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Triangle tests indicate that irrigation timing affects fresh cabbage sensory quality

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Abstract

A replicated triangle test was employed to determine if judges could distinguish, by tasting, between shredded samples of fresh cabbage drip-irrigated during different periods of plant development. Irrigation was provided either: (1) throughout plant development (no stress, NS), (2) during frame development only (head stress, HS), or (3) during head development only (frame stress, FS). Control plants received no irrigation for the duration of plant development (frame and head stress, FHS). In a total of three sessions, 14 judges evaluated two replications each of the six possible treatment comparisons in triangle tests. Results were analyzed using the beta-binomial model. Judges detected differences ($\alpha = 0.05$) between cabbage from NS plots and cabbage from the two plots that received no irrigation during head development (HS, FHS), as well as between heads from FS and FHS plots. Physical traits of cabbage heads (e.g. weight, mean diameter, shape) at harvest were also affected by irrigation treatment. This is the first report to suggest that the timing of irrigation relative to crop development may influence the sensory characteristics of fresh cabbage. The data also suggest that cabbage head physical traits may respond more frequently to irrigation than cabbage sensory attributes.

Keywords: Vegetable quality; Flavor; *Brassica oleracea* var. *capitata*; Head traits

1. Introduction

Vegetable crop sensory quality has received more attention in recent years as a result of efforts to secure and extend shares of increasingly competitive markets for fresh produce (Kuchenbuch, Auerswald, Bruckner, & Krumbein, 1999). Although the cultural requirements to maximize production of head cabbage (*Brassica oleracea* Capita Group) are well documented (Wien & Wurr, 1997), the effects of field management on cabbage sensory characteristics are less known. Variety, plant spacing and planting date are reported to affect a wide range of organic compounds associated with cabbage flavor (MacLeod & Nussbaum, 1977; Rosa, David, & Gomes, 2001; Van Etten, Daxenichler, Williams, & Kwolek, 1976). Some production factors may also play a role in human perception of cabbage quality. For example, panelists in triangle tests distinguished among cabbage grown under varying soil moisture and sulfur conditions (Freeman & Mossadeghi, 1972, 1973). Also, in employing a three-point hedonic scale and 82 panelists, Yano, Saijo, Sugawara, and Ohta (1990) detected differences in preference for shredded samples of five cabbage varieties and concluded that flavor and moisture content are highly important in determining preference. It is clear that flavor may differ among cabbage varieties and that flavor has a strong effect on sensory quality (Martens, 1985; Radovich et al., in press). However, although soil moisture availability strongly influences plant physiology, the effect of irrigation on cabbage flavor is under-studied. Freeman and Mossadeghi (1973) used a variety currently not of commercial importance and failed to account for the crop developmental stage at which irrigation was applied or corresponding effects on important physical head traits. Although utilized in other areas, irrigation is not regularly applied to cabbage grown in the Midwest, partly due to the relative scarcity of water resources and costs

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associated with irrigation (Swaider, Ware, & Shoemaker, 2002). The potential to improve head quality has recently increased interest in the use of irrigation in Midwest cabbage production. However, additional information is needed to determine if irrigation-related expenses are justified and, if so, how best to employ irrigation to optimize crop sensory quality. Therefore, the objectives of this work were to determine: (1) if irrigation leads to a discernable change in fresh cabbage quality and (2) whether the plant developmental period during which irrigation is applied influences human differentiation between samples. The study was also designed to help estimate the relative sensitivity of cabbage physical and sensory traits to irrigation.

