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Black garlic: Food safety considerations during production and storage

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Key Messages

- Black garlic is produced by aging fresh garlic in high-temperature (60–90°C) and high-humidity (70–90%) conditions for several weeks.
- *Clostridium botulinum* spores are prevalent in soil and consequently naturally found in agricultural products, including garlic. If black garlic is improperly produced in commercial or household settings in the danger zone between 4°C and 60°C under anaerobic conditions, *C. botulinum* spores may germinate and produce botulinum neurotoxin, which may cause a rare but serious paralytic disease.
- Good Manufacturing Practices must be followed during production, and the thermal conditions of the processing equipment must be consistently monitored to ensure that the optimal temperature is maintained to prevent the production of botulinum neurotoxin.
- The pH and water activity (Aw) of the final black garlic product influences how the product should be stored to prevent the growth of spoilage microorganisms and mould.
- Due to the lack of temperature monitoring in household appliances such as slow cookers and rice cookers, production of black garlic in such appliances is not recommended.

Introduction

Garlic is a well-known plant that is widely used around the world and throughout history as a spice and as a herbal remedy.[1,2] It is rich in many organosulfur compounds, polyphenols, flavonoids, and carotenoids, many of which have antifungal, antibacterial, antioxidant, anti-cancer, anti-inflammatory, and cardio-protective properties.[2-6] Despite the potential health benefits, people may be reluctant to consume raw/fresh garlic due to its pungent odour and spicy flavor caused by the presence of organosulfur compounds such as alliin and allicin (which are only produced when garlic is cut or crushed).[1,2,7] In addition, several side effects such as nausea, vomiting, and other types of gastric discomfort associated with consumption of excessive amounts of fresh garlic have been documented.[5,8]

As a result of its taste and odour, garlic has been transformed into many different products such as garlic powder, garlic juice, and supplement pills in an attempt to make it more palatable.[1] One of these products is black garlic. Some studies demonstrated that levels of biologically active compounds such as *S*-allyl cysteine, polyphenols, and flavonoids increased significantly in black garlic compared to fresh garlic, contributing to the higher antioxidant capacity of black garlic.[7,9] In addition, multiple in-vitro and

animal studies have shown that black garlic has anti-inflammatory, anti-obesity, hepatoprotective, anti-cancer, anti-allergy, immunomodulation, cardio-protective, and neuro-protective properties.[1,2,9]

While the author did not find any foodborne illness outbreaks associated with black garlic, there are food safety risks associated with black garlic if it is improperly processed or handled, especially in household settings. Many recipes for homemade black garlic in household appliances such as slow cookers or rice cookers can be found online, and the products may even be available for sale through private online platforms. This evidence brief will discuss the potential food safety risks associated with the production of black garlic and how to mitigate these risks.

Methodology

Literature search

A search of academic and grey literature in English that pertain to the health benefits of black garlic, its production methods, and associated food safety hazards was conducted in EBSCOhost databases (includes Medline, Cinahl, Academic Search Complete, ERIC, etc.) and Google Scholar, with no specific date restrictions. Keywords used for the database searches include the following:

(“black garlic” OR “black aged garlic” OR “fermented garlic” OR “black Allium sativum L”)

AND

(health OR benefit OR risk OR illness OR botulism OR outbreak OR safety OR toxicology OR toxicological OR enteropathogen OR enteropathogenic OR “e coli” OR gastroenteritis)

Other

(black AROUND(5) garlic OR “Allium sativum L”) OR (aged AROUND(5) garlic OR “Allium sativum”)

"black garlic" in title (black OR fermented) AND “functional food”

Additional keywords used in supplemental searches using Google and the University of British Columbia Library include variations of black garlic, fresh garlic, raw garlic, *Clostridium botulinum*, and *Clostridium perfringens*. Additional literature was identified through the reference sections of relevant literature in the above-mentioned search results.

Results

How is black garlic produced and what are the physicochemical changes during processing?

