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# Heat Treatment Affects Postharvest Quality of Kale and Collard, but not of Brussels Sprouts

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***Abstract.*** **Mature leaves of kale (*Brassica oleracea* L., Alboglabra group) and collard (*Brassica oleracea* L., Acephala group), and Brussels sprouts (*Brassica oleracea* L., Gemmifera group) were heated by moist air at 40, 45, 50, or 55 °C for durations of 0, 30, 60, or 90 minutes. Heating of kale at 45 °C for 30 minutes was effective in maintaining better postharvest quality, delaying yellowing, and reducing losses of sugars and organic acids during subsequent storage at 15 °C. Exposure of collard at 40 °C for 60 minutes also delayed yellowing and maintained turgidity of the leaves. Other treatments were either less beneficial, not effective, or caused injury. Heat injury occurred when temperature and duration exceeded the tolerance levels. In some cases, heat-injured tissues remained green but developed fungal infection. Heat treatments had no measurable effects on the rate of senescence or storage quality of Brussels sprouts.**

Postharvest heat treatment has been used in horticultural crops to kill insects and control diseases (Couey, 1989). Various methods of heat treatment have been employed, including hot water dip, vapor heat, and hot forced air (Lurie, 1998). One of the primary considerations in devising heat treatments for controlling insects or diseases is that the treatment should not reduce the quality of the commodity or cause heat injury. Several reports have indicated that adequate heat shock or heat stress can maintain quality and reduce physiological disorders. Heat treatment at proper temperatures and durations maintained firmness of 'Golden Delicious' apples (Conway et al., 1994), reduced superficial scald in 'Granny Smith' apples (Lurie et al., 1991), and alleviated chilling injury in avocados (Woolf et al., 1995), citrus fruits (Rodov et al., 1995), cucumbers (McCollum and McDonald, 1993), mangoes (McCollum et al., 1993), sweet peppers (Mencarelli et al., 1993), persimmons (Lay-Yee et al., 1997), tomatoes (Lurie and Klein, 1991), zucchini squash (Wang, 1994), and germinating seeds (Jennings and Saltveit, 1994).

One of the major postharvest problems of green vegetables is the yellowing of the tissues. Hot water treatment can delay yellowing of broccoli florets (Forney, 1995; Kazami et al., 1991; Tian et al., 1996, 1997). However, the effect of heat treatment on other green vegetables, or on their storage quality, such as sugar or organic acid levels, has not been investigated. The objective of this study was to determine if heat treatment is beneficial in maintaining storage quality of such vegetables, including kale, collard, and Brussels sprouts.

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## Materials and Methods

*Plant materials.* Brussels sprouts, collard, and kale were obtained from a local farm near Beltsville, Md. Six Brussels sprouts were placed on a supporting plastic rack above 100 mL water within a 1-L beaker and three beakers were used for each treatment. Three mature leaves of collard or kale were placed inside a 32-μm low-density polyethylene plastic bag perforated with ten 6-mm diameter holes; three bags of each species were used for each treatment. The experiments were replicated three times.

*Heat treatment.* An incubator was used for heat treatment. The desired temperature was set and allowed to stabilize for at least 2 h before commencing the heat treatment. A pan of water was placed on the bottom to provide moisture to the air inside the incubator. Moisture content in the air was measured by a thermohygrometer (Hanna Instruments, model HI 8564). Relative humidity during heat treatments was maintained at 95% or higher. Brussels sprouts, collard, and kale were treated at 40, 45, 50, or 55 °C for 0, 30, 60, or 90 min for a total of 16 treatments. After the heat treatments, the Brussels sprouts were transferred to 1-L plastic trays, while the collard and kale remained in the plastic bags; all the vegetables then were stored at 15 °C.

*Visual quality rating.* Visual quality and decay were ranked subjectively according to criteria described previously (Wang and Hruschka, 1977). Numerical ratings were used for the following traits: decay, 10 = none, 5 = five or more fungal spotting, and 0 = rotten; color, 10 = dark green, 5 = moderate yellow, and 0 = completely yellow; turgor, 10 = turgid, 5 = limp; and 0 = brittle; marketability, 10 = acceptable, 5 = not salable, and 0 = not salvageable.

