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Abstract

This study aimed to evaluate the impact of different preservation methods; drying, freezing, and freeze-drying on the quality of Egyptian and Chinese garlic, using Toum Sauce as a model food product. Samples of garlic were analyzed for chemical composition (moisture, ash, fat, fiber, protein, carbohydrates, and vitamin C), bioactive compounds (total phenolic content and flavonoid content), and sensory attributes (color, odor, taste, texture, chewing, and overall acceptability) over storage periods of 0, 3, and 7 days. The results demonstrated that drying significantly increased the concentrations of nutrients such as protein, ash, fat, and fiber, while freeze-drying preserved the highest levels of vitamin C, phenolics, and carbohydrates. Freezing effectively maintained the moisture content. Egyptian garlic generally exhibited higher nutritional values, whereas Chinese garlic showed better stability in color and flavor, particularly after freeze-drying. Sensory evaluation revealed that samples made from freeze-dried and dried Chinese garlic (CHFD and CHD) maintained superior stability and acceptability throughout the storage period. In contrast, samples prepared from fresh and dried Egyptian garlic (EF and ED) exhibited rapid sensory deterioration. pH decline was more evident in dried samples, while phenolic content increased in some frozen samples due to cell disruption; flavonoids appeared more sensitive to processing, particularly freezing. Freeze-drying proved to be the most effective preservation method for maintaining both nutritional and sensory quality, followed by drying. These findings offer valuable insights into optimizing garlic-based food products and emphasize the critical role of preservation techniques in ensuring functional quality and consumer acceptability.

Keywords: Garlic, Freeze-drying, Phenolic compounds, Toum Sauce, Physicochemical properties.

Graphical abstract

تقييم تأثير طرق الحفظ على جودة الثوم المصري والصيني باستخدام صوص الثومية كنموذج تطبيقي

الملخص

هدفت هذه الدراسة إلى تقييم تأثير طرق الحفظ المختلفة، التجفيف، التجميد، والتجفيد – على جودة الثوم المصري والصيني، وذلك باستخدام صوص الثومية كنموذج غذائي. تم تحليل عينات الثوم لتحديد التركيب الكيميائي (الرطوبة، الرماد، الدهن، الألياف، البروتين، الكربوهيدرات، وفيتامين ج)، والمركبات الحيوية الفعالة (الفينولات الكلية والفلافونويدات)، بالإضافة إلى التقييم الحسي لصفات وخواص (اللون، الرائحة، الطعم، القوام، القابلية للمضغ، والقبول العام) خلال فترات تخزين (٠ و٣ و٧ أيام). أظهرت النتائج أن التجفيف أدى إلى زيادة ملحوظة في تركيزات البروتين، الرماد، الدهون، والألياف، بينما حافظت طريقة التجفيد على أعلى مستويات فيتامين ج، والفينولات، والكربوهيدرات. أما التجميد، فقد كان فعالاً في الحفاظ على محتوى الرطوبة بوجه عام، وأظهر الثوم المصري قيمًا غذائية أعلى، بينما تمتع الثوم الصيني بثبات

أفضل في اللون والنكهة، خاصة بعد التجفيد. وكشف التقييم الحسي أن عينات الثومية المُحضّرة من الثوم الصيني المجفد والمجفف (CHFD و CHD) احتفظت بجودة واستساغة عالية طوال فترة التخزين، بينما أظهرت العينات المُحضّرة من الثوم المصري الطازج والمجفف (EF وED) تدهورًا حسيًا سريعًا. كان انخفاض الرقم الهيدروجيني أكثر وضوحًا في العينات المجففة. كما لوحظت زيادة في المحتوى الفينولي ببعض العينات المجمدة نتيجة لانفجار الخلايا، في حين بدت الفلافونويدات أكثر حساسية لعمليات الحفظ، وخاصة التجميد. وبشكل عام، تبين أن التجفيد هو أكثر طرق الحفظ كفاءةً في الحفاظ على الجودة الغذائية والحسية، يليه التجفيف. وتُسهم هذه النتائج في تقديم رؤى مهمة حول تحسين منتجات الثوم الغذائية، وتؤكد الدور الحاسم لطرق الحفظ في ضمان الجودة الوظيفية وقبول المستهلك.

<u>الكلمات المفتاحية:</u> الثوم، التجفيد، المركبات الفينولية، صوص الثومية، الخصائص الفيزوكيميائية.

Introduction

Food preservation is essential to prevent spoilage caused by microbial, chemical, and physical factors that affect nutritional value, texture, color, and edibility. Foods of plant or animal origin naturally contain moisture, proteins, carbohydrates, lipids, and minerals, making them prone to deterioration. Traditional preservation techniques such as drying, freezing, freeze-drying, and pasteurization have been widely used to extend shelf life. These methods have since evolved into more advanced, interdisciplinary approaches that maintain food quality and safety **(Monteiro *et al.*, 2010, and Rajabhuvaneswari *et al.*, 2022).**

Drying is one of the oldest methods used to preserve food, helping people extend its shelf life by reducing moisture, which slows down microbial and chemical spoilage. When done correctly, it can help maintain the color, flavor, and nutritional quality of vegetables **(Singh *et al.*, 2014).**

Freezing is among the oldest and most reliable techniques for preserving food. By reducing the temperature to below −18°C, a portion of the water in the food freezes, which helps slow down spoilage caused by enzymes, oxidation, and microorganisms. This process helps maintain the quality of the food and extends its shelf life **(Evans, 2009)**

Vacuum freeze-drying (FD), also known as lyophilization, removes moisture through sublimation and often results in higher quality food products compared to other drying methods. Foods preserved this way typically retain their color, flavor, and nutrients better, have a porous structure, and show good rehydration capacity. **(Jiang *et al.*, 2017).** Freeze-drying (FD) is a highly effective method for preserving food quality, particularly in terms of flavor, color, and nutrient retention. However, it has notable drawbacks, including long processing time and high energy consumption, making it more expensive than conventional methods such as hot air-drying **(Ambros *et al.*, 2016).**

Garlic is a very important crop in Egypt and in the whole world. Egypt ranks as the fourth leading country in the world for garlic production **(Hassan *et al.*, 2011)**. contains numerous bioactive organosulfur compounds like allitridin, allicin, alliin, garlicin, diallyl sulfide, and diallyl disulfide. These compounds are responsible for many of its health-promoting properties **(Bo *et al.*, 2021).**

Garlic *(Allium sativum L.)* is the main component of toum sauce, a traditional Middle Eastern sauce recognized for its rich flavor and smooth, creamy texture. In addition to its distinctive taste and aroma, garlic contributes to the emulsification process that gives the sauce its stable consistency. When blended with oil and lemon juice, the sulfur-containing compounds in garlic help it function as a natural emulsifier." **(Bravo-Núñez *et al.*, 2019).**

In process, which oil is finely dispersed within aqueous ingredients like lemon juice or water. Garlic plays a central role in this process, as it contains alliin, a compound that converts into allicin upon crushing, contributing both to the strong aroma and garlic's natural antimicrobial and antioxidant properties **(Ao Shang *et al.*, 2019).** Additionally, garlic contains polysaccharides and proteins that enhance the emulsion's stability during high-speed blending. However, if emulsification conditions are not properly controlled, the mixture may separate or "break," resulting in a failed texture **(Lopez-Alt, 2022).**

Materials and Methods

Materials

- Egyptian and Chinese garlic *(Allium sativum L.)* was obtained from a local market in Assiut City, Egypt.
- Salt, sunflower oil, and lemon were obtained from the local market, Assiut City, Egypt.

