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Opinion

Efficacy of Gas-Containing Conditioning Technology on Sterilization and Preservation of Cooked Foods

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Abstract: Gas-containing conditioning technology (GCT) employs mild sterilization methods to preserve the original qualities and nutrients of foods and is particularly suitable for processing various cooked foods or food ingredients. In this study, five kinds of dishes from daily life were processed with GCT. Thermal penetration detection technology was utilized to monitor the internal temperature of food and ambient temperature in real-time, and the optimal scheduled processes of each food were summarized. Additionally, foods were processed after GCT, and the total number of bacteria (<10^2 cfu/g) and coliform colonies (<50 MPN/100 g) were significantly reduced. Moreover, to detect the preservation effect of GCT, the processed foods were stored at 37 °C for 14 days, and the total number of colonies remained low (<10 cfu/g). These results revealed the multistage mild sterilization process, confirmed the excellent sterilization and preservation effects of GCT, and provided important experimental data for further applications of GCT in special environment foods.

Keywords: gas-containing conditioning technology; mild sterilization; scheduled process; preservation

Citation: Li, D.; Liang, D.; Li, Z.; Liu, Y.; Guo, Z.; Wu, Z.; Cao, C.; Zhang, C.; Chen, C. Efficacy of Gas-Containing Conditioning Technology on Sterilization and Preservation of Cooked Foods. *Agriculture* **2022**, *12*, 2010. https://doi.org/10.3390/agriculture12122010

Academic Editor: Quan-Sheng Chen

Received: 12 October 2022
Accepted: 9 November 2022
Published: 25 November 2022

1. Introduction

With the development of social living standards, customers have paid increasing attention to the nutrition and taste of food, resulting in the increasingly strict demand for fresh food preservation. Given the limited, traditional conditions on food processing and preservation, food acceptability is rather poor, with the original odor, flavor, texture and nutrition largely affected [1]. To solve these problems, the international society has newly developed a kind of gas-containing conditioning technology (GCT) for food processing and preservation [2].

GCT indicates a technology applicable to the processing of various convenience foods or semi-finished products preserved at room temperature. It was developed to overcome the shortcomings of traditional sterilization methods, such as vacuum packaging and dry heat sterilization [3]. With this new technology, the original color, flavor, taste, form, and nutrients of cooked foods can be perfectly preserved by using mild sterilization methods, including raw material sterilization treatment, nitrogen-filled packaging, and multi-stage heating without any preservative additives [4,5]. GCT is particularly suitable for processing various cooked foods or food ingredients, such as meat, eggs, vegetables, fruits, and staple foods. The preservation effect can be rather impressive, especially for soft foods and foods for which deoxidizers cannot be used [6]. This technology can be widely applied to traditional food industry processing for further developing new food varieties, expanding the application scope of food processing, and exploiting a new food market [6–8]. Since food

products can be stored, transported, and sold at room temperature, the cost of distribution is dramatically reduced [6].

At present, special environment foods mainly consist of canned foods and dried foods, and the canned foods had become the most commonly used food because of the rich nutrition and ready-to-eat feature, which fully satisfy modern emergency needs [9]. However, for persons working in special environments for a long time, the present flavor and taste of canned foods (high salt, high sugar) are not suitable for long-term large consumption. Therefore, developing high-quality, instant food with low salt and few additives as the major daily component of finished foods can be considered an imperative research direction [10,11].

GCT adopts a multi-stage mild sterilization technique, which allows it to preserve food nutrition and original qualities [12]. The biggest difference between the food processed with GCT and traditional dry heat sterilization is the taste after sterilization. One of the main causes is that the latter is subjected excessively to high temperature and pressure [1]. In the processing of food with GCT, the pretreatment of food ingredients should be combined with flavoring and steaming, while the bacterial reduction treatment should be performed simultaneously. Sterilization treatment should be complementary to multi-stage temperature rising, and the optimal sterilization conditions should be set according to the different food materials [13]. Generally, sterilization at a low F-value (generally below 4) can meet commercial sterility requirements, contributing to limiting the temperature and time of food being heated to a minimum, maximizing the changes in the physical properties of the food, and maintaining the original color, aroma, and intact taste of the food [1]. Moreover, GCT uses flexible packaging to substitute traditional tinplate packaging. The former not only improves the acceptability of food but also reaches the same storage period and shelf life of tin cans. Additionally, applications of the flexible packaging technology has largely resolve problems of difficult opening and disposal of waste. Hence, the nitrogen-filled method can be employed to process dry food so as to avoid fat oxidation and extend shelf life. Collectively, these advantages of GCT provide technical support for the safety and nutrition of foods in special environments.

