Antioxidant Activity of Several *Allium* Members

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A liposome model was used to examine the antioxidant activity of several members of the *Allium* family, including garlic bulb, bakeri garlic bulb, Chinese leek, Chinese chive, onion bulb, scallion, and shallot bulb. Allicin formation of these plants was analyzed. The influence of heat, pH, and salt upon the antioxidant activity of these foods was studied. The results showed that part of the *Allium* family possessed antioxidant capability ($p < 0.05$). Beside onion, allicin was present in other tested *Allium* members. Beside allicin, other compounds could be involved in the antioxidant activity performance because the allicin concentration was not strongly correlated to the antioxidant activity observed in these *Allium* foods. Heat treatments at 65 or 100 °C and acid treatment at pH = 2 reduced the antioxidant activity for most foods ($p < 0.05$). The pH treatments at values of 4, 6, and 8 as well as the salt treatments at concentrations of 0.2 or 0.4 M did not affect the antioxidant or prooxidant activity of these plant foods ($p > 0.05$). The combined treatments of heat and acid showed a greater negative impact upon the antioxidant activity for most food samples ($p < 0.05$). Heating and the use of acid should be carefully considered when *Allium* plants are used for antioxidant protection in food preparation or food processing, while the presence of NaCl should be safe.

Keywords: *Antioxidant activity; Allium members; allicin; liposomes*

INTRODUCTION

The antioxidant activity of many vegetables, fruits, and teas has been widely studied (Bors and Saran, 1987; Gey, 1990; Willett, 1994; Cao et al., 1996). These authors indicated that the antioxidant capacity of these plant foods was due to the presence of antioxidant vitamins (vitamin C, β-carotene) or flavonoids. Garlic bulb and onion, two members of *Allium* family, are also known to possess antioxidant activity (Yang et al., 1993; Cao et al., 1996). Although the antioxidant capacity of garlic and onion bulbs has been investigated, little is known about the antioxidant activity of other members of the *Allium* family. Prasad et al. (1996) indicated that allicin, a scavenger of peroxy radicals, was responsible for the antioxidant activity of garlic bulb. It is known that allicin is absent in an intact garlic bulb, but it is produced when the bulb is injured (Cavallito et al., 1944). Allicin and other thiosulfinates formation in garlic and other *Allium* members have been analyzed (Lawson et al., 1991; Block et al., 1992). These authors confirmed the presence of allicin in these plants but did not study the antioxidant activity of these plants.

There are seven to eight commonly seen and consumed *Allium* members in Taiwan markets. These edible plant foods are used as vegetables (e.g. onion, Chinese leek and Chinese chive) or used as flavoring agents (such as garlic bulb, scallion, and shallot bulb). Yin and Cheng (1998) studied the antifungal activity of garlic bulb (*Allium sativum* L.), garlic greens (*Allium sativum* L.), and scallion (*Allium fistulosum* L.) and reported that these three plant foods have different antifungal capacities under the same conditions. It should be pointed out that garlic bulb and garlic greens are different parts of the same plant. Since the different antifungal capacity of these two plant foods was observed, these two plant foods might also have different antioxidant activity. Heating and the addition of acid or salt are often used for food preparation and food processing. In the study of Yin and Cheng (1998), the antifungal activity of these plant foods was affected by heat and/or acid treatments. Therefore, it is worthy to study the influence of heat, acid, base, or salt upon the antioxidant activity of these *Allium* members.

Liposomes, artificial biomembranes, have been used as a model system to study the oxidation behavior of lipids and lipid-soluble compounds (Yin and Faustman, 1993; Yin et al., 1993). Yin and Cheng (1997) also used liposomes incorporated with oxymyoglobin to compare the antioxidant activity of α-tocopherol and β-carotene. The first objective of this study was to examine and compare the antioxidant activity of several *Allium* extracts by using this liposomes model. Second, the formation of allicin in these *Allium* foods was analyzed. Third, the extracts of heat, pH, and salt treated *Allium* members will be investigated for antioxidant activity.

