



Heat treatments control sprouting and rooting of garlic cloves

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Abstract

Hot water dips (45–60 °C for 2.5–60 min) were evaluated as potential treatments to reduce sprout and root growth in peeled or unpeeled cloves in which sprouts had begun internal development but not yet emerged. Water dips at ≤ 50 °C did not reduce sprout and adventitious root growth in cloves stored at 10 °C and >95% RH, while treatments at 55 °C for 10 min were effective. Several dips at 60 °C inhibited sprout and root growth, although only a 2.5 min treatment was both effective and non-injurious. Respiration rates of heat-treated garlic were higher than those of untreated cloves. L* color value (lightness) of the peeled cloves was sometimes decreased by heat treatment, but chroma and hue were not affected. The hot water dips had no effect on firmness or pungency (thiosulfinate concentrations). Methyl jasmonate dips at 10⁻³ and 10⁻⁴ M were ineffective for sprout control but did reduce root development. A dip at 60 °C 2.5 min was as effective as 1% O₂+10% CO₂ atmosphere to retard sprout and root growth during 6 months at 0–1 °C.

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1. Introduction

Peeled garlic cloves are a convenient minimally processed vegetable and volumes have increased in retail and foodservice markets (Cantwell and Suslow, 2002; Kang and Lee, 1999). Surface discoloration, moisture loss, and microbial spoilage contribute to loss of shelf life and quality in peeled cloves (Park, 1999; Kang and Lee, 1999;

Ramirez-Moreno et al., 2001). Other important causes of quality loss are sprouting and rooting, which occur because of high humidity conditions in plastic packaging and because of storage at higher than the recommended 0–2 °C (Cantwell and Suslow, 2002). Modified atmospheres containing high CO₂ (15–25%) concentrations reduce sprout development but are less effective in control of adventitious rooting under high humidity conditions (Kang and Lee, 1999; Park, 1999).

Peeled cloves may be prepared from garlic that has been stored for many months and storage conditions will affect termination of dormancy and sprout development at the time of processing (Hardenburg et al., 1986; Cantwell et al., 2003).

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Although garlic bulbs may be stored at -1 to 0 °C in air or controlled atmospheres, dormancy eventually ends and sprout development begins (Takagi, 1990). Poor air circulation through storage bins may result in areas of high humidity and heat accumulation which lead to significant sprout growth after several months. The longer garlic is stored, the shorter the period required for sprout growth upon removal from storage (Takagi, 1990). Pre-storage handling conditions and delays may substantially reduce the dormant period during storage as well (Mann and Lewis, 1956; Takagi, 1990).

Heat treatments have been used as a non-chemical means to modify the postharvest quality of a wide variety of horticultural products (Lurie, 1998). In addition to effects on fruit ripening (Paull and Chen, 2000), chilling tolerance (Lurie, 1998), decay (Cantwell and Nie, 1996; Schirra et al., 2000) and insect control (Lurie, 1998), heat treatments can reduce undesirable postharvest growth. Short hot water dips controlled geotropic curvature in asparagus (Paull and Chen, 1999), reduced sprouting and spoilage in potatoes (Ranganna et al., 1998), and reduced extension growth in cut green onions (Hong et al., 2000; Cantwell et al., 2001).

Other treatments may also reduce postharvest sprout and root growth. Sprouting of stored garlic is retarded by pre-storage irradiation at 0.5 – 1.5 kGy (Crocchi and Curzio, 1983; Fenwick and Hanley, 1985). Controlled atmospheres containing 5 – 15% carbon dioxide retarded sprout development in stored (Cantwell et al., 2003) and peeled garlic (Kang and Lee, 1999). Jasmonates are naturally occurring plant bioregulators that affect many ripening and senescence processes including growth (Creelman and Mullet, 1997). Dipping topped radishes in solutions of methyl jasmonate (10^{-3} and 10^{-4} M) reduced sprout and root growth at 15 °C (Wang, 1998).

