EFFECT OF PRETREATMENTS AND PROCESSING CONDITIONS ON THE CHEMICAL, PHYSICAL, MICROBIOLOGICAL AND SENSORY CHARACTERISTICS OF GARLIC PASTE

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ABSTRACT

The influence of storage temperature of garlic bulb and chemical additives (including ascorbic acid, citric acid and potassium sorbate) on the chemical, physical, microbiological and sensory characteristics of garlic paste was evaluated. Formation of undesirable greenish pigment was avoided by storing fresh garlic bulbs at 25 and 40C. Moreover, heating bulbs to 40C a few minutes before processing facilitated skin removal. Garlic paste was processed, packed and thermally treated at 85C for 5 min. The color of garlic paste was affected by chemical treatment, temperature and storage period. The rate of color difference (ΔE*) increase was divided into two linear periods with different slopes. Garlic paste exhibited pseudoplasticity with yield stress and flow adequately described by the Herschel–Bulkley model (*$r^2 > 0.990$*). Both consistency index and apparent viscosity decreased with increase in temperature.*

INTRODUCTION

Garlic (*Allium sativum* L.) is a bulbous herb of the lily family and closely related to the onion. The plant dates back 5000 years to the Middle East, where it was one of humanity's first cultivated plants. Garlic has long been used both in medicine and as a spice, and useful for controlling dysentery, fighting parasites, detoxification, lowering fever and relieving stomachaches.

Allicin is the chief component of garlic. This compound is a strong antibacterial, antifungal and antibiotic agent, and released when its bulbs are crushed (Ankri and Mirelman 1999). Garlic contains 32 additional sulfur compounds and 17 amino acids. Fresh garlic is characterized as having a

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distinct aromatic odor, which is seldom carried over into processed garlic (Pezzutti and Crapiste 1997). The quality of garlic products is evaluated on the basis of their sensory characteristics, mainly color and flavor intensity or pungency.

At present, garlic is mostly transported fresh to the market in Argentina. A low percentage is dried by conventional methods to maintain its quality for prolonged storage. The drying process and phenomenological changes that occur during drying markedly affect the product quality attributes such as color, flavor and texture (Prachayawarakorn *et al.* 2004). However, as garlic is a semi-perishable spicy herb, some form of processing is also necessary to accommodate the excess production. Apart from this, the cost of the raw spice vegetable is widely fluctuating in the Argentinean market; as a result, demand of ready-to-use products has increased recently. Hence, there is an urgent need to explore some other process of conservation of garlic.

Paste is a potential alternative that would retain the delicate and fresh odor of garlic. The garlic paste manufacturing process dates back 40 years and stems from the need to find a product with an industrial or semi-industrial process able to compete in the international market. Another advantage is that the surplus from the nonmarketable part of the harvest (broken-up bulbs, loose cloves, etc.) may be used for paste manufacture. The processing of garlic paste consists basically in the peeling of the bulb, separating the cloves and removing the skin; followed by the grinding of cloves and the addition of preservatives and antioxidants. Process ends with a thermal treatment of paste, which is finally packed in hermetically sealed glass pots or metallic flask.

An obstacle in the manufacture of garlic paste is the coloring by oxidation of the phenolic components. Lukes (1986) indicated that the amino acid S-(1-propenyl) cysteine sulfoxide was responsible for the development of green color and recommended that the garlic bulbs should be stored at, or above, 23C for at least one month to prevent greening of the product. However, no specific information is available on the production of paste and its greening during preparation and storage.

Some methods for garlic paste preparation are based on the inactivation of alliinase, which would otherwise give rise to odorous and irritant compounds. The garlic cloves are heated to 99–120C by hot water, steam or microwaves before crushing (Sumi *et al.* 1987). The liquid obtained from pressing the solids is then mixed with soybean flour or soybean milk flour to form a paste. The resulting garlic paste lacks the undesirable odor of garlic but still retains an excellent flavor and can be used in sauces for roast meat, nutritious beverages, garlic butter, garlic salt, snacks, rice crackers, etc. Other methods of manufacturing garlic paste with the same flavor as fresh garlic previously described (Sica-sol 1969; Bernhardt and Delazari 1980) are based on the preparation of a salted garlic paste by addition of NaCl to ensure a pleasing appearance and good shelf life. One of our objectives is the manufacturing of garlic paste with no salt addition.

Browning is a problem also during garlic preparation and storage. Browning is an irreversible reaction caused by the reactive components in the food activated during processing. Color development is the result of various reactions such as nonenzymatic browning reactions and pigment destruction (Wong and Stanton 1993). For enzymatic browning to occur, four essential components must be present: oxygen, enzyme, copper and substrate. Sulfite-containing additives have been used extensively as antibrowning agents to keep vegetables and fruits fresh looking. Because sulfites have been linked to allergic reactions, the Food and Drug Administration (FDA) prohibited the use of sulfite preservatives in fresh vegetables and fruits (Langdon 1987).