MATERIALS AND METHODS

Water Content, pH Value Analysis, and *Allium* Extract Preparation. The antioxidant activity of the following *Allium* foods was examined: garlic bulb (*Allium sativum* L.), garlic greens (*Allium sativum* L.), bakeri garlic bulb (*Allium bakeri* L.), Chinese leek (*Allium odorum* L.), Chinese chive (*Allium tuberosum* Rottler), scallion (*Allium fistulosum* auct.), onion bulb (*Allium cepa* L.), and shallot bulb (*Allium asca-*

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10.1021/jf980344x CCC: $15.00
Published on Web 09/30/1998

lonicum L.). These plant foods were purchased from the local markets. Water content and pH value of these *Allium* foods were measured by using the official methods of AOAC (1990). The method of Yin and Cheng (1998) was used to prepare *Allium* extracts as described. A 20-g edible portion of each food sample was homogenized in 20 mL of sterile distilled water in a Waring blender at high speed for 3 min at 25 °C. The mixture was filtered through Whatman No. 1 filter paper. The filtrate was collected in a sterile vial and stored at 4 °C until used for liposome preparation.

Analysis of Allicin Formation. Allicin used for standard was synthesized from diallyl sulfide (Aldrich, Milwaukee, WI) by oxidation with 3-chloroperbenzoic acid (Jansen et al., 1987). The method of Lawson et al. (1991) was used for the analysis of allicin formation. Ten grams of food sample was chopped and blended with 100 mL of distilled water in a Waring blender for 1 min. The homogenate was allowed to stand at room temperature for 5 min for thiosulfinates production. Then, the homogenate was filtered through Whatman No. 1 filter paper and further passed through 0.45 μM filter. Two microliters of the filtrate was injected directly into the HPLC. The samples were analyzed by normal phase HPLC (Waters system, Model 600E) with Supelco LC-Si 250 mm × 4.6 mm column at 254 nm and quantified by comparing with standard. The solvents were hexane/2-propanol (95/5), 2 mL/min. The interference of pigments and waxy materials as mentioned in Block et al. (1992) was mild and did not result in severe difficulty.

Heat, pH, and Salt Treatments. The method of Yin and Cheng (1998) was used for these treatments. For heat treatment, 20 g of a food sample was chopped, wrapped in aluminum foil, and placed into ovens at temperatures of 25, 65, or 100 °C for 15 min before the food sample was prepared for homogenization. The heating treatment, especially at 100 °C, resulted in the formation of sticky residue on aluminum foil. This sticky material should be from the food sample. To remove the sticky residue from aluminum foil, the food sample was collected, and the aluminum foil was mixed with 10 mL of sterile distilled water in a Waring blender. The sticky residue was separated from aluminum foil by filtering the mixture through Whatman No. 1 filter paper. Then, food sample, filter paper, and filtrate containing sticky residue were further mixed with another 10 mL of sterile distilled water for homogenization in a Waring blender at high speed for 3 min. After being filtered again, the filtrate was used for antioxidant activity analysis. For pH or salt treatments, a 20-g edible portion of food sample was chopped, soaked in 20 mL of sterile distilled water, and adjusted for pH (2, 4, 6, or 8) with HCl or NaOH, for 15 min before the food sample was homogenized. The same procedure was followed using 0, 0.2, and 0.4 M solutions of NaCl in place of the distilled water. The interaction of temperature and pH value was studied by treating food sample with acid or base first. Then, the food sample was collected and wrapped in aluminum foil for heat treatment. The allicin content of solutions for pH and NaCl treatments was analyzed. There was no detectable allicin found in these solutions.

