Valorization of Chicken Deboner Residues: Gelatin Extraction and Application

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Abstract

In recent decades, the amount of waste in the food industry has significantly increased worldwide. Food waste can be categorized into two types: waste from human consumption and non-edible industrial by-products. One type of these by-products is known as animal by-products. This study aims to reduce this waste by repurposing valuable animal parts as raw materials for gelatin extraction. We optimized the gelatin extraction process from mechanically deboned chicken meat residues and thoroughly analyzed its physicochemical and rheological properties. The controlled independent factors were temperature and extraction time which were analyzed by Taguchi experimental design. As a result, we acquired that all of our gelatins perform high gel strength (between 196 and 353 Bloom) and viscosity (between 3.2 and 7.6 mPa·s), with the highest values at the maximum set temperature or maximum set extraction time. Our results indicate that our gelatins' high gel strength and viscosity make them ideal for use as a gelling agent in jelly confectioneries within the food industry. The processing technology of mechanically deboned chicken meat residues is environmentally friendly and meets the requirements of zero-waste technology.

***Keywords**: animal by-products, gelatin, gel strength, yield, surface properties, mechanically deboned chicken meat residue, multi-stage extraction*

Introduction

Two major issues currently facing developed countries are the high level of food waste and the increase in animal husbandry, both of which have significant environmental impacts. Addressing these problems is essential for the well-being of both the planet and its inhabitants.

Animal production and consumption contribute to increased greenhouse gas emissions (GHGEs), land use and degradation, water scarcity, nutrient pollution (e.g., acidification and eutrophication), the use of fertilizers and pesticides, and food waste along the entire supply chain, which exacerbates climate change and leads to further environmental deterioration, such as natural disasters, habitat and biodiversity loss, and freshwater scarcity in food systems [Espinosa-Marrón et al., 2022].

Food waste

The largest portion of food waste comprises vegetables and fruits (39%), followed by dairy products (17%) and meat (14%). In the European Union, nearly one-third of food produced for human consumption is wasted annually [Conrad et al., 2018]. Discarding food also wastes the water, energy, and labor invested in growing, processing, packaging, and transporting it, while increasing GHGEs, eutrophication, cropland use, and disposal costs. Food waste is a hidden issue that often goes unnoticed [Espinosa-Marrón et al., 2022]. Besides food waste intended for human consumption, other types of waste are not edible for humans. This summary will focus on a specific kind of inedible food waste: animal by-products (ABPs), specifically chicken deboner residues (CDRs), which are primarily generated in slaughterhouses during meat production and can be further processed into high-quality, protein-rich products such as gelatin. The reusage of these ABPs promotes the reduction of food waste and provides new potential for the sustainable food industry [UNEP, 2021; Regulations (EC), 2009].

Poultry consumption

Poultry meat consumption continues to grow, with projections indicating an increase to 12,568 million tons by 2033 (currently around 12,386 million tons), leading to a rise in the production of high-protein ABPs [Statista, 2024]. In 2021, 677,200 tons of gelatin were produced from pork and beef. It is anticipated that annually the consumption of gelatin will increase by 8%. By 2035, porcine and bovine gelatin production is expected to be insufficient to meet global demand, making the production of gelatin from alternative collagen sources desirable. Prioritizing the valorization of animal by-products from slaughterhouses will be essential for managing solid waste. Additionally, porcine and bovine gelatin products are prohibited or have limited permission in Jewish and Muslim areas, whereas poultry (chicken), fish, frog, and insect-origin gelatins can be used without complications worldwide. Poultry gelatin is preferable to fish gelatin due to its lack of unpleasant odor [Prokopová et al., 2023].

Chicken deboner residues

The production of gelatin from CDRs is a relatively unexplored area, with only a few studies conducted on the topic so far. Consequently, our research is pioneering in this field. Before delving deeper, it is important to define what CDRs are. CDRs are chicken parts obtained from chicken waste through mechanical deboning operations. During this process, pressure is applied to separate the chicken meat from a slurry of ground meat and bones in a mechanical deboner. The resulting waste material, known as CDRs, contains a high percentage of bone, skin, and connective tissues, with its composition depending largely on the raw input material. Typically, CDRs consist of about 20% protein, of which approximately 30-40% is collagen [Rafieian et al., 2011].

