Comparison of processing technology on quality of “Laba” garlic products

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**ABSTRACT**

In order to comparison of processing technology on quality of “Laba” garlic products, the garlic was dipped in acetic acid and fumigated by acetic acid with carbon dioxide, CO\textsubscript{2}, respectively, until became green. The pigment formation, texture characteristics, and bioactivities of “Laba” garlic was investigated. Garlic fumigated by acetic acid with 80\% CO\textsubscript{2} exhibited the most discoloration, while the hardness and pigment bioavailability of garlic fumigated by acetic acid with 20\% CO\textsubscript{2} presented the highest value. Correlation test showed that scavenging rate of DPPH\* of garlic products is highly dependent on allicin content, while showed a good negative correlation between allicin content and blue, yellow pigments. Though formation of new pigments, the scavenging rate of DPPH\* decreased indicating that pigments of “Laba” garlic exhibited much poorer clearance rate of DPPH\* than allicin. In summary, “Laba” garlic fumigated with acetic acid and 20\% CO\textsubscript{2} showed the best quality.

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1. Introduction

Garlic products such as power, puree, oleoresin, and minced paste and oleoresin (Balasubramani, Viswanathan, & Vairamani, 2013; Soria et al., 2010; Yamazaki, Yamamoto, & Okuno, 2012), which are popular around all over world because of their kinds of functional values. Undesirable discoloration occurred a greening color frequently generate during the processing and storage of garlic products. Thus, the commercial value of garlic will be limited and reduced. However, green color is necessary for “Laba” garlic.

“Laba” garlic is one kind of Chinese garlic product having a green color and unique taste, which is made with vinegar during winter in Northern China and is usually eaten with dumplings for Chinese New Year (Bai, Chen, Wang, Hu, & Zhao, 2005). Generally, “Laba” garlic was made by pickling garlic into vinegar at home, and carried out in the laboratory by soaking the aged garlic in 5\% (v/v) acetic acid solution, which consist of yellow and blue species to form garlic greening (Bai et al., 2005; Kubec & Velíšek, 2007). The green pigment of garlic is water-soluble, and thus can be transferred to the soaking solution, resulting in reduced nutritive value of garlic. Hence, we made “Laba” garlic by dry process, that is, fumigating with acetic acid and different concentration of carbon dioxide (CO\textsubscript{2}). The products were not soaked in solution, which could not transfer out the water-soluble nutrition. However, different making methods exhibited different qualities, such as color, nutrition and texture features, which affects the sensory property of products.

A large number of researchers are focused on the mechanism of garlic greening during last 70 years. Garlic greening was a multistep process, consisting of enzymatic and non-enzymatic stages, which could not occur with freshly harvested garlic because of lacking for enough S-(1-propenyl)-L-cysteine sulfoxide (Imai, Akita, Tomotake, & Sawada, 2006a, 2006b; Kubec & Velíšek, 2007; Lukes, 1986). The mechanism of the greening (Bai et al., 2005; Kubec & Velíšek, 2007).
garlic greening had systematically researched and proposed a six-step pathway (Wang, Nanding, Han, Chen, & Zhao, 2008; Zang, Wang, & Zhao, 2013). Among the pathway, the fourth stage is formation of blue pigments produced by the reaction of pigment precursor(s) (PP) and di(2-propenyl) allicin, so the allicin content decreased during garlic greening (Wang et al., 2008). Allicin is one of the most important nutritive ingredients in garlic. A great deal of research show that allicin reveal antimicrobial (Ruddock et al., 2005), antiviral (Weber et al., 2007), anti-inflammatory (Wilson & Demmig-Adams, 2007), pathological function for both hyperlipidemia and arteriosclerosis in animal models and human clinical trials (Chi, 1982; Lawson & Gardner, 2005), and anti-platelet aggregation activities in vitro (Lawson, Ransom, & Hughes, 1992). It was not clear that whether decreasing allicin content and formation new compounds, green pigments, induced the functional change of garlic or not. Furthermore, the bioavailability of compounds has been defined as the fraction of a compound that is released from its matrix in the gastrointestinal tract and thus exhibits the oral absorption ability (Fernández-García, Carvajal-Lerida, & Pérez-Gálvez, 2009). The information from bioavailability studies would contribute to ensure or improve its nutritional efficacy (Rahaman, Roy, Roy, Ray, & Roy, 2018; Torres-Palazzolo et al., 2018). The present study was undertaken to investigate the bioavailability of pigments in “Labā” garlic.