Methods

All analyses were conducted in the central laboratories of the Faculty of Agriculture, Assiut University, Egypt.

1. Preparation of garlic samples using different preservation methods

The garlic cloves were hand-peeled and stored at room temperature (20°C) until used in the experiments, following the method described by **Figiel, (2009)**.

1.1. Preparation of fresh garlic samples

Fresh Egyptian and Chinese garlic (EF and CHF) were chopped using a grinder and analyzed immediately according to the method of **James *et al.*, (2015).**

1.2. Preparation of dried garlic samples

Egyptian and Chinese garlic bulbs (ED and CHD) were peeled and sliced into uniform pieces of 3 mm thickness. A single layer of 100.00 ± 2.00 g of garlic slices was spread evenly on stainless-steel trays and dried in a hot air oven at 65 °C for 24 hours. The method followed was adapted from **Zhou *et al.*, (2017)** with slight modifications.

1.3. Preparation of frozen garlic samples

For frozen samples (EFr and CHFr), peeled and chopped garlic cloves were immediately stored at –40 °C for one month. This process was based on the method of **Rahman *et al.*, (2005),** with slight modifications.

1.4. Preparation of freeze-dried garlic samples

To produce freeze-dried Egyptian and Chinese garlic (EFD and CHFD), garlic slices were evenly placed on the heating plate of the freeze-dryer. They were first pre-frozen at −40 °C for 3 hours, then dried at −18 °C under a vacuum of 0.518 mbar, with the cold trap set at −95 °C. following the method described by **Feng *et al.*, (2021).**

2. Preparation of "Toum Sauce"

According to **Olaimat *et al.*, (2020)**, with some modifications, "Toum" content (makes about 3/4 cup): 6 to 8 cloves peeled garlic, 1 teaspoon salt**,** 2 teaspoons freshly squeezed lemon juice**,** 1/2 cup corn oil, and 2 teaspoons ice water**.** After combining the garlic with salt and lemon juice, begin adding tiny drops of oil. To ensure successful Toum preparation, oil should be added slowly and incrementally, preferably by teaspoon, while continuously whisking the garlic, salt, and lemon juice mixture. This gradual emulsification is key to achieving a stable and creamy texture.

Table 1. Formulation ingredients of "Toum Sauce" prepared with garlic treated by different preservation methods

Samples	Ingredients					
	Garlic (g)	Lemon (ml)	Oil (ml)	Water (ml)	Salt (g)	Toum (g)
EF	30	10	85	35	1	143
CHF	30	10	85	35	1	148
ED	11	10	85	50	1	137
CHD	11	10	85	50	1	165
EFr	30	10	62	20	1	133
CHFr	30	10	62	20	1	117
EFD	9	10	58	42	1	110
CHFD	9	10	58	42	1	118

- EF: Egyptian Fresh garlic, CHF: Chinese Fresh garlic, ED: Egyptian Dried garlic, CHD: Chinese Dried garlic, EFr: Egyptian Frozen garlic, CHFr: Chinese Frozen garlic, EFD: Egyptian Freeze-dried garlic, CHFD: Chinese Freeze-dried garlic.

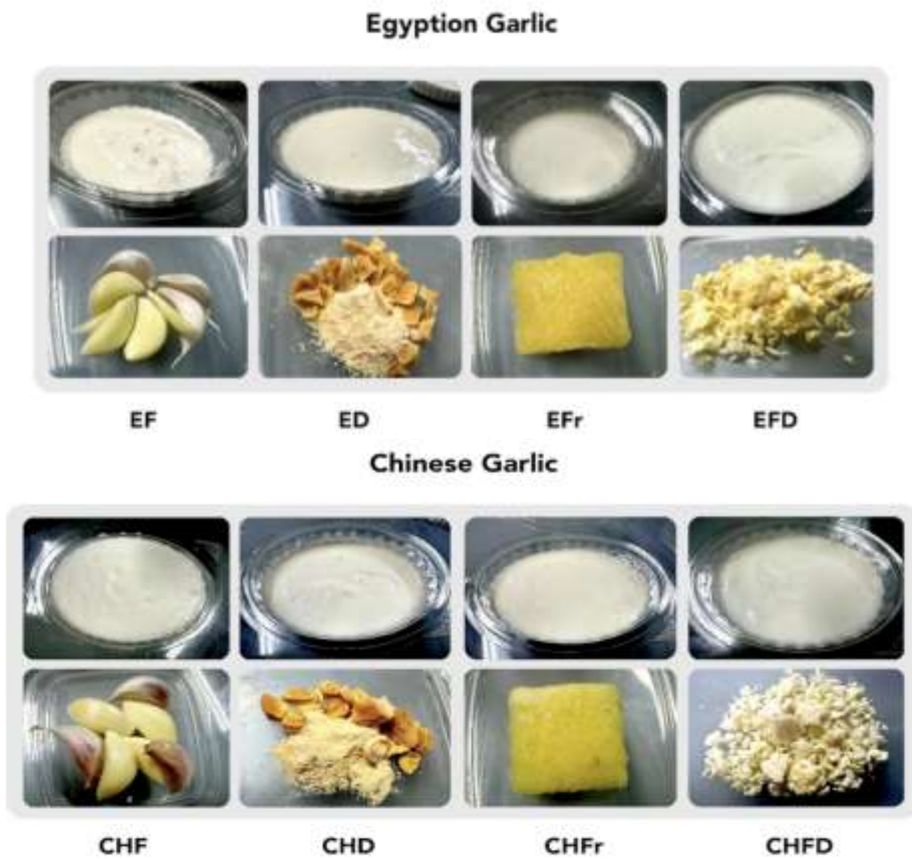

Fig. 1 "Toum Sauce" Prepared with Garlic Treated by Different Preservation Methods

3. Chemical composition

Moisture, total protein, total fat, and ash were analyzed according to the methods described by **AOAC, (2012)** and **AOAC, (2015).** Total dietary fiber (TDF) was determined according to the method described by **AOAC, (2012) and Prosky *et al.*, (1992).** Total carbohydrates were calculated by difference as mentioned by **Abd El-Latif, (1990)** according to the following equation: Total carbohydrates = 100 – [moisture (%) + crude protein (%) + crude fat (%) + ash (%)]. While total energy was calculated as mentioned by **Merrill and Watt, (1955)** according to the following equation: Energy (kcal) = [4 × (g protein + g carbohydrates) + 9 × g fat].

4. Determination of antioxidant activity of garlic and vitamin C

The total phenolic (TPC) and total flavonoid content of "Toum" were determined as described by **Singleton and Rossi, (1965)** and **Brand-Williams *et al.*, (1995)**, respectively**.** The vitamin C content was analyzed according to the methods described by **AOAC (2015).**

5. Determination of pH values

The pH value of all “Toum” samples was measured separately by a digital pH meter (model 3505-JENWAY-UK) after 0 times, 3 days, and 7 days at 4°C, as described in **AOAC (2015).**

6. Sensory evaluation

Sensory evaluation was carried out for different product characteristics: color, odor, degree of chewing, taste, texture, and overall acceptability. Organoleptic evaluation was carried out by 15 well-trained staff members from the Home Economics Department, Faculty of Specific Education, Assiut University, Assiut, Egypt, using a score sheet. All characteristics were evaluated on a 5-degree scale (1 represents very poor and 5 represents very good general acceptability), according to **Penfield and Campbell, (1990)**.