Collagen and its derivative

Collagen, the most abundant structural protein in animals and humans, constitutes about 30% of the total protein content. It is primarily found in connective tissues, where it provides strength and flexibility. Although collagen is indigestible by humans, gelatin, produced through the partial hydrolysis of collagen, is a digestible, water-soluble, odorless, and transparent polypeptide with a high molecular weight. The properties of gelatin are significantly influenced by factors such as the raw material, the age of the animal, the type of collagen, the processing method, the tissue type, and the species involved.

However, gelatin consists of various collagen fractions and peptide chains, which differ in size and weight. These variations contribute to gelatin's low melting temperature, which is below 35°C [Boran & Regenstein, 2010; Liu et al., 2015].

Gelatin and its utilization

Gelatin is one of the most versatile biopolymers, utilized across multiple industries due to its properties. In the cosmetic industry, it is a gelling agent in products such as bath salts, shampoos, sunscreens, body lotions, hair sprays, and facial creams. In the food industry, gelatin is used as a gelling, foaming, clarifying, and stabilizing agent in canned meats, wine and beer brewing, and confectionery items like fruit salads, ice cream, foam, and cottage cheese. Its film-forming capability allows it to be used as a coating material or edible film. In the medical and pharmaceutical sectors, gelatin is employed in soft and hard capsule shells, hydrogels, nano microsphere containers, nanofibers, absorbable sponges, pharmaceutical additives, matrices for intravenous infusions, injection drug delivery microspheres, implants, and cell transplantation carriers. Emerging medical applications include using ink for 3D/4D printing, tissue engineering, and gelatin-based 3D scaffolds. In the photographic industry, gelatin is used as an adhesive additive to silver salts. In forensic science, gelatin is applied as a gelatin-lifter for shoe print lifting, fabric imprints, and fingerprints [Echave et al., 2019; Alipal et al., 2021].

Processing of collagen to gelatin

The processing of collagen comprises a sequence of technological steps like chemical, thermal, physical, and mechanical techniques. These various treatments affect the properties of the nascent collagen, such as its solubility, physical stability, DNA content, and colony-forming units. The chemical extraction of gelatin through partial acid-controlled hydrolysis of collagen is known as type A gelatin, while partial alkaline-controlled hydrolysis produces type B gelatin. Both traditional acid and alkaline hydrolysis methods are slow, costly, and have a significant environmental impact [Meyer, 2019; Prokopová et al., 2023].

Aim of the study

Our research aimed to minimize the volume of inedible ABPs in the food industry by exploring the potential of a lesser-studied ABP, the CDRs, as an alternative secondary raw material for gelatin production. Several properties were evaluated to determine the efficiency and usefulness of this type of gelatin. The most

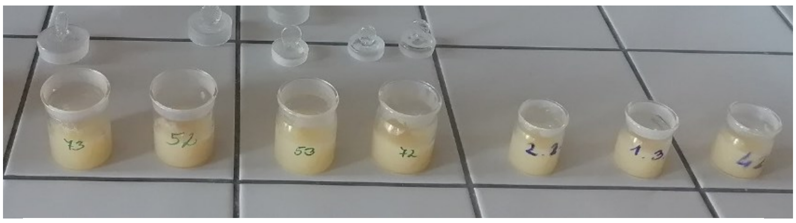

Figure 1. The prepared gelatin gels.

critical physicochemical property is the gel strength (GS), which primarily determines the potential applications of the gelatin. The second most important properties are dynamic viscosity (DV), ash content (AC), gelling point (GP), and melting point (MP). Less frequently measured properties include water-holding capacity (WHC), fat-binding capacity (FBC), foaming capacity (FC), foaming stability (FS), emulsifying capacity (EC), and emulsifying stability (ES). In industrial applications, gelatin yield is a key factor, as it plays a vital role in the efficiency of commercial production and the overall financial viability. [Bystricky-Berezvai, 2022].

