Comparison between vertical and horizontal air flow for fruit and vegetable precooling

I. EDEOGU, J. FEDDES and J. LEONARD

Agricultural, Food and Nutritional Sciences, University of Alberta, Edmonton, AB, Canada T6G 2P6. *Received 5 February 1996; accepted 17 February 1997.*

Edeogu, I., Feddes, J. and Leonard, J. 1997. **Comparison between vertical and horizontal air flow for fruit and vegetable precooling**. Can. Agric. Eng. **39**:107-112. Three methods of precooling fresh fruits and vegetables were tested, a vertically-directed forced-air cooling (VFC) treatment, a horizontally-directed forced-air cooling (HFC) treatment and a control, room cooling (CRC) treatment. Six boxes each, of carrots, lettuce, and strawberries were cooled by the three treatments. Cooling was conducted in a cold room with temperatures varying between 0°C and 2°C. The airflow through the produce in the forced-air cooling treatments was adjusted to 2 $L{\bullet}s^{-1}{\bullet}kg^{-1}$. Temperatures of the produce and the room were measured, mass losses determined, and quality of the produce evaluated. A modified cooling coefficient, C_{cm}, was used to describe cooling. The rate of cooling under the VFC treatment was generally higher compared to the rate of cooling under the HFC treatment. Average half-cooling times of the carrots, lettuce, and strawberries cooled under the VFC treatment were 31.6, 40.9, and 26.0 min, respectively, compared with 33.5, 62.7, and 57 min under the HFC treatment. The results also indicated that the HFC and VFC treatments cooled the produce in about 25 to 50% less time than the CRC treatment. However, the least moisture loss occurred in the CRC treatment.

Trois méthodes utilisées pour le refroidissement des fruits et légumes frais ont été testées: le refroidissement par air pulsé dans la direction verticale (RPV), le refroidissement par air pulsé dans la direction horizontale (RPH), et le refroidissement conventionnel (RC). Six boîtes de carottes, de laitues et de fraises ont été refroidies en utilisant chacune des trois méthodes. Le refroidissement a été fait dans une chambre froide où la température variait entre 0°C et 2°C. Le débit d'air utilisé pour les méthodes à air pulsé a été maintenu à 2 $L{\bullet}s^{-1}{\bullet}kg^{-1}$. On a mesuré la température du produit et de la pièce, déterminé la perte de poids et évalué la qualité des produits. Un coefficient de refroidissement modifié, C_{cm} a été utilisé pour décrire le refroidissement. Le taux de refroidissement par la méthode RPV a généralement été plus élevé que celui de la méthode RPH. Les demi-temps de refroidissement des carottes, de la laitue et des fraises avec la méthode RPV ont été respectivement de 31.6, 40.9 et 26.0 minutes, comparativement à 33.5, 62.7 et 57.0 minutes avec la méthode RPH. Les résultats montrent que les temps de refroidissement avec les méthodes RPH et RPV sont de 25 à 50% inférieurs à ceux de la méthode RC. Cependant, les pertes d'humidité avec la méthode RC sont les plus faibles.

INTRODUCTION

The need to maintain freshness and quality of freshly harvested fruits and vegetables to prolong quality has long been established. Recently, consumer preference for fresh food of high quality has increased (Boyette and Rohrbach 1993; Émond et al. 1994; Wood 1994), thus putting pressure on fruit and vegetable growers to institute and improve postharvest preservatory practices to meet these demands.

Studies have shown that the stored heat (field heat) in fruits and vegetables at harvest is high and if not removed increases the rate of deterioration of these products (Salunkhe et al. 1991; Kays 1991; Schofer et al. 1992). Field heat in fresh produce is removed by cooling, also referred to as precooling. Rohrbach et al. (1984) reported that 37 to 46% less decay could occur in blueberries if the field heat is removed by precooling to 2°C.

Vacuum cooling, hydrocooling, forced-air cooling, icing, and room cooling are common methods of precooling used in commercial horticultural operations. Of these methods, forced-air cooling has characteristics best-suited to market gardening. Forced-air cooling cools produce in 25% of the time taken by room cooling (Sargent et al. 1988); does not wet produce as in hydrocooling (Boyette and Rohrbach 1989; Mackinnon and Bilanski 1992) or icing, which is critical for produce such as strawberries; is cost effective (Fraser 1992); and has a potentially wide range of applications (Hackert et al. 1987).

