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UPCYCLING OF SOYBEAN RESIDUES FOR OBTAINING PROTEIN HYDROLYSATES: A REVIEW

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ABSTRACT

The agro-industrial activity yields a significant quantity of waste with potential for reutilization, yet is typically disposed of within the confines of the Linear Economy model. The emergence of the Circular Economy presents itself as an alternative avenue to break away from this linear production model, rooted in the sequential processes of resource extraction, manufacturing, utilization, and disposal. The repurposing of agro-industrial waste serves to bolster sustainability efforts, particularly in a global landscape marked by an escalating demand for natural resources. Brazil, as a leading agricultural nation, presents many opportunities for ventures specializing in waste upcycling. Within this framework, research and innovation play pivotal roles, facilitating the development of technologies such as protein hydrolysis, which transforms waste materials into higher-value commercial products. This approach not only mitigates waste generation and environmental footprints but also contributes significantly to the tenets of Circular Economy and market product diversification. The objective of this study was to collate information concerning enzymatic conditions conducive to the upcycling of soy waste for application in protein hydrolysis. Soy derivatives emerge as a promising raw material source for hydrolysis across diverse applications within the food industry, owing to attributes such as protein concentration, mitigation of the characteristic unpleasant taste associated with certain soy varieties, enhanced solubility, and emulsification capacity, among others.

Keywords: Circular Economy. Reuse. Vegetable protein.

1 INTRODUCTION

Agro-industrial activity generates a high amount of waste and despite industries' efforts to minimize losses, an ideal, fully optimized process that does not generate waste or is capable of fully reintegrating it into the process is difficult to achieve. Given this scenario, the Circular Economy (CE) has been gaining ground, seeking to break the traditional model of linear production, whose concept is based on the extraction of resources, production, distribution, use, and disposal. The Circular Economy maintains resources in the process, either by reusing waste in the process itself or by reinserting it into other processes and creating new products.

The reuse of agro-industrial waste promotes the sustainability of the industrial sector, generating many opportunities aimed at the enzymatic hydrolysis of proteins, a process by which the protein's peptide bonds are broken, generating free peptides and amino acids. Soybean processing generates several residues with great potential for exploitation due to the remaining protein content. In this sense, the objective of this work was to gather available information on the upcycling of soybean residues for application in the enzymatic hydrolysis of proteins.

2 MATERIAL & METHODS

The literature review was carried out to gather a set of information on the upcycling of soybean agricultural waste and its potential for obtaining protein hydrolysates. The search took place in February 2024, using the keywords: upcycling, soybean waste, hydrolyzed, enzymatic, protein, peptides, and amino acids. For the survey, the following publication banks were used: SciELO, Science Direct, Scopus, Wiley, Springer, Google Scholar, and CAPES journals, specifying the period from 2018 to 2024.

3 RESULTS & DISCUSSION

The 2021/2022 soybean harvest in Brazil was 125,549.8 thousand tons and 154,603.4 thousand tons for the 2022/2023 harvest,[1] being the most produced grain in the country. The main products obtained from soybeans are soybean oil, soy protein, soy flour, tofu, soy yogurt, soymilk, and fermented products, among others. Soy processing generates several by-products and residues with high potential for reuse, such as soy bran, okara, soy whey, soy hulls, residue from the processing of protein concentration, and lecithin, among others.[2]

The valorization of soy by-products helps mitigate negative environmental effects, reducing costs and the quantity of material requiring treatment and disposal, while also providing the opportunity to generate income from material sales. Soy lecithin serves as a widespread example of a by-product utilized as an emulsifier in the food and pharmaceutical industries.[3] Additionally, okara and soy whey can serve as viable ingredients in food products.[4] Other residues, such as soy hulls and soybean meal, find application in animal feed.[5] However, soybean hulls can also be utilized in the production of dietary fiber, ethanol, and peptides, while soybean meal can be hydrolyzed to yield peptides and amino acids.[2] Residues from protein concentration processing are typically allocated for composting and the production of organic fertilizer.

The absence of a sustainable and profitable processing system for certain soy waste results in underutilization of a portion of the waste. Enzymatic hydrolysis emerges as a promising process capable of generating peptides and amino acids with enhanced value, applicable in various sectors including animal feed, fertilizers, cosmetics, and hygiene products.[6] However, significant challenges persist in the processing and industrial application of waste through enzymatic hydrolysis. These challenges encompass the complexity of the waste matrix, variability in physicochemical composition, and granulometry, as well as the optimization of hydrolysis conditions (e.g., temperature, inhibition, separation) and associated enzyme costs.

However, these technological risks present opportunities for the creation of new equipment, processes, and systems, potentially positioning Brazil at the forefront of waste upcycling technology. Collaborations between companies, universities, and research funding bodies offer an ideal framework for technological advancement, including physical-chemical characterization, adjustment of process parameters, and the development of more efficient and robust enzymes for industrial applications. Therefore, laboratory studies are essential to optimize process conditions for scale-up. Table 1 provides a summary of studies conducted on the enzymatic hydrolysis of soybean products and residues.

Table 1 – Summary of conditions and results in the literature for the enzymatic hydrolysis process of soy derivatives.