*Measurement of leaf color and chlorophyll content.* Leaf color was measured with a Minolta colorimeter (Model CR-10, Minolta Corp., Ramsey, N.J.) equipped with an 8-mm measuring aperture and calibrated with a white standard tile. Color of the leaves was expressed as *L, a, b, C,* and *h,* where *L* indicates lightness, *a* and *b* are chromaticity coordinates, *C* is chroma, and *h* is hue angle. The coordinates *a* and *b* indicate color directions: $+a$ is the red direction, $-a$ is the green direction, $+b$ is the yellow direction, and $-b$ is the blue direction. Chroma *C* indicates the degree of departure from gray toward pure chromatic color. Hue angle *h* is defined as degrees away from $+a$ axis, with $0° = +a$ (red), $90° = +b$ (yellow), $180° = -a$ (green), and $270° = -b$ (blue). Chlorophyll content of the leaves was determined with the spectrophotometric method as described by Bruinsma (1961).

*Analysis of sugars and organic acids.* Two grams of kale leaf tissue were homogenized with a Polytron homogenizer (Brinkmann Instruments, Westbury, N.Y.) in imidazole buffer (20 mM, pH 7.0). The extracts were centrifuged and the supernatants were dried *in vacuo* in derivatizing vials. Procedures described by Li and Schuhmann (1980) was modified for the derivatization of sugars. A known amount of β-phenyl-D-glucopyranoside was included in all samples as an internal standard. One mL Trisil reagent (Pierce, Rockford, Il.) was mixed with each sample vigorously and then heated at 75 °C for 30 min. After silylation, one μL (=1 μg) of each derivatized sample was injected into a Hewlett Packard 5890 gas chromatograph (Hewlett Packard, Palo Alto, Calif.) equipped with a flame ionization detector and a 25-m crosslinked methyl silicon gum capillary column (0.2 mm ID, 0.33 μm film thickness). Temperatures were as follows: injector 250 °C, detector 275 °C, and column 100 to 250 °C programmed at 10 °C/min with 0 min initial and 23 min final times. Organic acids were analyzed after extraction with imidazole buffer and purification with a Baker-10 solid phase extraction system. Supernatants from the extracts were passed through quaternary amine columns, which were previously conditioned with hexane and methanol. The samples were then eluted from the columns with 0.1 N HCl. The eluates were concentrated to dryness *in vacuo* in derivatized vials. Procedures of derivatization and chromatography for organic acids were the same as those for sugars except that column temperature was programmed from 180 to 250 °C at 10 °C/min with 3 min initial and 12 min final times. The sugars and organic acids were quantified by comparison with derivatized standards. A Hewlett Packard ChemStation was used to calibrate the peaks, record the data, and calculate the results. Data were analyzed by analy-

sis of variance and Duncan's multiple range test at $P \leq 0.05$ was used to calculate least significant differences.

## Results and Discussion

*Visual quality*. Treatment with moist hot air at 40 °C for 30 min had little or no effect on the rate of yellowing or deterioration of the mature leaves of kale during subsequent storage for 7 d at 15 °C (Table 1). In contrast, treatment at 45 °C for 60 min or at 50 °C for 30 min or longer caused heat injury (data not shown); leaves remained green after 7 d at 15 °C, but were wilted, limp, and moldy. Treatment at 45 °C for 30 min or at 40 °C for 90 min reduced yellowing, maintained turgidity of the leaves, and did not cause decay.

Collard responded to the heat treatment in much the same way as did kale, except that the leaves were slightly more sensitive to heat injury; leaves showed signs of heat injury after exposure to 40 °C for 90 min or 45 °C for 60 min or longer. The 50 or 55 °C treatment caused scorching, browning, and shrivelling of leaves (data not shown). On the other hand, treatment at 40 °C for 30 min did not affect visual quality during storage at 15 °C. The best treatments for maintaining the storage quality of collard were 40 °C for 60 min or 45 °C for 30 min; leaves remained greener and more turgid than those in all other treatments, including the control.

Outer leaves of Brussels sprouts tend to turn yellow as they senesce. Heat treatments used in this study ranging from 40 to 55 °C and durations from 30 to 90 min were not effective in delaying yellowing (data not shown). Heat injury occurred after treatment at 50 °C for 90 min or at 55 °C for 60 min.