Liposomes Preparation and Lipid Oxidation Measurement. Phosphatidylcholine (PC) with linoleic acid (C18:2 n-6, at both Sn-1 and Sn-2 positions) was purchased from Wako Chemical Co. (Tokyo, Japan). The other chemicals were purchased from Sigma Chemical Co. (St. Louis, MO). Liposomes (Multilamellar vesicles, MLVs) were prepared at 4 °C as described by Yin and Faustman (1993). A 10-mL *Allium* extract was used to replace phosphate buffer for liposomes preparation. For the control group, 10 mL of distilled water was used to replace *Allium* extract. After preparation, all samples were incubated at 25 °C for oxidation measurement. At the start, 5 μM $FeSO_4$ was added to induce liposome oxidation. Liposome phospholipid oxidation was measured at 0 and 36 h by the thiobarbituric acid (TBA) assay as described by Yin and Faustman (1993). Absorption of the final solution was measured by UV−vis spectrophotometry at 532 nm and recorded as TBA-number. The lipid stability of purchased PC was examined, and the PC with TBA-No. ≤ 0.01 was used for liposomes preparation.

Table 1. Water Content and pH Value of *Allium* Foods[a] (n = 5)

	water content (%)	pH value
garlic bulb	74.5 ± 3.3	6.64 ± 0.08
garlic greens	81.9 ± 2.8	6.81 ± 0.12
bakeri garlic bulb	76.4 ± 3.0	6.73 ± 0.05
Chinese leek	87.6 ± 3.5	7.05 ± 0.16
Chinese chive	83.1 ± 4.2	7.12 ± 0.14
scallion	78.7 ± 2.9	6.35 ± 0.07
onion bulb	90.3 ± 5.4	6.21 ± 0.10
shallot bulb	77.8 ± 2.3	6.44 ± 0.21

[a] Data expressed as means ± SD.

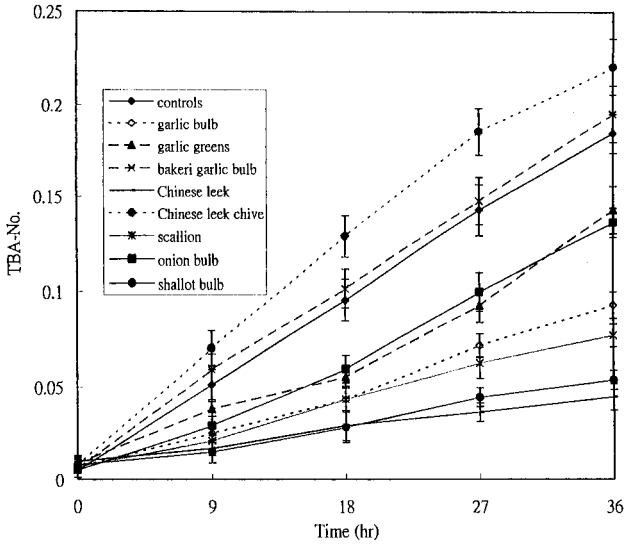

Figure 1. Effect of *Allium* foods on lipid oxidation (TBA-No.) during 36 h incubation (n = 5).

Statistic Analysis. The effect of each experimental condition was analyzed on liposomes from five different preparations. Data were treated by analysis of variance (ANOVA) and computed using the SAS General Model (GLM) procedure (SAS Institute, Inc., 1985). Difference among means were determined by the Least Significance Difference Test with significance defined at $p \leq 0.05$.

RESULTS AND DISCUSSION

The water content and pH value of these plant foods are shown in Table 1. The pH values of these food samples were in the range of 6.2−7.1. After 15 min incubation, the pH value of solution and food sample was measured again. The change was mild and not significant. The effect of *Allium* foods on lipid oxidation during 36 h incubation at 25 °C is shown in Figure 1. The TBA-No. increased with increasing incubation time for all food samples and controls ($p < 0.05$). During incubation, Chinese chive revealed greater lipid oxidation (higher TBA-No.) than controls at 9, 18, 27, and 36 h ($p < 0.05$). The difference in TBA-No. between bakeri garlic bulb and controls within the 36 h incubation was not significant ($p > 0.05$). The effect of heat-treated plant foods on lipid oxidation in liposomes after 36 h incubation is shown in Table 2. The presence of garlic bulb, garlic greens, Chinese leek, scallion, onion bulb, and shallot bulb significantly delayed lipid oxidation ($p < 0.05$) at 25 °C when compared with controls. The antioxidant activity of these six plant foods at this condition followed the order Chinese leek = shallot