Enzyme	**Raw material**	**Condition**	**Results**	**Reference**
Bromelain	Commercial soy protein isolate (SPI)	SPI was dispersed at 35 mg/mL in 0.01 mol/L phosphate buffer (pH 8) and the enzyme in the same buffer (0.8 mg/mL). SPI:enzyme ratio 4:1 at 40°C for 180 min.	Degree of hydrolysis from 5 to 16% and gelling property and good emulsion activity, but emulsions with lower stability than the non-hydrolyzed sample	Lopes-da-Silva e Monteiro [7]
Alcalase™	Soybean meal	Soybean meal mixed with water or 0.1 M phosphate buffer in a ratio of 1:10 (m/v) and stirring at 150 rpm, at 55°C and pH 8	Hydrolysis degree of 14.19% and improvement in taste and odor after hydrolysis	Weng et al. [8]
Alcalase™	Soybean flour	Proportion between soy flour and water was 3 to 5; enzyme was 1% to 2%, temperature 35, 45 and 55ºC respectively; the hydrolysis time was 7 to 9 h	Soluble proteins between 74 to 80 mg/mL with potential for application as fertilizers	Son et al. [9]
Flavourzyme™ Alcalase™ Neutrase™ Novozym™	Residue from soybean flour production	Material:water ratio 1:20, stirring at 350 rpm for 15 min. Addition of 2% enzyme in relation to protein. Flavourzyme (pH 7.0 and 50 °C), Alcalase (pH 8.0 and 65 °C), Neutrase (pH 7.0 and 50 °C) and Novozyme (pH 8.0 and 50 °C) for 180 min	The protein content in the hydrolysates ranged from 41.87% for Flavourzyme and 54.29% for Alcalase	Tkaczewska et al. [5]
Alcalase™	Soybean meal	Enzyme ratio of 5% for residual soybean meal matrix, 50 °C and pH 8 for 5 h	Degree of hydrolysis of 31.76% with potential for generating inputs for cultured meat.	Flaibam, B., e Goldbeck, R. [10]
Protamex™ Alcalase™	Ground soybean seeds	Protamex: 3% enzyme, enzyme:substrate ratio of 1:2, temperature of 55 ºC and pH 7 for 7 h. Alcalase: 2.5% enzyme, enzyme:substrate ratio of 1:3, temperature of 50 ºC and pH 8 for 4.5 h	Protamex: degree of hydrolysis of 20%, with a yield of 19.77% and protein of 51.64%. Alcalase: degree of hydrolysis 17.79%, yield 16% and protein 50.21%.	Islan et al. [11]

The residue from soy flour production, as evaluated in the work of Tkaczewska et al.[5] presented a protein content of 33%. Following the hydrolysis process, the authors observed protein values of approximately 42% and 54%. In addition to increasing the protein content, hydrolysis can enhance the solubility and emulsifying capacity of residues and by-products derived from soy, thus facilitating their application in both foods and cosmetics.[7,11] Soy processing often yields products with a characteristic unpleasant taste, and the controlled hydrolysis process has been studied as a potential solution to this issue.[8,12]

The degree of hydrolysis serves as one of the primary parameters assessed to gauge the efficacy of the hydrolysis process. It is defined as the percentage ratio between the number of cleaved peptide bonds and the total number of peptide bonds per unit weight.[10] The enzyme-to-substrate ratio, reaction time, temperature, enzymatic activity, and type of protein all influence the degree of hydrolysis, necessitating careful control as prolonged hydrolysis can yield a product with undesirable characteristics and a bitter taste. The optimal degree of hydrolysis varies depending on the protein type and the intended application of the hydrolyzed product. For instance, a low degree of hydrolysis is preferred for products requiring high emulsifying capacity, while a higher degree of hydrolysis may be preferable to enhance antioxidant properties.[13]

The proteases utilized in the process are diverse and can be employed either individually or in combination. Alcalase™ stands out as one of the most efficient proteases employed for enzymatic hydrolysis.[14] This serine endoprotease is comprised of a liquid enzyme preparation containing 50% (m/m) glycerol, 41% (m/m) water, and 9% (m/m) *Bacillus licheniformis* protease extract.[12] Bromelain, a primary cysteine endoprotease sourced from *Ananas comosus*, is commercially derived from a crude aqueous extract of the pineapple stem.[15] Neutralase™, a zinc metalloprotease, is obtained from *Bacillus amyloliquefaciens*.[16] Flavourzyme™ is a blend of exo and endoproteases, including aminopeptidases and carvoxypeptidases, sourced from *Aspergillus oryzae*.[16] Protamex™ comprises a complex of *Bacillus* protease enzymes.[11]

The experimental conditions delineated in the tests documented in Table 1 hold the potential to stimulate further inquiries into the valorization of soy residues or alternative protein sources, with the objective of their utilization in the food industry, animal nutrition, cosmetics, and/or hygiene product sectors.

4 CONCLUSION

The acceptance of the vegan market is expanding, combined with this there is an intense search to reduce waste generation and reincorporate it into production processes, enhancing the development of products based on the Circular Economy. The reuse of residues and by-products from soy processing through the hydrolysis process can contribute to the creation of new sustainable ingredients and products, further strengthening the offer of conscious food alternatives aligned with the principles of the Circular Economy.

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