7. Statistical analysis

Statistical analysis was carried out using SAS statistical software; the results were expressed as mean ± SD. Data were analyzed by one-way analysis of variance (ANOVA), with Tukey post hoc testing at $p \leq 0.05$ **(Steel and Torrie, 1980).**

Results and discussion

1. Changes in garlic quality due to preservation

Drying

As presented in **Table (2),** the drying process led to a notable reduction in sample weight, dropping from 100 g to 37 g for Egyptian garlic and to 31 g for Chinese garlic. This highlights the extent of moisture loss associated with this preservation method.

The results showed that dehydrated garlic exhibited reduced bulk and weight, facilitating easier transport and storage. Drying processes effectively removed up to 90% of the water content and reduced transportation costs. However, noticeable quality issues such as poor rehydration capacity, flavor loss, and discoloration were observed, highlighting color and flavor as key quality indicators of dried garlic. Importantly, the drying method significantly influenced these properties. Similarly, **An *et al.*, (2015)** reported that intermittent microwave-convective drying (IM-CD) yielded ginger products with high quality and lower energy consumption. Therefore, selecting the appropriate dehydration technique is critical to achieving optimal sensory and nutritional quality in garlic, as confirmed by **Feng *et al.*, (2021).**

1.2. Freezing

Although freezing was discussed among the preservation techniques, it was not included in **Table (2),** as it does not result in measurable weight loss compared to drying and freeze-drying. Its impact is primarily on sensory and textural qualities rather than mass reduction.

Freezing resulted in the retention of most bioactive compounds during storage. However, thawed garlic showed undesirable quality changes such as softening and deterioration in texture and color. Freezing effectively preserves the freshness-related attributes of foods better than conventional methods such as drying; however, it significantly affects the texture of certain foods, such as garlic Toum during its production. These results comply with **Zhang *et al.*, (2021),** who reported that freezing is useful in overcoming storage and seasonal limitations of garlic; however, once thawed, frozen garlic may undergo undesirable changes such as browning, softening, and deterioration in texture and color.

Freeze-dried

Table 2 demonstrates the significant weight reduction observed after freeze-drying, with Egyptian and Chinese garlic samples decreasing from 100 g to 29 g and 25 g, respectively. This confirms the high moisture removal efficiency of this technique while preserving the overall product integrity.

This method effectively preserves the original sensory attributes of garlic, such as color, aroma, and taste, while minimizing nutrient, flavor, and color degradation. Compared to other drying methods, freeze-drying leads to lower shrinkage and avoids surface hardening, ensuring better product quality. As a result, freeze-dried garlic exhibits excellent storage stability at room temperature and high porosity. Although it significantly extends shelf life and maintains nutritional value, the process remains time-consuming and costly due to its complex heat and mass transfer mechanisms.

Freeze-dried garlic demonstrates clear advantages over other drying methods. Due to the low-temperature dehydration process, it retains most of its natural nutrients, active compounds, color, and aroma. The porous, spongy texture of freeze-dried garlic allows for excellent rehydration without surface hardening. Moreover, it exhibits significantly lower shrinkage compared to fresh or hot-air-dried garlic, and it can be stored at room temperature for extended periods without compromising quality **(Liu *et al.*, 2022).**

Table 2. Weight of Egyptian and Chinese garlic samples pre- and post-drying and freeze-drying

Samples	Pre-drying (g)	Post-drying (g)
Egyptian G	100	37
Chinese G	100	31
	Pre-freeze-drying (g)	**Post freeze-drying (g)**
Egyptian G	100	29
Chinese G	100	25

2- Nutritional composition of garlic samples

Table 3 demonstrates the impact of different preservation methods on the nutritional composition of Egyptian and Chinese garlic. Fresh garlic samples, both Egyptian and Chinese, showed high moisture content (59.23% and 58.50%, respectively). Drying significantly reduced moisture levels to 3.88% in Egyptian garlic and 4.90% in Chinese garlic. In contrast, frozen samples retained higher moisture content, reaching up to 65.94% in frozen Egyptian garlic, indicating minimal water loss during freezing. These findings align with **Singh *et al.*, (2014),** who reported that drying effectively removes water by evaporation and concentrates nutrients, while freezing retains moisture due to preservation of cellular integrity.

Ash content increased notably in the dried samples, particularly in Egyptian and Chinese garlic processed by freeze-drying (4.17% and 4.42%, respectively), reflecting mineral concentration as a result of water removal. This finding is consistent with **Chen and Xu (2022),** who reported that drying enhances ash content by reducing moisture and concentrating the remaining solids. In contrast, frozen samples exhibited moderate ash levels (ranging from 1.26% to 4.42%), indicating less extensive moisture loss.

The crude fat content showed highly significant differences among the samples ($p < 0.01$), ranging from 0.56 ± 0.03% in CHF to 2.96 ± 0.05% in EFD. The highest fat contents were observed in freeze-dried and dried samples, such as EFD (2.96%) and ED (1.76%), while the lowest values were found in fresh samples like CHF (0.56%) and EF (0.59%). In general, dried samples (e.g., CHD, ED) exhibited higher fat levels compared to fresh counterparts. This increase in fat content is primarily attributed to moisture loss during drying and freeze-drying, which concentrates the remaining nutrients, including fats. Additionally, thermal processing may disrupt cellular structures, thereby enhancing the efficiency of fat extraction during proximate analysis.

Dried garlic samples exhibited the highest protein concentrations, with values of 20.19% and 18.90% for Egyptian and Chinese garlic, respectively. Similarly, freeze-dried samples showed elevated protein levels (19.91% and 17.72% for Egyptian and Chinese garlic, respectively). In contrast, fresh and frozen samples had lower protein contents. These findings are consistent with those reported by **Ahmed *et al.*, (2022),** who stated that drying enhances protein concentration due to water removal, whereas freezing preserves structural integrity but does not concentrate nutrients.

Dried garlic samples recorded the highest carbohydrate content and caloric values, reaching 68.82% and 371.9 kcal for Egyptian garlic and 70.57% and 370.7 kcal for Chinese garlic. Freeze-dried samples also showed elevated carbohydrate and energy levels, with 63.21% and 359.1 kcal for Egyptian garlic and 68.60% and 358.8 kcal for Chinese garlic, respectively.

Vitamin C content was highest in dried garlic samples, reaching 3.90 mg/100 g and 3.30 mg/100 g in Egyptian and Chinese garlic, respectively. In contrast, the lowest value was observed in frozen Chinese garlic (0.21 mg/100 g). These findings are consistent with **Wang *et al.*, (2023),** who reported that vitamin C is a heat-sensitive and water-soluble nutrient; while drying under controlled conditions can help retain it, freezing may lead to oxidative degradation over time.