A treatment to control sprout and root development on fresh peeled garlic would be useful. Packaging of peeled garlic permits very high humidity conditions and temperature management through the marketing system may be deficient. Here we report on the use of heat treatments to achieve control of sprouting and rooting defects.

We also compared the efficacy of heat treatments to controlled atmosphere storage and methyl jasmonate treatments.

2. Materials and methods

2.1. Plant material

'CA Late' garlic (*Allium sativum* L.) was obtained from commercial sources and had been air-stored for 6–10 months at -1.5 to -1 °C. Bulbs were transported to the lab under ambient conditions, peeled garlic was transported in plastic bags in coolers with ice. All samples were held at 0 – 1 °C until used. Cloves were either unpeeled (outer well-formed cloves of manually cracked bulbs) or had been commercially peeled, and both types had initial sprout development near 50% of full clove length.

2.2. Sprout control treatments and storage conditions

For hot water dips, about 45 peeled or unpeeled garlic cloves were submerged in a circulating water bath (15 l) within ± 0.5 °C of the specified temperature. Treatment temperatures ranged from 45 to 60 °C. Following treatment, cloves were stored on moist paper towels in plastic trays enclosed in polyethylene bags (unsealed with ends overlapped) at 10 °C, conditions which favor sprout and root development in peeled and unpeeled garlic. One test involved storage of cloves for 6 months at 0 – 1 °C in containers with flows of air, 0.1% O_2 or 1% O_2 + 10% CO_2 . The atmospheres were prepared as mixtures from gases in cylinders and gas concentrations were monitored periodically by an electrochemical oxygen analyzer (Model S-3A, Applied Electrochemistry, Inc.) and an infrared CO_2 gas analyzer (Model PIR-2000, Horiba Ltd.) and maintained within $\pm 5\%$ of the indicated values. Humidity was controlled by addition of calcium chloride sachets to the storage containers and varied from 65 to 75%.

2.3. Respiration measurements

Approximately 50 g of garlic cloves were placed in 0.5 l glass containers at 10 °C and connected to an air flow to maintain CO₂ concentrations at 0.25–0.5%. The CO₂ concentrations were measured twice daily by taking 1 ml gas samples and injecting into an infrared gas analyzer. For calibration, a standard mixture of 0.5% CO₂ was used, and calculations of respiration rates were based on the difference between inlet and outlet concentrations.

2.4. Dry weight and thiosulfinates

Peeled cloves were longitudinally sliced into four to five pieces, weighed and freeze-dried. The percent dry weight was calculated from the fresh and freeze-dried weights. A colorimetric procedure based on the reaction of 5,5'-dithio-bis-(2-nitrobenzoic acid) (DTNB) was used to measure the concentration of thiosulfinates (Riddles et al., 1979; Han et al., 1995). One gram of freeze dried garlic powder was shaken at 250 min⁻¹ with 30 ml distilled water at 37 °C for 30 min, centrifuged at 14 000 min⁻¹ for 20 min and diluted ten times. An aliquot of 375 µl of diluted garlic extract was added to a test tube on ice, and a similar aliquot of distilled water was added to a reference test tube. Aliquots of 625 µl of 0.8 mM cysteine solution were added to both sample and reference test tubes. After shaking they were held for 10 min on ice. Other test tubes at room temperature contained 0.8 ml of 200 µM DTNB which was prepared with 50 mM HEPES buffer, pH 7.5. An aliquot of 200 µl of garlic/cysteine solution or water/cysteine solution was added to the DTNB test tubes. For a blank, 200 µl of pure water was added to the DTNB tube. After shaking, test tubes stood for 10 min for color development. Absorbance was measured at 412 nm, and thiosulfinate concentrations were calculated according to Han et al. (1995).