Table 2. Effect of Heat-Treated *Allium* Foods on Lipid Oxidation (TBA-No.) after 36 h Incubation ($n = 5$)[a]

	TBA-No.		
food sample	25 °C	65 °C	100 °C
controls	0.184 ± 0.11^{d}	0.177 ± 0.015^{c}	0.182 ± 0.009^{c}
garlic bulb	0.092 ± 0.007^{b}	0.102 ± 0.016^{a}	0.167 ± 0.012^{bc}
garlic greens	0.142 ± 0.013^{c}	0.153 ± 0.01^{b}	0.228 ± 0.012^{d}
bakeri garlic bulb	0.195 ± 0.016^{d}	0.262 ± 0.018^{d}	0.315 ± 0.021^{e}
Chinese leek	0.044 ± 0.007^{a}	0.089 ± 0.01^{a}	0.159 ± 0.014^{b}
Chinese chive	0.221 ± 0.015^{e}	0.271 ± 0.017^{d}	0.346 ± 0.023^{f}
scallion	0.076 ± 0.006^{b}	0.106 ± 0.008^{a}	0.132 ± 0.006^{a}
onion bulb	0.135 ± 0.008^{c}	0.195 ± 0.014^{c}	0.324 ± 0.025^{e}
shallot bulb	0.053 ± 0.005^{a}	0.093 ± 0.007^{a}	0.175 ± 0.013^{c}

[a] Means with a common superscript within a column are not different ($p > 0.05$). Data expressed as means ± SD.

Table 3. Allicin Yield from *Allium* Foods ($n = 8$)[a]

	allicin (mg/g fresh weight)
garlic bulb	3.48 ± 0.15^{e}
garlic greens	3.27 ± 0.21^{e}
bakeri garlic bulb	0.89 ± 0.13^{a}
Chinese leek	2.21 ± 0.17^{c}
Chinese chive	2.06 ± 0.24^{c}
scallion	1.65 ± 0.31^{b}
onion bulb	*b*
shallot bulb	2.87 ± 0.11^{d}

[a] Means with a common superscript within a column are not different ($p > 0.05$). [b] No detectable amount.

bulb> scallion = garlic bulb > onion bulb = garlic greens ($p < 0.05$) (Table 2). Although bakeri garlic bulb and Chinese chive belong to the *Allium* family, bakeri garlic bulb did not show either antioxidant or prooxidant activity, but Chinese chive showed a prooxidant activity in this model at 25 °C (Figure 1 and Table 2). When the applied temperature was 65 °C, the onion bulb lost its antioxidant activity ($p > 0.05$), whereas the other five plant foods still possessed antioxidant activity ($p < 0.05$), but the presence of bakeri garlic bulb or Chinese chive significantly facilitated lipid oxidation ($p < 0.05$) (Table 2). When the treatment temperature was 100 °C, only Chinese leek and scallion showed antioxidant activity ($p < 0.05$), garlic bulb and shallot bulb lost their antioxidant activity ($p > 0.05$). However, the other four *Allium* extracts showed prooxidant activity under the same condition ($p < 0.05$). These results suggested that the members of *Allium* family had different antioxidant or prooxidant activity, and heat treatment was a factor which affected the antioxidant activity. Cao et al. (1996) also examined the antioxidant activity of garlic bulb and onion. These authors reported that garlic bulb had a higher antioxidant score than onion. The result of our study was in agreement with this previous study. Prasad et al. (1996) studied the influence of heating on the hydroxyl radical-scavenging property of garlic and reported that its activity was reduced by approximately 10% when heated to 100 °C for 20, 40, or 60 min. The results of our study agreed that heating treatment reduced the antioxidant activity of garlic bulb, while the hydroxyl radical-scavenging property was not determined in this study.