Commercial applications and research studies related to forced-air cooling have been limited to vertically-directed air flow through produce packed in bulk bins (Lindsay et al. 1975; Chau et al. 1985; Mackinnon et al. 1991) or horizontally-directed air flow through produce in cartons (Arifin and Chau 1988; Boyette and Rohrbach 1993; Talbot et al. 1993). Few studies, if any, have investigated the effects of directing air vertically through produce packed in cartons or similar-sized containers.

This study was designed to investigate and compare the possible benefits of precooling by forcing air vertically through carton-sized packing containers over forcing air horizontally through the containers. Room cooling was used as a reference method against which the effects of the forced-air cooling methods could be evaluated.

THEORETICAL BACKGROUND

Heat flow during fruit or vegetable cooling may be described by Newton's law of cooling (Mohsenin 1980). The relationship between temperature and time is described by the exponential function:

$$(t - t_a) / (t_i - t_a) = \exp\left[-\frac{hA}{C_w V}\,\theta\right] \qquad (1)$$

where:

h = unit surface conductance ($kW{\bullet}m^{-2}{\bullet}K^{-1}$),

θ = time (s),
A = surface area (m^2),
t = temperature of any point within the product (°C),
t_a = ambient temperature (°C),
t_i = initial temperature (°C),
C = specific heat ($kJ \cdot kg^{-1} \cdot K^{-1}$),
w = density (kg/m^3), and
V = volume (m^3).

The expression, $(t-t_a)/(t_i-t_a)$, is defined as the ratio of the unaccomplished temperature change at any time, θ, in relation to the total temperature change possible for the cooling condition (ASHRAE 1990). According to Hackert et al. (1987) and Mohsenin (1980) the expression, $hA/(CwV)$, is referred to as the cooling coefficient (C_c) which denotes the change in product temperature per unit increase of cooling time for each degree temperature difference between the product and its surroundings (ASHRAE 1990). Thus, Eq. 1 can also be expressed as (Mohsenin 1980):

$$(t - t_a) / (t_i - t_a) = \exp(-C_c \theta) \quad (2)$$

or:

$$C_c = \frac{\ln[(t_i - t_a) / (t - t_a)]}{\theta} \quad (3)$$

MATERIALS AND METHODS

Cooling systems

Packing containers were designed and modified to accommodate cooling by vertically-directed forced-air cooling (VFC), horizontally-directed forced-air cooling (HFC), and room cooling (CRC) treatments. Six boxes were used in each treatment, i.e., two stacks, each three boxes high. The boxes were built of 19 mm fir plywood and measured 460 mm x 310 mm x 190 mm. Strawberry picking containers-fruit tills (MRP Plastic, Laval, QC) - measuring 159 mm x 159 mm x 50 mm were also modified for use under the different treatments. A brief description of the setup in each treatment is given below.

Vertically-directed forced-air cooling The bottom of each box was replaced with a plastic-coated wire grate of mesh size 25 mm x 50 mm (Fig. 1) and lined with foam weather stripping (19 mm wide) to provide an air seal between the boxes when stacked. Stacks of three boxes were set on a plenum connected to a 150 mm x 150 mm x 1000 mm duct. At the other end of each duct, a centrifugal fan (MagneTek, St. Louis, MO) with a fan speed control switch, was installed to deliver air at a rate of 2 $L \cdot s^{-1} \cdot kg^{-1}$ of produce.

The strawberry picking containers were modified for VFC by making an additional 16 holes (each 10 mm in diameter) in the bottom of each container. Each container had a total of 21 vent holes.

Horizontally-directed forced-air cooling Under HFC, the two opposite sides along the length of the boxes were replaced with the coated wire grate and lined with weather stripping, as illustrated in Fig. 2. Two boxes were connected along their lengths and three sets of the paired boxes were stacked and connected to a plenum. The plenum was constructed to distribute similar airflow rates through the three sets of boxes. A plywood duct, 150 mm x 300 mm x 1000 mm in dimension, was attached to the other side of the plenum to deliver air to the boxes. An airflow rate of 2 $L \cdot s^{-1} \cdot kg^{-1}$ of produce was supplied by a centrifugal fan (MagneTek, St. Louis, MO) fitted with a fan speed control switch.