2.5. Quality evaluations

Quality evaluations were done after 0, 2 and 4 or 5 weeks at 10 °C or after 0, 2, 4, and 6 months at

0–1 °C. Heat injury was determined by visual examination of the peeled cloves and recorded as a percentage. For sprout development, peeled garlic cloves were sectioned longitudinally and the length of sprout was reported as a fraction of full clove length (sprout ratio). A value >1.0 indicates sprout emergence. Root growth of garlic cloves was scored on a 1–7 scale, where 1 = 0 mm (none), 2 = 1–2 mm (barely noticeable), 3 = 3–5 mm (slight), 4 = 6–10 mm (moderate), 5 = 11–15 mm (moderately severe), 6 = 16–20 mm (severe), and 7 ≥ 20 mm (extreme growth). Firmness of individual cloves was determined on a texture analyzer (TA-XT2i, Texture Technologies Corp.) as force in Newtons to penetrate the convex side of the clove with a 3 mm flat cylindrical probe to a depth of 5 mm. L*, a* and b* color values of the convex surface of the peeled garlic cloves were measured by a color difference meter (Minolta CR-200) and chroma ($C^* = (a^{*2} + b^{*2})^{1/2}$) and hue ($h^\circ = \tan^{-1} \cdot (b^*/a^*)$) were calculated.

2.6. Experimental design and statistical analysis

Experiments were conducted as completely randomized designs with three replicates of 10–15 garlic cloves each per treatment. Data were analyzed as averages ± standard deviations, or by a 2-way analysis of variance (ANOVA) with calculation of LSD at $P < 0.05$.

3. Results and discussion

3.1. Efficacy of hot water dips to control sprouting and rooting

Various water temperature and dip times were evaluated on peeled garlic cloves which had an initial sprout growth near 50% of clove length (0.5 sprout ratio). Hot water dips at 45 °C had no impact on sprout (Fig. 1A) or root (Fig. 1E) growth during 5 weeks at 10 °C. Fifteen and 20 min water dips at 50 °C (Fig. 1B and F) began to significantly retard sprout and adventitious root growth, while shorter exposures to 55 and 60 °C water were particularly effective (Fig. 1C, D, G, H). The peeled cloves receiving the 5 and 7.5 min