Most of the advanced technology of food sterilization and preservation in the world is based on GCT. A research group headed by Xiong Shanbai, a professor in Food Science and Technology at Huazhong Agricultural University, systematically studied the law of microbial growth and quality. Based on the study of microbial changes and quality during the processing and storage of surimi products, ice temperature preservation and air-controlled preservation technology were combined to establish the related quality evaluation index system and HACCP quality control system for surimi products. Compared with traditional freezing preservation technology, ice temperature and gas-controlled preservation technology can extend the shelf life of food products by 3–4 times. The new method not only extends the shelf life of processed products but also contributes to the better appearance, color, and taste of the processed products. Moreover, a targeted-sterilization technology for the preparation of dishes has been developed in France. The ingredients of the dish are mixed in specific bags and sterilized under vacuum conditions with low-temperature conditioning, which can prevent the negative effects of repeated heat sterilization on the quality of the finished product. The packaging of special collective rations for US ships has been largely improved based on the UGR~H system in the US. The general specifications are for flexible bags, and the bagged rations can be heated directly and have a shelf life up to 18 months. In addition, Chinese chestnuts are characterized by a sweet taste and high quality. Thus, they are well-known around the world and are very popular among Japanese consumers. For the last 200 years, chestnuts from Hebei and other regions have been exported to Japan through the ports of Tianjin. For this reason, the name "Tianjin chestnuts" was formed. At present, "Tianjin Sweet Chestnut" has become a generic term for chestnuts in Japan, and the new chestnuts in small packages containing gas are natural in flavor, preservative-free, long in shelf life, and easy-to-use. They are also a favorite food among consumers in the Chinese mainland, Hong Kong, and Taiwan.

China is currently adapting to building a well-off society in an all-around way, and the food security level and die-tary needs transitioned from simple physiological satisfaction to the pursuit of physiological and psycho-logical satisfaction. Moreover, psychological needs in special environments should be concerned and satisfied.

In the present study, five kinds of food products, including fish fillet in chili sauce, preserved vegetables and pork, fried mixed vegetables, roast pork with bamboo shoots, and stewed bamboo were processed with GCT and evaluated for sterilization and preservation effects. This study will provide experimental support for the widespread application of GCT.

2. Materials and Methods

2.1. Raw Materials, Acceptance, and Bagging

We used bamboo shoots, carrots, kelp, pork, grass carp, dried plum vegetables, vegetable oil, edible salt, white granulated sugar, yellow rice wine, green onion, ginger, star anise, sodium glutamate, soy sauce, monosodium glutamate, and other raw and auxiliary materials. All raw materials and additives were obtained from the qualified suppliers of the company, inspected according to the company's Procurement and Acceptance Standards for Raw and Auxiliary Materials, and stored and used only after passing inspection.

We weighed the ingredients accurately, and tipped them into bags with food bagger. The discharge port of the food bagger should be cleaned regularly so as not to influence the sealing effect. Also notice that the air of bags should be exhausted before seal, then inject nitrogen, and finally heat sealing. Sealing widths were $\geq$8 mm; thermal bonding strengths were $\geq$40 N/15 mm; bag mouths were tight and smooth after sealing. After sealing, the mouth of bags is tight and smooth, and keep the vacuum inside bags. During the production process, visual inspection was conducted every 5 min, and sealing strengths were tested and recorded every 2 h.

2.2. Product Sterilization, Cleaning and Drying

A water bath spray sterilization pot was used. The products were not stacked in multiple, overlapping layers in the sterilization cage to avoid incomplete sterilization. The sterilization process was divided into three stages, and the main parameters (time, temperature, and pressure) of each stage are as follows: stage 1 (100 °C, 10 min, 0.12 Mpa), stage 2 (110 °C, 30 min, 0.15 Mpa) and stage 3 (121 °C, 25 min, 0.18 Mpa).

The sterilized products were transferred to the automatic cleaning and drying production line for cleaning and drying. The dried products were placed in clean turnover boxes or cartons. If the undried products were found, they were dried again. The products should not be over pressed during the packing process

2.3. Product Inspection

The insulation time was 10 d, the insulation temperature was controlled at 37 $\pm$ 2 °C, and records were made. After heat preservation, the samples were tested for quality (color, taste, tissue morphology, taste, and odor), and PH values were detected. We performed microbiological tests and recorded when the PH dropped. We conducted X-ray foreign body detection using a machine on the packaged products one by one to eliminate the products with problems and ensure that the canned products after testing were qualified products. After heat preservation and qualified inspection, the products were packed as required. The entire process was performed exactly as required by the HACCP system.