The yield of allicin of these *Allium* members was analyzed, and the results are shown in Table 3. Besides onion, allicin was present in other *Allium* members. The yield of allicin was followed the order garlic bulb = garlic green > shallot bulb> Chinese leek = Chinese chive > scallion > bakeri garlic bulb ($p < 0.05$). It was interesting to find that allicin was also present in bakeri garlic bulb and Chinese chive, although these two plants did not show antioxidant activity in this liposome model (Figure 1 and Table 2). On the other hand, allicin was not present in onion bulb although this plant showed antioxidant activity. Allicin and other thiosulfinates in garlic clove and other *Allium* members have been analyzed (Lawson et al., 1991; Lawson and Hughes, 1992; Block et al., 1992). These authors reported that although there was a great variation in the content of allicin and other thiosulfinates in garlic and other *Allium* plants, allicin, accounting for about 65−75% of the total thiosulfinates or 0.3% of the fresh weight, was thought to be the major thiosulfinate in garlic. Block et al. (1992) observed that allicin was present in garlic (*Allium sativum* L.) but not in onion (*Allium cepa L.*), scallion (*Allium fistulosum* L.), Chinese chive (*Allium tuberosum* L.), and shallot bulb (*Allium ascalonicum* auct.). In the study of Block et al. (1992), thiosulfinates from bakeri garlic bulb and Chinese leek were not analyzed. The results of our study showed that allicin was present in scallion (*Allium fistulosum* auct.), Chinese chive (*Allium tuberosum* Rottler), and shallot (*Allium ascalonicum* L.). The different variety of *Allium* used in this study may account for the opposing observation of Block et al. (1992) regarding the allicin content of the *Allium* food. In our study, allicin was absent in onion. This result was in agreement with those previous studies. Lawson et al. (1991) indicated that onion bulb contained large and dominant amounts of *trans*-1-propenyl cysteine sulfoxide but no alliin. The absence of alliin in onion bulb may explain why allicin was not produced in onion.

It was reported that allicin was responsible for the antioxidant activity of garlic bulb (Prasad et al., 1995). In our study, Chinese leek with lower allicin yield than garlic bulb (Table 3) showed greater antioxidant activity than garlic bulb at 25 °C (Table 2); scallion with lower allicin yield than garlic bulb (Table 3) showed similar antioxidant activity to garlic bulb at 25 °C (Table 2). Bakeri garlic bulb showed prooxidant activity, and Chinese chive did not show antioxidant activity although allicin was present in these two plants. These above results suggested that compounds other than allicin were involved in determining the antioxidant or prooxidant activity of these plant foods. Apparently, the antioxidant activity of onion bulb should be due to the compounds other than allicin. Beside allicin, other thiosulfinates have been found in onion bulb (Block et al., 1992). These thiosulfinates might also play an important role in the antioxidant activity of onion. It was reported that antioxidant vitamins and phenolic compounds also contribute to the antioxidant activity of many fruits and vegetables (Willett, 1994; Wang et al., 1996). Therefore, the presence of other potential antioxidant compounds such as vitamin C, vitamin E, β-carotene, flavonoids, or phenolic compounds in onion bulb and other *Allium* plants also needs to be verified.