Method

In contrast to chemical agents such as alkalis and acids, enzymes are more environmentally friendly because they are biodegradable and do not produce unwanted by-products. Additionally, they are cost-effective by reducing production expenses and helping achieve the desired functional properties of gelatin. During enzymatic protein hydrolysis, proteins are broken down into soluble forms through the catalytic action of proteases. Commonly used enzymes include industrially produced microbial enzymes, animal enzymes like trypsin and pepsin, and plant enzymes such as papain [Prokopová et al., 2023].

Our study utilized an innovative biotechnological approach that involved conditioning collagen with a microbial endoproteinase (Protamex®) at 0.4% concentration, followed by hot-water extraction, to control collagen's chemical and thermal denaturation for gelatin preparation. The experiments were designed using the Taguchi method with two factors at three levels: factor A represented extraction time (20, 40, and 60 minutes), and factor B represented extraction temperature (60, 64, and 68°C) [Bystricky-Berezvai, 2022].

Number of experiments	Number of extractions	GS (Bloom)	DV (mPa·s)	WHC (%)/ WHC (mL/g)	FBC (mL/g)	EC (%)	ES (%)	AC (%)	FC (%)	FS (%)	GP (°C)	MP (°C)	Temperature interval of viscous state (°C)
1.	2nd	208	3.2	-	6.9	43.3	96.2	-	-	-	15.6	35.2	19.6
	3rd	231	5	-	7.2	46.6	94.5	-	-	-	22.1	35.5	13.4
2.	2nd	241	3.6	-	7.7	48.1	98.1	-	54	12	18.9	35	16.1
	3rd	297	6.9	33.2/ 8.3	5.0	44.1	96.2	-	60	4	22.2	34.2	12
3.	2nd	334	4.5	38.4/ 9.6	4.6	44.1	100	0.01	36	2	19.9	37.8	17.9
	3rd	281	5.6	36.8/ 9.2	4.2	45.8	92.6	-	52	2	22.8	37.2	14.4
	2nd	217	3.9	-	5.4	45.6	100	-	-	-	21.8	36.4	14.6

4.	3^{rd}	295	7.6	32.4/ 8.1	5.3	50	94.7	-	42	0	23.8	34.6	10.8
5.	2^{nd}	256	4.1	37.2/ 9.3	5.6	44.8	100	-	32	0	19.9	37	17.1
	3^{rd}	200	4.4	41.6/ 10.4	7.6	45.8	100	-	36	0	19.9	35.4	15.5
6.	2^{nd}	278	4.9	37.6/ 9.4	7.8	45.8	100	-	50	4	21.8	35.3	13.5
	3^{rd}	267	7.2	38.9/ 9.7	8.3	43.9	100	-	30	0	23.7	35.5	11.8
7.	2^{nd}	271	4.4	37.7/ 9.3	8.8	47.5	96.4	-	42	0	19.3	37.5	18.2
	3^{rd}	217	4.4	30.9/ 7.7	7.6	46.6	92.6	-	40	0	19.1	35.7	16.6
8.	2^{nd}	341	4.5	39.3/ 9.8	9.5	45.6	96.2	-	44	4	20.9	32.3	11.4
	3^{rd}	274	5	24.2/ 6.1	8.7	46.6	98.1	-	44	2	20.2	35.5	15.3
9.	2^{nd}	289	3.4	34.3/ 8.6	8.1	44.8	96.2	0.004	42	4	18	34.4	16.4
	3^{rd}	268	4	21.7/ 5.4	7.7	44.8	100	-	44	4	22.4	32.8	10.4
10.	2^{nd}	304	4.2	36.0/ 9.0	6.2	46.6	96.3	-	46	2	20.6	35.5	14.9
	3^{rd}	308	5.5	30.3/ 7.6	7.9	44.8	96.2	-	46	0	18.8	32.4	13.6

Table 1. Results of all 2^{nd} and 3^{rd} gelatin fractions in each experiment. In all cases the following parameters were measured: gel strength (GS), dynamic viscosity (DV), water-holding capacity (WHC), fat-binding capacity (FBC), emulsification capacity (EC), and stability (ES), ash content (AC), foaming capacity (FC) and stability (FS), gelling point (GP), melting point (MP), and temperature interval of viscous state. Some parameters could not be measured due to the lack of a gelatin sample.