2.4. Thermal Penetration Detection

Through Sichuan Meining Food Co., Ltd., the horizontal static all-water sterilization pot (Weifang, China, R2020-0111) was used to sterilize five kinds of canned food (fish fillet in chili sauce, preserved vegetables and pork, fried mixed vegetables, roast pork with bamboo shoots, and stewed bamboo), and the wireless temperature verification system (Esbjerg, Denmark, TrackSense Pro) was used to detect the temperature [14]. The net weight

of the tested food was 1000 g/bag. The thermal processing of the products was divided into several stages, such as water injection, temperature rise, constant temperature, and cooling. The sterilization process was realized by the automatic control program operation of the sterilization pot. The temperature verification system was used, in which 2 probes (LC11 and LC12) were used to test the ambient temperature in the sterilization pot and the remaining 10 probes were inserted into the centers of the products and placed at the cold point of the sterilization pot to test the center temperature of the products. The above tests were carried out according to the relevant provisions of industry standard SN/T 0400.13-2014 for thermodynamic sterilization.

2.5. Total Colony Determination

The aerobic plate and coliforms count were measured according to the methods of GB 4789.2-2022 Determination of Total Colonies in Food Microbiology Test of National Food Safety Standard and GB 4789.3-2016 Coliform Count in Food Microbiology Test of National Food Safety Standard, respectively. The 25 g sample was weighed and put into 225 mL of sterile normal saline, and the homogenizer was beat twice/s for 1–2 min and then diluted 10-fold to an appropriate dilution. Two petri dishes were made for each dilution and then cultured at 37 °C for 48 h to calculate the total number of aerobic plate and coliforms.

3. Results and Discussion

3.1. Thermal Penetration Detection of Foods

In this study, heat penetration tests were carried out on five kinds of food (1000 g each) in Sichuan Meining Food Co., Ltd., including fish fillet in chili sauce, preserved vegetables and pork, fried mixed vegetables, roast pork with bamboo shoots, and stewed bamboo. According to the detection results, the environmental temperature in the sterilization pot experienced three constant temperature stages [6]: Since the sterilization pot began to time the temperature rise, after 4–6 min in the first phase of constant temperature, all sites reached 103 °C and maintained that for 12 min; after 2 min of heating, the pot entered the second stage of constant temperature, and all points reached above 110.0 °C and maintained that for 31 min; and after 3 min of heating, the three stages of constant temperature were entered, and all points reached above 121.0 °C and maintained that for 20–30 min (Figure 1). Under the above hot working conditions, the F0 value (Standard sterilization time) of the product was less than 10 after the stages of water injection, heating, and cooling. According to the above data and combined with Ball's formula method, we summarized the optimal scheduled processes (Tables S1–S5) to be used as the reference basis for enterprises to set the critical limit values of thermal processing.

3.2. Detection of GCT Sterilization Effect

Five kinds of food were processed with GCT. Table 1 shows the changes of the total number of bacteria and coliform bacteria in the products before and after GCT processing. Before food processing, the total number of bacteria was greater than 10^4 cfu/g, and the coliform colonies were greater than 100 MPN/100 g. After processing, the total number of bacteria (<10^2 cfu/g) and coliform colonies (<50 MPN/100 g) were significantly reduced, which fully reached the standard of the total number of food colonies. These results indicate that GCT had an obvious bactericidal effect and could effectively prevent food nutrition destruction and food contamination [13,15].

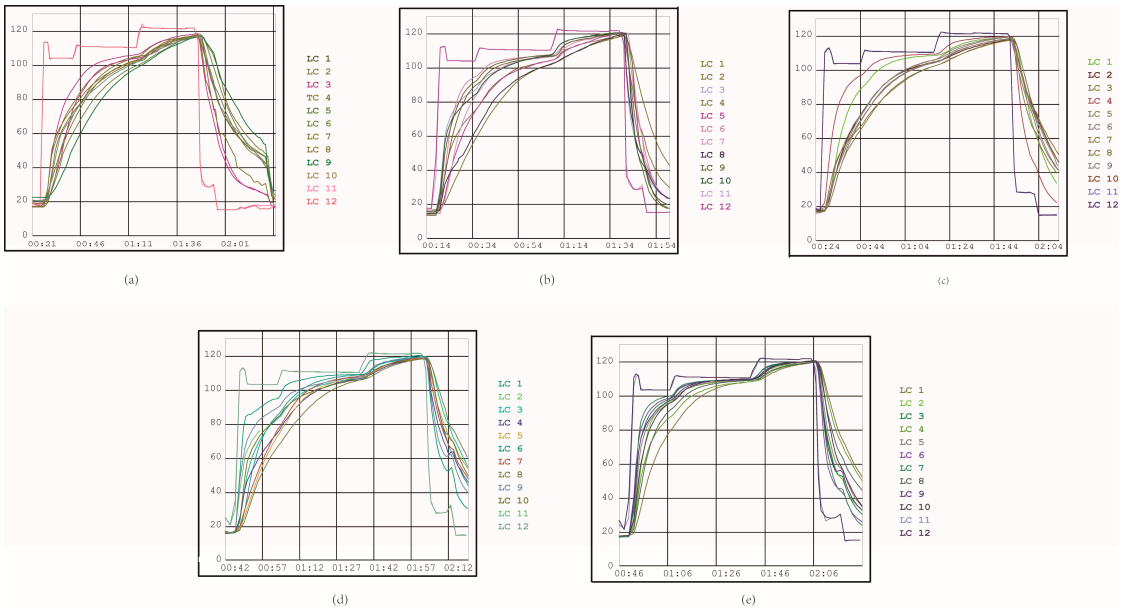

Figure 1. Heat penetration curves of 1 kg/bag of (**a**) fish fillet in chili sauce, (**b**) preserved vegetables and pork, (**c**) fried mixed vegetables, (**d**) roast pork with bamboo shoots, and (**e**) stewed bamboo products in sterilization workshop.