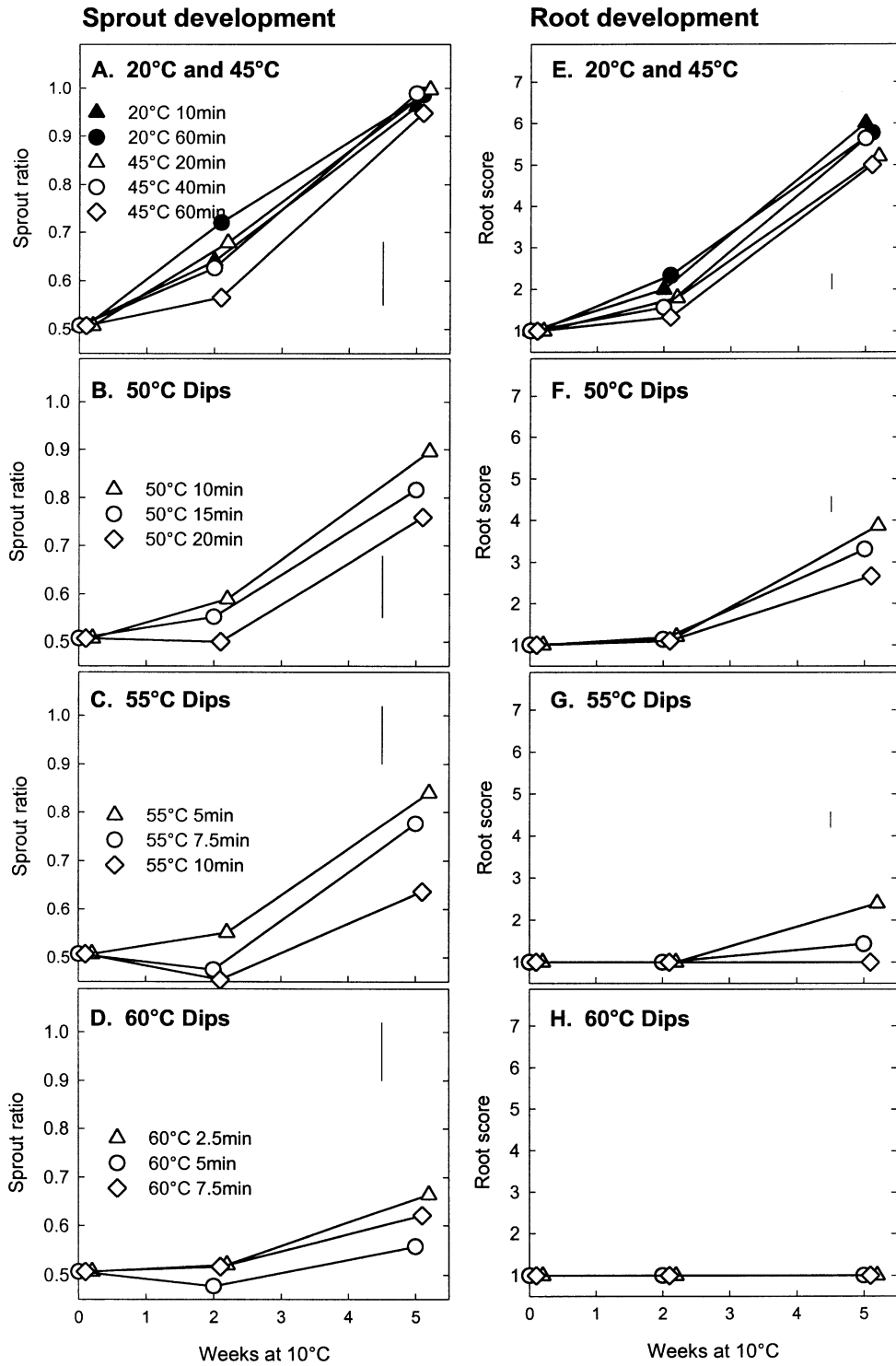


Fig. 1

Fig. 1. Sprout and root growth in peeled garlic cloves subjected to various hot water dip treatments and stored for 5 weeks at 10 °C. Sprout ratio is the length of the sprout measured in a longitudinal section relative to clove length. Root scores ranged from 1 to 7 where 1 = 0 mm (none), 2 = 1–2 mm (barely noticeable), 3 = 3–5 mm (slight), 4 = 6–10 mm (moderate), 5 = 11–15 mm (moderately severe), 6 = 16–20 mm (severe), and 7 ≥ 20 mm (extreme growth). Data are averages from 30 cloves.

treatments at 60 °C were visibly damaged and these treatments were not evaluated further. Heat injury on garlic cloves appeared as translucent and/or discolored areas, especially on the convex side of the peeled cloves. Adventitious root growth was more easily controlled than sprout growth, perhaps because the location of the root initials permitted more direct exposure to the hot water treatments.

Hot water dips of unpeeled garlic cloves produced similar results (Fig. 2). The 55 °C 10 min and 60 °C 2.5 min treatments were very effective whereas 20 and 40 min dips at 50 °C retarded

sprout growth less. Root development at 10 °C was more rapid in unpeeled than in peeled cloves (Fig. 1E–H, Fig. 2). The peeling, washing, and drying steps in commercial processing may have caused some damage to root initials resulting in the slower growth rate.

Treatment regimes must control sprout and root development, but also be non-damaging to the garlic cloves. A curvilinear graph (Fig. 3) describes the effective time–temperature combinations that retarded sprout development and caused no visible injury to the peeled garlic cloves after 4 or 5 weeks at 10 °C. Treatments below 50 °C were ineffective to control sprout or root growth in garlic or to control extension growth of cut green onions (Cantwell et al., 2001). Treatments < 55 °C were ineffective for sprout control in potatoes (Ranganna et al., 1998). The effective temperature range for sprout control in garlic is very similar to that described for control of cut green onion extension growth (Cantwell et al., 2001) although effective exposures were much longer in garlic

