production, three procedures are commonly adopted: acid leaching (pH = 4.5), water-alcohol protein extraction (60–80%) and moist heat water leaching. The acid leaching and water-alcohol protein extraction are usual processes in industry. These procedures aim to obtain insoluble proteins and remove soluble carbohydrates [34,39]. For SPI production, the adopted procedure is the isoelectric precipitation of proteins, which consists of the solubilization of proteins in alkali media (pH = 7–10), removal of insoluble residues by centrifugation and protein precipitation in isoelectric pH of soy proteins (pH = 4.5), separating the solid proteins by decantation and neutralizing them afterwards, if necessary [39]. Both SPC and SPI productions present conditions for antinutritional factor removal, such as pH and temperature variation.

In PBMA patty labels from Brazil, it is not clear which of these three proteins are used, making the sustainability assessment of these products imprecise. Recently, ANVISA [40] approved a new format for labels, which must show more clearly if the product is rich in sugar, fat or sodium, for example. The agency also implemented norms for standardization of nutritional labels, making the process of comparing products simpler. Despite these changes, they are not enough to discuss origin, nomenclature and the processing adopted for the ingredients in the lists, which are important aspects to make the products more transparent and to enable making sustainable choices when buying a soy-based food and others.

Impacts of Products and Processes Involved in Soybean Processing

When considering sustainable aspects, a holistic view must be used. Therefore, in addition to the environmental issues behind soy production, soy processing steps and their socio-environmental implications also need to be assessed. Although plant-based hamburgers are widely publicized by the market as an excellent alternative to decrease meat consumption, plant-based foods are often highly processed products (it should be clear that this fact, alone, is not an indicator of health and environmental issues), and, hence, it is important to critically analyze the processes involved in their manufacture.

Many chemical products and processes are required for plant-based ingredients, such as soy burgers, to have similar characteristics to a meat product and/or to have a high protein content. To obtain textured, concentrated and isolated soy proteins, the chemical and food industries play an important role both in the ingredient transformation processes and the supply of resources to be used for this purpose.

Direct extraction with organic solvent is the most common method used industrially to extract oil from soybean seeds and to obtain defatted soybean flakes, after some steps mentioned earlier. The defatted flakes resulting from this process are mainly destined for the animal feed industry, indeed about 98% of waste from soy grain processing is designated for feeding cattle and other livestock [34]. These data are alarming because our challenge is to feed the future population with a healthy and sustainable plant-based food diet, but the current scenario is the expansion of soybean crops which, when associated with unsafe agricultural practices, devastate Brazilian biomes to feed cattle to become food for humans, while we are increasingly looking for a plant-based diet. If soy remains the resource of our protein intake, are we really moving towards the most sustainable option?

Analyzing the chemistry behind soy protein extraction to produce PBMA, the primary step is conventional solid–liquid extraction with organic solvent. As mentioned before, the most used extracting solvent is hexane (C_6H_{14}) [34]. Despite being a simple recovery solvent, its use is surrounded by emblematic environmental and health issues, and, therefore, it is considered a dangerous and not green option [41,42]. Hexane is produced from natural gas, crude oil and petroleum distillate, which are non-renewable sources of energy with considerable global warming potential due to the release of GHGs [34,43].

Due to its low water solubility and volatility, hexane has a tendency to migrate to the atmosphere after its release into the environment. Its volatility is a matter of concern, as human exposure to hexane occurs primarily through inhalation. Human data indicate that central nervous system depression is the most relevant adverse effect of acute exposure (short-term to high levels) to hexane, indicating low toxicity, but data are still limited [44]. Chronic exposure (long-term) to this solvent can lead to cases of delayed distal polyneuropathy, including numbness, muscle weakness, blurred vision, headache and fatigue [43]. For these reasons, the Environmental Protection Agency (EPA) regulated hexane as a hazardous air pollutant under the Clean Air Act. Some introductory measures have been taken, such as controls on outdoor air emissions, limits on workplace exposures, and some disclosure requirements for environmental releases [45].