The use of citric and ascorbic acid was reported to prevent enzymatic browning. Ascorbic acid is a very effective reducing agent. Citric acid has a double inhibitory effect on phenolase, lowering the pH of media and chelating the copper portion of certain phenolases. Citric acid also has a protective effect on ascorbic acid, and tends to slow its auto-oxidation. The strong chelating property of citric acid results in sequestration of trace metals that have a deleterious effect on ascorbic acid.

Paste processing is in general largely dependent on the rheological characteristics. Moreover, examination of the rheological properties of garlic paste is an important step in the characterization and understanding of its functional properties. Thus, a study on the rheological parameters of garlic paste with temperature would help not only to maintain the quality of the product, but also would optimize mechanical production using an appropriated milling and extrusion system. Although the rheological properties of several fruit and vegetable pastes and purees have received much attention in the literature (Costell and Durán 1982; Qiu and Rao 1988), the rheology of unsalted garlic pastes with browning inhibitors has not been investigated extensively.

The main objective of the present work was to select a method for unsalted garlic paste preparation combining different agents to prevent changes in the sensory properties (no-sulfite additives) which would be acceptable to consumers, make the product shelf stable and retain the characteristic flavor of fresh garlic. This work attempts to determine the effect of processing conditions and pretreatments on the chemical, physical, microbiological, sensory and rheological characteristics of garlic paste.

MATERIALS AND METHODS

Fresh garlic bulbs of the "red" variety, grown in the southeast of Buenos Aires province (Argentina) were selected for this study. They were harvested

TABLE 1.
CHEMICAL TREATMENTS APPLIED TO GARLIC PASTE

Treatment	Ascorbic acid (mg/g)	Citric acid (mg/g)	Potassium sorbate (mg/g)
None (control)	–	–	–
#1	0.5	–	0.8
#2	–	2	0.8
#3	0.5	2	–
#4	0.5	2	0.8

in December 2003, and cured naturally in the field for about 10 days. Afterwards bulbs were packed in 5-kg bags and stored at room temperature for 3 months before use. According to the Visual Index of Dormancy (VID) determined at 15C (Ceci 1991), the garlic was classified as of long dormancy variety (155 days). Before processing, garlic bulbs were stored at three different temperatures (2, 25 and 40C) for 4 weeks. Peeling was done manually; the garlic bulbs were separated into the individual sound cloves, the cloves were then carefully peeled with a stainless steel knife, cut in half, and the inner green shoots removed. Garlic bulbs, prepared as above, were crushed in a blender until a smooth puree was obtained (3 min), with the addition of 0.1 mL/g of sunflower oil to facilitate preparation.

In an attempt to prevent changes in sensory characteristics, some chemical additives were added during bulb crushing. The selected chemical treatments are listed in Table 1. Descriptive analysis was applied to select sensory attributes which best define the changes in flavor when different concentrations of aggregates were used. The garlic paste was packaged in aseptic glass containers and hermetically closed. Selected paste aliquots were thermally processed at 85C for 5 min. Samples were stored at room temperature until analysis.

Color Measurements

Color was determined as Hunter L, a and b parameters with a Hunter Ultrascan XE Spectrophotometer (Hunterlab, Reston, VA) in the reflection mode. This is the simplest instrumental method proved to be valuable in describing discoloration and providing useful information for quality control of food products (Garza *et al.* 1999; Maskan 2001).

The instrument was calibrated using a standard white reference tile ($L = 94.3$, $a = -1.0$ and $b = 0.8$). The color of samples was measured in black painted glass cells (40 cm^3). Total reflectance of garlic paste was recorded after different storage times ($t = 0$, 7, 14, 21 and 28 days). Color difference,

ΔE, was calculated from *a, b* and *L* parameters, using Hunter–Scotfield's equation (Francis and Clydesdale 1975):

$$\Delta E = (\Delta a^2 + \Delta b^2 + \Delta L^2)^{1/2} \tag{1}$$

where $\Delta a = a - a_0$; $\Delta b = b - b_0$; and $\Delta L = L - L_0$. Subscript '$_0$' indicates color of garlic paste at $t = 0$. Hue angle was also calculated as $\tan^{-1} b/a$. *Hue* describes what the average person thinks of when he or she speaks of color (i.e., green, red, yellow, etc.)

Chemical and Physical Analysis

Total soluble solids (°Brix) were determined with a digital bench top Reiohert-Jung Abbe Mark II refractometer at 20C (Cambridge Instruments, Buffalo, NY). To determine the total soluble solids, the paste was dried under vacuum at 70C to constant weight. The dried samples were allowed to cool in a desiccator for 30 min and then weighed (AOAC 2000). Density was determined with a 50-cm^3 pycnometer for semisolid material. The following equation resulted as the best fit for the obtained density data ($r^2 = 0.994$): $\rho = 1.1899 \pm 0.0010\ T$; where ρ is the density (g/cm^3) and T is the temperature (C).