2. Materials and methods

2.1. Cabbage production

Seeds of the commercially significant cabbage variety 'Bravo' were planted in late April 2002 and grown in the greenhouse for approximately six weeks. Seedlings were then transplanted to the field on 10 June, 2002 at the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio (latitude 40° 47′N, longitude 81° 55′W) using a single-row mechanical transplanter. Plant spacing was 0.31 m within single 18 m long rows with 1.5 m between treatment rows. Fertilizer was applied to the field prior to transplanting at rates of 56, 49 and 93 $kg\,ha^{-1}$ of nitrogen, phosphorous and potassium, respectively. The field experiment was arranged in a randomized complete block design with five replications. The three irrigation treatments were: irrigation throughout plant development (no stress, NS), irrigation during frame (non-heading leaves) development only (head stress, HS) and irrigation during head development only (frame stress, FS). Control plants (frame and head stress, FHS) received no irrigation for the duration of plant development. All plants were irrigated for 14 d after transplanting to aid in their establishment. Thereafter, irrigation treatments were imposed. Drip irrigation tape (3.4 $l^{-1}\,h^{-1}\,m^{-1}$, T-Systems International, San Diego, California) was laid within 8 cm of the base of seedlings in irrigated rows. Valved connectors allowed for watering of individual rows by turning valves on or off as necessary. During the treatment period, irrigation was applied when soil sampled from the top 18 cm of the soil profile was unable to maintain its shape when formed into a ball in the hand (Klocke & Fischbach, 1984). Gypsum blocks (Delmhorst, Towaco, New Jersey) were installed within the crop root zone at 18 and 38 cm deep 28 d after planting to the field (DAP) to record soil water potential during the remainder of the study. The amount of water (irrigation + precipitation) received by all plots is shown in Fig. 1. Gypsum block readings confirmed that soil moisture was lowest in non-irrigated treatments (data not shown). At 86 DAP, three adjacent heads were harvested from each of three randomly selected positions in each row. Physical characteristics were immediately recorded on two groups of three heads. Head weight was measured with a commercial field scale (model FV-60KWP, A and D Corp., Tokyo, Japan). Head diameter was measured in two directions; stem end to apex (polar) and perpendicular to the polar transect (equatorial). Head shape was calculated as the ratio of polar to equatorial diameter (1.0 = round). Percent moisture (PM) was calculated with the formula PM = 100 − (FW/DW), where FW = fresh weight (g) of a representative sample of head tissue (minus core) and DW = weight (g) of the same tissue dried for 7 d at 70 °C. The third group of heads was held in darkened storage at 7 °C in nylon mesh bags for 30 d prior to sensory evaluation. Storage of commercial fresh market cabbage for 30 d is not uncommon (Billingsley, 1994).

2.2. Sample preparation for sensory evaluation

Each day for three days (8–10 October 2002), samples were prepared 1 h prior to evaluation. One head from each replication was halved along its longitudinal axis to ensure that treatment samples were homogenized composites of heads from all field replications. The core and damaged tissue were discarded, as was one half of the head. The remaining half was cut into smaller sections and shredded using a FoodPro2 food processor (Hamilton Beach/Proctor-Silex, Washington, North Carolina). Four-liter plastic containers with airtight lids (Rubbermaid, Wooster, Ohio) were filled with homogenized sample, sealed and held in the dark at 7 °C until use. PM of three sub-samples from each treatment composite was determined as above (Section 2.1). At the time of evaluation, approximately 35 g of sample was

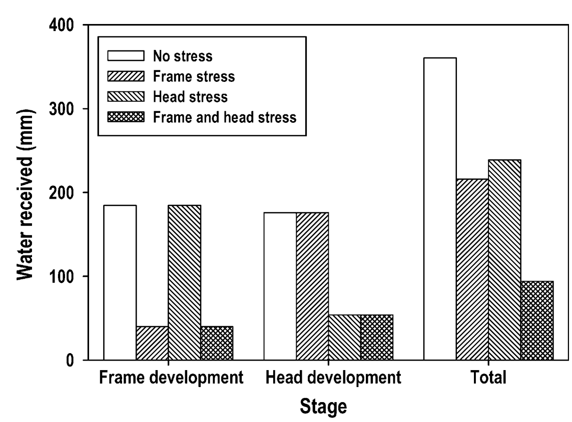

Fig. 1. Water (mm) received by the crop as irrigation and rainfall after establishment. Frame development occurred 14–50 days after planting in the field (DAP) and head development occurred 51–86 DAP.

placed in 0.125 l polystyrene cups (Dart Container Corp., Mason, Michigan), assigned a random three-digit code and loosely covered with tinfoil.

