Effects of temperature on the quality of black garlic

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Abstract

BACKGROUND: Black garlic is a type of garlic product that is generally produced by heating raw garlic at high temperature with controlled humidity for more than 30 days. Black garlic has appeared on the market for many years. It is crucial to investigate the characteristics of quality formation of black garlic during processing at various temperatures.

RESULTS: In this study, fresh garlic was processed to black garlic at temperatures of 60, 70, 80 and 90 °C. Moisture, amino acid nitrogen and allicin contents decreased gradually during thermal processing of various temperatures. Reducing sugar, 5-hydroxymethylfurfural, total phenols, total acids content and browning increased. The changing rate of quality indicators and flavour of black garlic varied at different temperatures. Browning intensity reached about 74 when black garlic aged. The sensory score was significantly higher in black garlic aged at 70 °C (39.95 ± 0.31) compared with that at other temperatures, suggesting that 70 °C might facilitate formation of good quality and flavour of black garlic during processing.

CONCLUSION: Temperature had a remarkable impact on the quality and flavour of black garlic.

Keywords: black garlic; temperature; quality; flavour; processing

INTRODUCTION

Garlic (Allium sativum L.) is a species of the onion genus. It has been used widely both as a culinary seasoning and a medical herb throughout history.1 Garlic could promote appetite and help digestion. The main effective components in garlic are organosulfur compounds and bioactive enzymes. Among these, allicin is well known for its pharmacological properties, including anti-bacterial, anti-hyperlipidaemia, anti-tumour and immuno-regulatory activity.2

Although garlic has been widely used as one of the popular seasonings for food and medicinal purpose in China, Korea and America, consumption of raw garlic is limited due to its unpleasant odour and taste. The unpleasant odour and taste could be removed by heat treatment. Also, by this way, the palatability of garlic could be improved.3 Accordingly, heating treatment has been widely used to process black garlic to improve the flavour and quality of garlic, and further endow garlic with new functions.4,5

When garlic is heated, its bioactive aspects are changed.3 Alliin and deoxidised alliin are decomposed to allyl sulfur-containing compounds, and some sulfur-containing compounds in thermal degradation have a fragrant smell.6 In fermented garlic much of odorous smell from fresh garlic is removed and many sulfur-containing compounds are formed, which contribute to health benefits. Through the heating process, unstable and unpleasant compounds in raw garlic are converted into stable and tasteless compounds. As a result, black garlic generally has a sweet–sour flavour instead of the offensive odour and taste.5,7 Moreover, black garlic does not cause abdominal pain or other gastrointestinal problems.8 It is reported that black garlic has stronger antioxidant activity than fresh garlic,5,9,10 and better efficacy in preventing metabolic diseases and alcoholic hepatotoxicity.11,12 Moreover, the heating process could lead to non-enzymatic browning reactions, for example the Maillard reaction, caramelisation and the chemical oxidation of phenols. Non-enzymatic browning reactions can give black garlic a typical dark brown colour, and lead to the formation of some antioxidant compounds.13–17

In recent years, many studies have been conducted to investigate the bioactive compounds in black garlic (i.e. total phenols, 5-hydroxymethylfurfural) and their functional activities. However, limited information is available regarding changes in the quality indicator content of black garlic and the characteristic of quality formation during thermal processing. The purpose of this study was to measure the content of quality indicators in the black garlic during processing with different temperatures. These results might contribute to our understanding the role of temperature in the quality formation of black garlic.

EXPERIMENTAL

Chemicals and materials

Garlic (Allium sativum L.) was purchased from Laiwu (Shandong, China). Fresh garlic was converted to black garlic by heating in a drying oven for several days at 60, 70, 80 and 90 °C with 80%
Reagents used in the study were as follows: potassium ferrocyanide, zinc acetate, sodium hydroxide, zinc sulfate, barbituric acid, sodium carbonate, glacial acetic acid, glucose, phenol, sodium hydrogen sulfate, isopropanol, formaldehyde, diethyl ether, methanol, trichloroacetic acid and were purchased from Kaitong Chemical Technology Co., Ltd (Tianjin, China). Potassium sodium tartrate was obtained from Yongda Chemical Reagent Co., Ltd (Tianjin, China). 3,5-Dinitrosalicilic acid was obtained from Lanji Technology Co., Ltd (Shanghai, China). Folin–Ciocalteu reagent was purchased from Solarbio Science & Technology Co., Ltd (Beijing, China). Gallic acid was purchased from Baishi Chemical Industry Co., Ltd (Tianjin, China). 5-Hydroxymethylfurfural (HMF) was purchased from Sigma (St Louis, MO, USA). 4-Methylaniline was purchased from Jin Shanting new chemical reagent factory (Shanghai, China). Alliin (> 99% purity) was obtained from Xinxing Allexin Pharmacy Co., Ltd (Urumqi, China). All other chemicals used in this work were of analytical grade, and all solutions were prepared with distilled water.