Crude fiber was determined according to Weende, AOAC (2000) 920.169 method, based on the solubilization of noncellulosic compounds by sulfuric acid and sodium hydroxide solutions. The garlic paste was tested for crude protein using the Macro Kjeldahl method (AOAC 2000) and was analyzed for percentage of ether-extractable lipid with the Soxhlet extraction procedure (AOAC 2000). Total sugars were determined according to a modified Fehling solution method (AOAC 2000). The paste sample (5 g) was diluted with 45 mL distilled water, and the pH was measured with a pH meter with glass electrode (Orion Research, Boston, MA). The ash content was determined according to AOAC (2000) method 925.51. The concentrations of K, Fe, Ca, Cu and Zn were determined with a GBC AA Spectrophotometer (GBC Scientific Equipment, Victoria, Australia) after digestion with concentrated HCl.

Microbial Analysis

Paste samples were analyzed for total mesophilic microbial count by standard plate counts (SPC) with peptone–casein agar; and *Clostridium perfringens* and yeast and mould counts using the AOAC (2000) method (sulfit-polimixine-sulfadiacine [SPS]). Assays were replicated three times. The results are presented as colony-forming units per gram of material (cfu/g).

Sensory Evaluation

The sensory analysis of garlic paste was carried out using a hedonic scale for acceptability (Cabezudo 1982). In a preliminary study, the samples were tested for overall acceptance to determine the appropriate concentration of chemical additives. In the second step, the samples were tested for color, flavor and overall acceptance. In both cases, the tests were carried out by an untrained panel of 30 judges. The samples were evaluated at room temperature and under cool white fluorescent lighting. The panelists were asked to evaluate the descriptors, rating each sample on a 9-point hedonic scale.

Measurements of Viscosity

The viscosity of thermally treated (85C/5 min) garlic paste, with the addition of ascorbic acid (0.5 mg/g) and citric acid, (2 mg/g) was measured using a Brookfield Viscometer (model DVII+, Brookfield Laboratories Middleboro, MA) and spindles numbers RV-4, RV-5 and RV-6 at speeds 0.5, 1, 2.5, 5, 10, 20, 50 and 100 rpm. The reading at each spindle speed was taken after a constant reading was observed. Viscosity measurements were conducted in the range of temperatures 10–70C ± 0.2. The readings of the viscometer were converted into average shear stress (Pa) and average shear rate (1/s) values (Mitschka 1982; Briggs and Steffe 1997).

To better describe the rheological data of certain foods like pastes, it is advisable to use more than one flow model (Rao 1999). Those used in the present study are listed below:

$$\text{Power law:} \quad \tau = K_P \dot{\gamma}^n \tag{2}$$

$$\text{Herchel}-\text{Bulkey:} \quad \tau = \tau_0 + K_{HB} \dot{\gamma}^n \tag{3}$$

$$\text{Casson:} \quad \sqrt{\tau} = \sqrt{\tau_0} + K_C \sqrt{\dot{\gamma}^n} \tag{4}$$

$$\text{Mizrahi}-\text{Berk:} \quad \sqrt{\tau} = \sqrt{\tau_0} + K_{MB} \dot{\gamma}^n \tag{5}$$

In these models, τ, τ_0, $\dot{\gamma}$, K and n are considered as the shear stress, yield stress, shear rate, consistency and rate index, respectively. The average shear rate and shear stress data were analyzed statistically (Systat 8.0, SPSS, 1998) to calculate yield stress, consistency and flow behavior index. The significance of the correlation coefficient was judged at ≤ 0.05 level.

Statistical Analysis

All determinations were carried out in triplicate. Data were analyzed for statistical significance using the Systat (1998) program.