*Changes in color and chlorophyll content.* Large differences were detected in hue angle ($h$) after 7 d of storage of kale at 15 °C (Table 2). Marked differences were also found in $a$ and $b$ measurements. As the leaf color turned from green to yellow, $L$ and $C$ readings were also affected.

Treatment at 45 °C for 30 min maintained green color (low $a$ value) of the leaves during 7 d of storage at 15 °C. The $a$ values were also low for treatments at 45 °C for 60 or 90 min, but leaves were moldy and wilted, indicating heat injury. Substantial increases in the $b$ values were found in control leaves after 7 d at 15 °C. Treatment with 40 °C for 30 min also showed a high $b$ value. Hue angles in both were near 90°, indicating that the leaves had turned yellow. Hue angles changed from 124.1° to 113.8° and 115.7° in the 45 °C treatments for 30 and 60 min, respectively, indicating that much of the green color was retained. The $C$ value was initially 8.9. This increased to 33.1 in the control leaves, but to only 12.3 in leaves heated at 45 °C for 30 min. The $L$ values, which represent surface lightness, tended to be lower in green leaves and higher in yellow leaves.

Collard had relatively higher $a$ and $b$ values than did kale leaves initially, indicating that they were less green and more yellow. In control samples, the $a$ value changed from –3.7 to +4.2 and the $b$ value increased from 11.2 to 49.3 within 7 d at 15 °C (Table 2). Less dramatic changes were detected in the heat-treated leaves, particularly in the treatments at 40 °C for 60 min or at 45 °C for 30 or 60 min. However, decay occurred in the 45 °C, 60 min treatment, indicating heat injury. Hue angle of the controls decreased from 108.3° to below 90°, indicating that these leaves had turned completely yellow. Hue angles remained above 90° in leaves held at 40 °C for 60 or 90 min or at 45 °C for 30 or 60 min, indicating retention of the chlorophyll.

The total chlorophyll content in kale was 685 mg·kg$^{-1}$ fresh mass at the beginning of the experiment (Table 2), but declined more than 60% after 7 d of storage of control leaves at 15 °C. However, leaves heated at 40 °C for 90 min or at 45 °C for 30 min retained about 75%

Table 1. Quality[z] of kale and collard after 7 d at 15 °C as affected by temperature and duration of prestorage moist hot air treatment.

| | Heat treatment[y] | | | | | |
|---|---|---|---|---|---|---|
| Commodity | Temp (°C) | Duration (min) | Color | Turgor | Decay | Marketability |
| Kale | 40 | 0 | 2.6 c[x] | 4.7 bc | 10.0 a | 3.0 cd |
| | | 30 | 2.9 c | 5.3 b | 10.0 a | 3.8 c |
| | | 60 | 5.1 b | 6.9 a | 10.0 a | 5.6 b |
| | | 90 | 7.4 a | 7.2 a | 10.0 a | 7.8 a |
| | 45 | 0 | 2.3 c | 5.1 bc | 10.0 a | 3.2 cd |
| | | 30 | 8.2 a | 7.8 a | 10.0 a | 8.6 a |
| | | 60 | 8.6 a | 3.7 c | 2.8 b | 2.1 d |
| Collard | 40 | 0 | 1.6 c | 4.5 bc | 10.0 a | 4.3 b |
| | | 30 | 2.5 c | 4.2 bc | 10.0 a | 4.0 bc |
| | | 60 | 6.4 b | 6.6 a | 10.0 a | 6.1 a |
| | | 90 | 6.9 ab | 3.6 cd | 4.5 b | 3.6 bc |
| | 45 | 0 | 1.8 c | 4.9 b | 10.0 a | 3.9 bc |
| | | 30 | 6.1 b | 6.8 a | 10.0 a | 5.8 a |
| | | 60 | 7.8 a | 3.1 d | 3.7 b | 3.3 c |

[z]Rated as follows: color, 10 = dark green, 5 = moderate yellow, and 0 = completely yellow; turgor, 10 = turgid, 5 = limp, and 0 = brittle; decay, 10 = none, 5 = five or more fungal spotting, and 0 = rotten; marketability, 10 = acceptable, 5 = not salable, and 0 = not salvageable.
[y]Data for treatments with longer durations or higher temperatures omitted because of severe heat injury.
[x]Mean separation within columns and commodities by Duncan's multiple range test, $P \leq 0.05$.