2.3. Triangle test procedure

The testing protocol was approved by The Ohio State University Office of Research Risks Protection (ORRP). The sensory panel group consisted of 14 untrained volunteers: six males, eight females, smokers and non-smokers, aged 21–65 years. The triangle test was chosen as it allows one to distinguish between samples without having to specify the sensory characteristic(s) that differ. As it is a discrimination task, especially for untrained panelists, it is also better at detecting small differences between samples than are intensity ratings (Lawless & Heymann, 1998).

Panelists were not trained, but prior to sample evaluation, panelists received instruction regarding the evaluation procedure in both written and verbal formats. The following written instructions were placed on the ballot: "Taste samples from left to right. Two of the samples are identical. Determine which one is the *odd* sample. You may re-taste samples. If no difference is apparent, you must guess". Verbal instruction prior to evaluation included reiteration of written instructions, as well as instructions to focus on flavor, evaluate samples one at a time, keep samples capped when not being tasted, proceed at own pace, and to cleanse the palate with bread and water between samples.

Panelists seated at partitioned booths were presented with three samples simultaneously, two from one irrigation treatment and one from another treatment. To minimize visual comparison of samples and eliminate side-by-side comparisons, panelists were instructed to keep samples capped until use, removing caps only to obtain the sample and to disregard visual cues. While it is not possible for panelists to "disregard" cues, it is possible to redirect their focus to other sensory characteristics. Panelists tasted samples at a self-determined pace with no time limit for completing the session, although sessions tended to last 20–30 min. To minimize adaptation, a 2–3 min break occurred between triads and panelists were instructed to take additional breaks as they desired. Panelists were provided with bottled spring water (White House Artesian Springs, Inc., Elyria, Ohio) and white bread (Beuhler's Fresh Food Market Bakery, Wooster, Ohio) for palate cleansing, which they used between samples and between triads. Samples were swallowed and re-tasting was permitted. Panelists evaluated two treatment pairs (replicated twice) per day during the 3-d evaluation period following a counter-balanced design. Replicates were employed to test for overdispersion and improve test power (Dacremont & Sauvageot, 1997; Ennis & Bi, 1998). The presentation order of treatment comparisons was counter-balanced across panelists and sample presentation was randomized within triads. Evaluations were conducted each day between 10:00 A.M. and 1:00 P.M.

2.4. Data analysis

Overdispersion, symbolized by gamma, is a measure of panelist variability. Similar to the coefficient of determination, gamma varies from zero to one. A gamma of zero indicates that there is no overdispersion, panelist variability is minimal, and panelists are assessing products in an identical fashion. A gamma of one indicates that there is complete overdispersion, panelist variability is high, and each panelist is making product assessments in a unique fashion. An intermediate value indicates that panelist variability lies between these two extremes, and one can test to see if this intermediate value is significantly different from zero. To account for potential overdispersion in the sensory evaluation data, the beta-binomial model, which allows one to account for gamma (i.e., panelist variability), was used to determine whether there was a significant difference in cabbage sensory characteristics across treatment conditions and if panel overdispersion was significant (Ennis & Bi, 1998).

Head physical trait data were subjected to analysis of variance using the General Linear Model procedure of SAS (Statistical Analysis System for Windows™, v. 8, Cary, North Carolina). Treatment means were compared using Fisher's protected least significant difference (LSD) test ($\alpha = 0.05$) in SAS.

3. Results

Analysis of the triangle test data with the beta-binomial model indicated that gamma was less than 0.0001 for all comparisons. Therefore, the simpler binomial model was used to evaluate differences between comparisons. Panelists detected differences ($\alpha = 0.05$) between heads irrigated throughout development (NS) and heads from the two plots that received no irrigation during head development (HS and FHS) (Table 1). Differences were also detected between heads irrigated only during head development and the control (FHS). No differences were detected in the NS vs. FS, FS vs. HS or HS vs. FHS comparisons.