Black garlic is produced by aging fresh garlic (either unpeeled or peeled) in high-temperature (60–90°C) and high-humidity (70–90%) conditions for several weeks.[1,7] During thermal treatment, several physical and chemical changes take place, resulting in a dark brown or black colour, chewy or jelly-like texture, and sweet and sour tastes. Processing temperatures and humidity levels of black garlic vary depending on regional recipes and desired product characteristics. While some refer to black garlic as fermented garlic, it is not a true fermented product as no active cultures are involved in its production.[10] Rather, it is an oxidation and crystallization process.[11] Heat treatment causes cell walls in the garlic to rupture, releasing the compounds within and allowing them to be transformed or degraded.[7] During thermal treatment, alliin, allicin, and other organosulfur compounds responsible for garlic's pungent odour are broken down and carbohydrates are reduced to simple sugars, which result in black garlic's sweet taste.[9,12] These sugars contribute to the Maillard reaction—a non-enzymatic browning reaction—which causes black garlic to take on its characteristic dark brown or black colour.[1,7,9,12] The pH of black garlic declines during thermal processing due to the release of organic acids from the rupturing of cells as well as additional production of organic acids during thermal processing, resulting in a sour taste.[13]

Studies have found that processing technology, time, temperature, humidity, and pH can directly affect the amount of biologically active compounds as well as the moisture content and quality of the final black garlic product.[1] High temperature results in faster browning, greater loss of moisture, shorter aging time, and an increase in bioactive compounds.[14] A study by Zhang et al. found that at 90°C, although processing time was faster, the end product was more bitter and sour.[14] The same study found that 70°C was the ideal temperature for the best black garlic product.[14] Another study by Choi et al. found that at 70°C with 90% relative humidity (RH), 21 days of aging resulted in optimal levels of antioxidants, while moisture levels dropped by 50% after seven days of aging.[15] The pH of the samples dropped gradually over the experimental period and reached 3.74 after 28 days of aging.[15] Table 1 shows the moisture levels and pH of unpeeled garlic samples over the experimental period.[15]

Table 1. Moisture content and pH of unpeeled garlic samples at 70°C and 90% RH.[15]

Aging period (days)						
	0	7	14	21	28	35
Moisture (%)	64.21 ± 1.48	32.72 ± 0.97	31.77 ± 2.60	31.12 ± 0.17	29.55 ± 0.39	29.88 ± 0.49
pH	6.33 ± 0.07	5.49 ± 0.09	4.41 ± 0.17	4.22 ± 0.08	4.07 ± 0.02	3.74 ± 0.062

Toledano-Medina et al. found that when garlic was aged at higher temperatures, lower pH was reached more rapidly than at lower temperatures.[16] Tables 2–4 show changes in water activity and pH for whole and peeled garlic samples aged at different temperatures at nearly 90% relative humidity.[16]

Table 2. Water activity and pH of whole and peeled garlic samples at 78°C and nearly 90% RH.[16]

Aging period (days) @ 78°C								
	0		5		10		14	
	Whole	Peeled	Whole	Peeled	Whole	Peeled	Whole	Peeled
Water activity (A_w)	0.97 ± 0	0.98 ± 0	0.96 ± 0	0.98 ± 0	0.94 ± 0	0.94 ± 0	0.93 ± 0	0.94 ± 0
pH	5.93 ± 0.01	6.31 ± 0.07	4.96 ± 0.01	5.22 ± 0.01	3.82 ± 0.07	4.19 ± 0.13	3.80 ± 0.06	3.74 ± 0.02

Table 3. Water activity and pH of whole and peeled garlic samples at 75°C and nearly 90% RH.[16]

Aging period (days) @ 75°C								
	0		7		14		21	
	Whole	Peeled	Whole	Peeled	Whole	Peeled	Whole	Peeled
Water activity (A_w)	0.97 ± 0	0.98 ± 0	0.96 ± 0	0.97 ± 0	0.93 ± 0	0.94 ± 0	0.94 ± 0	0.93 ± 0
pH	5.93 ± 0.01	6.31 ± 0.07	4.91 ± 0.07	5.08 ± 0.03	4.10 ± 0.04	4.11 ± 0.02	3.53 ± 0.04	3.52 ± 0.01