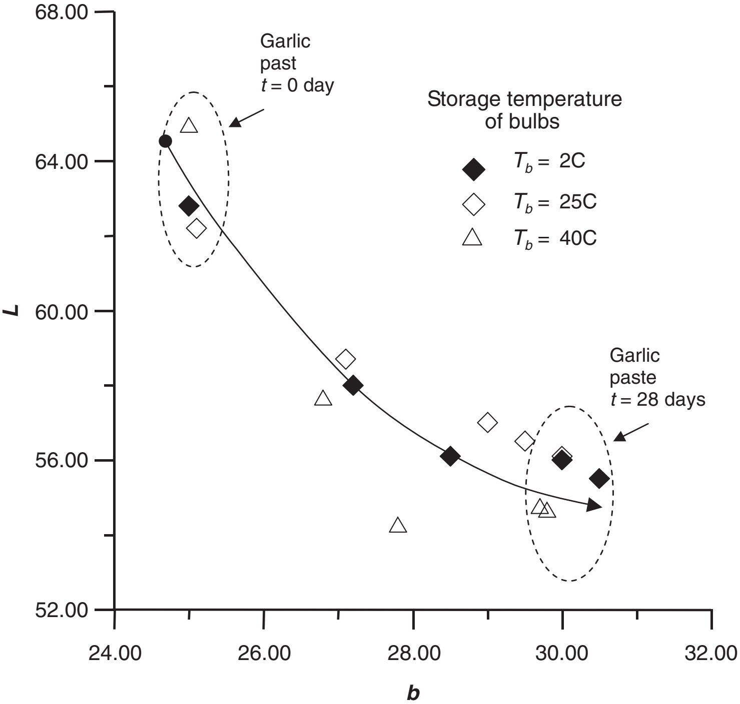

FIG. 1. EFFECT OF STORAGE TEMPERATURE OF GARLIC BULBS ON THE COLOR CHANGE OF GARLIC PASTE

Bulbs were stored at 2, 25 and 40C for 7 days. Pastes were stored at room temperature for 4 weeks.

RESULTS AND DISCUSSION

Storage Conditions of Garlic Bulbs

Figure 1 shows the effect of storage time (t) and temperature (T_b) of bulbs on the browning of garlic paste. Paste samples initially had a creamy-white color, represented by a Hunter L parameter value between 62 and 66, and b-values about 25. As Hunter parameters L and b show, garlic paste was significantly affected by the storage conditions of bulbs. It was also found that 7 days of storage at 40C facilitates skin removal of bulbs. However, bulbs stored at 40C showed a higher rate of browning as compared with bulbs stored at 25C. Storage of garlic bulbs at 2C, however, shows good Hunter L and b parameters (yellowness and lightness), and the Hunter a value (not plotted) decreased significantly from 1.9 to 5.4 ($P = 0.95$). This parameter indicates

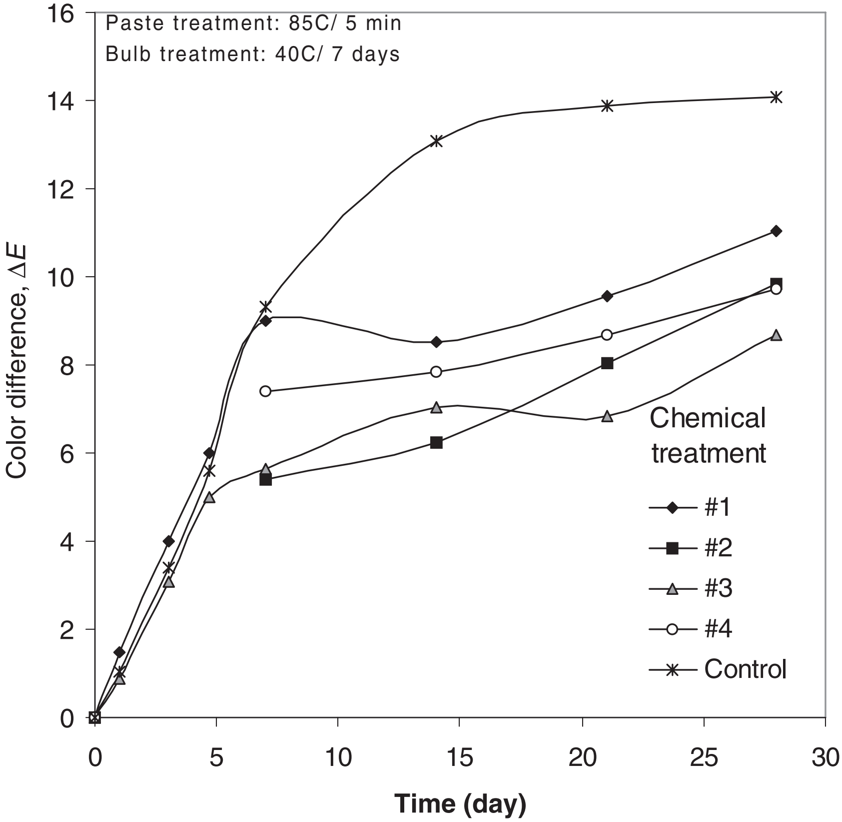

FIG. 2. COLOR DIFFERENCE (ΔE) DEVELOPMENT IN GARLIC PASTE AT ROOM TEMPERATURE, MADE WITH BULBS STORED DURING 7 DAYS AT 40C, WITH THERMAL TREATMENT (85C; 5 min)

The effect of the different chemical treatments applied to garlic paste is also shown and compared with control sample.

greening when negative. As garlic paste must have a light tan to cream color, this greening was considered unacceptable and the treatment was discarded. That is, low storage temperatures condition of bulbs considerably favored the formation of green pigment. Lukes (1986) and Rejano *et al.* (1997) reported similar observation.