In the food industry scenario, the volatility of hexane is a positive factor as it does not pose risks of remaining in the food chain, as it is easily evaporated from processed foods [45]. However, it is important to note that residual amounts of hexane can still be found in food. In the Brazilian context, ANVISA establishes maximum limits of 30 mg/kg of hexane residues in defatted soy products and food supplements, while for other foods, based on defatted proteins or defatted flakes, this limit is 10 mg/kg [46]. The residual limit of substances in foods varies from country to country and there are regulatory institutions that do not impose a ceiling on hexane residue in soy foods, such as the Food and Drug Administration (FDA) [47].

Despite concerns about this topic, hexane remains the most widely used solvent on an industrial scale [34,48], which reinforces the fact that the existing regulations are not protective enough for workplace exposures and that there is great resistance to replacing it with alternative solvents for preparing soy proteins. However, new technologies are already being developed and used for this purpose; for example, enzyme-assisted aqueous extraction, in which the organic solvent is replaced by water [48]. Accordingly, safer alternatives must be implemented to make soy protein processing green, sustainable and better for health and the environment, especially considering that soybean dominates the market of plant-based proteins and is the main product of Brazilian agriculture [49].

In addition to hexane extraction, other methods are used to obtain the different types of soy proteins. The sustainability of these processes is dependent on the alcohols, acids and base choices used, and on the energy fuel for extraction techniques [17,34]. Extraction steps are responsible for cell disruption, which results in the release of the intracellular content to the extractor medium. Without a successful cell membrane rupture, it would not be possible to proceed to the subsequent steps of obtaining STP, SPC and SPI [50]. Analyzing these aspects concerning the extractions is an important point, as they are essential steps for obtaining soy protein obtention.

STP is produced by an aggressive extrusion process at elevated temperatures (>100 °C). Although it presents a great energy use in the form of heating, the mixing solvent that conveys the protein through the extruder barrel is water, being a fast and mostly mechanical process with no apparent environmental and health issues [51]. The question that remains is about the purpose of this procedure carried out for decades by the processing industries. Soybeans are submitted to several physical and chemical variations resulting, respectively, from the texturing processes and the inclusion of many additives, increasing the amount of ingredients compared to those found in meat burgers, just to give the soy protein structure and textures similar to meat, which is just a market strategy to make it more attractive to consumers [51], despite the high values associated with soy-based products [17]. What price are we literally paying for soy-based foods that imitate meat?

SPC is mainly obtained by extraction using ethanol as the solvent in concentrations of 60–80% [34]. Ethanol (C_2H_6O) is a biodegradable solvent that originates from renewable energy sources, and most of it is prepared by fermentation. Regarding human toxicity, there is little data on health hazards from inhalation, but studies have not reported symptoms in workers exposed to less than 1 kg m^3 (high amount) of ethanol in the air [52]. As it is an alternative solvent to conventional organic solvents from non-renewable sources, with health and environmental safety, and is widely available in Brazil, it is recommended for use and considered a green solvent [41,42]. Due to its wide use in the food processing industries, residual amounts of ethanol can be found in foods, such as soy proteins. However, ANVISA regulations establish the maximum limits for ethanol residues as *quantum satis* [46], meaning that there is no defined amount, or it may vary according to the product, indicating few or no risks.

Traditionally, the production of SPC follows two steps. First, the oil is separated from the soy and heated to remove the solvent (hexane) and, then, the soluble carbohydrates are removed by extraction with ethanol, which is also removed by heating. There are already patented initiatives from Brazilian industries that have optimized these processes by removing the oil and carbohydrates at the same time, heating only once [53]. Initiatives at an industrial level that design a one-step system are important to move towards more sustainable processes with lower consumption of time, energy and resources.