It is known that allicin is heat-labile (Lawson et al., 1991). In this liposome model, the TBA-No. increased for every *Allium* food when the applied temperature increased from 25 °C to 65 °C or 100 °C. These results suggested that antioxidant component(s) in these *Allium* foods was (were) also sensitive to heat. Heat treatments may have promoted the decomposition of those antioxidant components, resulting in the loss of antioxidant activity. It was interesting to find that both Chinese leek and scallion still showed greater antioxi-

Table 4. Effect of Acid- or Base-Treated *Allium* Foods on Lipid Oxidation (TBA-No.) after 36 h Incubation ($n = 5$)[a]

	TBA-No.			
food sample	2	4	6	8
controls	0.187 ± 0.012^{b}	0.175 ± 0.008^{d}	0.185 ± 0.014^{e}	0.180 ± 0.013^{d}
garlic bulb	0.178 ± 0.009^{b}	0.083 ± 0.006^{b}	0.095 ± 0.008^{c}	0.097 ± 0.01^{b}
garlic greens	0.176 ± 0.006^{b}	0.136 ± 0.012^{c}	0.138 ± 0.012^{d}	0.139 ± 0.008^{c}
bakeri garlic bulb	0.203 ± 0.01^{c}	0.187 ± 0.013^{d}	0.19 ± 0.013^{e}	0.177 ± 0.016^{d}
Chinese leek	0.136 ± 0.011^{a}	0.034 ± 0.004^{a}	0.041 ± 0.004^{a}	0.037 ± 0.006^{a}
Chinese chive	0.206 ± 0.017^{c}	0.192 ± 0.014^{d}	0.20 ± 0.01^{e}	0.196 ± 0.012^{d}
scallion	0.171 ± 0.014^{b}	0.093 ± 0.007^{b}	0.077 ± 0.007^{bc}	0.088 ± 0.007^{b}
onion bulb	0.187 ± 0.013^{b}	0.127 ± 0.005^{c}	0.132 ± 0.011^{d}	0.131 ± 0.012^{c}
shallot bulb	0.172 ± 0.015^{b}	0.086 ± 0.006^{b}	0.063 ± 0.007^{b}	0.076 ± 0.008^{b}

[a] Means with a common superscript within a column are not different ($p > 0.05$). Data expressed as meansSD.

Table 5. Effect of Heat × pH-Treated *Allium* Foods on Lipid Oxidation (TBA-No.) after 36 h Incubation ($n = 5$)[a]

	TBA-No.					
	65 °C			100 °C		
food sample	2	4	6	2	4	6
controls	0.181 ± 0.007^{bc}	0.179 ± 0.008^{c}	0.185 ± 0.011^{d}	0.18 ± 0.013^{a}	0.185 ± 0.015^{b}	0.183 ± 0.017^{c}
garlic bulb	0.197 ± 0.011^{c}	0.113 ± 0.01^{a}	0.10 ± 0.008^{ab}	0.290 ± 0.023^{c}	0.221 ± 0.018^{c}	0.17 ± 0.009^{c}
garlic greens	0.204 ± 0.013^{c}	0.164 ± 0.014^{c}	0.151 ± 0.012^{c}	0.306 ± 0.021^{d}	0.255 ± 0.016^{d}	0.224 ± 0.018^{d}
bakeri garlic bulb	0.356 ± 0.02^{e}	0.271 ± 0.019^{e}	0.265 ± 0.02^{f}	0.438 ± 0.025^{f}	0.341 ± 0.023^{e}	0.318 ± 0.02^{e}
Chinese leek	0.153 ± 0.013^{a}	0.110 ± 0.009^{a}	0.085 ± 0.006^{a}	0.204 ± 0.018^{b}	0.157 ± 0.018^{a}	0.153 ± 0.013^{b}
Chinese chive	0.381 ± 0.023^{f}	0.336 ± 0.022^{f}	0.281 ± 0.021^{e}	0.411 ± 0.021^{e}	0.371 ± 0.022^{f}	0.34 ± 0.021^{f}
scallion	0.174 ± 0.008^{b}	0.142 ± 0.016^{b}	0.109 ± 0.008^{b}	0.205 ± 0.018^{b}	0.162 ± 0.017^{a}	0.13 ± 0.012^{a}
onion bulb	0.257 ± 0.022^{d}	0.187 ± 0.01^{cd}	0.191 ± 0.011^{d}	0.406 ± 0.022^{e}	0.357 ± 0.025^{e}	0.319 ± 0.02^{e}
shallot bulb	0.197 ± 0.015^{c}	0.137 ± 0.013^{b}	0.089 ± 0.008^{a}	0.293 ± 0.02^{c}	0.209 ± 0.007^{c}	0.182 ± 0.008^{c}