Overall, drying significantly enhanced nutrient concentrations, including proteins, ash, fiber, and vitamin C, while freezing was more effective at preserving moisture but could compromise certain micronutrients, such as vitamin C. The Egyptian garlic variety generally demonstrated superior nutritional quality, particularly when processed by drying.

Table 3. Nutritional comparison of Egyptian and Chinese garlic using different preservation methods (Mean ±SD)

Samples	Moisture (%)	Ash (%)	Crude fat (%)	Protein (%)	Crude fiber (%)	Total carbohydrates (%)	Caloric value (kcal)	Vit. C mg/100g
EF	59.23^{B}±1.6	0.97^{D}±0.08	0.59^{D}±0.02	7.66^{B}±0.2	1.11^{D}±0.2	30.44^{B}±0.5	157.7^{B}±1.6	1.80^{B}±0.1
CHF	58.5^{B}±2.3	1.94^{C}±0.06	0.56^{D}±0.03	7.00^{B}±0.3	0.80^{F}±0.1	31.20^{B}±0.7	157.8^{B}±2.3	1.12^{C}±0.3
ED	3.88^{D}±0.4	3.86^{AB}±0.09	1.76^{B}±0.01	20.19^{A}±0.5	1.49^{B}±0.3	68.82^{A}±0.8	371.9^{A}±4.2	3.90^{A}±0.2
CHD	4.9^{CD}±0.3	2.89^{B}±0.05	1.42^{C}±0.04	18.9^{A}±0.2	1.32^{C}±0.2	70.57^{A}±1.1	370.7^{A}±3.8	3.30^{A}±0.4
EFr	65.94^{A}±1.1	1.26^{D}±0.02	0.65^{D}±0.02	4.88^{C}±0.3	0.60^{F}±0.3	26.67^{B}±0.9	132.1^{C}±2.5	1.60^{B}±0.04
CHFr	59.53^{B}±1.5	1.67^{C}±0.04	0.64^{D}±0.02	5.85^{C}±0.1	0.70^{F}±0.1	31.61^{B}±0.5	155.6^{B}±1.6	0.60^{D}±0.03
EFD	7.27^{C}±0.8	4.17^{A}±0.06	2.96^{A}±0.05	19.91^{A}±0.4	2.48^{A}±0.4	63.21^{A}±0.4	359.1^{A}±5.1	0.74^{D}±0.04
CHFD	6.5^{C}±0.6	4.42^{A}±0.07	1.50^{C}±0.03	17.72^{A}±0.2	1.26^{C}±0.3	68.60^{A}±0.8	358.8^{A}±4.7	0.21^{F}±0.1
Sig	**0.00****	**0.00****	**0.00****	0.01**	**0.00****	**0.03***	**0.02***	**0.00****
F-test	**13.16**	**11.25**	**17.89**	**9.86**	**14.15**	**4.88**	**5.26**	16.98

- Mean of three replicates.
- SD: standard deviation.
- Means with superscript different symbols differed significantly at $p \leq 0.05$ by one-way ANOVA followed by Tukey's post hoc test.
- EF: Egyptian Fresh garlic, CHF: Chinese Fresh garlic, ED: Egyptian Dried garlic, CHD: Chinese Dried garlic, EFr: Egyptian Frozen garlic, CHFr: Chinese Frozen garlic, EFD: Egyptian Freeze-dried garlic, CHFD: Chinese Freeze-dried garlic.
- Total carbohydrate = 100 – (Moisture +Ash+ Crude fat + Protein)
- Energy (kcal) = 4 × (g protein + g carbohydrates) + 9 × (g fat).
- **: Highly significant.

3. Phenolic and flavonoid content in garlic samples

Table 4 and Figure 2 present the effects of different preservation methods on the total phenolic content (TPC) and total flavonoid content (TFC) in Egyptian and Chinese garlic. Fresh Egyptian garlic exhibited the highest phenolic content (830.45 mg/100 g), while fresh Chinese garlic showed a lower level (645.00 mg/100 g). After drying, phenolic content decreased in Egyptian garlic (493.12 mg/100 g) but increased in Chinese garlic (720.71 mg/100 g). This may be due to varietal differences in the phenolic compound profiles and their response to thermal degradation or release during the drying process. In Chinese garlic, drying may have facilitated the release of bound phenolics from the cell matrix, while in Egyptian garlic, thermal sensitivity of certain phenolic compounds could have led to partial degradation.

Freezing led to a substantial rise in phenolic content in Chinese garlic (2439.55 mg/100 g), whereas it decreased in frozen Egyptian garlic (609.89 mg/100 g). Meanwhile, freeze-dried samples recorded a significant increase in total phenolic content, reaching 2010.39 mg/100 g and 2237.45 mg/100 g for Egyptian and Chinese garlic, respectively. The highest flavonoid content was observed in dried Egyptian garlic (313.34 mg/100 g), suggesting that the drying process effectively concentrated flavonoids in this variety. In contrast, freeze-dried samples of both Egyptian and Chinese garlic recorded the lowest flavonoid levels (64.51 mg/100 g and 47.45 mg/100 g, respectively), indicating potential degradation or structural modification of flavonoid compounds caused by freezing stress.

This reduction in flavonoid content may be attributed to the sensitivity of certain flavonoid compounds to extremely low temperatures and the structural stress caused by sublimation during freeze-drying **(Zhang *et al.*, 2023).** Additionally, **Rahmanian *et al.*, (2015)** reported that thermal and physical processing methods can significantly alter the phenolic profile of plant foods, depending on their matrix and structural characteristics. These processes may act as abiotic stressors that either stimulate the synthesis of bioactive compounds or lead to their breakdown.

Furthermore, **Ali *et al.*, (2022)** emphasized that drying conditions, including temperature and exposure time, play a crucial role in flavonoid retention, with certain methods promoting preservation while others lead to degradation.

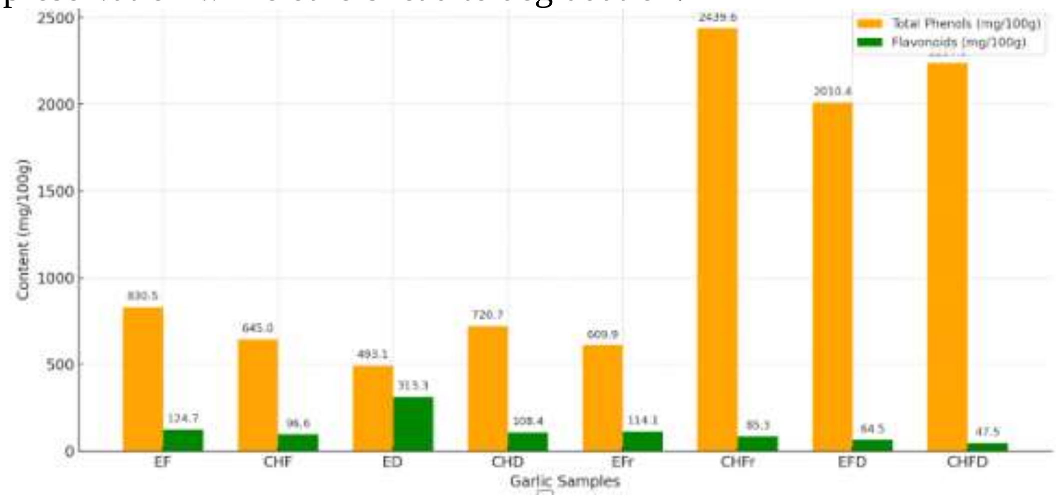

Fig. 2 Total phenolic and flavonoid content in garlic samples

Table 4. Total Phenolic and flavonoid content in garlic samples (Mean ±SD)