Sensory evaluation

Non-professional evaluators (30 people) who acknowledged the quality attributes of black garlic well were randomly chosen to carry out a quality evaluation of black garlic. Every garlic sample was evaluated in terms of the following characteristics: colour, flavour, texture, taste quality and general acceptability. Each characteristic was assessed on an 11-point scale, i.e. a midpoint of ‘5’, the highest score of sensory evaluation of black garlic was considered as the score of sensory evaluation. We chose the optimal processing condition concerning temperature and time on the basis of the highest score of sensory evaluation of black garlic.

Browning intensity

A colorimeter (CM-700d; Konica Minolta, Tokyo, Japan) was used to measure the colour attributes of samples. Before the determinations, the colorimeter should be calibrated by using a standard white reflector plate. The standard values appeared as L (whiteness), a (red–green), and b (yellow–blue) values.

Browning intensity (ΔE) was calculated as $\Delta E = (\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2$, where $\Delta L = L - L'$, $\Delta a = a - a'$, and $\Delta b = b - b'$. L, a, and b represent the colours of the samples; and $L'$, $a'$, and $b'$ represent the colours of the base at time zero.

Measurement of reducing sugar content

The heated garlic sample (5 g) was chopped, ground and diluted with distilled water, then transferred to a 100 mL volumetric flask with distilled water. The solution was extracted by using ultrasound for 30 min, allowed to stand for a moment, and then filtered. The filtrates (2 mL) were dissolved in 60 mL of distilled water, and put in a beaker. A glass electrode of a pH meter was put into the mixture, which was stirred using a magnetic stirrer. The solution was titrated to pH 8.2 with 0.05 mol L\(^{-1}\) NaOH, and the amount of NaOH solution consumed was recorded. Then, formaldehyde (10 mL) was added to the mixture. NaOH solution (0.05 mol L\(^{-1}\)) was used to titrate the mixture to pH 9.2. The amount of consumed NaOH solution was recorded. Distilled water (80 mL) served as a blank group. The amount of NaOH solution consumed was used to calculate the amino acid nitrogen content and the total acids content.

Determination of amino acid nitrogen content and total acids content

The heated garlic sample (5 g) was chopped, ground and transferred to a 100 mL volumetric flask with distilled water. The solution was extracted by using ultrasound for 30 min, allowed to stand for a moment, and then filtered. The filtrates (20 mL) were dissolved in 60 mL of distilled water, and put in a beaker. A glass electrode of a pH meter was put into the mixture, which was stirred using a magnetic stirrer. The solution was titrated to pH 8.2 with 0.05 mol L\(^{-1}\) NaOH, and the amount of NaOH solution consumed was recorded. Then, formaldehyde (10 mL) was added to the mixture. NaOH solution (0.05 mol L\(^{-1}\)) was used to titrate the mixture to pH 9.2. The amount of consumed NaOH solution was recorded. Distilled water (80 mL) served as a blank group. The amount of NaOH solution consumed was used to calculate the amino acid nitrogen content and the total acids content.

Determination of 5-hydroxymethylfurfural content

The heated garlic sample (10 g) was chopped, ground and diluted with distilled water, and then transferred to a 100 mL volumetric flask which contained 2 mL of potassium ferrocyanide solution (150 g L\(^{-1}\), w/v) and 2 mL of zinc sulfate solution (300 g L\(^{-1}\), w/v). The mixture was extracted by using ultrasound for 30 min, allowed to stand for a moment, and then filtered. The filtrates (2 mL) were added to two tubes containing 5 mL of 4-methylaniline solution (60 g L\(^{-1}\), w/v) respectively. Distilled water (1 mL) (blank solution) was added to one tube and 1 mL of barbituric acid solution (5 g L\(^{-1}\), w/v) (sample solution) was added to the other tube. The absorbance of the solution was determined immediately at 550 nm.