Differential irrigation also affected physical traits of cabbage heads recorded at harvest, with head PM, weight and mean diameter greatest in the NS and FS treatments (Table 2). Differences among treatments in PM were also found at sample preparation, 30 d after harvest (Table 2). Freshly shredded head tissue from the HS and FHS plots was slightly discolored (i.e. brown) relative to head tissue from the NS and FS plots (data not shown).

Table 1
Results of the triangle test data analysis

Treatment comparison	*p*-Value	Power
NS vs. FS	0.1138	0.394
NS vs. HS	**0.0003**	0.989
NS vs. FHS	**0.0132**	0.733
FS vs. HS	0.0827	0.423
FS vs. FHS	**<0.0001**	1.000
HS vs. FHS	0.4470	0.036

The *p*-values and power were generated with the binomial model and are based on the responses of 14 panelists over two replications with gamma < 0.0001. Treatments were irrigation throughout plant development (NS, no stress), irrigation during head development only (FS, frame stress), irrigation during frame development only (HS, head stress) and no irrigation for the duration of plant development (FHS, frame and head stress).

4. Discussion

4.1. Triangle test results

As the primary ingredient of coleslaw and other salads, the value of fresh, shredded cabbage depends on its sensory characteristics (Ball, Skog, Smith, Murr, & McKeown, 1999; Martens, 1985; Yano et al., 1990). Data in Table 1 demonstrate that irrigation and its timing affected the sensory perception of fresh cabbage. Cabbage irrigated during head development (NS, FS) was identified as tasting different from cabbage receiving no irrigation (FHS). Panelists had greater difficulty distinguishing cabbage irrigated early in plant growth only (HS) from cabbage receiving no irrigation (FHS). Similarly, cabbage watered only during head development (FS) was difficult to distinguish from cabbage watered throughout development (NS). Therefore, these data suggest that to obtain large perceptible differences in cabbage sensory characteristics from a non-irrigated control group, water may need to be applied only during head development. Major production factors (e.g., irrigation) that contribute to cabbage that consumers prefer remain to be determined. However, these data establish irrigation conditions which may lead to significant differences in cabbage sensory characteristics. Studies of the influence of cultural practices on fresh vegetable quality have been largely limited to effects on physical characteristics contributing to yield (Barber & Raine, 2002; Kuchenbuch et al., 1999; Sanchez, Roth, & Gardener, 1994). This first report of an effect of irrigation timing on fresh cabbage sensory characteristics is a unique contribution to the expanding body of work demonstrating a direct link between field management and the perception of fresh vegetable sensory quality (Radovich, Cavaletto, & Valenzuela, 2000; Scheerens & Hosfield, 1976; Simonne, Simonne, & Wells, 2001).

Triangle tests are unable to determine the magnitude or direction of perceived changes in sensory quality (Lawless & Heymann, 1998). In our study, the relatively small size, light weight, elongated shape and slightly discolored tissue of heads produced in HS and FHS plots during the relatively warm and dry 2002 growing season reduced their potential commercial value. PM and the related attributes crispness and juiciness are thought to be important to the acceptability of fresh cabbage (Martens, 1985; Yano et al., 1990). The smallest perceptible change in PM of fresh cabbage is not known. However, earlier reports (Martens, 1985; Yano et al., 1990) suggest that preference ratings would favor cabbage irrigated during head development, which had significantly (~3%) higher PM values than treatments not irrigated during head development (Table 2). The lower PM of cabbage not irrigated during head development may have resulted in stronger flavor due to a higher concentration of dry matter, including organic flavor compounds. Freeman and Mossadeghi (1973) reported both stronger flavor and higher concentrations of volatile isothiocyanates (flavor compounds) in water-stressed cabbage relative to well-watered cabbage. Strong flavor generally corresponds to a decrease in acceptability of fresh cabbage (Ball et al., 1999; Yano et al., 1990). Therefore, we speculate that the flavor of cabbage from FHS plots would have been judged stronger and less desirable relative to cabbage from NS or FS plots.