Table 1. Changes in the amount of food bacteria before and after GCT.

Foods	Before GCT		After GCT	
	Total Bacterial Count cfu/g	Coliforms MPN/100 g	Total Bacterial Count cfu/g	Coliforms MPN/100 g
Fish fillet in chili sauce	6.8×10^6	190	$<10^2$	<42
Preserved vegetables and pork	5.3×10^5	170	$<10^2$	<335
Roast pork with bamboo shoots	5.8×10^5	160	$<10^2$	<30
Fried mixed vegetables	4.7×10^5	120	$<10^2$	<30
Stewed bamboo	8.0×10^4	100	$<10^2$	<30

3.3. Detection of GCT Preservation Effect

In order to further test the fresh-keeping ability of GCT, the food was stored at 37 °C for 14 days to detect the viable bacterial count. The results show that the viable bacterial count of each food was less than 10 cfu/g, the F-values were lower than 2, and no potential pathogens, such as *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* and *Clostridium botulinum*, were detected (Table 2). These results suggest that GCT can effectively inhibit the growth of microorganisms and well-control the number of microorganisms during food storage at room temperature.

Table 2. F-values and amounts of bacteria amount in processed foods.

Samples	Weight g	F-Value	Kept at 37 °C for 14 d	
			Viable Count	Facultative Anaerobic Bacteria
Fish fillet in chili sauce	200	1.92	<10	Negative
Preserved vegetables and pork	250	1.83	<10	Negative
Roast pork with bamboo shoots	250	1.70	<10	Negative
Fried mixed vegetables	150	0.91	<10	Negative
Stewed bamboo	150	0.84	<10	Negative

4. Conclusions

In this study, five kinds of dishes (fish fillet in chili sauce, preserved vegetables and pork, fried mixed vegetables, roast pork with bamboo shoots, and stewed bamboo) in daily life were processed with GCT, and the optimal scheduled processes were summarized. Additionally, excellent sterilization and preservation effects of GCT were confirmed by calculating the total number of viable bacteria. The present study provides important experimental data for further applications of GCT in special environment foods.

GCT is a revolutionary technology, completely different from existing preservation methods. It can successfully seal cooked dishes inside a package filled with inert gas, which can perform continuous seasoning and sterilizing for the food. After that, it can be circulated, stored, transported, and sold at room temperature without changing the tastes, colors, and flavors of the ingredients. GCT provides a potential strategy for Chinese cooking to enter an era of standardization, of large-scale and automatic production, and provides new impetus for the development of food deep processing technology [8,13].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture12122010/s1, Table S1–S5: Scheduled process of Fish fillet in chili sauce (Table S1), Preserved vegetables & Pork (Table S2), Roast pork with bamboo shoots (Table S3), Fried mixed vegetables (Table S4), and Stewed bamboo (Table S5).

Author Contributions: Conceptualization, D.L. (Dan Li), D.L. (Dong Liang), C.Z., and C.C. (Cunkun Chen); methodology, D.L. (Dan Li) and D.L. (Dong Liang); investigation, D.L. (Dan Li), Z.L., Y.L., Z.G., Z.W., and C.C. (Chunping Cao); resources, D.L. (Dan Li); data curation, D.L. (Dan Li); writing—original draft preparation, D.L. (Dan Li) and D.L. (Dong Liang); writing—review and editing, D.L. (Dong Liang); visualization, D.L. (Dan Li) and D.L. (Dong Liang); supervision, C.Z. and C.C. (Cunkun Chen); pro-ject administration, D.L. (Dan Li), C.Z., and C.C. (Cunkun Chen); funding acquisition, D.L. (Dan Li), C.Z., and C.C. (Cunkun Chen). All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by Key Laboratory of Storage of Agricultural Products, Ministry of Agriculture and Rural Affairs (kf2022002), Research Projects of National Priority (14A644), Departmental scientific Research Project (20M0603), and 2021 Excellent Construction Project (21TPQN0601).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Most of the data are available in the tables and figures of the manuscript. If scholars need more specific data, they can send an email to the corresponding author or the first author.

Conflicts of Interest: The authors declare no conflict of interest.

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