Samples	T. phenols (mg/100g)	Flavonoids (mg/100g)
EF	830.5^{D}±2.5	124.7^{B}±1.6
CHF	645.0^{DF}±3.2	96.6^{C}±0.8
ED	493.1^{F}±3.5	313.3^{A}±2.6
CHD	720.7^{DF}±4.2	108.4^{BC}±0.9
EFr	609.9^{F}±5.1	114.1^{B}±1.3
CHFr	2439.6^{A}±7.6	85.27^{C}±0.8
EFD	2010.4^{C}±8.9	64.51^{D}±0.7
CHFD	2237.5^{B}±9.5	47.45^{F}±0.6
Sig	**0.00****	**0.00****
F-test	12.65	16.55

- Mean of three replicates
- SD: standard deviation.
- Means with superscript different symbols differed significantly at $p \leq 0.05$ by one-way ANOVA followed by Tukey's post hoc test.
- EF: Egyptian Fresh garlic, CHF: Chinese Fresh garlic, ED: Egyptian Dried garlic, CHD: Chinese Dried garlic, EFr: Egyptian Frozen garlic, CHFr: Chinese Frozen garlic, EFD: Egyptian Freeze-dried garlic, CHFD: Chinese Freeze-dried garlic.
- **: High significant

4. Sensory evaluation

Tables 5 show the sensory evaluation results of "**Toum Sauce"** using EF, CHF, ED, CHD, EFr, CHFr, EFD, and CHFD over different storage periods (zero time, after 3 days, and after 7 days) and revealed noticeable variations in all tested sensory attributes: color, odor, degree of chewing, taste, texture, and overall acceptability.

At zero time, most samples exhibited acceptable color, except for the ED sample, which recorded a score of 2.71 ± 0.48. However, the color changed over time, particularly in the ED sample, which showed the lowest color scores after 3 and 7 days (2.14 and 1.29, respectively). This decline is attributed to the drying process, which significantly affected the color of Egyptian garlic due to its smaller size. In contrast, Chinese garlic, being larger, was less affected. This observation aligns with the findings of **Samakradhamrongthai and Utama-ang (2018)**, who reported that drying temperature and the physical structure of garlic had a significant impact on color values. Conversely, samples such as CHD, EFD, and CHFD maintained high color scores even after 7 days (>4), indicating the effectiveness of these treatments in preserving color stability. These results are consistent with those reported by **Fante and Noreña (2015),** who found that freeze-dried garlic powder retained a color closer to that of fresh garlic.

There were no significant differences in odor among the samples at zero time, except that dried Egyptian garlic showed statistically significant differences in the first evaluation compared to other samples, likely due to the impact of the drying process on aroma compounds. **Li *et al.,* (2021)** showed that the dry-treated samples presented significant differences in the volatile profile compared with the raw garlic**.** This result is consistent with **González (2017),** who showed that different processing conditions significantly affected the flavor quality of garlic-flavored products.

The odor of fresh Chinese garlic initially received low scores due to its strong, pungent smell, which many panelists found unappealing. However, its odor improved in subsequent evaluations as the pungency decreased. This strong odor is likely due to the high concentration of flavonoids and sulfur compounds, as supported by its chemical composition and antioxidant profile, which differ notably from those of Egyptian garlic. Odor scores declined over storage time, particularly in samples ED, EE, and EF, which showed marked deterioration after 7 days (scores ranged from 1.29 to 2.57). This decline may be due to microbial activity or enzymatic degradation of sulfur-containing volatile compounds. In contrast, samples such as CHFD and EFD maintained better odor scores (4.29 and 3.29, respectively), indicating delayed spoilage. These results align with **Fante and Noreña (2015),** who reported that one of the advantages of freeze-drying foods and biological materials is the preservation of flavor and reduced structural damage.

In terms of chewing, the samples did not record any significant differences during the three sensory evaluations. This consistency reflects the effectiveness of the manufacturing process and the successful formation of a stable emulsion. Emulsion stability refers to the ability of a food emulsion to resist any change in its physicochemical properties over time **(McClements and David, 2004).** The types of instability that cause the breakdown of emulsions that exist in food emulsions include sedimentation, coalescence, flocculation, Ostwald ripening, creaming, etc. **(Awuchi *et al.*, 2019).**

There were no significant differences in taste among the samples at zero time, except that dried Egyptian garlic showed statistically significant differences in the first evaluation (2.57±0.53) compared to other samples (4.43±0.53 to 4.86±0.37), due to the impact of the drying process on aroma compounds. The findings of **Feng *et al.*, (2021)** reported that drying garlic led to the loss of some volatile compounds and the formation of new ones. This might be related to the chemical reactions enhanced due to the drying process, such as the Maillard reaction, the interaction between different molecules, and the degradation of macromolecules **(Guo *et al.*, 2018)**. Fresh Chinese garlic also recorded a low score, likely due to its strong, pungent taste that was initially unappealing to panelists. However, its taste improved in subsequent evaluations as the pungency decreased.

A significant decline in taste was observed over the storage period, particularly in samples ED and EF, which recorded scores as low as 1.00 after 7 days. This deterioration was likely due to the development of off-flavors resulting from lipid oxidation or the degradation of sulfur-containing compounds. These findings are consistent with those of **Nijssen, (2017).** Samples such as CHHF, CHD, and EFD maintained relatively high taste scores (>4), reflecting better flavor stability. Freeze-drying could preserve some original volatile substances of fresh garlic compared to thermal drying techniques. These findings were consistent with those reported earlier **(An *et al.*, 2015, and Li *et al.*, 2019).**

There were no significant differences in texture among the samples at zero time, except for the frozen Egyptian and Chinese garlic, which recorded lower scores (3.43 ± 0.44 and 3.57 ± 0.53, respectively) compared to the other samples. Over the storage period, texture scores declined, particularly in samples ED, CHD, EFr, and CHFr, which recorded values of 2.43 ± 0.53, 3.29 ± 0.48, 1.00 ± 0.00, and 2.14 ± 0.37, respectively, after 7 days. Texture changes are likely related to moisture loss or protein breakdown. These results agree with **Lewicki (2006),** who found that dehydration produces shrinkage and may negatively affect the rehydration ability of dehydrated vegetables. This is due to a series of factors related to physical and physicochemical changes occurring in the tissues **(Krokida and Maroulis, 1997)** and also to chemical changes that might affect saccharides and proteins **(Soria *et al.*, 2010)**. On the other hand, samples EF, CHF, EFD, and CHFD maintained acceptable texture values (above 4), indicating better physical integrity.

Overall acceptability reflects the general perception of quality. At day 0 and day 3, all samples had high acceptability scores, but a sharp decrease was observed in samples EF, ED, EFr, and CHFr after 7 days (2.71±0.48, 1.57, 1.43±0.53, and 1.57±0.53, respectively), indicating unsatisfactory sensory quality. However, CHF, CHD, EFD, and CHFD retained scores above 3.2, suggesting acceptable retention of sensory quality over time.