Color Changes Kinetics

Figures 2 and 3 show the ΔE development in garlic paste, made with bulbs stored 7 days at 40C, as a representative temperature, with and without

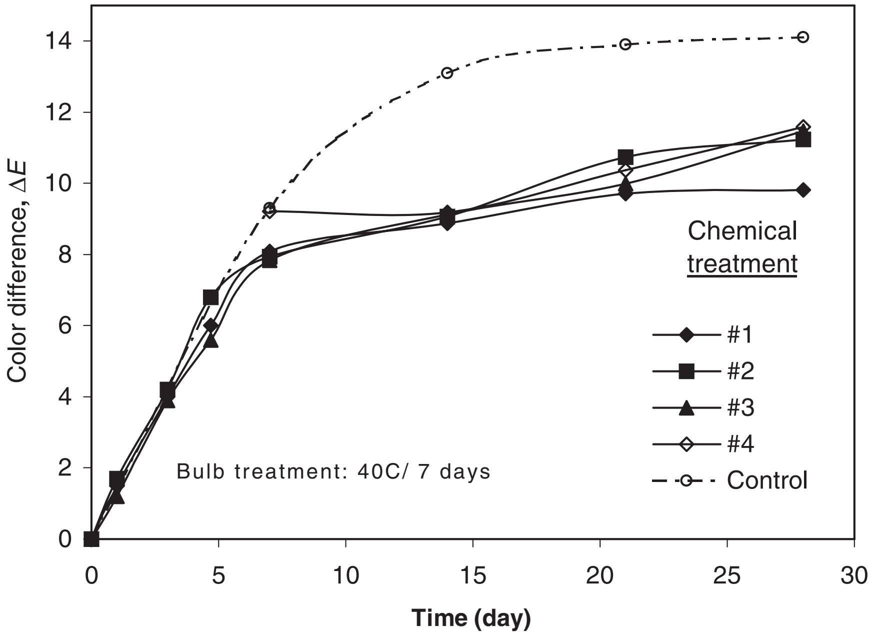

FIG. 3. COLOR DIFFERENCE (ΔE) DEVELOPMENT IN GARLIC PASTE MADE WITH BULBS STORED DURING 7 DAYS AT 40C, WITHOUT THERMAL TREATMENT
The effect of the different chemical treatments applied to garlic paste is also shown and compared with control sample.

thermal treatment, respectively. The effect of the different chemical treatments applied to garlic paste (Table 1) are also shown and compared with the control sample. As pointed out by Labuza and Riboh (1982), most of the quality-related reaction rates are either zero or first-order reactions, and the statistical difference between both types may be small. Kinetic measurement of complex food systems usually gives reaction constant values, which are frequently the combination of rate constants for several steps.

The rate of ΔE could be divided in the case of the garlic pastes assayed in this work, in two zero-order kinetics in series: (1) an initial period characterized by a pronounced rise in color from $\Delta E = 0$ to a breaking point value; followed by (2) a lower slope zone from the breaking point to the end of the storage. The breaking point was estimated from the intersection of the slopes of the two periods, approximately between 4 and 9 days of storage, depending on treatments. During the second period, the rate of discoloration had lower and similar slopes independently of the applied chemical treatment. However, treatments #2 and #3 reached lower ΔE values, and were shown to be a few

TABLE 2.
PARAMETERS FOR LINEAR PORTION OF COLOR DIFFERENCE (ΔE) DEVELOPMENT IN GARLIC PASTE AFTER BREAKING POINT, t_{bp} (EQ. 6)

Garlic bulb	Garlic paste		t_{bp} (days)	k ($\Delta E/t$)	r^2
Thermal treatment	Thermal treatment	Chemical treatment			
7 days at 25C	None	#1	9.0	0144	0.987
	None	#2	8.5	0196	0.889
	None	#3	8.4	0187	0.988
	None	#4	8.6	0177	0.887
	85C/5 min	#1	8.2	0086	0.923
	85C/5 min	#2	8.0	0165	0.965
	85C/5 min	#3	7.9	0168	0.991
	85C/5 min	#4	8.8	0119	0.884
7 days at 40C	None	#1	8.1	0133	0.983
	None	#2	7.0	0136	0.962
	None	#3	4.5	0175	0.991
	None	#4	4.6	0176	0.888
	85C/5 min	#1	8.5	0102	0.825
	85C/5 min	#2	4.3	0244	0.864
	85C/5 min	#3	5.7	0128	0.841
	85C/5 min	#4	7.2	0111	0.973

more effective color inhibitors than treatments #1 and #4, at least during the first two weeks of storage. Experimental data on the dependence of ΔE on treatment were fitted to the equation:

$$\Delta E = \Delta E_{bp} - k\,(t - t_{bp}) \tag{6}$$

where k is a reaction constant; ΔE_{bp} is the color difference value reached at the breaking point; and t_{bp} is the time at which breaking point occurs. Eq. (6) is valid for $t > t_{bp}$. The calculated values of k and t_{bp} are summarized in Table 2. As Table 2 shows, Eq. (6) resulted to a reasonable model of ΔE as a function of time, at the assayed temperatures. Fig. 4 shows a plot of *hue* ($\tan^{-1} b/a$) with storage time, which allows comparing the color differences among the four chemical treatments. (Hunter L moves to lower values.) The change of *hue* during heating was practically similar for chemical treatments #2, #3 and #4, and more pronounced in the case of treatment #1. As Fig. 4 shows, garlic paste changes its *hue* during the first linear zone, becoming more reddish and grayish. Limited Maillard reactions could explain initial rates (Madamba *et al.* 1996). In brief, the analysis of the data concerning the rate of color deterioration in garlic paste suggests that more than one mechanism contributes to color deterioration.

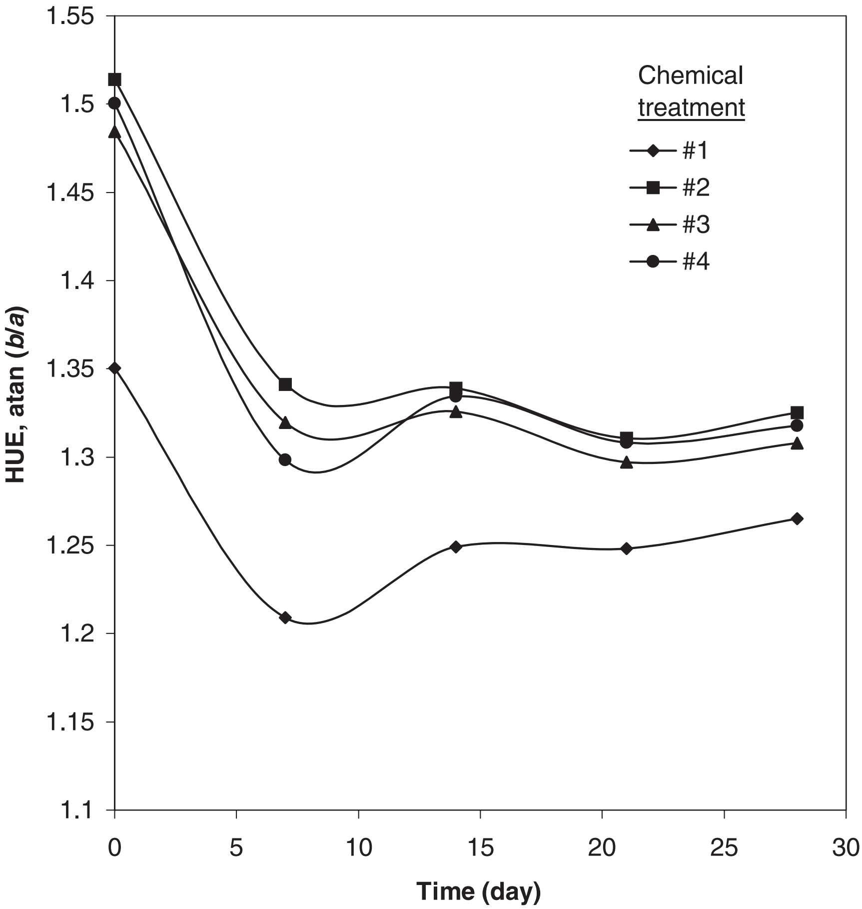

FIG. 4. PLOT OF HUE ($\tan^{-1} b/a$) CHANGE WITH TIME, DURING STORAGE OF GARLIC PASTE MADE WITH BULBS STORED DURING 7 DAYS AT 40C WITH THERMAL TREATMENT

The effect of the different chemical treatments applied to garlic paste is also shown.

Sensory and Microbiological Analysis

Sensory evaluation is carried out in two steps. It was found as a result of the first study designed to evaluate the appropriate concentration of additives (citric acid, ascorbic acid and potassium sorbate) that in the case of pastes with citric acid concentration greater than 2 mg/g, the acceptance was negative to acidity.

TABLE 3.
MEAN VALUES OF THE SENSORY ATTRIBUTES FOR GARLIC PASTE

Chemical treatment	Heat treatment	Color	Flavor	Overall acceptance
#1	No	7.9 ± (0.74)	8.0 ± (0.82)	8.0 ± (0.44)
	Yes	7.7 ± (0.67)	6.8 ± (0.79)	7.4 ± (0.27)
#2	No	7.9 ± (0.57)	8.0 ± (0.82)	8.2 ± (0.18)
	Yes	7.8 ± (0.63)	4.8 ± (0.79)	6.3 ± (0.23)
#3	No	8.0 ± (0.67)	8.5 ± (0.53)	8.2 ± (0.63)
	Yes	7.8 ± (0.63)	7.1 ± (0.74)	7.7 ± (0.48)
#4	No	8.1 ± (0.54)	8.1 ± (0.57)	8.2 ± (0.63)
	Yes	8.0 ± (0.82)	7.2 ± (0.79)	7.8 ± (0.42)

Numbers in parentheses indicate standard deviations.