Green color is desirable for “Labā” garlic, while hardness and brittleness are main textural feature, which are very important to evaluate the quality of product. Unfortunately, to our understanding, the effects of processing technologies on qualities of “Labā” garlic products are too little focused. Thus, in this paper, “Labā” garcics were made through traditional and dry processing technologies to evaluate the mechanical properties, discoloration, antioxidant activity and pigment bioavailability. The results would provide a useful technical support for the “Labā” garlic processing industry.

2. Experimental

2.1. Chemicals

Ethanol anhydrous, acetic acid, methanol, HCl, NaOH, NaCl and potassium dihydrogen phosphate were purchased from Beijing Chemistry Co. (Beijing, China). 1,1-Diphenyl-2-picylhydrazyl (DPPH), pepsin (EC 232-629-3) and trypsin (EC 232–468-9) were purchased from Sigma-Aldrich chemical Co. (Beijing, China). All solvents/chemicals used were of analytical grade or purer. Syringe filter units 0.22 μm were supplied by Hercules (Beijing, China). Distilled water was used throughout.

2.2. Preparation of “Labā” garlic

Garlic was purchased from Xinxiang, Shandong Province of China. After cracking the bulbs, the small, shrieveled, and damaged cloves were discarded. Then, the remaining cloves (about 35 mm × 25 mm) were peeled off and washed with distilled water. The cloves were divided into five equal parts after drying off. Five different treatments were used: (1) control: soaked into 5% (v/v) acetic acid solution; (2) 2 g/L acetic acid fumigation; (3) 5% CO₂ & 2 g/L acetic acid fumigation; (4) 20% CO₂ & 2 g/L acetic acid fumigation; (5) 80% CO₂ & 2 g/L acetic acid fumigation. All the treated samples were maintained in our lab at same condition (dark, 23–25°C). For the fumigated treatments, garlic cloves were placed in an identical 2.5 L glass jar obturator with 2 g/L acetic acid and different concentrations of CO₂. After treated and during the process time, the mechanical properties, content of allicin, color of product, and antioxidant activity of “Labā” garlic were measured every three days. Pigment bioavailability was measured after processing for 12 days.

2.3. Measurement of color quality by colorimeter

The treated garlic was homogenized in a blender, and then extracted by 120 mL of ethanol (75%, V/V) for 30 min. The resulting solutions were filtered and placed into a quartz cuvette. Color parameter (L*, a*, b*) was measured by a CM-3600d colorimeter (Konica Minolta, Japan).

2.4. Measurement of hardness and brittleness

Textural properties were analyzed at 25°C by a TA. XT. Plus texture instrument (Stable Micro System, England). Garlic was horizontal divided in half from the third of garlic root. Garlic slices, that the thickness of 5 mm was used. The test was carried out with a P/100 probe. The parameters were as follows: preloading speed, 1.50 mm/s; loading speed, 1.50 mm/s; upstream speed after the pressure, 1.50 mm/s; the time of two compressions, 3 s, compression deformation, 40%, triggering force, 0.1 N.