Table 2. Effects of temperature and duration of heat treatment on color and chlorophyll content of kale and collard after 7 d at 15 °C.

| Storage | Heat treatment[z] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| time | Temp | Duration | Color | | | | | Chlorophyll |
| (day) | (°C) | (min) | L | a | b | C | h | (mg·kg$^{-1}$ fresh mass) |
| | | | | | *Kale* | | | |
| 0 | | | 39.9 c[y] | –4.8 c | 7.3 c | 8.9 c | 124.1 a | 685 a |
| 7 | 40 | 0 | 61.2 a | +2.7 a | 36.6 a | 33.1 a | 87.2 d | 259 de |
| | | 30 | 57.6 a | +1.9 ab | 32.8 a | 27.3 a | 91.6 cd | 296 d |
| | | 60 | 48.1 b | +1.1 b | 17.3 b | 15.5 b | 98.3 bc | 406 c |
| | | 90 | 44.8 bc | –3.8 c | 12.9 bc | 16.2 b | 102.1 b | 513 b |
| 7 | 45 | 0 | 59.3 a | +2.2 a | 35.2 a | 31.9 a | 86.6 d | 231 e |
| | | 30 | 42.8 c | –4.1 c | 10.1 c | 12.3 bc | 113.8 a | 524 b |
| | | 60 | 41.6 c | –4.4 c | 11.7 bc | 12.8 bc | 115.7 a | 543 b |
| | | | | | *Collard* | | | |
| 0 | | | 42.1 c | –3.7 c | 11.2 d | 12.0d | 108.3 a | 473 a |
| 7 | 40 | 0 | 64.2 a | +4.2 a | 49.3 a | 46.4 a | 82.2 c | 150 d |
| | | 30 | 60.9 a | +3.6 a | 44.7 a | 41.3 a | 87.7 c | 189 d |
| | | 60 | 47.8 b | –2.8 bc | 20.6 bc | 22.1 b | 98.1 b | 383 bc |
| | | 90 | 45.1 bc | –3.1 bc | 14.7 cd | 19.8 bc | 102.9 ab | 394 bc |
| 7 | 45 | 0 | 62.8 a | +3.9 a | 46.1 a | 44.3 a | 83.5 c | 147 d |
| | | 30 | 48.3 b | –2.2 b | 22.9 b | 18.6 bc | 107.6 a | 356 c |
| | | 60 | 44.7 bc | -3.4 c | 13.5 cd | 15.8 cd | 106.8 a | 414 b |

[z]Samples not taken from treatments with longer durations or higher temperatures because of severe heat injury.
[y]Mean separation within columns and species by Duncan's multiple range test, $P \leq 0.05$.

Table 3. Effects of temperature and duration of heat treatment on carbohydrate and organic acid contents of kale after 7 d at 15 °C.

| Storage time (day) | Heat treatment[z] Temp (°C) | Duration (min) | Carbohydrates (mg·g$^{-1}$ fresh mass) Fructose | Glucose | Sucrose | Total | Organic acids (mg·g$^{-1}$ fresh mass) Malic | Citric | Total |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | 59.5 a[y] | 30.4 a | 3.0 a | 92.9 a | 1.24 a | 3.86 a | 5.10 a |
| 7 | 40 | 0 | 17.7 d | 10.5 c | 1.1 ef | 29.3 e | 0.32 e | 1.12 d | 1.44 e |
| | | 30 | 28.6 c | 10.8 c | 1.3 ef | 40.7 cd | 0.65 d | 1.28 cd | 1.93 de |
| | | 60 | 26.4 c | 11.6 c | 1.6 de | 39.6 cd | 0.81 cd | 2.79 b | 3.60 bc |
| | | 90 | 51.2 b | 24.7 ab | 2.5 ab | 78.4 b | 0.93 bc | 2.95 b | 3.88 b |
| 7 | 45 | 0 | 18.3 d | 11.9 c | 0.9 f | 31.1 de | 0.41 e | 1.17 d | 1.58 de |
| | | 30 | 54.2 ab | 23.1 b | 2.2 bc | 79.5 b | 1.02 b | 3.32 ab | 4.34 ab |
| | | 60 | 29.1 c | 12.4 c | 1.9 cd | 43.4 c | 0.76 cd | 1.89 c | 2.65 cd |