Measurement of total phenols content

The heated garlic sample (5 g) was chopped, ground and diluted with distilled water, and then transferred to a 100 mL volumetric flask with distilled water. The solution was extracted by using ultrasound for 30 min, allowed to stand for a moment, and then filtered. Folin–Ciocalteu reagent (1.5 mL of sodium carbonate solution (100 g L\(^{-1}\), w/v) and 7.5 mL of distilled water were mixed in a 10 mL volumetric flask. The mixture was incubated at 75 \(^\circ\)C for 10 min, and then placed in darkness for 2–3 h. The absorbance of the solution was measured at 760 nm.

Analysis of allicin content

The reduced amount of alliin was used to calculate the allicin content. An alliin standard solution (0.45 g L\(^{-1}\)) 10 mL was prepared and analysed by HPLC. The HPLC column was an Atlantis C\(_{18}\) column, 5 \(\mu\)m, 4.6 mm \(\times\) 250 mm. The detection wavelength was 214 nm. The mobile phase was methanol–water (60:40, v/v) at a flow rate of 0.8 mL min\(^{-1}\). Alliinase solution (1 mL) was added to the alliin standard solution. After reaction for 10 min at 35 \(^\circ\)C, trichloroacetic acid (100 g L\(^{-1}\), w/v) 1 mL was added to the solution quickly. The residual alliin content was determined. Diethyl ether (20 mL) was used to extract the generated allicin three times. The extracts were combined and evaporated under nitrogen, and then 2 mL of methanol was used for redissolving the extracts. The mixture was filtered and 10 \(\mu\)L of test solution was injected into the HPLC system for analysis. The amount of allicin (in micrograms) was calculated as follows:

$$\text{w}_{\text{alli}} = \frac{(w_{\text{alli}} - w_{\text{res.alli}}) \times MW_{\text{alli}}}{2 \times MW_{\text{alli}}}$$

where $w_{\text{alli}}$ is the alliin content, $w_{\text{res.alli}}$ is the residual alliin content, and $MW_{\text{alli}}$ is the molecular weight of alliin.
analyses of data were performed using SPSS software version 18.0. Differences among means at different temperatures of 60, 70, 80, and 90 °C were statistically significant (P < 0.05). The rate of Maillard reaction was accelerated at high temperatures (80 and 90 °C in this study) than at low temperatures. Similar results have been reported by Benzing-Purdie et al.29

Effect of temperature on browning
During the black garlic processing, development of the black colour is usually connected with the non-enzymatic browning reaction and greatly depends on the heating temperature.26,27 There were melanoidins forming in Maillard reaction. The colour of melanoidins might be connected with the enolisation of sugars and racemisation of amino acids.28 As shown in Fig. 1, regardless of the temperature, the browning in all garlic samples increased gradually, and then levelled off during processing. The browning rate was faster in the samples treated with higher temperature than in those treated with lower temperatures. Similar results have been reported by Benzing-Purdie et al.29

We divided the ageing procedure of garlic samples into three stages (i.e. early period, middle period, and later period) according to the colour development of garlic sample during thermal processing. Under conditions where the temperatures were 60 and 70 °C, during the early period of processing, the colour development of the garlic sample was from white to pale brown. The inside colour of the garlic sample showed an uneven distribution of white flecks. In the middle period of processing, the colour development of the garlic sample was from pale brown to dark brown. The inside of garlic sample had some white flecks. In the later period of processing, the appearance of the garlic sample was

\[ w_{\text{allicin}} = w_{\text{allicin}} - w_{\text{allicin res}} \]

where \( w_{\text{allicin}} \) is the amount of allicin, \( w_{\text{allicin res}} \) is the residual amount of allicin, and MW is molecular weight.

### Statistical analysis
The data were analysed by analysis of variance (ANOVA) followed by Duncan’s multiple range test. Differences among means at different temperatures of 60, 70, 80, and 90 °C were statistically significant (P < 0.05). The statistical analyses of data were performed using SPSS software version 18.0 (IBM Corporation, Chicago, IL, USA).