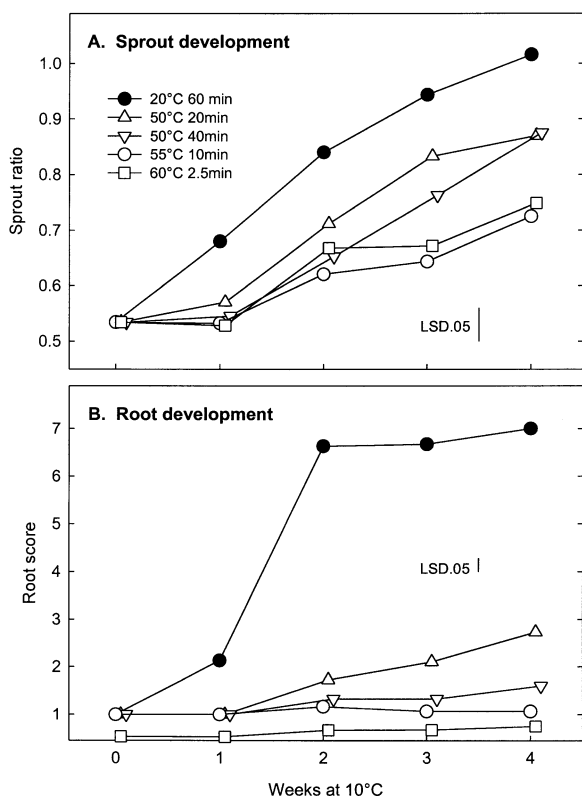


Fig. 2. Sprout and root growth in unpeeled garlic cloves treated with four hot water dips and stored 5 weeks at 10 °C. See Fig. 1 for details. Data are averages from 45 cloves.

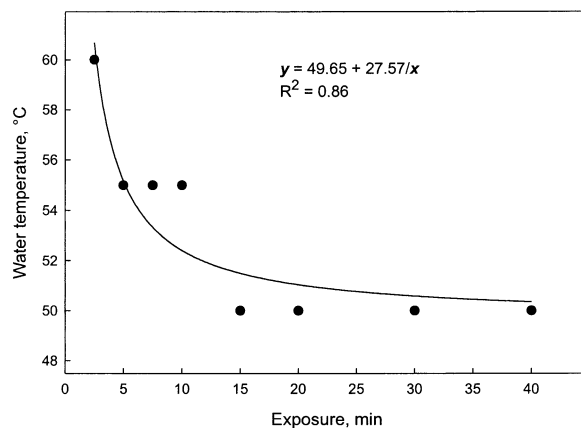


Fig. 3. Average time–temperature water dip conditions required to control sprout growth of peeled and unpeeled garlic cloves. Initial sprout growth was half clove length (0.5). An effective treatment was one in which sprout growth was retarded sufficiently to prevent emergence after 4 or 5 weeks at 10 °C and in which there was no visible injury.

cloves. The sprout of garlic is physically less accessible to the heat treatments than the cut ends of green onions. The lower water content of garlic (~ 60 vs. $> 95\%$ in green onion) likely also contributed to the longer required treatment times. Because garlic has a lower specific heat capacity ($\sim 2800 \text{ J kg}^{-1} \text{ K}^{-1}$, Kramkowski et al., 2001) than green onions ($\sim 4000 \text{ J kg}^{-1} \text{ K}^{-1}$), it will store less energy at the same temperature, and therefore, longer time will be required for the same heating effect.

Heat could be applied commercially as hot water or as hot air treatments. Although we have not demonstrated the effectiveness of hot air to retard sprout development in garlic, heat therapy in both forms has been shown effective for decay control (Cantwell and Nie, 1996), enhancement of chilling resistance, insect disinfestation, and modification of fruit ripening (Lurie, 1998). Currently garlic may be conditioned with warm forced air to facilitate “cracking” of the bulbs to individual cloves. A modification of this process could provide an effective sprout control treatment. Alternatively, a short hot water dip (i.e. 2.5 min at 60°C) could be a feasible addition to current garlic processing operations. This might be implemented only when there is significant internal sprout development and increased risk of sprout emergence during commercialization of the peeled product. Because of the effectiveness of the hot water dips to control root growth, however, this alone may be sufficient to warrant use of a heat treatment in garlic processing.