Analysis of variance (F-test) showed highly significant differences ($P < 0.01$) among the samples, indicating that both storage duration and treatment type had a considerable impact on sensory quality. Samples treated with preservation methods maintained better sensory quality over time. The storage period significantly affected sensory properties, especially after 7 days. Products like CHF, CHD, EFD, and CHFD showed the highest stability in color, taste, texture, and overall acceptability. In contrast, EF, ED, EFr, and CHFr demonstrated rapid sensory degradation and were less acceptable after 7 days.

Table 5. Sensory evaluation of Toum Sauce samples using Egyptian and Chinese garlic (fresh, dried, frozen, freeze-dried) after 0 time, 3 days, and 7 days.

Samples	After 0 time					
	Characteristics					
	Color	Odor	Degree of chewing	Taste	Texture	Overall acceptability
EF	5.00 ± 0.0^{A}	4.57 ± 0.53^{A}	4.71 ± 0.48^{A}	4.86 ± 0.37^{A}	4.71 ± 0.48^{A}	5.00 ± 0.0^{A}
CHF	4.57 ± 0.53^{A}	3.71 ± 0.38^{B}	4.71 ± 0.48^{A}	3.86 ± 0.37^{AB}	4.86 ± 0.37^{A}	4.26 ± 0.48^{A}
ED	2.71 ± 0.48^{B}	2.71 ± 0.48^{BC}	4.29 ± 0.49^{A}	2.57 ± 0.53^{B}	4.57 ± 0.53^{A}	3.0 ± 0.00^{BC}
CHD	4.71 ± 0.49^{A}	4.10 ± 0.54^{A}	4.57 ± 0.54^{A}	4.43 ± 0.53^{A}	4.43 ± 0.53^{A}	4.57 ± 0.54^{A}
EFr	4.43 ± 0.53^{A}	4.22 ± 0.53^{A}	3.57 ± 0.43^{B}	4.57 ± 0.53^{A}	3.43 ± 0.44^{B}	3.39 ± 0.48^{B}
CHFr	4.86 ± 0.37^{A}	4.43 ± 0.53^{A}	4.71 ± 0.48^{A}	4.43 ± 0.53^{A}	3.57 ± 0.53^{B}	3.71 ± 0.48^{B}
EFD	4.71 ± 0.48^{A}	4.45 ± 0.53^{A}	4.57 ± 0.53^{A}	4.71 ± 0.48^{A}	4.86 ± 0.37^{A}	4.71 ± 0.48^{A}
CHFD	4.71 ± 0.48^{A}	4.43 ± 0.53^{AB}	4.71 ± 0.48^{A}	4.86 ± 0.37^{A}	4.57 ± 0.53^{A}	4.71 ± 0.48^{A}
F-test	8.60**	5.06**	7.36**	8.21**	20.69**	12.83**

After 3 days						
Samples	Color	Odor	Degree of chawing	Taste	Texture	Overall acceptability
EF	4.71 ± 0.76^{A}	3.71 ± 0.48^{AB}	4.43 ± 0.53^{A}	4.29 ± 0.53^{A}	4.57 ± 0.53^{A}	4.29 ± 0.48^{A}
CHF	4.71 ± 0.48^{A}	4.57 ± 0.53^{A}	4.57 ± 0.53^{A}	4.71 ± 0.48^{A}	4.71 ± 0.48^{A}	4.86 ± 0.37^{A}
ED	2.14 ± 0.37^{B}	2.57 ± 0.53^{B}	3.86 ± 0.37^{A}	2.00 ± 0.57^{C}	3.57 ± 0.53^{AB}	2.71 ± 0.48^{BC}
CHD	4.71 ± 0.49^{A}	3.29 ± 0.48^{B}	4.43 ± 0.54^{A}	4.29 ± 0.48^{A}	4.29 ± 0.48^{A}	4.29 ± 0.48^{A}
EFr	4.29 ± 0.48^{A}	3.29 ± 0.47^{B}	2.43 ± 0.52^{B}	3.57 ± 0.53^{AB}	2.01 ± 0.42^{C}	2.43 ± 0.53^{C}
CHFr	4.43 ± 0.53^{A}	4.57 ± 0.53^{A}	4.57 ± 0.53^{A}	4.29 ± 0.48^{A}	2.29 ± 0.48^{C}	3.43 ± 0.53^{B}
EFD	4.57 ± 0.53^{A}	4.31 ± 0.53^{A}	4.57 ± 0.53^{A}	4.57 ± 0.53^{A}	4.57 ± 0.53^{A}	4.43 ± 0.53^{A}
CHFD	4.57 ± 0.53^{A}	4.29 ± 0.48^{A}	4.57 ± 0.53^{A}	4.71 ± 0.48^{A}	4.29 ± 0.48^{A}	4.57 ± 0.53^{A}
F-test	18.60**	13.55**	14.59**	21.96**	43.28**	22.92**

After 7 days						
Type of garlic	Color	Odor	Degree of chawing	Taste	Texture	Overall acceptability
EF	3.86 ± 0.37^{B}	2.57 ± 0.53^{B}	3.24 ± 0.37^{B}	1.00 ± 0.00^{B}	4.00 ± 0.00^{A}	2.71 ± 0.48^{AB}
CHF	3.57 ± 0.53^{B}	3.0 ± 0.00^{B}	3.14 ± 0.37^{B}	2.29 ± 0.48^{A}	4.43 ± 0.53^{A}	3.43 ± 0.53^{A}

ED	1.29±0.48^{C}	1.29±0.48^{D}	2.86±0.37^{B}	1.00±0.00^{B}	2.43±0.53^{C}	1.57±0.53^{B}
CHD	4.43±0.53^{A}	3.14±0.37^{B}	4.71±0.48^{A}	2.14±0.53^{A}	3.29±0.48^{B}	3.29±0.48^{A}
EFr	4.14±0.37^{A}	2.29±0.48^{C}	3.00±0.00^{B}	1.29±0.48^{B}	1.00±0.00^{D}	1.43±0.53^{B}
CHFr	4.43±0.53^{A}	4.29±0.48^{A}	4.29±0.48^{A}	1.43±0.53^{B}	2.14±0.37^{C}	1.57±0.53^{B}
EFD	4.43±0.53^{A}	3.29±0.48^{B}	4.43±0.53^{A}	1.43±0.53^{B}	4.29±0.48^{A}	3.02±0.37^{A}
CHFD	4.43±0.53^{A}	3.0±0.00^{B}	4.43±0.53^{A}	1.71±0.48^{AB}	4.29±0.48^{A}	3.14±0.69^{A}
F-test	33.07**	30.26**	58.17**	9.08**	61.92**	15.86**

- SD: standard deviation.
- Means with superscript different symbols differed significantly at *p≤0.05* by one-way ANOVA followed by Tukey's post hoc test.
- EF: Egyptian Fresh garlic, CHF: Chinese Fresh garlic, ED: Egyptian Dried garlic, CHD: Chinese Dried garlic, EFr: Egyptian Frozen garlic, CHFr: Chinese Frozen garlic, EFD: Egyptian Freeze-dried garlic, CHFD: Chinese Freeze-dried garlic.
- **: Highly significant.