Table 4. Water activity and pH of whole and peeled garlic samples at 72°C and nearly 90% RH.[16]

Aging period (days) @ 72°C								
	0		11		24		33	
	Whole	Peeled	Whole	Peeled	Whole	Peeled	Whole	Peeled
Water activity (A_w)	0.97 ± 0	0.98 ± 0	0.96 ± 0	0.97 ± 0	0.93 ± 0	0.94 ± 0	0.91 ± 0	0.92 ± 0
pH	5.93 ± 0.01	6.31 ± 0.07	4.70 ± 0.06	4.87 ± 0.06	3.60 ± 0.01	3.72 ± 0.05	3.49 ± 0.06	3.52 ± 0.03

Pretreating raw garlic by freezing at 18°C prior to heat treatment increased the level of bioactive compounds and the overall quality of the end product, while speeding up the processing time.[17] One study found that peeled raw garlic yielded black garlic with higher antioxidant capacity than whole unpeeled raw garlic.[16]

What are the potential food safety risks and how can they be mitigated?

Given the reported health benefits of black garlic, manufacturers and consumers will want to optimize the levels of beneficial compounds in black garlic and enhance its flavour and texture while preventing the growth of harmful pathogens. One of the pathogens commonly associated with fresh garlic is *Clostridium botulinum*.[18] *C. botulinum* spores are prevalent in soil, aquatic segments, and the intestinal tracts of birds, animals, and fish.[19] They can also be found in agricultural products such as honey and vegetables.[19] *C. botulinum* spores can germinate in anaerobic conditions in the danger zone between 4°C and 60°C and produce botulinum neurotoxin, which may cause a rare but serious paralytic disease.[19-21] The danger zone is the temperature range in which foodborne pathogens are able to proliferate the quickest to levels that may cause illness. *C. botulinum* and the neurotoxin are sensitive to heat, and the bacteria cannot grow below pH 4.6.[22] However, the spores are resistant to heat and require much higher temperatures to be destroyed.[22]

As the processing temperature of black garlic is between 60°C and 90°C, the high temperature inhibits the growth of *C. botulinum*. During processing, once the pH reaches 4.6 or less and water activity (A_w) is 0.93 or less, the conditions further inhibit the growth of *C. botulinum.*[22,23] It is imperative to follow Good Manufacturing Practices during processing to prevent the growth of pathogens, especially considering the length of time of the aging process. A temperature data-logger would enable monitoring of the processing conditions and ensure that the temperature is maintained at the optimal temperature above 60°C.[20] Although black garlic can be made in household appliances such as slow cookers and rice cookers, it is unclear whether these appliances will be able to maintain the optimal temperature consistently over the aging period. Poorly ventilated or sealed household appliances may provide an anaerobic

environment in which *C. botulinum* spores are able to germinate. Additionally, the use of such appliances over a lengthy period of time without constant supervision may pose a fire hazard. Therefore, it is not recommended to produce black garlic in household appliances.[11]

In order to prevent the growth of spoilage microorganisms and mould, the storage conditions of the final black garlic product are determined by the pH and A_w, as follows[20,23]:

- If pH is ≤ 4.2, the product is considered to be shelf-stable and may be stored at room temperature.
- If pH is > 4.2, the product must be refrigerated.
- However, if the pH is > 4.2 and A_w is < 0.85, the product is considered to be shelf-stable and may be stored at room temperature.

Summary

Black garlic has numerous potential health benefits and is increasing in popularity due to greater awareness of the linkages between food and human health. As a result, environmental public health practitioners may encounter black garlic products in the field while carrying out their duties. This document outlined the potential health benefits and discussed the potential food safety risks associated with improper production of black garlic. It is important to consistently monitor the equipment to ensure that the temperature is held at above 60°C at all times during processing to prevent the production of botulinum neurotoxin. In addition, proper storage of the final black garlic product is also imperative to prevent the growth of spoilage microorganisms and mould.

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