[a] Means with a common superscript within a column are not different ($p > 0.05$). Data expressed as means ± SD.

dant activity after 100 °C treatment when compared with controls ($p < 0.05$). However, the yield of allicin in Chinese leek and scallion was not the highest when compared with other *Allium* plants (Table 3). Therefore, this finding once again suggested that compounds other than allicin contributed to the antioxidant activity of these *Allium* foods.

The effect of acid- or base-treated plant foods on lipid oxidation in liposomes after 36 h incubation is shown in Table 4. After being treated at pH 4, 6, and 8, lipid oxidation was significantly delayed by garlic bulb, garlic greens, Chinese leek, scallion, onion bulb, and shallot bulb when compared with controls ($p < 0.05$). There was no significant difference in TBA-No. among these three treatments for every food sample ($p > 0.05$). However, after being treated with pH = 2, only Chinese leek still showed antioxidant activity ($p < 0.05$). It was reported that alliinase responsible for the formation of allicin was completely inactivated at the acidic pH levels found in the stomach (Jansen et al., 1987). Lawson and Hughes (1992) studied the effect of pH on yield of thiosulfinates released from garlic powder and reported that the optimum pH for allicin formation was 4.5−5.0 and there was no thiosulfinate formation when the pH was below 3.6. In our study, the decrease or loss in antioxidant activity of these *Allium* plants after pH = 2 treatment may also be due to this acidic condition inactivate alliinase and interfere with the formation of allicin. In the study of Lawson and Hughes (1992), the yield of most thiosulfinates including allicin was > 80% at pH = 6, allicin yield was > 60% at pH = 8, and the yield of other thiosulfinates was < 50% at pH = 8. Although these authors reported that at pH = 8 treatments reduced the formation of allicin and other thiosulfinates, our results (Table 4) showed that the antioxidant activity of these *Allium* plants was not affected by pH = 8 treatment. This might suggest that the impact of thiosulfinates other than allicin on antioxidant activity of these food samples was less important, and allicin played only a partial influence upon the antioxidant activity of garlic and other *Allium* plants. Yin and Cheng (1998) reported that garlic bulb, garlic greens, and scallion after treatment with HCl at pH = 2 did not reduce their antifungal activity. Thus, these authors proposed that the antifungal components in these plant foods were stable to acid levels of pH 2. However, these three plant foods lost their antioxidant activity after the same treatment in this liposome model. These results suggested that the antifungal activity and antioxidant activity of these plant foods were not due to the same components although allicin was reported to be the major antifungal compounds in garlic (Barone and Tansey, 1977).

The effect of the combined heat and pH-treated plant foods on lipid oxidation in liposomes after 36 h incubation is shown in Table 5. At 65 °C or 100 °C, there was no significant difference in antioxidant activity between pH = 6 and pH = 8 ($p > 0.05$). The results of these treatments were similar to that of heat treatments only ($p < 0.05$). Therefore, the results of 65 °C × pH 8 and 100 °C × pH 8 were not shown in Table 5. After the combined treatment of 65 °C × pH 4, antioxidant activity was observed in garlic bulb, Chinese leek, scallion, and shallot bulb ($p < 0.05$). However, only Chinese leek and scallion showed antioxidant activity after treatment with 100 °C × pH 4 ($p < 0.05$). After being treated with 65 °C × pH 2, only Chinese leek showed antioxidant activity ($p < 0.05$). While the treatment of 100 °C × pH 2 led to complete loss in antioxidant activity for all food samples. Apparently, the combined treatments of heat plus acid resulted in greater loss in antioxidant activity or even enhanced the prooxidant effect in several food samples under certain conditions (Table 5) when compared with heat treatment or acid treatment alone (Table 2) ($p < 0.05$). The heat and acid combination may show an additive or synergistic effect upon alliinase inactivation, thiosulfinates formation reduction, and antioxidant com-