### RESULTS AND DISCUSSION

**Quality analysis of black garlic**

The typical label of black garlic quality is the formation of the black colour. Based on reports by other authors25 and our empirical results, we found that when the browning intensity was about 74–76, the appearance of black garlic was aterimus. This colour was a standard colour of black garlic and can be used as an indicator for maturation of black garlic. Based on reports from other authors25 and our empirical results, we found that when the browning intensity was about 74–76, the appearance of black garlic was aterimus. This colour was a standard colour of black garlic and can be used as an indicator for maturation of black garlic.

As shown in Table 1, the ageing time of black garlic is significantly different due to the heat treatment at various temperatures (P < 0.05). The higher the temperature, the shorter the ageing time of black garlic. Temperature had a significant impact on the quality of black garlic. Total phenols, total acids, and allicin contents in black garlic were significantly affected by heating temperatures (P < 0.05). The rate of Maillard reaction was accelerated at high temperatures (80 and 90 °C in this study) than at low temperatures. Similar results have been reported by Benzing-Purdie et al.29

### Table 1. Main characteristic parameters of black garlic (mean ± SD, n = 3)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity time (d)</td>
<td>69</td>
<td>30</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Browning intensity</td>
<td>74.14 ± 0.56a</td>
<td>74.44 ± 0.42a</td>
<td>74.55 ± 0.97a</td>
<td>74.60 ± 0.28ab</td>
</tr>
<tr>
<td>Moisture (g kg⁻¹)</td>
<td>490.23 ± 2.70a</td>
<td>460.61 ± 22.69a</td>
<td>471.19 ± 33.87a</td>
<td>470.84 ± 6.80a</td>
</tr>
<tr>
<td>Reducing sugar (g kg⁻¹)</td>
<td>335.21 ± 0.45c</td>
<td>357.96 ± 3.44a</td>
<td>348.93 ± 1.21b</td>
<td>154.91 ± 2.19d</td>
</tr>
<tr>
<td>Amino-N (g kg⁻¹)</td>
<td>3.15 ± 0.04b</td>
<td>3.29 ± 0.04a</td>
<td>1.49 ± 0.04c</td>
<td>1.03 ± 0.04d</td>
</tr>
<tr>
<td>HMF (g kg⁻¹)</td>
<td>1.88 ± 0.02d</td>
<td>4.32 ± 0.02b</td>
<td>4.82 ± 0.06a</td>
<td>4.08 ± 0.08c</td>
</tr>
<tr>
<td>Total phenols (g kg⁻¹)</td>
<td>13.30 ± 0.09b</td>
<td>12.35 ± 0.13b</td>
<td>15.12 ± 0.36a</td>
<td>13.27 ± 0.87b</td>
</tr>
<tr>
<td>Total acids (g kg⁻¹)</td>
<td>33.61 ± 0.17c</td>
<td>37.50 ± 0.17a</td>
<td>30.96 ± 0.17cd</td>
<td>36.37 ± 0.17b</td>
</tr>
<tr>
<td>Allicin (g kg⁻¹)</td>
<td>0.16 ± 0.07c</td>
<td>0.28 ± 0.07bc</td>
<td>0.93 ± 0.07a</td>
<td>0.41 ± 0.07b</td>
</tr>
<tr>
<td>Sensory evaluation</td>
<td>28.71 ± 0.44d</td>
<td>39.95 ± 0.31a</td>
<td>35.66 ± 0.46b</td>
<td>29.41 ± 0.41c</td>
</tr>
</tbody>
</table>

a–c Means followed by different superscripts in the same row are significantly different at P < 0.05.
from white to dark brown in the early period. The inside of the garlic sample had some white flecks. The colour of the garlic sample was from dark brown to all black in the later period. The quality of black garlic was connected with its colour; however, the degree of blackness of black garlic does not necessarily mean the quality is better. According to sensory evaluation, the quality of aged black garlic was better and its colour was homogeneous blackness under 70 and 80 °C conditions. Although black garlic formed black faster at 90 °C, it was more bitter and had a sour flavour. In the case of 60 °C, the colour of black garlic did not meet the requirement of homogeneous blackness.

**Effect of temperature on moisture content**

Figure 2 illustrates the changes in the moisture content of garlic samples during thermal processing with different temperatures. The moisture content decreased continuously under four temperature conditions. The decreased rate of moisture content was faster at higher temperature.