SPI, the main form which is commercialized for human consumption, is initially prepared by aqueous alkali extraction to solubilize the proteins in the medium, with pH ranging from 7–11 [34,54]. Sodium hydroxide (NaOH) is one of the substances that can be used for pH shift, and is a good choice as it is considered green, according to the GSK's guide [55], although sodium hydroxide is not recoverable by simple processes. Second, the proteins are precipitated at the equivalent isoelectric pH, between 4–5 [34,54]. In general, this technique also has no apparent environmental and health issues, but the significant variations in the pH during the process to obtain isolated protein decreases its sustainability. When the conditions used in the process are mild, less energy is required for it. In order to obtain the protein in isolated form, the soy needs to undergo an ultra-processing method, which adds more steps to the process. The nutritional quality with high protein content of SPI inevitably demands more resources [18], also impacting the amount required for purchasing these products.

These analyses are essential when planning a sustainable technique. Not only do extraction yields need to be improved in the industries, but consideration has to be paid to the quantity and quality of the resources used, and whether there are dangerous substances, large quantities of compounds and high energy consumption [17].

Another point of attention that should be considered to access more sustainable options is the amount of ingredients in the soy PBMA. The presence of a high number of compounds in a food product may indicate a larger environmental footprint, as each ingredient needs resource employment. Furthermore, the processing steps of a product must be known for a proper assessment of sustainability or even healthy characteristics. An investigation of origin and environmental impact of each item in the ingredients list can be conducted to determine the extent of the sustainability of products [56]. The ingredient list of some Brazilian brands of soy PBMA contains more items than a meat-based patty. For instance, methylcellulose was chosen for an in-depth analysis.

Methylcellulose is a term for a variety of cellulose esters, which is a byproduct of paper industries, obtained from a reaction of cellulose in an alkali media with methyl halides (MeCl, MeBr and MeI) [57]. Methyl halides are precursor molecules that can be converted into other chemicals and fuels. Plants and microorganisms naturally produce methyl halides, but in very low yields. For industrial use, methyl halides are manufactured by reactions with methane or methanol, which could be catalyzed or not. In the case of methyl chloride, there is a chlorination of methane or an excess of hydrogen chloride vapor is bubbled through methanol. Regarding the toxicity of methyl halides, they primarily impact portions of the central nervous system, with behavioral symptoms and neurological effects resulting from both acute exposures at high concentrations and chronic exposures to moderately high concentrations. Overexposures can be dangerous, including symptoms such as headache, confusion, ataxia, muscle weakness, tremor and even delayed death [58]. Based on cardiac lesions reported in developmental toxicity studies in mice, methyl chloride was classified as a developmental toxicant. However, a recent study showed that the cardiac effects reported in mice are unlikely to be relevant to humans [59]. However, given all the symptoms it can cause, it is a chemical species that needs attention.

Methylcellusose use as a food additive in food industries is allowed around the world without having great limitations. In the Brazilian context, ANVISA approved the use of methylcellulose as an additive classified as *quantum satis* [60]. It is used as a thickener, emulsifier, binding agent, where its most common use is for PBMA, and also as a laxative, due to its water retention capacity [61]. This substance cannot be digested by humans and it is considered not to be toxic, like cellulose. FDA and European Food Safety Authority (EFSA) consider methylcellulose safe for humans and establish that a daily maximum ingestion is unnecessary. However, EFSA regulations state that the data for characterization and identification of methylcellulose as a food additive is scarce and an assessment of toxic impurities occurrence is not possible [62]. For use in PBMA, a study compared the sensorial perception of soy PBMA and meat-based patties with different concentrations of methylcellulose. The authors found that comparable sensorial results with meat-based burgers were obtained with 3% of methylcellulose in soy PBMA patties [63]. Therefore, the healthy and sustainable aspects of this ingredient as a food additive remain inconclusive, due to no assessed maximum dietary levels and its laxative capacity, making the safety of methylcellulose in foods, probably containing concentrations of 3% or more of the compound, for vegetarians and vegans, who may use PBMA as a protein source, unknown.