Table 2
The effect of irrigation on physical and sensory characteristics of cabbage heads

Treatment	Weight (kg)	Mean diameter (cm)	Shape	Moisture content at harvest (%)	Moisture content of evaluated samples (%)	Perceived sensory differences
NS	1.6 a	15.5 a	1.00 d	91.3 a	91.6 a	a
FS	1.3 b	14.8 b	1.06 c	91.4 a	92.1 a	ab
HS	0.7 c	11.6 c	1.12 b	88.1 b	89.7 b	bc
FHS	0.5 d	10.7 d	1.23 a	88.7 b	89.7 b	c

Physical trait values are means of five replications. Values within columns followed by the same letter are not significantly different ($\alpha = 0.05$) according to Fisher's protected LSD test. Shape value is the ratio of head polar to head equatorial diameter (1.0 = round). Treatments were irrigation throughout plant development (NS, no stress), irrigation during head development only (FS, frame stress), irrigation during frame development only (HS, head stress) and no irrigation for the duration of plant development (FHS, frame and head stress). Sensory treatment comparisons containing the same letter are not significantly different ($\alpha = 0.05$) from each other as determined by the binomial model.

4.2. Cabbage head characteristics

Differences in head physical traits were found among all irrigation treatments (Table 2). Heads from plants receiving irrigation throughout plant development were larger, heavier and more round than heads from other treatments. Withholding water during head development resulted in a more than 50% reduction in head fresh weight (Table 2). This would correspond to unacceptable commercial losses. In addition to lower yields, a reduction in crop value would be expected to result from deviations in head shape and size from the optimum for packing, shipping and processing, as well as from the browning observed in shredded tissue from cabbage not irrigated during head development.

4.3. Head physical traits vs. sensory quality

Fewer significant differences among treatment comparisons were found in the sensory data compared to the physical trait data (Table 2). Three of six comparisons were significantly different in the triangle test. However, four comparisons were significantly different in PM data, and all six comparisons were significantly different with regard to head weight, mean diameter and shape. Therefore, as a group, the physical traits measured here responded more frequently to irrigation than cabbage flavor attributes. This may be due in part to the relatively low power of the triangle test to detect differences in the non-significant comparisons (Table 1). Irrigation applied only during head development resulted in an 18% decrease in head weight relative to irrigation throughout development. Yet, panelists perceived little difference in sensory properties between the two treatments. If some decrease in head weight is justified by reduced water cost and resource conservation, cabbage growers may need to irrigate only during head development to achieve crop flavor quality goals. However, testing this hypothesis in additional, commercially significant varieties is important.

5. Conclusions

These data demonstrate that irrigation and its timing relative to plant developmental stage can influence cabbage sensory quality. The data also suggest that physical head traits are affected by soil moisture availability, perhaps more frequently than sensory characteristics. Provided some decrease in head weight is acceptable, we conclude that, relative to irrigating throughout development, irrigating only during head development may help reduce irrigation costs and conserve water resources while maintaining sensory quality.

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References

Ball, S., Skog, L., Smith, R. B., Murr, D., & McKeown, A. (1999). Reducing pungency in commercial coleslaw by controlling glucosinolate levels. *Project Report 648*. Department of Plant Agriculture, University of Guelph, Ontario.

Barber, S. A., & Raine, S. R. (2002). Using commercial distribution uniformity and yield data to improve irrigation management. *International Water and Irrigation, 22*, 17–22.

Billingsley, G. (1994). Cabbage. *The Packer, 101*, 96–104.

Dacremont, C., & Sauvageot, F. (1997). Are replicate evaluations of triangle tests during a session good practice? *Food Quality and Preference, 8*, 367–372.

Ennis, D. M., & Bi, J. (1998). The beta-binomial model: accounting for inter-trial variation in replicated difference and preference tests. *Journal of Sensory Studies, 13*, 39–412.