Table 6. Effect of Salt-Treated *Allium* Foods on Lipid Oxidation (TBA-No.) after 36 h Incubation ($n = 5$)[a]

	TBA-No.		
food sample	0 M	0.2 M	0.4 M
controls	0.186 ± 0.01^{e}	0.187 ± 0.012^{d}	0.178 ± 0.017^{d}
garlic bulb	0.094 ± 0.008^{c}	0.098 ± 0.008^{b}	0.091 ± 0.009^{b}
garlic greens	0.139 ± 0.012^{d}	0.150 ± 0.014^{c}	0.147 ± 0.01^{c}
bakeri garlic bulb	0.192 ± 0.015^{e}	0.183 ± 0.016^{d}	0.19 ± 0.015^{d}
Chinese leek	0.045 ± 0.005^{a}	0.041 ± 0.005^{a}	0.053 ± 0.007^{a}
Chinese chive	0.203 ± 0.012^{e}	0.209 ± 0.014^{e}	0.207 ± 0.021^{e}
scallion	0.073 ± 0.006^{b}	0.081 ± 0.011^{b}	0.071 ± 0.006^{b}
onion bulb	0.129 ± 0.006^{d}	0.141 ± 0.017^{c}	0.131 ± 0.012^{c}
shallot bulb	0.053 ± 0.004^{a}	0.052 ± 0.006^{a}	0.049 ± 0.006^{a}

[a] Means with a common superscript within a column are not different ($p > 0.05$). Data expressed as means ± SD.

pounds decomposition and finally led to the greater loss in antioxidant activity. These results revealed that the combined treatments of heat and acid had a greater negative impact on antioxidant activity of these plant foods. *Merck Index* (1989) indicated that allicin was unstable in hot-alkaline solution. Our study showed that the results of pH = 8 plus 65 °C or 100 °C were similar to that of heat treatments only ($p < 0.05$). This may be due to the fact that the base, pH = 8, was not strong enough to affect the stability of allicin, or allicin played only a partial role in antioxidant activity.

The effect of salt-treated plant foods on lipid oxidation in liposomes after 36 h incubation is shown in Table 6. NaCl, at concentrations of 0.2 and 0.4 M, did not affect the antioxidant or prooxidant activity of these plant foods ($p > 0.05$). The combined treatments of heat plus salt and pH plus salt were also studied. The results (data not shown) were similar to those of heat treatments alone or pH treatments alone ($p > 0.05$). The prooxidant activity of NaCl in several food systems was reported (Andersen and Skibsted, 1991; Kanner et al., 1991). It was indicated that NaCl in food system was capable of displacing iron ions from binding macromolecules, which facilitated lipid oxidation (Ahn et al., 1993). In our study, these *Allium* foods were chopped and soaked in NaCl solution before homogenization. After food soaking, the iron content in NaCl solutions was measured. There was no detectable iron found (data not shown). Since NaCl did not affect the antioxidant activity of *Allium* plants, the application of *Allium* plants for antioxidant protection in food preparation and food processing should be safe if NaCl is also present.

In summary, only part of the *Allium* family possessed antioxidant activity in this liposome model. Beside allicin, other compounds could be involved for the antioxidant activity determination because the allicin concentration was not strongly correlated to the antioxidant activity observed in these *Allium* foods. Heat treatment, acid treatment, or combined treatment reduced the antioxidant activity or even enhanced prooxidant activity of these plant foods. Therefore, heating and the addition of acid should be carefully considered when *Allium* plants are used in food preparation or food processing for antioxidant protection.

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Received for review April 3, 1998. Revised manuscript received July 29, 1998. Accepted July 30, 1998.

JF980344X