3.2. Effect of hot water dips on quality and physiology of garlic cloves

Lightness (L^* color value) and firmness of garlic cloves decreased during storage at 10°C (Fig. 4A). Hot water dips generally resulted in a more rapid decline in lightness, but did not significantly impact firmness changes (Fig. 4B). Thiosulfinate concentrations, a measurement of alliinase-generated pungency in garlic, were not generally affected by hot water dips (Fig. 4C). Pungency slowly increased in garlic from all treatments during storage at 10°C . These results are consistent with the report that allicin, the major thio-

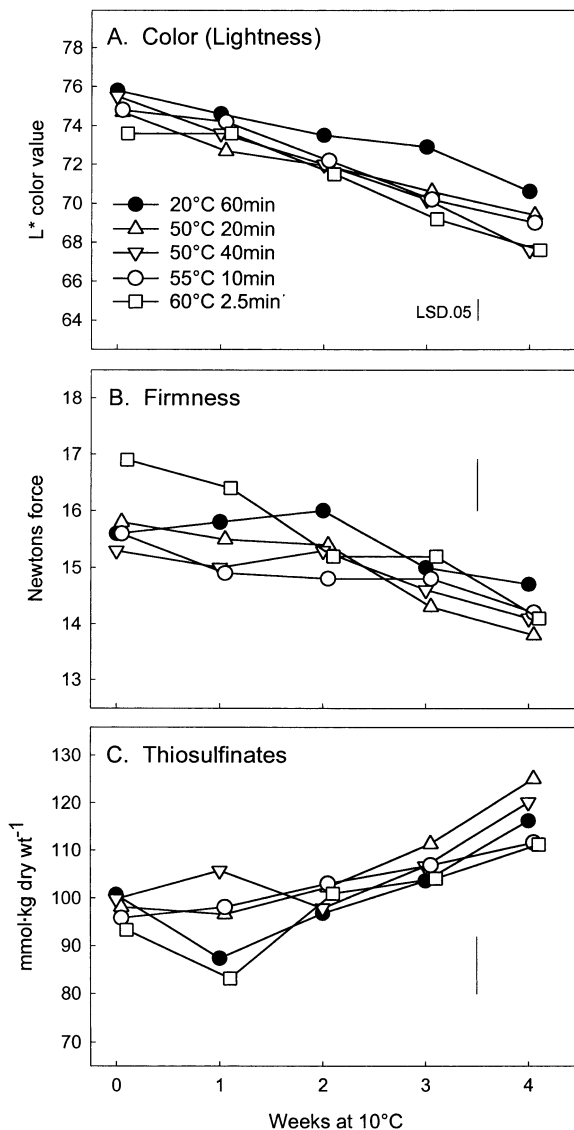


Fig. 4. Color, firmness, and thiosulfinate concentrations of unpeeled garlic cloves untreated or treated with four hot water dips and stored 5 weeks at 10°C . Color and firmness data are means from 45 cloves, and thiosulfinate data were three replicates from composite samples. Sprout and root growth of these cloves are described in Fig. 2.

sulfinate in garlic, was reduced by only 8% in garlic dried at 55°C compared with fresh garlic, although alliinase activity was reduced by about 50% in the same garlic (Lawson and Wang, 2001).

Hot water dips resulted in a sustained increase in respiration rates in garlic cloves (Fig. 5), although less modification was observed with the shortest exposure (2.5 min at 60 °C). The increased respiration rates probably did not result in increased dry weight loss. Similarly treated garlic cloves were stored for 6 months at 0 °C and had dry weight changes similar to those of untreated cloves (Fig. 6D). Heat treatment of cut green onion also resulted in a substantial and sustained increase in respiration rates (Cantwell et al., 2001). The effect of heat treatments on respiration rates of fruits and vegetables varies considerably and depends largely on treatment temperature and length of exposure (Lurie, 1998).