2.5. Determination of allicin content

The allicin of “Labā” garlic was measured by HPLC as previously described (Iberl, Winkler, Müller, & Knobloch, 2007). Allicin standard was used to prepare standard curve. Garlic (10 g) treated with microwave to destroy enzyme, added water (30 mL), and mashed for 2 min. Then, serous fluid was put in water to 50 mL, centrifugal treatment for 10 min (9000 rpm). Liquid supernatant (5 mL) was diluted to a constant volume of 50 mL using methanol/water (85/15, v/v), and filtered through a 0.22 μm syringe filter for Agilent 1200 series high performance liquid chromatography (HPLC) (Agilent, USA) analysis. DAD detection was performed at 254 nm. Duplicates of 20 μL of each sample were injected into a reverse-phase C18 column (250 mm × 4.6 mm, 5 μm). Chromatographic column was eluted using an isocratic phase, 85% ethanol at a flow rate of 1.0 mL/min for determination.

2.6. Scavenging DPPH- analysis

Scavenging rate of DPPH- was evaluated as previously described with a little modification (Wang, Hu, & Zhao, 2008). Basically, the meshed “Labā” garlic was extracted by methanol (95%, v/v), then 4.9 mL of the extracted liquor was mixed with 0.1 mL of DPPH- (1 mM) in methanol solution (95%, v/v). After incubation for 30 min in the dark, the absorbance was measured at 517 nm with a UV-1800 spectrophotometer (Shimadzu Co. Japan). Meanwhile, a solution consisting of 4.9 mL of methanol and 0.1 mL of DPPH- in methanol solution (1 mM) was mixed and kept for 30 min in the dark, and its absorbance at 517 nm was determined as the control. The scavenging activity of all samples was calculated by the equation of scavenging rate (%)= (1-sample /control) × 100%.
2.7. Correlation analysis (CA)

CA was used to study the correlations among measures of color indexes (a*, b*), allicin, and scavenging rate of DPPH for “Laba” garlic.

2.8. In-vitro bioavailability analysis

The “Laba” garlic samples were sliced, quickly frozen in liquid nitrogen, pulverized and stored in the refrigerator. Each sample was processed in parallel for three times.

Preparation of simulated gastric fluid: 2.0 g of NaCl and 3.2 g of pepsin (EC 232–629-3) were dissolved in 750 mL distilled water. The pH of solution was adjusted to 2.0 with 37% HCl, then diluted to 1000 mL.

Preparation of simulated intestinal fluid: 6.8 g of potassium dihydrogen phosphate dissolved in 500 mL of water, then added 10 g of trypsin (EC 232–468-9). The pH of solution was adjusted to 6.8 with NaOH (0.2 M), then diluted to 1000 mL with water.

In-vitro gastrointestinal digestion was carried out according to Miller, Schricker, Rasmussen, and Campen (1981) and Georgé, Brat, Alter, and Amiot (2005) with slight modifications. 2 g of freeze-dried “Laba” garlic samples were extracted with 4 mL of 75% ethanol for 30 min. 10 mL of simulated gastric fluid was added. The pH of mixture was adjusted to 2.0 by HCl addition, and reacted at 37°C for 120 min. Then, the pH of solution was adjusted to 6.8 by 0.2 M NaOH addition, and 10 mL of simulated intestinal fluid was added. Samples were incubated at 37°C for 120 min. At the end point, they were immediately centrifuged at 4°C and 10,000 r/min for 30 min. The supernatant was diluted with the deionized water to 25 mL. Then, they were added into the amicon ultra filter test tube (15 g) and ultrafiltration centrifuged at 4°C and 10,000 r/min for 30 min. About 3 mL of ultrafiltrate was obtained. The absorbance was measured at 440 and 590 nm with a UV-1800 spectrophotometer (Shimadzu Co. Japan). Bioavailability (%) was determined as the ration between absorbance value after enzymolysis (A1) and initial value (A0). The bioavailability of blue pigment was calculated by the equation of bioavailability (%) = A1/440 nm/A0/440 nm × 100%. The bioavailability of yellow pigment was calculated by the equation of bioavailability (%) = A1/590 nm/A0/590 nm × 100%.

2.9. Statistical analysis

All data were expressed as the mean value ± standard deviation (n = 3). Statistics on a completely randomized design were determined using SAS 9.0 for windows. Correlation analysis was determined using SPSS 21.0 for windows.