The strawberry picking containers used under the HFC treatment were also modified by making an additional 16 holes (each 10 mm in diameter), distributed around the four sides of the containers. Each container had only 16 vent holes.

Room cooling Vent holes (each 60 mm in diameter) were cut in the sides of the boxes used for room cooling (Fig. 3). The percentage vent area for each box was 10%. The outer face of

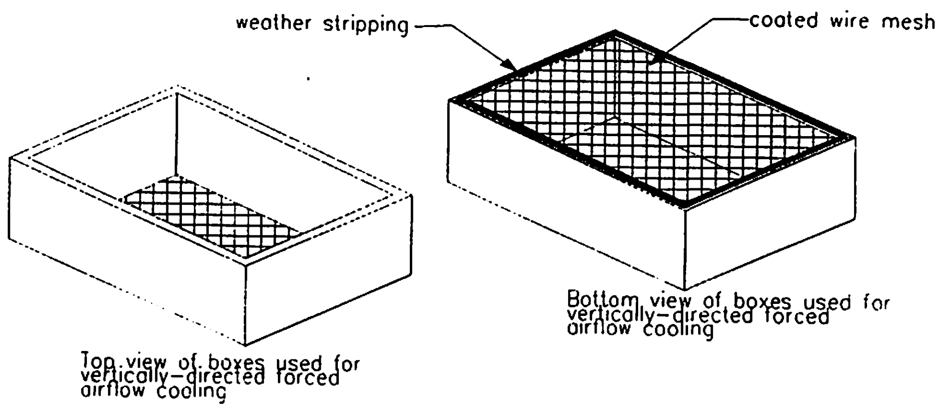

Fig. 1. Schematic of boxes used for vertically-directed forced-air cooling.

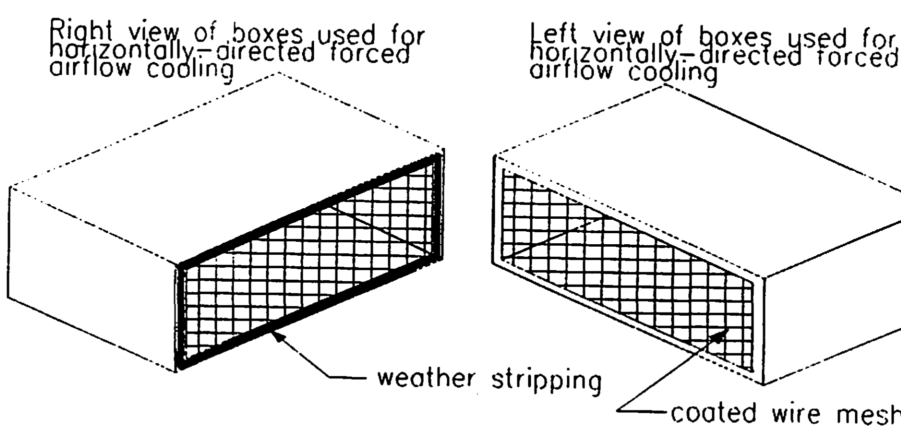

Fig. 2. Schematic of boxes used for horizontally-directed forced-air cooling.

the top of each box was lined with weather stripping to allow air movement only through the vents.

The strawberry picking containers were not modified for this treatment.

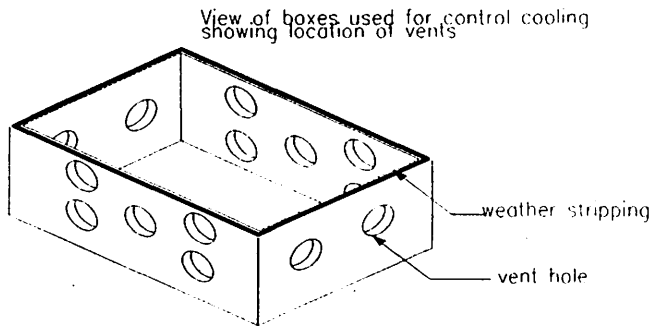

Fig. 3. Schematic of boxes used for control room cooling.