5. pH Variation in Toum Sauce made from preserved Egyptian and Chinese garlic

Table 6 summarizes the pH values of Toum Sauce samples prepared using Egyptian and Chinese garlic subjected to different preservation methods (fresh, dried, frozen, and freeze-dried) over three storage intervals: at 0 time (fresh), after 3 days, and after 7 days.

A gradual decline in pH was observed across most garlic samples during storage. The fresh Chinese garlic showed the highest initial pH (4.85), while the freeze-dried Egyptian garlic reached the lowest after 7 days (3.88). This pronounced decrease in dried samples is likely due to compositional changes during dehydration and enzymatic conversion of sulfur compounds like alliin into mildly acidic molecules such as allicin **(Amagase, 2006, and Borlinghaus *et al.*, 2014).**

Frozen samples (Egyptian and Chinese) maintained relatively stable pH values (4.46 – 4.27), indicating that freezing helped preserve acidity by suppressing enzymatic and biochemical reactions **(Leistner and Gorris, 1995).** Freeze-dried garlic exhibited a moderate pH decrease (4.24 – 3.88), especially in Egyptian samples, which may relate to sulfur compound profiles or microbial load influenced by pre-harvest conditions **(Krinjar and Nemet, 2009).**

Although moderate acidification improves microbial safety, excessively low pH (<3.9) can negatively impact sensory attributes, while pH >4.6 may increase spoilage risk and support Clostridium botulinum growth under anaerobic conditions **(Ray and Bhunia, 2013).**

Interestingly, despite pH changes, the overall spoilage pattern was not strongly correlated with pH values. The formulation's low water activity, high oil content, and inclusion of lemon and salt likely limited microbial acid production. Instead, sensory deterioration, such as off-flavor or odor, was more likely due to enzymatic degradation in garlic or the activity of spoilage microbes that release volatile compounds rather than acids **(Sobhan *et al.*, 2022).**

Table 6. pH Variation in Toum Sauce made from preserved Egyptian and Chinese garlic

Samples	pH (fresh: 0 times)	pH (after 5 days)	pH (after 7 days)
EF	4.49	4.24	4.15
CHF	4.85	4.31	4.20
ED	4.83	4.48	4.30
CHD	4.34	4.06	3.95
EFr	4.46	4.46	4.35
CHFr	4.36	4.35	4.27
EFD	4.24	3.97	3.88
CHFD	4.63	4.12	4.00

- EF: Egyptian Fresh garlic, CHF: Chinese Fresh garlic, ED: Egyptian Dried garlic, CHD: Chinese Dried garlic, EFr: Egyptian Frozen garlic, CHFr: Chinese Frozen garlic, EFD: Egyptian Freeze-dried garlic, CHFD: Chinese Freeze-dried garlic.

Conclusion

This study confirmed that the method of preservation significantly affects the quality of garlic when used in Toum Sauce. Freeze-drying was the most effective technique, maintaining high nutritional value (especially vitamin C and phenolics) and preserving sensory properties like color, taste, and texture during storage. Drying improved the concentration of protein, fat, and fiber but caused a reduction in pH stability. Egyptian garlic had higher nutritional content, while Chinese garlic showed better sensory quality, especially after drying or freeze-drying. In summary, freeze-drying is the best method for producing high-quality garlic-based products with longer shelf life and better consumer acceptance.

References

Abd El-Latif, B. M. (1990). Improvement of some bakery products (Doctoral dissertation). Faculty of Agriculture, Zagazig University, Moshtohor, Egypt.

Ahmed, M.; Khan, A.; Farooq, S. and Nadeem, M. (2022). *Protein retention in processed garlic*. Journal of Food Processing and Preservation**,** 46(2), e16247.

Ali, M., Khan, F. and Ahmad, N. (2022). Effect of thermal processing on the phytochemical composition of garlic. Food Chemistry Advances, 1, 100032.

Amagase, H. (2006). Clarifying the real bioactive constituents of garlic. *Journal of Nutrition*, *136*(3 Suppl), 716S–725S.

Ambros, S., Bauer, S. A. W., Shylkina, L., Foerst, P. and Kulozik, U. (2016). Microwave-vacuum drying of lactic acid bacteria: influence of process parameters on survival and acidification activity. Food and Bioprocess Technology, 9(11), 1901-1911.

An, K., Zhao, D., Wang, Z., Wu, J., Xu, Y. and Xiao, G. (2015). Comparison of different drying methods on Chinese ginger (Zingiber officinale Roscoe): Changes in volatiles, chemical profile, antioxidant properties, and microstructure. *Food Chemistry*, *197*, 292–1300.

Ao Shang, X., Xu, X.-Y., Gan, R.-Y., Tang, G.-Y., Corke, H., Mavumengwana, V. and Li, H.-B. (2019). Bioactive Compounds and Biological Functions of Garlic (Allium sativum L.) . *Foods* 2019, *8*(7), 246.

AOAC. (2012). *AOAC official methods of analysis* (18th ed.). AOAC International.

AOAC. (2015). *Official methods of analysis of Association of Official Analytical Chemists*. AOAC.

Awuchi, C. G., Igwe, V. S. and Echeta, C. K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research*, *5*(11), 139-160.

Bo, R., Ji, X., Yang, H., Liu, M. and Li, J. (2021). The characterization of optimal selenized garlic polysaccharides and its immune and antioxidant activity in chickens. International journal of biological macromolecules, 182, 136-143.

Borlinghaus, J., Albrecht, F., Gruhlke, M. C. H., Nwachukwu, I. N. and Slusarenko, A. J. (2014). Allicin: Chemistry and biological properties. *Molecules, 19*(8), 12591–12618.

Brand-Williams, W., Cuvelier, M. E. and Berset, C. (1995). Use of a free-radical method to evaluate antioxidant activity. *LWT - Food Science and Technology, 28*, 25–30.

Bravo-Núñez, Á., Golding, M., McGhie, T. K., Gómez, M. and Matía-Merino, L. (2019). Emulsification properties of garlic aqueous extract. *Food Hydrocolloids, 93*, 111–119.

Chen, Y. and Xu, B. (2022). Mineral retention in thermally processed garlic. *Journal of Food Composition and Analysis, 109*, 104478.

Evans, J. A. (Ed.). (2009). Frozen food science and technology. *John Wiley & Sons*.

Fante, L. and Noreña, C. P. Z. (2015). Quality of hot air dried and freeze-dried garlic (Allium sativum L.). *Journal of Food Science and Technology, 52*, 211–220.

Feng, Y., Xu, B., Yagoub, A. E. A., Ma, H., Sun, Y., Xu, X. and Zhou, C. (2021). Role of drying techniques on physical, rehydration, flavor, bioactive compounds and antioxidant characteristics of garlic. *Food Chemistry, 343*, 128404.

Figiel, A. (2009). Drying kinetics and quality of vacuum-microwave dehydrated garlic cloves and slices. *Journal of Food Engineering*, *94*(1), 98-104.

González, R., Vidoni, M., Locatelli, D. and Camargo, A. (2017). Quality evaluation and discrimination of flavouring process of garlic-flavoured vegetable oils. *International Journal of Food Properties, 20*(sup1), S1016–S1024.