4. Case Study: Unpacking Burgers in Chemistry Curricula

Based on the findings related to the use of soy protein as a plant-based alternative for patties, a study case was designed by the Green Chemistry, Sustainability and Education Research Group at the Federal University of São Carlos (UFSCar, Brazil) with the potential to address topics among Chemistry students and professionals, such as sustainable agriculture, food production, protein extraction, transition from Green Chemistry (GC) to Sustainable Chemistry (SC) and the role of Chemistry in the "Farm to Fork" strategy, aiming for more sustainable and healthier ways of producing, processing and consuming food.

Case studies have been used and recognized in the GC and SC classes as an effective way to address topics, such as Sustainability, Circular Economy, Bioeconomy, Renewable Resources and Climate Crisis. This methodology promotes experience-based learning and is a way to invite students and researchers to investigate and produce their own findings regarding the proposed case, as well as stimulating creativity, promoting questioning and inspiring the search for critical answers [64–67]. The case study entitled "Unpacking Burgers" was designed to be used as an educational material for Chemistry courses at universities, where concepts such as GC, SC, renewables, chemical processes (extraction) and chemical additives could be worked, exemplified and debated to provoke broad discussions and new findings among the students.

To do this, a Brazilian soy PBMA was investigated and compared to a meat-based patty. Both of them were from the same brand, and this was already the first finding: why and how companies that traditionally produced meat-based foods are investing in plant-based products. The labels of these products (plant-based vs. meat-based) were evaluated and an LCA was applied to those products, leading to the second finding: plant-based hamburgers have a huge list of ingredients, making the application of an LCA harder. Moreover, the lack of information and transparency from the industry made it difficult to find the origin of the ingredients to apply the LCA.

The meat-based patty consisted of two ingredients: beef and beef fat, while the plant-based one had sixteen different components: water, soy protein, cottonseed oil, vegetable fat, gluten, salt, methylcellulose, nature-identical flavor, antioxidant ascorbic acid, sugar, iron, garlic, vitamin B12, onion, malt and beetroot red. The origin of beef was easier to track when it was clear where the meat came from that was used by the company producing these patties. Differently, for the soy hamburger the origins of the ingredients were not clear, nor the type of protein used in the manufacture, and, consequently, the protein extraction method used for it.

The use of methylcellulose was also discussed in the study case, inviting students to search for other brands of plant-based hamburgers and if the competitors were also using this additive. Among the findings, most of the products without methylcellulose used eggs as an option, making the product not suitable for vegan diets.

The prices of the products were also evaluated. The 360 g of meat-based hamburger cost 22.19 Brazilian Reais (4.21 US dollars), while 310 g of soy-based hamburger was sold for 21.99 Brazilian Reais (4.17 US dollars). Although the prices look similar, it is important to point out that both products were from a gourmet line, while there were other options of cheaper meat-based patties, while the plant-based had a similar range of prices. These prices might also lead to a discussion on accessibility to the plant-based novelties, concentrating it among a group of consumers with higher incomes and putting aside low-income groups and people having difficulties with access to food. This point also links to the discussion on promoting sustainability in the food processing chain to make food accessible to everyone. Another topic evaluated is the nutritional aspects of these foods. In the products that were compared, the number of proteins and fat was very similar. The meat-based patty had 15 g of protein and 4 g of fat, while the soy PBMA had 14 g of protein and 3 g of fat. What stands out is the amount of sodium. While the meat-based product had 255 mg of sodium, the soy PBMA had 490 mg.

Some additional questions were raised concerning this topic, such as: (1) How can Chemistry contribute to a "Farm to Fork" strategy based on sustainable ways of food producing and eating? (2) Are plant-based patties a real environmental solution for meat replacement? (3) Could plant-based burgers be a healthy option in terms of eating? (4) Is it possible for a product based on the concept of "eatertainment" to be sustainable? (5) How can we observe if green materials and processes are used? and (6) Is it possible from this wider perspective to observe the transition from GC to SC?