Under these four temperature conditions, the moisture content was 500–700 g kg⁻¹ at the early stage of black garlic processing, garlic sample was soft and wet at this period. When the moisture content reached 400–500 g kg⁻¹, black garlic was soft and elastic. Similar results have been reported by Sang et al. The study by Lei et al. reported that moisture content in black garlic was 436 g kg⁻¹. When moisture content reaches 350–400 g kg⁻¹, black garlic was drier and its elasticity was not good. When moisture content reaches below 350 g kg⁻¹, black garlic was much harder.

When black garlic aged under 60 °C process conditions, the quality of was not good, with high humidity of the internal surface. The appearance of black garlic was dry with better elasticity and quality under 70 °C conditions. The appearance of black garlic was bone-dry with something burning, and its quality was not better at 80 °C. The texture of black garlic was very hard with an obvious burning smell at 90 °C.

**Effect of temperature on reducing sugar content**

During the black garlic processing, the reducing sugar content in black garlic depended on two factors. On the one hand, polysaccharide in garlic was degraded to reducing sugar. On the other hand, reducing sugar was consumed during the Maillard reaction. During the heat treatment at various temperatures, the trend of reducing sugar content was different and the rising curve of reducing sugar content increased with the temperature (Fig. 3). The reducing sugar content showed a rising trend in the samples heated at 60 and 70 °C during the whole process, indicating that under these temperatures the rate of formation of reducing sugar was faster than its rate of consumption. The reducing sugar content increased remarkably at the early stage of 80 and 90 °C, suggesting that the accumulation rate of reducing sugar exceeded its consumption rate. The rate of the Maillard reaction and caramelisation reaction was improved at high temperatures, thus leading to the consumption rate of reducing sugar exceeding its accumulation rate. As a result, the reducing sugar content showed a downward trend at the later stage of high temperature (80 and 90 °C) processing.

Black garlic did not have the appropriate sweet flavour because of the large amount consumption of reducing sugar in high-temperature conditions. The relationship between reducing sugar content and quality of black garlic might be inferred as follows. When black garlic aged under 70 °C, the accumulation amount of reducing sugar was very high, relatively, with abundant sweet flavour, and thus the quality of black garlic was better than others. The reducing sugar content was the highest when black garlic was heated at 80 °C for 12 days, and black garlic had ripened basically with a nice flavour by this time. If black garlic continued to be processed under this condition, its quality would become...
poor with a burning smell. In the case of 60 °C, the reducing sugar content in black garlic was lower than others, thus it was unsweetened and its quality was also worse. When black garlic aged at 90 °C, the accumulated amount of reducing sugar was the lowest, and the products had a strong burning smell and hard texture, suggesting that the quality of black garlic was the worst.

**Effect of temperature on amino acid nitrogen content**

The effect of processing temperatures on amino acid nitrogen content of black garlic is shown in Fig. 4. During the progression of the heat treatment process, the amino acid nitrogen content decreased gradually, and the reduced rate of amino acid nitrogen was faster at higher temperature. When the garlic sample was processed at 60 °C, the consumption of amino acid nitrogen was the lowest among all treatments. This phenomenon might be explained by considering that the rate of the Maillard reaction at 60 °C was very slow so that amino acid nitrogen was hardly consumed in the Maillard reaction. With increased temperature (70, 80 and 90 °C), the rate of the Maillard reaction in black garlic was accelerated, and thus led to a faster consumption of amino acid nitrogen. The consumed amount of amino acid nitrogen also increased at high temperature (80 and 90 °C). Therefore, the amino acid nitrogen content was much lower at the final stage of high temperature (80 and 90 °C) processing compared with that at low temperature (60 and 70 °C) processing, which was in accordance with changes in reducing sugar content.

**Effect of temperature on 5-hydroxymethylfurfural content**

HMF is an important intermediate product in Maillard reaction and it is one of the main antioxidant ingredients in black garlic. The accumulation of HMF was connected with the rate of black formation of the garlic sample. When the HMF content accumulated to some extent (about 4 g kg⁻¹), the colour of the garlic sample became black. Therefore, changes in HMF content can serve as a significant monitoring index to predict the rate of black formation of garlic samples.