3.3. Efficacy of hot water dips compared with methyl jasmonate and controlled atmosphere treatments

Dipping garlic cloves in methyl jasmonate solutions from 10^{-5} to 10^{-3} M was ineffective in slowing sprout development during 5 weeks at 10 °C (data not shown). Root growth was not affected with a 10^{-5} M dip, but was reduced 35

and 70% with the 10^{-4} or 10^{-3} M treatments, respectively (data not shown). Lack of sprout control may have been due to lack of penetration of the methyl jasmonate through the dry leaf sheaf to the meristematic area. The methyl jasmonate treatments also induced severe purple discoloration on the unpeeled cloves. Results were similar in a second experiment done on peeled cloves, although discoloration was less (data not shown). Although methyl jasmonate was effective for both sprout and root control on radish (Wang, 1998), only root development was reduced in treated garlic cloves.

Two hot water dip treatments were compared with controlled atmospheres for effectiveness in retarding sprout and root development over longer-term storage at 0–1 °C. A very low O₂ concentration (0.1%) alone was insufficient to retard sprout and root development (Fig. 6A, B), but a 1% O₂+10% CO₂ treatment was as effective as the 60 °C 2.5 min water dip (Fig. 6A). Over the 6 months storage period, these treatments slowed sprout growth enough to prevent emergence. Root development was also retarded by the 50 °C 20 min dip (Fig. 6B). The 60 °C 2.5 min water dip and

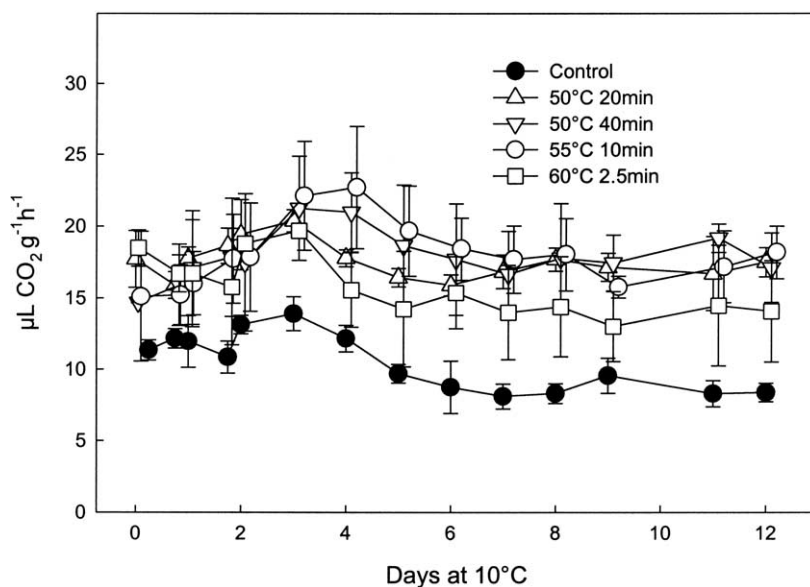


Fig. 5. Respiration rates of unpeeled garlic cloves untreated or treated with four hot water dips and stored at 10 °C. Data are means of three replicates + standard deviation. Sprout and root growth and quality changes of these cloves are described in Figs. 2 and 4, respectively.