Produce

'Presto-nantes' carrots and 'Tristar' strawberries (day neutrals) used for this study were provided by the Crop Diversification Centre North (CDCN), Edmonton, AB. Romaine lettuce ('Paris island') were supplied by Sunnyside Fruit and Vegetables, Vimy, AB.

Temperature sensors and data collection

Standard ntc-thermistors (ISO-CHIP^{tm} SERIES, Fenwal Electronics, Milford, MA) were used to measure temperature. Five thermistors were placed in each box and connected via 22-gauge wire conductors and connectors to a datalogger which sampled data every minute. One thermistor was used to record the ambient temperature. The data were stored on the hard drive of an IBM-286 compatible computer.

Airflow rate

An air velocity meter (Velocicalc 8350, TSI, St. Paul, MN) was used to measure air velocity. Nine and 25-point traverses were made across the cross-section of each VFC and HFC duct, respectively, approximately 950 mm downstream from the fans.

Experimental procedure

Produce was harvested and packed directly into the fabricated boxes in the field. The carrots were washed prior to packing into boxes and the strawberries were first picked into the picking containers and then packed into the boxes. Spaces (e.g. head-spaces) in the boxes used for HFC cooling of carrots and strawberries were filled with plastic wrap to minimize air flow through the spaces.

During harvesting, the boxed produce was covered with burlap to prevent moisture loss and scorching from solar heat gain. Masses of the produce were measured and recorded prior to and after cooling. After weighing, the boxes were loaded into one of the cold rooms at the CDCN. Airflow rates were set based on the mass of produce to be cooled. Temperature of the air in the room ranged between 0^{o}C and 2^{o}C. Cooling occurred until the temperature of the produce under VFC or HFC or both dropped to 4^{o}C or lower.

Six runs were conducted between the months of July and September, 1994, to obtain two replicates each for the three types of produce. The experiment was set up such that only one run was conducted a day.

Quality evaluation

Quality of the lettuce and strawberries was subjectively evaluated by a vegetable specialist at the CDCN. The quality of the lettuce was evaluated based on the level of wilting and desiccation. Ratings of 1 to 5 were used, with 1 signifying "worst" and 5 signifying "excellent".

Quality of the strawberries cooled in the second replicate was evaluated based on the appearance of the berries with respect to their marketability. Ratings of 1 to 5 were used with 1 signifying "discard" and 5 signifying "excellent".

Check

To check the methodology and obtain an indication of the influence of non-uniformity of produce properties and evaporation on cooling, treatments were also applied to golf balls. A thousand golf balls were divided into three groups. One box from each treatment was filled with the golf balls, masses were measured, airflow rates set, and the balls cooled. The golf balls were of uniform shape, size, and mass, which remained constant throughout cooling.

RESULTS AND DISCUSSION

Cooling curves for carrots, lettuce, and strawberries are shown in Fig. 4. For each run, regression curves were established between temperature and time. Note that in each figure the cooling curves have the same initial temperature. This was achieved by replacing the different intercept values in each regression equation with a single value, for illustration purposes. The cooling curves for the carrots, lettuce, and strawberries, presented in Fig. 4, are based on the averaged values of predicted temperature from the two replicates. The graphed data showed that cooling in the VFC treatment was more rapid than the HFC and CRC treatments.

Equation 3 was initially used to establish cooling coefficients, C_c, for each treatment and produce. However, the correlation coefficients ranged between 0.40 and 0.99 for the plot of $\ln[(t-t_a)/(t_i-t_a)]$ against time. Thus, Eq. 3 was modified by removing, t_a, to give:

$$C_{cm} = \frac{\ln(t / t_i) - k}{\theta} \qquad (4)$$

where:

k = intercept on the y-axis, and

C_{cm}, = cooling coefficient.

The modified equation (Eq. 4) resulted in higher correlation coefficients in the range of 0.98 to 1.00 for the plot of ln $[t/t_i]$ against time.