TABLE 4.
MICROBIOLOGICAL QUALITY OF GARLIC PASTE

Chemical treatment	Heat treatment	SPC (cfu/g)	*Clostridium perfringens*/g	Yeast and mold/g
#1	No	10	< 10	< 10
	Yes	10	< 10	< 10
#2	No	10	< 10	< 10
	Yes	10	< 10	< 10
#3	No	40	< 10	10
	Yes	10	< 10	< 10
#4	No	< 10	< 10	< 10
	Yes	< 10	< 10	< 10

SPC, standard plate count.

During the second study, the effect of additives plus selected thermal treatment on sensory attributes were evaluated. Mean values of the sensory scores for color, flavor and overall acceptance are shown in Table 3. No significant color preferences were detected in any of the paste samples. In the flavor evaluation, it was found that samples without heat treatment got significantly favorable scores ($P = 0.95$). The sensory panelists rejected heat-processed paste with citric acid and potassium sorbate (#2) because of its bitter flavor ($P = 0.99$). SPC of microorganisms was <10 cfu/g in all samples, with the exception of sample #3 (SPC = 40 cfu/g). Counts of *C. perfringens* were also <10 cfu/g. The results (Table 4) indicated that all samples were sanitarily appropriate for consumption.

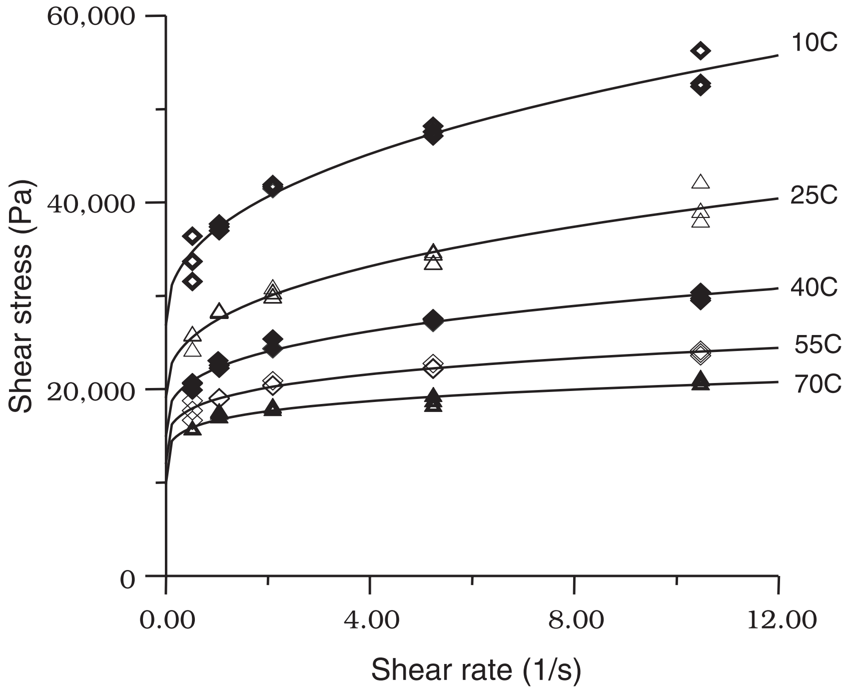

FIG. 5. TYPICAL AVERAGE SHEAR RATE AND AVERAGE SHEAR STRESS BEHAVIOR OF GARLIC PASTE IN THE RANGE OF TEMPERATURES 10–70C

Rheological Characteristics

Figure 5 shows the typical average shear rate and average shear stress behavior of garlic paste in the range of temperatures 10–70C. Samples exhibited shear thinning behavior with yield stress. The average shear rate and average shear stress data of flow curves were fitted to the Power Law, Herschel–Bulkley, Casson and Mizrahi–Berk models (Sherman 1970). All the models gave similar fit, depending on temperature. However, the Herschel–Bulkley model, including more empiric parameters to fit, gave the best fit with r^2 of 0.95–0.99 for all treatments. The yield stress (Pa), consistency index (Pa·s^n) and flow behavior index (dimensionless) values of the different garlic pastes derived from the Herschel–Bulkley model are shown in Table 5.

As supposed, the experimental yield stress values of garlic paste decreased from 26.8 to 9.8 Pa, as temperature increased from 10 to 70C.