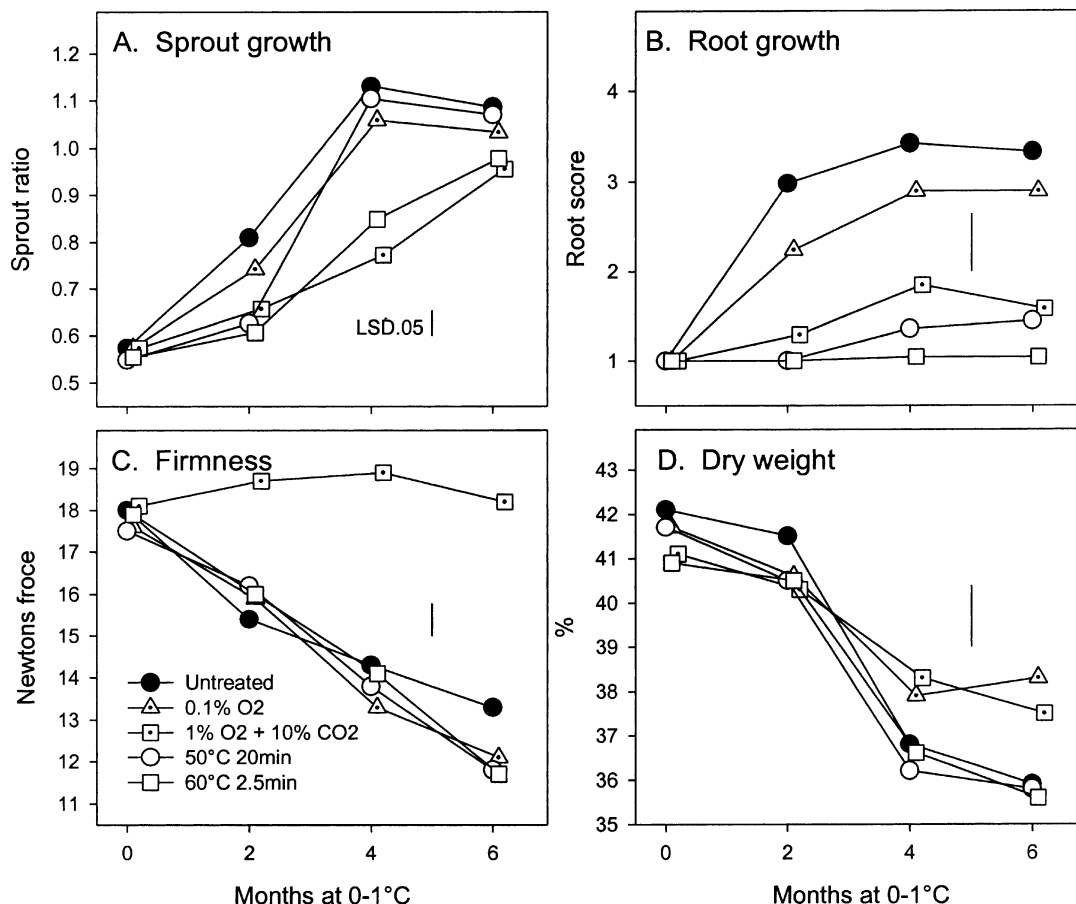


Fig. 6. Sprout and root growth in unpeeled garlic cloves stored at 0–1 °C and 65–75% relative humidity for 6 months. Cloves were untreated, treated with two hot water dips or stored in controlled atmospheres. See Fig. 1 for details of sprout and root measurements.

the 1% O₂+10% CO₂ atmosphere resulted in lower L* color values than in control cloves after 4 and 6 months (data not shown). The 1% O₂+10% CO₂ atmosphere was the only treatment tested that maintained clove firmness (Fig. 6C). CA storage of peeled garlic cloves was previously shown to reduce firmness loss (Ramirez-Moreno et al., 2001) as well as reduce sprout development (Park, 1999; Kang and Lee, 1999). The percentage dry weight was higher in bulbs from the CA and 60 °C 2.5 min water dip treatments after 4 and 6 months (Fig. 6D). Using data from all treatments, clove dry weight was inversely and linearly correlated to sprout development ($R^2 = 0.77$).

4. Conclusions

Several hot water treatments controlled sprout and root growth in peeled or unpeeled garlic cloves stored at 10 °C and 95%RH. The time–temperature combinations of 60 °C for 2.5 min and 55 °C for 10 min were particularly effective. Effective treatments did not cause visible injury or notable changes in color, firmness or pungency of the garlic cloves, although respiration rates were increased 1.5–2 fold. The effect of hot water treatment on sprout growth persisted during storage at 0–1 °C for 6 months and was as effective as an atmosphere of 1% O₂+10% CO₂.

Hot water treatments may be useful to peeled garlic processors when raw product has undesirable internal sprout growth, but is otherwise of excellent quality.

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