Half-cooling time is the time required to achieve half of the potential cooling of a product. Using similar triangles the following relationship for determining half-cooling time, $\theta_{1/2}$, was derived from the plot of ln $[t/t_i]$ against time:

$$\theta_{1/2} = \theta_a \left(\frac{\ln\left(\frac{t_i + t_a}{2}\right) - \ln(t_i)}{\ln(t_a / t_i)} \right) \qquad (5)$$

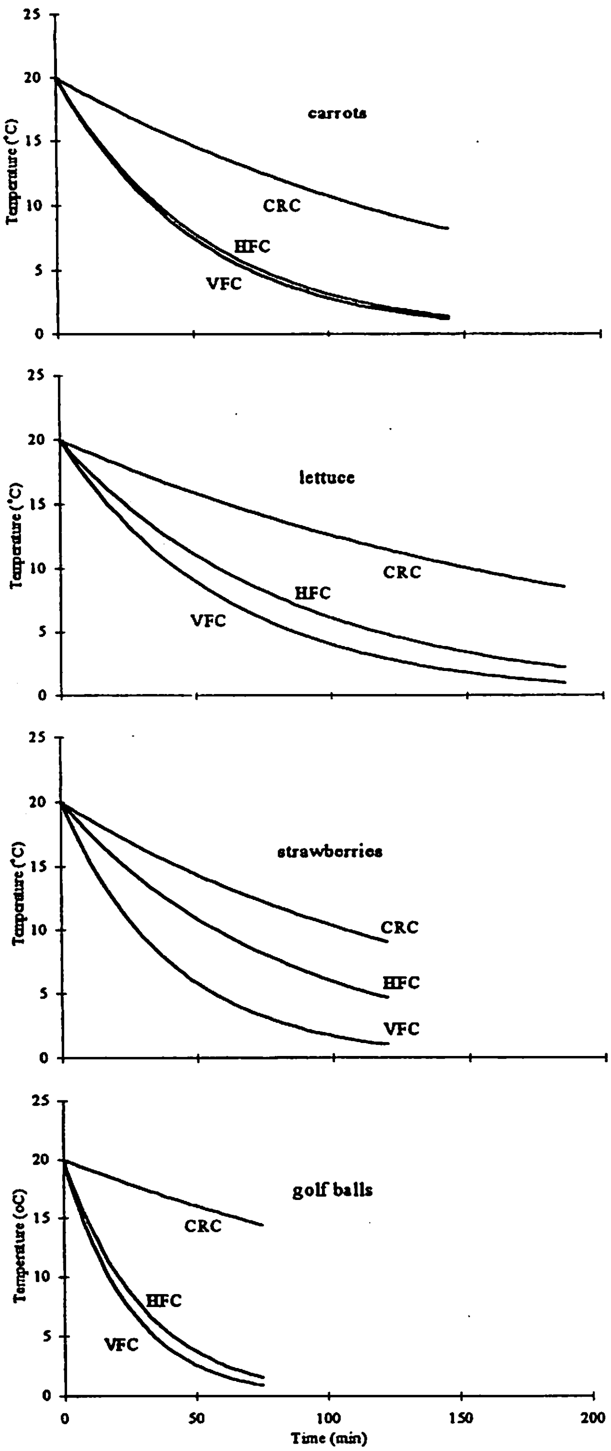

Fig. 4. Cooling curves of fresh produce and golf balls cooled by different precooling treatments. The curves are plots of the predicted temperatures. For illustrative purposes, each curve has been adjusted by replacing the intercept in the regression equation with a single value of 20 °C.

where: θ_a is the time taken for the temperature of the product to reach t_a. The value of θ_a is determined from Eq. 4 using values of k and C_{cm} obtained from the plot of ln $[t/t_i]$ against time. Note that Eq. 5 does not apply when t_a is less than or equal to zero.

The effect of the three cooling treatments on half-cooling time of the carrots, lettuce, and strawberries was compared using the GLM procedure in SAS (SAS 1994). The results of these comparison are presented in Table I.

Table I: A comparison of the vertically and horizontally directed forced-air cooling and room cooling methods

	Mean values of half-cooling time (min)*		
Method	Carrots	Lettuce	Strawberries
VFC	31.6[a]	40.9[b]	26.0
HFC	33.5[a]	62.7[b]	57.0
CRC	99.5	161.0	92.0

* Means with the same letter are not significantly different at the 5% confidence interval.