Freeman, G. G., & Mossadeghi, N. (1972). Influence of sulphate nutrition on flavor components of three cruciferous plants: radish (*Raphanus sativus*), cabbage (*Brassica oleracea capitata*) and white mustard (*Sinapis alba*). *Journal of the Science of Food and Agriculture, 23*, 387–402.

Freeman, G. G., & Mossadeghi, N. (1973). Studies on the relationship between water regime and flavour strength in watercress (*Rorippa nasturtium-aquaticum* (L) Hayek), cabbage (*Brassica oleracea capitata*) and onion (*Allium cepa*). *Journal of Horticultural Science, 48*, 365–378.

Klocke, N. L., & Fischbach, P. E. (1984). Estimating soil moisture by appearance and feel. *Cooperative Extension Service, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, Nebraska Guide B-12*.

Kuchenbuch, R., Auerswald, H., Bruckner, B., & Krumbein, A. (1999). Use of sensory analysis for fresh vegetables. *Acta Horticulturae, 483*, 221–223.

Lawless, H. T., & Heymann, H. (1998). *Sensory evaluation of food: principles and practices*. New York: Chapman and Hall.

MacLeod, A. J., & Nussbaum, M. L. (1977). The effect of different horticultural practices on the chemical flavor composition of some cabbage varieties. *Phytochemistry, 16*, 861–865.

Martens, M. (1985). Sensory and chemical quality criteria for white cabbage studied by multivariate analysis. *Lebensmittel Wissenschaft und Technologie, 18*, 100–104.

Radovich, T., Cavaletto, C., & Valenzuela, H. (2000). Effect of compost and mineral fertilizer applications on the sensory quality of basil (*Ocimum basilicum* L.). *HortScience, 35*, 464.

Radovich, T. J. K., Kleinhenz, M. D., Sanchez-Vela, A., Scheerens, J. C., & Schult, B. Fresh cabbage sensory quality: components and the impact of production factors. *Acta Horticulturae*, in press.

Rosa, E., David, M., & Gomes, M. H. (2001). Glucose, fructose and sucrose content in broccoli, white cabbage and Portuguese cabbage grown in early and late seasons. *Journal of the Science of Food and Agriculture, 81*, 1145–1149.

Sanchez, C. A., Roth, R. L., & Gardener, B. R. (1994). Irrigation and nitrogen management for sprinkler-irrigated cabbage on sand. *Journal of the American Society for Horticultural Science, 119*, 427–433.

Scheerens, J. C., & Hosfield, G. L. (1976). The feasibility of improving eating quality of table carrots by selecting for total soluble solids. *Journal of the American Society for Horticultural Science, 101*, 705–709.

Simonne, E., Simonne, A., & Wells, L. (2001). Nitrogen source affects crunchiness but not lettuce yield. *Journal of Plant Nutrition, 24*, 743–751.

Swaider, J. M., Ware, G. W., & Shoemaker, W. H. (2002). Irrigating and mulching. In J. M. Swaider & G. W. Ware (Eds.), *Producing vegetable crops* (pp. 145–162). Illinois: Interstate Publishers, Inc.

Van Etten, C. H., Daxenichler, M. E., Williams, P. H., & Kwolek, W. F. (1976). Glucosinolates and derived products in cruciferous vegetables: analysis of the edible part of twenty-two varieties of cabbage. *Journal of Agricultural and Food Chemistry, 24*, 452–455.

Wien, H. C., & Wurr, D. C. E. (1997). Cauliflower, broccoli, cabbage and brussels sprouts. In H. C. Wien (Ed.), *The physiology of vegetable crops* (pp. 511–552). New York: CAB International.

Yano, M., Saijo, R., Sugawara, W., & Ohta, H. (1990). Influence of physical and chemical properties on consumer preference of shredded cabbage. *Nippon Shokuhin Kogyo Gakkaishi, 7*, 478–483.