The main properties of gelatin that we tested and evaluated included dry matter content, gel strength (GS), dynamic viscosity (DV), foaming capacity (FC), foaming stability (FS), gelling point (GP), melting point (MP), ash content (AC), water-holding capacity (WHC), fat-binding capacity (FBC), emulsification capacity (EC), and emulsification stability (ES). Among these properties, GS is the primary attribute that most significantly indicates the quality of gelatin. The obtained results are presented in Table 1. The data were statistically processed and analyzed at a 95% significance level [Bystricky-Berezvai, 2022].

Results

The obtained results identified two optimal conditions: the highest yield with a Bloom value suitable for the confectionery industry (260 Bloom) and the highest Bloom value gelatin fraction. The highest yield was achieved in the 9^{th} experiment (68°C extraction temperature and 60 minutes extraction time), where the Bloom value in the 2^{nd} fraction was 289 Bloom, and in the 3^{rd} fraction, it was 268 Bloom. The highest Bloom value was obtained in the 2^{nd} fraction of the 8^{th} experiment (68°C extraction temperature and 40 minutes extraction time), with a value of 341 Bloom [Bystricky-Berezvai, 2022].

The prepared jellies were subjected to sensory testing to compare their key properties with those of commercially available jellies. During this testing, 13 individuals aged between 26 and 65, all from Central Europe, evaluated the jellies based on the following attributes: 1) appearance; 2) chewiness; 3) color; 4) smell; 5) taste; and 6) overall acceptability. The average results of each sample are shown in Table 2. Sample **A** was the jelly made from 260 Bloom porcine skin gelatin in a bottom-like shape; sample **B** was also from 260 Bloom porcine skin gelatin in a sea creature form; sample **C** was made from 289 Bloom CDR gelatin (9^{th} experiment, 2^{nd} fraction) in a bottom-like shape; and sample **D** was made from 268 Bloom CDR gelatin (9^{th} experiment, 3^{rd} fraction) in a bottom-like shape, shown in Figure 2. [Bystricky-Berezvai, 2022].

Jelly	Appearance	Chewiness	Color	Smell	Taste	Overall acceptability
A	2.3	2.8	1.8	2.9	2.5	2.4
B	1.7	2.9	1.8	2.2	2.5	2.3
C	4.8	2.7	4.5	3.8	3.1	3.8
D	4.8	4.6	4.3	3.9	3.5	4.8

Table 2. The average results of sensory testing of each sample at each criterion.

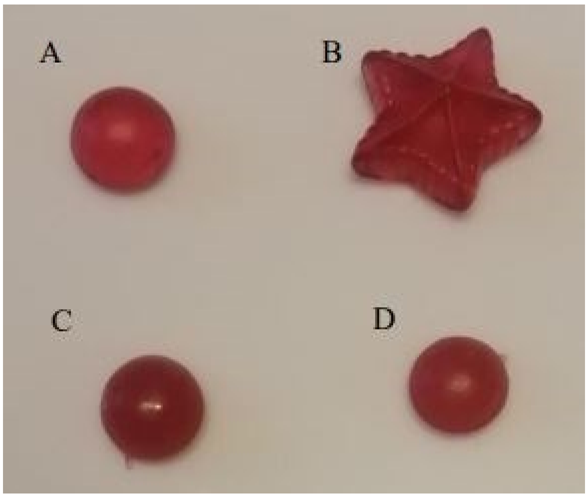

Figure 2. Samples: A sample was the jelly from 260 Bloom porcine skin gelatin in a bottom-like shape; B sample was also from 260 Bloom porcine skin gelatin in a sea creatures form; C sample was made out of 289 Bloom CDR gelatin in a bottom-like shape; and D sample was out of 268 Bloom CDR gelatin in a bottom-like shape.