3. Results and discussion

3.1. The color determination

Plenty of research proved that garlic greening mainly consists of yellow pigment and blue pigment (Bai et al., 2005; Kubec & Velšek, 2007; Wang et al., 2008). It means that green color is determined by blue and yellow color. The parameters of a* and b* was chosen to measure the change of color quality. Figure 1 displays a* and b* values of “Laba” garlic made by different methods, respectively. There were obvious changes in hunter color values, which a* value decreased and b* value increased gradually in all of treatments during storage period except the control, confirming the change of visual color attributes the yellow and green pigments produced. a* value decreased and b* value increased of the control from beginning to the ninth day. However, the color represented a slight decrease with increasing storage period, which might have induced by transferring the pigments to the acetic acid solution. The garlic processed by fumigation represented pronounced discoloration than that of control, which might have induced by transferring the pigments to the acetic acid solution. The garlic processed by fumigation represented pronounced discoloration than that of control from the ninth day. More important, the fumigated garlic with CO2 processing, green discoloration was higher with increasing concentrations of CO2. The reason might be that CO2 accelerated fracture of cytodermin, which caused thiosulfinates released from cell, increasing the formation of precursors, and then produced the garlic greening (Wang et al., 2008).

3.2. Textural analysis

Physical texture which is of important property of food products determines the choice of consumers. The hardness of garlic at different processes during storage period is
shown in Figure 2(a). The hardness of garlic decreased during storage period, except the sample fumigated with acetic acid. This kind of sample had not pronounced change for six days, which exhibited the highest hardness than other conditions, and then decreased with increasing the storage time after six days. The garlic treated with acetic acid and 20% CO\textsubscript{2} had the highest value after treating for six days while the group fumigated with acetic acid and 80% CO\textsubscript{2} displayed the lowest hardness after storage for 12 days. Under the effect of a small amount of CO\textsubscript{2} gas, most cells had more stereoscopic sense and exhibited better hardness during storage time. Although CO\textsubscript{2} can also form monogenic weak acid, plant cells can regulate it by themselves which cannot damage the cell membrane by changing the pH value in the cytoplasm. However, high concentration of CO\textsubscript{2} (80%) can disrupt respiration, interfere with physiological metabolism, inhibit the activity of succinic acid dehydrogenase, accumulate succinic acid, and lead to tissue injury seriously which results in low hardness (Liu, Yang, Murayama, Taira, & Fukushima, 2004; Song et al., 2015). Brittleness represents the force that makes the food staffs collapse. Brittleness reflects quiet important property for crispy products, which determines the mouth feel of products (Lazou & Krokida, 2010), so the taste as well as texture properties should be paid attention in the process of food staffs. The effect of processing methods on brittleness of garlic is displayed in Figure 2(b). All treatments decreased gradually during storage period. The brittleness had a similar trend to that of hardness when storage for three days, which the control showed the least value, and other samples became lower with increasing the concentration of CO\textsubscript{2}. However, the brittleness of garlic which was fumigated by acetic acid without CO\textsubscript{2} showed the biggest brittleness at the sixth day. And then, they were not difference at the ninth day. Interestingly, the brittleness of the fumigated garlic with acetic acid showed a slightly higher again at the twelfth day, followed with the control and fumigated by acetic acid with 20% CO\textsubscript{2}, the sample fumigated by acetic acid with 5% CO\textsubscript{2} exhibited the lowest brittleness.