The proposal is not to receive specific answers, but to promote debate on this topic, which has plenty of room to keep being researched and improved [68], but most importantly, to bring up new ideas and solutions to reflect on more sustainable and healthier food processing and consuming systems, where the Chemistry industry has an important role to play.

5. Conclusions and Perspectives

There are plenty of versions of the history of hamburgers. Regardless of whether there is an original or most reliable one, hamburgers are a great example of the industrialization, standardization and fast-food culture of highly processed food. Meat patties between two slices of bread are connected to stories related to decreasing the time of lunch breaks at work, allowing workers to take shorter breaks, eat faster, and get back to their jobs. Later, hamburgers were seen as the superstars of the "eatertainment" industry. Thematic restaurants offer a colorful, shiny, visually stimulating atmosphere where the food is just one more detail of the experience. Some restaurants have made combinations of hamburgers with toys and other products, letting consumers choose a meal based on the gift combined with it and not solely because of the food itself.

However, it is not just these social-historical aspects that are connected with hamburgers. The nutritional aspects of a food that is most often high in calories, fat and sodium place hamburgers on the list of foods that should be consumed as an exception and not on a daily basis. More recently, environmental issues were also connected with any type of meat-based food. Deforestation to open space for livestock attracts the attention of society, and also the need for chemicals, such as fertilizers, pesticides, antimicrobials and pharmaceutical products to feed livestock related meat-based diets, to the climate crisis. Then, the choice of vegetarian and/or vegan diets appeared as an important player to tackle the impacts of meat-based products. Having a much lower carbon footprint and avoiding the slaughtering of animals (and, therefore, animal suffering), vegetarian and vegan diets were identified as promising for sustainable food transitions. To follow this trend, the big players of the food industry came up with novelties of goods simulating meat products. Taste, texture, smell and colors. People can now eat a PBMA experiencing the same taste as meat. To do this, a combination of ingredients and chemical additives is needed.

This work is not a criticism of vegetarian and vegan diets and their culture. On the contrary, it recognizes how vegetarian and vegan diets can contribute to the environment and people's health. However, it leads to a discussion about sustainability regarding these vegetarian and vegan products that are being sold as environmental superheroes and a solution for sustainability, while they keep reproducing the same food systems and chains, emphasizing ultra-processed products. Moreover, the massive production of soy is still related to environmental and health problems. Increasing the demand for soy to feed the growing market of PBMA could lead to more environmental challenges than solutions.

Finally, this paper recognizes the role of the chemistry industry in the transition to more sustainable and healthier food systems. This is the reason why a case study was designed and developed to support professionals and future professionals in Chemistry to think in a bio-circular and systematic way, considering the different stages of food production, the presence of chemistry in all these stages, and how Sustainable Chemistry is related to indicators that go beyond material aspects. Social-environmental and health issues are also important topics to be considered when SC is discussed and practiced. It is expected with this work that future research and products can be considered, taking into account principles of GC, and mainly SC, to provide a wider perspective on food production and consumption globally. If new models for food production and consumption are necessary for a transition to sustainability and zero carbon societies, novel ways of thinking are also needed. Patty by patty, a transition is possible where sustainability will be the basis for offering greener and healthier plant products, and not products that are sold without any scientific basis, which is a distorted appearance of sustainability at any cost.

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Abbreviations

ANVISA	Brazilian Health Regulatory Agency
DSM	defatted soy meal
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
EU	European Union
FDA	Food and Drug Administration
GC	Green Chemistry
GHG	Greenhouse gas
IBGE	Brazilian Institute of Geography and Statistics
LCA	Life Cycle Assessment
MT	Mato Grosso
PBMA	plant-based meat analogs
RS	Rio Grande do Sul
SC	Sustainable Chemistry
SDGs	Sustainable Development Goals
SP	São Paulo
SPC	soy protein concentrate
SPI	soy protein isolate
STP	soy textured protein
UN	United Nations

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