The results indicated that all the products cooled faster under VFC compared to HFC and CRC. In Table I, the means of half-cooling time of the carrots, lettuce, and strawberries were lowest under the VFC cooling treatment. However, the comparison of these methods suggested that the effect of cooling by directing air vertically through the carrots and lettuce did not differ significantly from directing the air horizontally, at the 5% significance level. On the other hand, there was significant difference between the two methods when the strawberries were cooled. The comparison also showed that VFC and HFC differed significantly from CRC in all cases.

In addition, the mass loss which occurred in the carrots, lettuce, and strawberries is shown in Table II. Mass loss from the produce was least in the CRC treatment compared with the VFC or HFC treatments.

Carrots

The effects of VFC and HFC on the rate at which the carrots cooled were similar, as suggested by the comparison of half-cooling time presented in Table I. Furthermore, the difference in weight loss (0.09%) which occurred between the two methods was low. The differences in weight loss which occurred under VFC and HFC compared with CRC were 0.39% and 0.48%, respectively.

The closeness of the cooling effects under VFC and HFC may be attributed to the fact that equal air-to-product contact occurred under both methods. VFC may have resulted in more rapid cooling had the head-spaces overtop the carrots cooled under HFC not been filled with plastic wrap. As a consequence, the filled head-space constrained the air to flow through the bulk of carrots packed below.

Lettuce

The comparison of VFC and HFC showed no significant difference in the effects of these methods on the rate at which the Romaine lettuce cooled. The difference in half-cooling

Table II: Percentage mass loss of fresh produce (kg/kg) after cooling

Method	Average mass loss (%)		
	Carrots	Lettuce	Strawberries
VFC	1.61	3.78	1.87
HFC	1.52	4.36	2.22
CRC	1.13	2.64	1.78

times between the two methods was approximately 22 min. On the other hand, the differences in half-cooling time of lettuce cooled under VFC and HFC compared with lettuce cooled under CRC were about 120 min and 98 min, respectively.

Although the statistical comparisons indicated no significant differences between the VFC and HFC treatments, effects of the 22-min time lapse between both treatments appeared evident in the results of mass loss. Table II shows that 0.58% more mass was lost under VFC compared with HFC. Furthermore, the quality evaluation of the lettuce after 4 days (Table III) showed that only about 17% of the lettuce heads cooled under HFC were of acceptable quality compared with 83% of the heads cooled by VFC. The relatively larger differences in half-cooling time between CRC and VFC and HFC may have influenced the results of the statistical comparison.

The favourable effects of VFC over HFC may relate primarily to the orientation of the lettuce heads in the boxes with respect to the direction of airflow through the boxes under either method. The lettuce heads were packed with the stalk facing up, a typical market garden practice. Hence, under the VFC treatment, the air was forced to flow through each layer of the lettuce foliage as it traveled vertically upwards. This resulted in faster and more uniformly cooled produce. On the other hand, under the HFC treatment, most air-to-product contact only occurred across a fraction of the outer layer of the lettuce foliage. In effect, cooling was slower and less uniform.

In addition, the various sizes of lettuce heads harvested may have led to the creation of relatively larger head-spaces in some boxes compared to others. Thus, when boxes of relatively larger head-space were used under the HFC treatment, more air may have flowed through the head-space thereby further reducing air-to-product contact.

An interesting observation from the tests conducted with the lettuce shows that 75% of the heads cooled under CRC were acceptable (Table III) despite the much slower rate of cooling. This seems to suggest that maintaining the quality of lettuce does not only depend on quickly lowering the temperature of the heads but also on limiting the amount of moisture loss which may occur.

Strawberries

The spaces between the picking containers and in the head-spaces of the boxes used under the HFC treatment were filled with plastic wrap. Similar to the runs conducted with the carrots, this was done in order to restrict airflow through the picking containers only. However, the strawberries still took twice as long to cool under this method than under the VFC treatment (Table I).

The significant difference in half-cooling time of the strawberries, between VFC and HFC, may have been a consequence of the location of the vent holes in the picking containers, relative to the direction of airflow. Under the HFC treatment, only a fraction of the 16 vent holes in the sides of the picking containers were located directly in the path of airflow. On the other hand, under the VFC treatment the 21 vent holes were appropriately located in the bottom of the container such that air-to-product contact was enhanced.