3.3. Determination of allicin content

The bioactivity of garlic mainly derives from allicin. Thus, the content of allicin should be paid attention because it was correlated with functional and flavor properties of garlic. Figure 3 presents the content of allicin, which is detected by HPLC. In the process of storage, the allicin content sharply decreased from beginning to the ninth day. From the ninth day, the allicin content turned to stability. Moreover, the content order of sample was fumigation with acetic acid and 5% CO\textsubscript{2} > control > fumigation with acetic acid > fumigation with acetic acid and 80% CO\textsubscript{2} > fumigation with acetic acid and 20% CO\textsubscript{2} at the third day, and then, all treatments showed no pronounced difference on the content of allicin. Since formation of pigments produced by the reaction of PP and di (2-propenyl) allicin (Wang et al., 2008), the allicin content of garlic decreased which was in good agreement with the results that the pigments increased. Moreover, garlic greening contained a reaction of that the production of allicin from S-(2-propenyl)-L-cysteine sulfoxide catalyzed by alliinase. High concentration of CO\textsubscript{2} (80%) could lead to tissue injury which increased the contact between alliinase and substrate, then produce more allicin than sample fumigated with acetic acid and 20% CO\textsubscript{2}.

Figure 2. Effect of processing methods on textural property of garlic during storage period. (a) Effect of processing methods on hardness of garlic. (b) Effect of processing methods on brittleness of garlic.

Figure 3. Change of allicin content in garlic at different processing conditions.

Figure 2. Efecto de los métodos de procesamiento sobre las propiedades de textura del ajo durante el periodo de almacenamiento. (a) Efecto de los métodos de procesamiento sobre la dureza del ajo. (b) Efecto de los métodos de procesamiento sobre la fragilidad del ajo.

Figure 3. Cambio en el contenido de alicina del ajo en diferentes condiciones de procesamiento.
3.4. Analysis of DPPH

The antioxidant capacity of garlic was assessed by scavenging rate of DPPH. DPPH is of commonly used free radical to evaluate bioactivity (Bozin, Mimica-Dukic, Samojlik, Goran, & Ljic, 2008; Nuuttila, Puupponen-Pimiä, Aarni, & Oksman-Caldentey, 2003; Wang et al., 2008). The antioxidants usually present hydrogen-donating, which can form DPPH-H by chemical reactions (Shon, Kim, & Sung, 2003). Figure 4 presents that the scavenging rate of DPPH of garlic decreased during storage period. The clearance rate of DPPH sharply reduced from the beginning to the ninth day, then trended towards stability, except the sample fumigated with acetic acid and 5% CO₂ containing two sharply decreasing periods, which were at the third day and the twelfth day, respectively. The tendency of decreases in scavenging rate was similar to the changes of allicin.

3.5. Correlation analysis of scavenging rate of DPPH and allicin, pigments

Allicin is one of the most active organosulfur compounds in garlic, accounting for 60–80% of the thiosulfonates that are called color developer (Block, 1992; Miron, Mirelman, Weiner, Wilchek, & Rabinkov, 1998). The functional properties of allicin are proved by a great number of experiments, such as antimicrobial, antiinflammatory, lower blood pressure, and antioxidant properties. Okada et al. proved that DPPH was scavenged by allicin. Meanwhile, the kinetic mechanistic studies of allicin as a kind of antioxidant was demonstrated (Okada, Tanaka, Sato, & Okajima, 2006). However, the relationship of allicin, pigments and scavenging rate of DPPH is unknown during “Laba” garlic processing period. As shown in Table 1, there were positive correlations (p < 0.01) among allicin content and scavenging rate of DPPH. Furthermore, linear regression equation was established by simple linear regression. The equations of treatments, control, fumigated with acetic acid, fumigated with acetic acid and 5%, 20%, 80% CO₂ were SR = 417.07CA - 0.33, R² = 0.98; SY = 429.22CA-7.87, R² = 0.94; SR = 288.29CA+6.20, R² = 0.71; SR = 431.69CA+1.04, R² = 0.89; SR = 494.83CA-5.656.20, R² = 0.82, respectively (where CA was concentration of allicin (mol/L), SR was scavenging rate of DPPH (%), R² was coefficient of determination). The results also showed that the content of allicin was linearly correlated with scavenging rate of DPPH. Judging by the results, allicin contributed to great ability of scavenging DPPH. Consistent with present observation, allicin content was positively correlated with a* (p < 0.01), but negatively correlated with b* (p < 0.01) indicating that allicin content decreased with increasing of blue and yellow pigments. Scavenging rate of DPPH was positively correlated with a* (p < 0.01), but negatively correlated with b*, revealing that blue and yellow pigments exhibited less scavenging rate of DPPH than allicin.