[z]Samples not taken from treatments with longer durations or higher temperatures because of severe heat injury.
[y]Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

of the total chlorophyll during the same period of time. Chlorophyll content of control collard leaves declined nearly 70% during 7 d at 15 °C, while only 24% and 19% of the chlorophyll was lost in leaves heated at 45 °C for 30 min and at 40 °C for 60 min, respectively (Table 2).

*Sugar and organic acid content.* Fructose and glucose were the major sugars in kale, with sucrose at much lower concentrations (Table 3). Concentrations of all sugars declined after 7 d of storage at 15 °C. Heat treatments at 40 °C for 60 or 90 min, or at 45 °C for 30 min or longer tended to reduce the decline of sugars. The better retention of sugars in the treated samples might be associated with the maintenance of quality in the treated samples rather than directly related to the heat treatment itself. Heat-treated muskmelons (Lingle et al., 1987) and squash (Bycroft et al., 1998) also reduced the loss of sugars. Heat treatment also favors the retention of other components associated with quality. For example, prestorage dipping of broccoli heads in hot water retarded the breakdown of soluble proteins and ascorbic acid (Kazami et al., 1991). In our work, exposure to moist air at 45 °C for 30 min or at 40 °C for 60 min or longer also reduced the loss of the organic acids, citrate and malate (Table 3).

One of the risks of heat-treating fresh fruits or vegetables is heat injury. Fresh commodities are very sensitive to such injury, either by excessive temperature or duration. In some instances, a slight prolongation in duration can produce responses that might be harmful to the tissue. For example, concentrations of ethanol increased 6, 160, and 490 times over that in the control when broccoli was dipped in hot water (52 °C) for 1, 2, and 3 min, respectively (Forney and Jordan, 1996). Our study showed that quality was improved by holding kale at 40 °C for 90 min or at 45 °C for 30 min and by holding collards at 40 °C for 60 min or at 45 °C for 30 min. However, leaves of kale were injured upon exposure to 45 °C for 60 min or longer or to 50 °C or higher temperatures, and collard leaves were injured when heated to 40 °C for 90 min or to 45 °C for 60 min or longer.

Heat treatment affects various physiological events by promoting certain reactions and inhibiting synthesis or activities of other processes (Lurie, 1998). Accumulation of heat shock proteins is a common response to heat stress; this may induce thermotolerance (Vierling, 1991) and resistance to chilling injury (Sabehat et al., 1996). On the other hand, heat treatment can retard synthesis of enzymes such as ACC oxidase (Lurie et al., 1996) and chlorophyll oxidase (Blackbourn et al., 1989). Whether the delay of yellowing and the maintenance of storage quality in kale and collard is associated with any of the above events warrants further study.

## Literature Cited


Blackbourn, H., P. John, and M. Jeger. 1989. The effect of high temperature on degreening in ripening bananas. Acta Hort. 258:271–278.

Bruinsma, J. 1961. A comment on the spectrophotometric determination of chlorophyll. Biochem. Biophys. Acta 52:576–578.

Bycroft, B., V. Corrigan, and G. Boulton. 1998. Sweetening squash with heat treatments. Acta Hort., in press.

Conway, W.S., C.E. Sam, C.Y. Wang, and J.A. Abbott. 1994. Additive effects of postharvest calcium and heat treatment on reducing decay and maintaining quality in apples. J. Amer. Soc. Hort. Sci. 119:49–53.

Couey, H.M. 1989. Heat treatment for control of postharvest diseases and insect pests of fruits. HortScience 24:198–201.

Forney, C.F. 1995. Hot-water dips extend the shelf life of fresh broccoli. HortScience 30:1054–1057.