Conclusion

The properties of the extracted gelatin are comparable to those of conventional gelatins, making CDR gelatin a suitable substitute. This applies to various industries, including pharmaceuticals (for nano- and microsphere containers, and hydrogels), medicine (as an encapsulating material for drugs or chemicals), and food (for jellies, gelatin desserts, and meat emulsions). Sensory testing on jellies made from CDR gelatin confirmed its potential in the food industry. However, a higher Bloom value (>260 Bloom) was necessary to achieve a texture similar to commercial jellies during candy production [Bystricky-Berezvai, 2022].

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Sources

[1] Alipal, J., Mohd Pu’ad, N. A. S., Lee, T. C., Nayan, N. H. ., Sahari, N., Basri, H., Idris M. I., Abdullah, H. Z. (2021). A review of gelatin: Properties, sources, process, applications, and commercialization. Materials Today: Proceedings, 42, 240– 250. doi:10.1016/j.matpr.2020.12.922

[2] Boran, G., & Regenstein, J. M. (2010). Fish Gelatin. Advances in Food and Nutrition Research, 119–143. doi:10.1016/s1043-4526(10)60005-8

[3] Bystricky-Berezvai, Orsolya. The Influence of Processing Conditions on Extraction of Gelatines from Chicken Deboner Residues. Zlín, 2022. diplomová práce (Ing.). Univerzita Tomáše Bati ve Zlíně. Fakulta technologická < https://digilib.k.utb.cz/handle/10563/51340>

[4] Conrad, Z., Niles, M. T., Neher, D. A., Roy, E. D., Tichenor, N. E., & Jahns, L. (2018). Relationship between food waste, diet quality, and environmental sustainability. *PLOS ONE*, 13(4), e0195405. doi:10.1371/journal.pone.0195405

[5] Echave, M. C., Hernáez-Moya, R., Iturriaga, L., Pedraz, J. L., Lakshminarayanan, R., Dolatshahi-Pirouz, A., Nayere, T., Orive, G. (2019). Recent advances in gelatin-based therapeutics. Expert Opinion on Biological Therapy. doi:10.1080/14712598.2019.1610383

[6] Espinosa-Marrón, A., Adams, K., Sinno, L., Cantu-Aldana, A., Tamez, M., Marrero, A., Bhupathiraju, S. N., and Mattei, J. (2022). Environmental Impact of Animal-Based Food Production and the Feasibility of a Shift Toward Sustainable Plant-Based Diets in the United States. Front. Sustain., Vol 3., doi: 10.3389/frsus.2022.841106

[7] Liu, D., Nikoo, M., Boran, G., Zhou, P., & Regenstein, J. M. (2015). Collagen and Gelatin. Annual Review of Food Science and Technology, 6(1), 527–557. doi:10.1146/annurev-food-031414-111800

[8] Meyer, M. (2019). Processing of collagen based biomaterials and the resulting materials properties. BioMedical Engineering OnLine, 18(1). doi:10.1186/s12938-019-0647-0

[9] Prokopová, A.; Gál, R.; Mokrejš, P.; Pavlačková, J. Preparation of Gelatin from Broiler Chicken Stomach Collagen. *Foods* 2023, 12, 127. https://doi.org/ 10.3390/foods12010127

[10] Rafieian, F., Keramat, J., & Kadivar, M. (2011). Optimization of gelatin extraction from chicken deboner residue using RSM method. Journal of Food Science and Technology, 50(2), 374–380. doi:10.1007/s13197-011-0355-7

[11] Regulation (EC). No 1069/2009 of the European Parliament and of the Council of 21 October 2009 Laying Down Health Rules as Regards Animal by-Products and Derived Products Not Intended for Human Consumption and Repealing Regulation (EC) No 1774/2002 (Animal By-Products Regulation); Official Journal of the European Union: Brussels, Belgium, 2009.

[12] Statista: *Forecast volume of poultry meat consumed in the European Union (EU-27) from 2015 to 2033** (02.08.2024) <https://www.statista.com/statistics/545577/poultry-meat-consumption-volume-european-union-28/>

[13] UNEP (2021) FOOD WASTE INDEX REPORT 2021 accessible from https://www.unep.org/resources/report/unep-food-waste-index-report-2021 [cit. 05.01.2022.]