Guo, Y., Chen, D., Dong, Y. F., Ju, H. P., Wu, C. and Lin, S. Y. (2018). Characteristic volatiles fingerprints and changes of volatile compounds in fresh and dried Tricholoma matsutake Singer by HS-GC-IMS and HS-SPME-GC–MS. Journal of Chromatography B, 1099, 46-55.

Hassan M.A., El-Tohamy M.A. and Mohamed A.A.A. (2011). Response of garlic cultivated in alkaline soil to foliar application of some plant nutritive compounds. Egypt. J. of Appl. Sci., 26(5), 113-123.

James, C., Reitz, B. and James, S. J. (2015). The freezing characteristics of garlic bulbs (Allium sativum L.) frozen conventionally or with the assistance of an oscillating weak magnetic field. *Food and bioprocess technology*, *8*, 702-708.

Jiang, N., C., Liu, D., Li, Z., Zhang, C., Liu, D., Wang, L., Niu, and Zhang, M. (2017). Evaluation of freeze drying combined with microwave vacuum drying for functional okra snacks: Antioxidant properties, sensory quality, and energy consumption. LWT - Food Science and Technology 82:216–226. doi: 10.1016/j.lwt.2017.04.015.

Krinjar, M. and Nemet, N. (2009). Antimicrobial effects of spices and herbs essential oils. *Acta Periodica Technologica, 40*, 195–209.

Krokida, M. K. and Maroulis, Z. B. (1997). Effect of drying method on shrinkage and porosity. *Drying Technologies*, 15, pp. 2441–2458. 18.

Leistner, L. and Gorris, L. G. M. (1995). *Food preservation by hurdle technology.*Trends in Food Science & Technology, 6(2), 41–46.

Lewicki, P. P. (2006). Design of hot air drying for better foods. *Trends in Food Science & Technology, 17,* 153–163.

Li, K., Zhan, P., Tian, H., Wang, P. and Ji, Y. (2021). Effects of drying time on the aroma of garlic (Allium sativum L.) seasoning powder. *Flavour and Fragrance Journal, 36*(1), 99–110.

Li, L. L., Zhang, M. and Bhandari, B. (2019). Influence of drying methods on some physicochemical, functional and pasting properties of Chinese yam flour. *LWT - Food Science and Technology, 111,* 182–189.

Liu, Y., Zhang, Z. and Hu, L. (2022). High efficient freeze-drying technology in food industry. *Critical Reviews in Food Science and Nutrition*, *62*(12), 3370-3388.

Lopez-Alt, J. K. (2022). Toum (Garlic Sauce) Recipe – The Science Behind Emulsion Failures. *Serious Eats*. https://www.seriouseats.com/traditional-toum-garlic-sauce-recipe

McClements, D. J. (2004). Food emulsions: Principles, practices, and techniques (2nd ed.). *Taylor & Francis.* pp. 269–. ISBN 978-0-8493-2023-1.

Merrill, A. L. and Watt, B. K. (1955). *Energy value of foods: Basis and derivation* (No. 74). Human Nutrition Research Branch, Agricultural Research Service, US Department of Agriculture.

Monteiro, C. A., Levy, R. B., Claro, R. M., Castro, I. R. and Cannon, G. (2010). A new classification of foods based on the extent and purpose of their processing. *Cadernos de Saúde Pública, 26*(11), 2039–2049.

Nijssen, B. (2017). Off-flavors. In *Volatile compounds in foods and beverages* (pp. 689–735). Routledge.

Olaimat, A. N., Al-Holy, M. A., Abu Ghoush, M. H., Abu Hilal, H. M., Al-Nabulsi, A. A., Osaili, T. M. and Rasco, B. A. (2020). Population dynamics of Salmonella spp. and Shigella spp. in ready-to-eat Mediterranean vegetable salads. *Journal of Food Safety, 40*(1), e12734.

Penfield, M. P. and Campbell, A. M. (1990). *Experimental food science* (3rd ed., pp. 452–470). Academic Press.

Prosky, L., Asp, N. G., Schweizer, T. F., DeVries, J. W. and Furda, I. (1992). Determination of insoluble and soluble dietary fiber in foods and food products: Collaborative study. *Journal of AOAC International*, *75*, 360–367.

Rahman, M. S., Sablani, S. S., Al-Habsi, N., Al-Maskri, S. and Al-Belushi, R. (2005). State diagram of freeze-dried garlic powder by differential scanning calorimetry and cooling curve methods. Journal of Food Science, 70(2), E135-E141.

Rahmanian, N., Hosseinpour, F. E. and Jafari, S. M. (2015). The influence of drying techniques on phenolic content and antioxidant activity of fruits and vegetables: A review. *Journal of Food Science and Technology, 52*(4), 2010–2021. https://doi.org/10.1007/s13197-013-1127-6

Rajabhuvaneswari, A., Albert, V. R. and Je, S. (2022). An overview of food preservation using conventional and modern methods. *Journal of Food and Nutrition Sciences, 10*(3), 70–79.

Ray, B. and Bhunia, A. (2013). *Fundamental food microbiology* (5th ed.). CRC Press.

Samakradhamrongthai, R. S. and Utama-ang, N. (2018). Effect of drying condition of Thai garlic (Allium sativum L.) on physicochemical and sensory properties. *International Food Research Journal, 25*(4), 1365–1372.

Singh, P., Amar, S., Jaivir, S., Singh, S., Arya, A. M. and Singh, B. R. (2014). Effect of drying characteristics of garlic: A review. *Journal of Food Processing & Technology, 5*(4). https://doi.org/10.4172/2157-7110.1000317.

Singleton, V. L. and Rossi, J. A. Jr. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture, 16*, 144–158.

Sobhan, A., Muthukumarappan, K., & Wei, L. (2022). A biopolymer-based pH indicator film for visually monitoring beef and fish spoilage. *Food Bioscience, 46*, 101523.

Soria, A. C., Corzo-Martínez, M., Montilla, A., Riera, E., Gamboa-Santos, J. and Villamiel, M. (2010). Chemical and physicochemical quality parameters in carrots dehydrated by power ultrasound. *Journal of Agricultural and Food Chemistry, 58*, 7715–7722.

Steel, R. G. D. and Torrie, J. H. (1980). Principles and procedures of statistics: a biometrical approach. 2nd ed. New York: McGrawHill, 633 p.

Wang, X.; Liu, Y.; Zhang, L. and Zhao, H. (2023). *Impact of freezing and drying on vitamin C in garlic*. LWT - Food Science and Technology, 180, 115522.

Zhang, B., Qiu, Z., Zhao, R., Zheng, Z., Lu, X. and Qiao, X. (2021). Effect of blanching and freezing on the physical properties, bioactive compounds, and microstructure of garlic (Allium sativum L.). *Journal of Food Science*, *86*(1), 31-39.

Zhang, Y., Wang, X. and Li, Q. (2023). Impact of processing on phenolic and flavonoid stability in Allium vegetables: A comparative study. Journal of Functional Foods, 105, 105712.

Zhou, L., Guo, X., Bi, J., Yi, J., Chen, Q., Wu, X. and Zhou, M. (2017). Drying of garlic slices (Allium sativum L.) and its effect on thiosulfinates, total phenolic compounds and antioxidant activity during infrared drying. *Journal of Food Processing and Preservation*, *41*(1), e12734.