3.6. Bioavailability of “Laba” garlic pigment

Bioavailability refers to the ratio of food nutrients absorbed by digestive organs such as stomach and small intestine and involved in metabolic process after being eaten by human body. To our best knowledge, this is the first time that bioaccessibility of “Laba” garlic pigment has been evaluated. The bioavailability of pigments of “Laba” garlic from different processing techniques for 12 days was compared. The bioavailability of the blue pigment is shown in Figure 5(a). The bioavailability of the blue pigment extracted from the control group exhibited the weakest ability after digestion for 3 h which was similar with sample fumigated with acetic acid and 5% CO₂ while samples fumigated with acetic acid and 20% CO₂ exhibits the strongest. The order of blue pigment bioavailability was successively compared as follows: fumigated with acetic acid and 20% CO₂ ≈ fumigated with acetic acid and 80% CO₂ > fumigated with acetic acid > fumigated with acetic acid and 5% CO₂ ≈ traditional soaking method. The bioavailability of pigments could be significantly improved by fumigated with acetic acid and CO₂. Bioavailability of yellow pigment extracted from “Laba” garlic is displayed in Figure 5(b). The order of yellow pigment bioavailability was as follows: fumigated with acetic acid and 20% CO₂ > fumigated with acetic acid ≈ traditional soaking method > fumigated with acetic acid and 5% CO₂ > fumigated with acetic acid and 80% CO₂. According to the results, pigments of “Laba” garlic fumigated with acetic acid and 20% CO₂ showed the strongest bioavailability. Bioactive compounds’ bioavailability will be influenced by the composition of the digested food matrix, the synergisms and antagonisms of the different components, physicochemical properties, such as pH, temperature and texture of the matrix (Torres-Palazzolo et al., 2018). Moreover, processing of agricultural products can influence its ability (Carbonell-Capella, Bunionska, Barba, Esteve, & Frigola, 2014; Fernández-García et al., 2009; Rein et al., 2013). In our

![Figure 4](image-url)
experiment, the sample were obtained by extracting of “Laba” garlic with 75% ethanol. In addition to blue and yellow pigments, the extract also contained other compounds, such as phenolic acid, flavone, sugar, etc., also influencing the bioavailability which led to different bioavailability of garlic pigments in different processing techniques.

4. Conclusions

In this study, processing technologies on qualities of “Laba” garlic products were compared. Garlic fumigated by acetic acid and 80% CO$_2$ exhibited the greenest color, while sample fumigated by acetic acid and 20% CO$_2$ had the highest hardness in the latter storage period. The allicin was consumed to form blue and yellow pigments in the course of storage period; the decrease of allicin content reduced the antioxidant of garlic products. The content of allicin was linearly correlated with scavenging rate of DPPH, which indicating that allicin played a key function on scavenging DPPH, while the other ingredients such as pigments are of much less avail on eliminating DPPH. Furthermore, pigments of “Laba” garlic fumigated with acetic acid and 20% CO$_2$ exhibited the strongest bioavailability. From the above it could be concluded that “Laba” garlic fumigated with acetic acid and 20% CO$_2$ showed the best quality, which would give useful information for processing of garlic products.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Bai, B., Chen, F., Wang, Z., Hu, X., & Zhao, G. (2005). Mechanism of the greening color formation of “Laba” garlic, a traditional homemade Chinese food product. Journal of Agricultural and Food Chemistry, 53, 7103–7107.

Balasubramani, P., Viswanathan, R., & Vairamani, M. (2013). Response surface optimization of process variables for microencapsulation of garlic (Allium sativum L.) oleoresin by spray drying. Biosystems Engineering, 114, 205–213.