TABLE 5.
HERSCHEL–BULKLEY PARAMETERS

T (C)	τ_0 (Pa)	K(Pa·s^n)	n	r^2
10	26.81	10.38	0.41	0.981
25	19.06	8.34	0.38	0.960
40	14.93	7.34	0.31	0.991
55	11.98	6.96	0.23	0.987
70	9.80	6.89	0.19	0.930

Consistency Index. The consistency index values of garlic pastes at different temperatures were in the range of 10.38–6.89 Pa·s^n. The consistency index values showed a decreasing trend with increased temperature as expected, because of the reduction of water (or serum) viscosity. The volume distribution of the particles might have influenced the consistency index of the pastes.

Flow Behavior Index. The effect of temperature on garlic pastes showed that the flow behavior index varied in the range of 0.41–0.19, indicating that these pastes are non-Newtonian pseudoplastic fluids. The highest and lowest values were at lower and higher temperatures assayed.

Apparent Viscosity. Figure 6 shows the apparent viscosity of garlic paste at different temperatures, estimated with viscometer speeds of 5, 10, 20, 50 and 100 rpm. The apparent viscosity values decreased sharply as shear rate increased for all temperatures. Similar behavior was found with other food products (Berger 1990). The effect of temperature on apparent viscosity was represented by the Arrhenius relationship:

$$\eta = \eta_0 \exp\left(\frac{E_\eta}{RT}\right) \tag{7}$$

where η_0 is the pre-exponential parameter and E_η is the activation energy. Activation energy varied in the range of 10–13 kJ/mol ($r^2 = 0.981$), when the rate of shear as spindle speed increased from 5 to 100 rpm.

As a conclusion, to elaborate a good garlic paste, bulbs should be stored at ambient temperature (about 25C) and crushed with the addition of edible oil to facilitate the operation (0.1 kg/kg sunflower oil was used in this work) and the appropriated combination of citric and ascorbic acid (< 2 mg/g) added. Garlic bulbs may be heated to 40C a few minutes before processing to

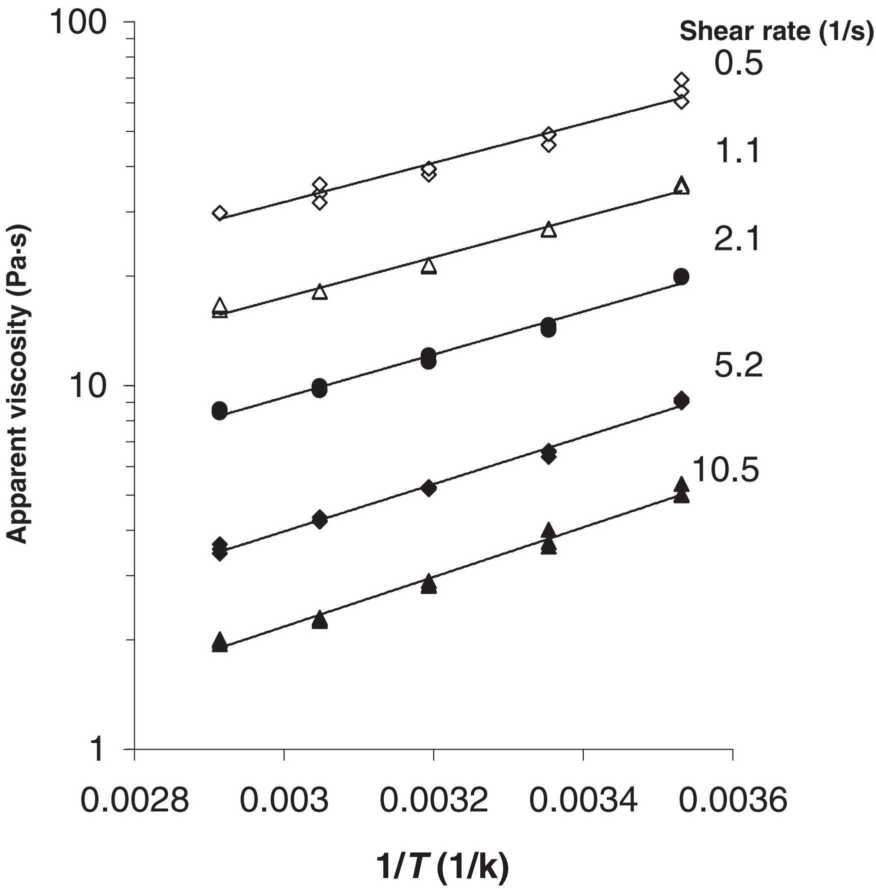

FIG. 6. APPARENT VISCOSITY VALUES OF GARLIC PASTE AT DIFFERENT TEMPERATURES, ESTIMATED AT VISCOMETER SPEEDS OF 5, 10, 20, 50 AND 100 rpm

facilitate skin removal. Rheological studies indicated that contrarily to what is reported in the literature (Ahmed 2000) for similar products, garlic paste exhibits shear thinning with yield-stress behavior.

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