Forney, C.F. and M.A. Jordan. 1996. Stress-induced ethanol production in fresh fruit and vegetables. HortScience 31:635.

Jennings, P. and M.E. Saltveit. 1994. Temperature and chemical shocks induce chilling tolerance in germinating *Cucumis sativus* (cv. Poinsett 76) seeds. Physiol. Plant. 91:703–707.

Kazami, D., T. Sato, H. Nakagawa, and N. Ogura. 1991. Effect of preharvest hot water dipping of broccoli heads on shelf life and quality during storage. J. Agr. Chem. Soc. Jpn. 65:19–26.

Lay-Yee, M., S. Ball, S.K. Forbes, and A.B. Woolf. 1997. Hot water treatment for insect disinfestation and reduction of chilling injury of 'Fuyu' persimmon. Postharvest Biol. Technol. 10:81–87.

Li, B.W. and P.J. Schuhmann. 1980. Gas-liquid chromatographic analysis of sugars in ready-to-eat breakfast cereals. J. Food Sci. 45:138–141.

Lingle, S.E., G.E. Lester, and J.R. Dunlap. 1987. Effect of postharvest heat treatment and storage on sugar metabolism in polyethylene-wrapped muskmelon fruit. HortScience 22:917–919.

Lurie, S. 1998. Postharvest heat treatments of horticultural crops. Hort. Rev. 21. In press.

Lurie, S., A. Handros, E. Fallik, and R. Shapira. 1996. Reversible inhibition of tomato fruit gene expression at high temperature. Plant Physiol. 110:1207–1214.

Lurie, S. and J.D. Klein. 1991. Acquisition of low temperature tolerance in tomatoes by exposure to high temperature stress. J. Amer. Soc. Hort. Sci. 116:1007–1012.

Lurie, S., J.D. Klein, and R. Ben Arie. 1991. Prestorage heat treatment delays development of superficial scald on 'Granny Smith' apples. HortScience 26:166–167.

McCollum, T.G., S. D'Aquino, and R.E. McDonald. 1993. Heat treatment inhibits mango chilling injury. HortScience 28:197–198.

McCollum, T.G. and R.E. McDonald. 1993. Tolerance of cucumber fruit to immersion in heated water and subsequent effects on chilling tolerance. Acta Hort. 343:233–237.

Mencarelli, F., B. Ceccantoni, A. Bolini, and G. Anelli. 1993. Influence of heat treatment on the physiological response of sweet pepper kept at chilling temperature. Acta Hort. 343:238–243.

Rodov, V., S. Ben-Yehoshua, R. Albagli, and D.O. Fang. 1995. Reducing chilling injury and decay of stored citrus fruit by hot water dips. Postharv. Biol. Technol. 5:119–127.

Sabehat, A., D. Weiss, and S. Lurie. 1996. The correlation between heat-shock protein accumulation and persistence and chilling tolerance in tomato fruit. Plant Physiol. 110:531–537.

Tian, M.S., T. Islam, D.G. Stevenson, and D.E. Irving. 1997. Color, ethylene production, respiration, and compositional changes in broccoli dipped in hot water. J. Amer. Soc. Hort. Sci. 122:112–116.

Tian, M.S., A.B. Woolf, J.H. Bowen, and I.B. Ferguson. 1996. Changes in color and chlorophyll fluorescence of broccoli florets following hot water treatment. J. Amer. Soc. Hort. Sci. 121:310–313.

Vierling, E. 1991. The roles of heat shock proteins in plants. Annu. Rev. Plant Physiol. Plant Mol. Bio. 42:579–620.

Wang, C.Y. 1994. Combined treatment of heat shock and low temperature conditioning reduces chilling injury in zucchini squash. Postharvest Biol. Technol. 4:65–73.

Wang, C.Y. and H.W. Hruschka. 1977. Quality maintenance in polyethylene-packaged broccoli. U.S. Dept. Agr., Mktg. Res. Rpt. 1085.

Woolf, A.B., C.B. Watkins, J.H. Bowen, M. Lay-Yee, J.H. Maindonald, and I.B. Ferguson. 1995. Reducing external chilling injury in stored 'Hass' avocados with dry heat treatment. J. Amer. Soc. Hort. Sci. 120:1050–1056.