Block, E. (1992). The organosulfur chemistry of the genus Allium—Implications for the organic chemistry of sulfur. Angewandte Chemie International Edition, 31, 1135–1178.

Bozin, B., Mimica-Dukic, N., Samojlik, I., Goran, A., & Ljic, R. (2008). Phenolics as antioxidants in garlic (Allium sativum L., Alliaceae). Food Chemistry, 111, 925–929.

Carbonell-Capella, J. M., Buniowska, M., Barba, F. J., Esteve, M. J., & Frigola, A. (2014). Analytical methods for determining bioavailability and bioaccessibility of bioactive compounds from fruits and vegetables: A review. Comprehensive Reviews in Food Science and Food Safety, 13, 155–171.

Chi, M. S. (1982). Effects of garlic products on lipid metabolism in cholesterol-fed rats. Proceedings of the Society for Experimental Biology and Medicine, 171, 174–178.

Fernández-García, E., Carvajal-Lérida, I., & Pérez-Gálvez, A. (2009). In vitro bioaccessibility assessment as a prediction tool of nutritional efficiency. Nutrition Research, 29, 751–760.

Georgé, S., Brat, P., Alter, P., & Amiot, M. J. (2005). Rapid determination of polyphenols and vitamin C in plant-derived products. Journal of Agricultural and Food Chemistry, 53, 1370–1373.

Iberlí, B., Winkler, G., Müller, B., & Knobloch, K. (2007). Quantitative determination of allin and allin from garlic by HPLC. Planta Medica, 56, 320–326.

Imai, S., Akita, K., Tomotake, M., & Sawada, H. (2006a). Identification of two novel pigment precursors and a reddish-purple pigment involved in the blue-green discoloration of onion and garlic. Journal of Agricultural and Food Chemistry, 54, 843–847.

Imai, S., Akita, K., Tomotake, M., & Sawada, H. (2006b). Model studies on precursor system generating blue pigment in onion and garlic. Journal of Agricultural and Food Chemistry, 54, 848–852.

Kubec, R., & Veilíšek, J. (2007). Allium discoloration: The color-forming potential of individual thiosulfinates and amino acids: Structural requirements for the color-developing precursors. Journal of Agricultural and Food Chemistry, 55, 3491–3497.

Lawson, L. D., & Gardner, C. D. (2005). Composition, stability, and bioavailability of garlic products used in a clinical trial. Journal of Agricultural and Food Chemistry, 53, 6254–6261.

Figure 5. Effect of processing methods on bioavailability of garlic pigments. (a) Effect of processing methods on bioavailability of blue pigment. (b) Effect of processing methods on bioavailability of yellow pigment. Different letters indicate significant differences among mean values (P < 0.05).

Figura 5. Efecto de los métodos de procesamiento sobre la biodisponibilidad de los pigmentos de ajo. (a) Efecto de los métodos de procesamiento sobre la biodisponibilidad del pigmento azul. (b) Efecto de los métodos de procesamiento sobre la biodisponibilidad del pigmento amarillo. Las letras diferentes indican diferencias significativas entre los valores medios (P < 0.05).
Lawson, L. D., Ransom, D. K., & Hughes, B. G. (1992). Inhibition of whole blood platelet-aggregation by compounds in clove extract and commercial garlic products. *Thrombosis Research*, 65, 141–156.

Lazou, A., & Krokida, M. (2010). Structural and textural characterization of corn–Lentil extruded snacks. *Journal of Food Engineering*, 100, 392–408.

Liu, S., Yang, Y., Murayama, H., Taira, S., & Fukushima, T. (2004). Effects of CO₂ on respiratory metabolism in ripening banana fruit. *Postharvest Biology and Technology*, 33, 27–34.

Lukes, T. M. (1986). Factors governing the greening of garlic puree. *Journal of Food Science*, 51, 1577–1577.

Miller, D. D., Schricker, B. R., Rasmussen, R. R., & Campen, D. V. (1981). An *in vitro* method for estimation of iron availability from meals. *American Journal of Clinical Nutrition*, 34, 2248–2256.