The garlic samples produced a large amount of HMF due to the Maillard reaction. Regardless of the temperature, HMF contents in all garlic samples increased during the thermal processing. The increment speed of HMF content was faster due to higher temperature treatment (Fig. 5). Thus, the change of HMF content was significantly affected by temperature. When the HMF content reached around 4 g kg⁻¹, black garlic had aged basically and presented black. The changes in colour of garlic samples was from dark brown to black when garlic was processed for about 9 days at 90 °C, for about 21 days at 80 °C, for about 33 days at 70 °C. HMF content increased very slowly during the whole process at temperature of 60 °C and when black garlic aged, its content was approximate 0.39 – 0.46 times that at other temperatures, which presented black. The changes in total phenols content of garlic sample at four temperature treatment conditions are shown in Fig. 6. Regardless of the temperature, the total phenols content significantly increased during thermal treatments (P < 0.05). The increased rate of total phenols content was faster at higher temperatures. Total phenols content was continuously increased during the processing at 60 °C, indicating that the accumulation rate of total phenols exceeded its consumption rate throughout the processing. In contrast, the total phenols content increased in the early stage of 70 °C, 80 °C and 90 °C processing. Additionally, the total phenols content decreased at the later stage of these conditions, which demonstrated that the accumulated rate of total phenols was less than its consumed rate.

Changes in total phenols content of garlic sample at four temperature treatment conditions are shown in Fig. 6. Regardless of the temperature, the total phenols content significantly increased during thermal treatments (P < 0.05). The increased rate of total phenols content was faster at higher temperatures. Total phenols content was continuously increased during the processing at 60 °C, indicating that the accumulation rate of total phenols exceeded its consumption rate throughout the processing. In contrast, the total phenols content increased in the early stage of 70 °C, 80 °C and 90 °C processing. Additionally, the total phenols content decreased at the later stage of these conditions, which demonstrated that the accumulated rate of total phenols was less than its consumed rate.
When total acids content in black garlic is within 30–40 g/kg, black garlic has a good sour flavour. When total acids content in garlic reaches 15–30 g/kg, it has little sour flavour. When the total acids content in black garlic is below 15 g/kg, black garlic is immature and its quality was bad. These results suggest that 80 °C might facilitate accumulation of total phenols in black garlic during processing.

**Effect of temperature on total acids content**

The increase of acidity of garlic samples due to heat treatment was partly associated with browning substances that formed during thermal processing. It is reported that the formation of carboxylic acids can lead to the increase of acidity.\(^1\,\(^2\)

According to sensory evaluation and our experience, when the total acids content in black garlic is below 15 g kg\(^{-1}\), black garlic has little sour flavour. When the total acids content in black garlic reaches 15–30 g kg\(^{-1}\), black garlic has a little sour flavour. When total acids content in black garlic is within 30–40 g kg\(^{-1}\), black garlic has a good sour flavour. When total acids content in black garlic exceeds 40 g kg\(^{-1}\), black garlic has an unpleasant sour flavour.

Regardless of the temperature, the total acids content gradually increased in black garlic during thermal processing. Moreover, its increasing rate in the samples was elevated with increasing temperature (Fig. 7). By the time of maturity of black garlic at 70 and 90 °C, total acids content in black garlic was higher than that in fresh garlic (4.6 g kg\(^{-1}\)). Total acids content did not increase at a temperature of 60 °C so the black garlic did not acquire a good sour flavour. Evaluation of the acid flavour showed that the total acids content in black garlic aged at 80 °C was appropriate, and its taste quality was better than other samples.

**Effect of temperature on allicin content**

Allicin is the main and symbolic flavour substance in fresh garlic. The allicin content in all samples decreased to very little during the black garlic process (Fig. 8). Therefore, in black garlic, the offensive odour from fresh garlic was removed. The allicin content rapidly decreased at the early stage of thermal processing, and its decreased rate was slightly discrepant. The allicin content of black garlic had declined to about 0.2 g kg\(^{-1}\) by the time of maturity of black garlic, significantly lower than that in fresh garlic (about 3.45 g kg\(^{-1}\)). These results suggest that black garlic hardly had an irritating odour, and allicin was no longer a significant functional substance in black garlic.

**CONCLUSIONS**

When garlic was processed to black garlic under different temperatures, biological activity and content of various substances in the garlic varied significantly. Temperature had a remarkable impact on the quality of black garlic. The flavour of black garlic was conspicuously different from that of fresh garlic. The results showed that good quality and flavour of black garlic occur under 70 °C processing conditions. However, quality formation of black garlic is a very complex process, which is influenced by many factors besides temperature, such as garlic varieties and relative humidity during thermal processing. More effort should be made to elucidate the effects of these factors on the quality of black garlic products in future studies.

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