Miron, T., Mirelman, D., Weiner, L., Wilchek, M., & Rabinkov, A. (1998). A Spectrophotometric Assay for allilic and alliinase (alliin lyase) activity of 2-nitro-5-thiobenzoate with thiosulfimates. *Anal Biochemistry*, 265, 317–325.

Nuutila, A. M., Puupponen-Pimiä, R., Aarni, M., & Oksman-Caldentey, K. (2003). Comparison of antioxidant activities of onion and garlic extracts by inhibition of lipid peroxidation and radical scavenging activity. *Food Chemistry*, 81, 485–493.

Okada, Y., Tanaka, K., Sato, E., & Okajima, H. (2006). Kinetic and mechanistic studies of allilic as an antioxidant. *Organic & Biomolecular Chemistry*, 4, 4113–4117.

Rahaman, H., Roy, N., Roy, A., Ray, S., & Roy, M. N. (2018). Exploring existence of host-guest inclusion complex of β-cyclodextrin of a biologically active compound with the manifestation of diverse interactions. *Emerging Science Journal*, 2, 251–260.

Rein, M. J., Renouf, M., Cruz-Hernandez, C., Actis-Goretta, L., Thakkar, S. K., & Pinto, M. D. S. (2013). Bioavailability of bioactive food compounds: A challenging journey to bioefficacy. *British Journal of Clinical Pharmacol*, 75, 588–602.

Ruddock, P. S., Liao, M., Foster, B. C., Lawson, L., Arnason, J. T., & Dillon, J. A. (2005). Garlic natural health products exhibit variable constituent levels and antimicrobial activity against Neisseria gonorrhoeae, Staphylococcus aureus and Enterococcus faecalis. *Phytotherapy Research*, 19, 327–334.

Shon, M. Y., Kim, T. H., & Sung, N. J. (2003). Antioxidants and free radical scavenging activity of phellinus baumii (phellinus hymenochaetaceae) extracts. *Food Chemistry*, 82, 593–597.

Song, M., Tang, L., Zhang, X., Bai, M., Pang, X., & Zhang, Z. (2015). Effects of high CO₂ treatment on green-ripening and peel senescence in banana and plantain fruits. *Journal of Integrative Agriculture*, 14(5), 875–887.

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

Torres-Palazzolo, C., Ramirez, D., Locatelli, D., Manucha, W., Castro, C., & Camargo, A. (2018). Bioaccessibility and permeability of bioactive compounds in raw and cooked garlic. *Journal of Food Composition and Analysis*, 70, 49–53.

Wang, D., Hu, X., & Zhao, G. (2008). Effect of the side chain size of 1-alkyl-pyrroles on antioxidant activity and ‘Labá’ garlic greening. *International Journal of Food Science and Technology*, 43, 1880–1886.

Wang, D., Nanding, H., Han, N., Chen, F., & Zhao, G. (2008). 2-(1H-Pyrrolyl) carboxylic acids as pigment precursors in garlic greening. *Journal of Agricultural and Food Chemistry*, 56, 1495–1500.

Weber, N. D., Andersen, D. O., North, J. A., Murray, B. K., Lawson, L. D., & Hughes, B. G. (2007). *In vitro* virucidal effects of Allium sativum (garlic) extract and compounds. *Planta Medical*, 58, 417–423.

Wilson, E. A., & Demmig-Adams, B. (2007). Antioxidant, anti-inflammatory, and antimicrobial properties of garlic and onions. *Nutrition & Food Science*, 37, 178–183.

Yamazaki, Y., Yamamoto, T., & Okuno, T. (2012). Causes and remedies for green discoloration of processed garlic puree: Effects of storage conditions on ingredient bulbs. *Food Science and Technology Research*, 18, 187–193.

Zang, J., Wang, D., & Zhao, G. (2013). Mechanism of discoloration in processed garlic and onion. *Trends in Food Science & Technology*, 30, 162–173.