The different cooling rates experienced under the two forced-air cooling treatments appeared to have influenced the results of the quality evaluation shown in Table IV. According to the evaluation, only about half the strawberries cooled under the HFC treatment were of marketable quality compared to those cooled under the VFC treatment.

Golf balls

The results of half-cooling time of the golf-balls cooled by HFC (16.1 min) compared to VFC (15.0 min) suggest that, unlike the lettuce, head-space had little effect on the cooling rate of the balls (Fig. 4). The comparable rate of cooling

Table III: Quality rating of cooled lettuce heads stored at 10°C for 4 days

Method	Four days after cooling	
	Rating*	Comments
VFC	3.7	83% acceptable
HFC	2.7	17% acceptable
CRC	3.6	75% acceptable

* Rating was based on wilting and desiccation. The following ratings were used: 1 = worst; 2 = poor; 3 = fair; 4 = good; 5 = excellent. Heads rated 1 to 3 were considered unacceptable and those rated 4 to 5, acceptable. The ratings in the above table are averaged values for the different methods.

Table IV: Quality rating of cooled strawberries stored at 1°C for 11 days

Method	Eleven days after cooling	
	Rating*	Comments
VFC	3.3	33% marketable
HFC	2.6	17% marketable
CRC	1.9	Reject all

* Rating was based on marketability. The following ratings were used: 1 = discard; 2 = poor; 3 = fair; 4 = good; 5 = excellent. Strawberries rated 1 to 3 were considered unmarketable and those rated 3.5 to 5, marketable. The ratings given above are the averages in each treatment.

achieved under HFC may have occurred due to the high porosity of the balls, thereby allowing most of the air to flow through the balls and not the head-space.

Furthermore, an airflow pattern similar to that observed by Émond et al. (1994) may have developed, whereby a fraction of the incoming air was deflected off the top of the box and diverted back through the golf balls.

CONCLUSIONS

The following conclusions were drawn from this study:

1. A cooling coefficient, C_{cm}, determined without t_a, described cooling better than C_c with correlation coefficients ranging between 0.98 and 1.00.
2. The rate of cooling under the VFC treatment was generally higher compared to the rate of cooling under the HFC treatment, but was not significantly different for the lettuce and carrots. Average half-cooling times of the carrots, lettuce, and strawberries cooled under the VFC treatment were achieved in 31.6, 40.9, and 26.0 min, respectively. The half-cooling times under the HFC treatment were 33.5, 62.7, and 57.0 min, respectively.
3. Horizontally-directed forced-air cooling (HFC) and vertically-directed forced-air cooling (VFC) treatments resulted in higher cooling rates in the carrots, lettuce, and strawberries than the room cooling (CRC) treatment. Cooling by HFC and VFC was two to four times faster than cooling by CRC. However, under the CRC treatment, moisture loss from the produce was least.
4. The lettuce and strawberries were of better quality after the VFC treatment than they were after the HFC treatment. The mass loss from the lettuce and strawberries was less under the VFC treatment, i.e., 3.78 and 1.87%, compared to 4.36 and 2.22% under the HFC treatment. Again, 83% of the lettuce heads cooled by VFC were of acceptable quality compared with only 17% of those cooled by HFC. For the strawberries, 33% of those cooled by VFC were of marketable quality compared with 17% of the strawberries cooled by HFC.

REFERENCES

Arifin, B.B. and K.V. Chau. 1988. Cooling of strawberries in cartons with new vent hole designs. *ASHRAE Transactions* 94(1):1415-1426.

ASHRAE. 1990. Methods of precooling fruits, vegetables and cut flowers. In *Refrigeration Systems and Applications Handbook*, Chapter 11: 11.1 - 11.9. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

Boyette, M.D. and R.P. Rohrbach. 1989. Cool and ship: low-cost portable forced-air cooling. ASAE Paper No. 89-1632. St. Joseph, MI:ASAE.

Boyette, M.D. and R.P. Rohrbach. 1993. A low-cost, portable, forced-air pallet cooling system. *Applied Engineering in Agriculture* 9(1): 97-104.

Chau, K.V., J.J. Gaffney, C.D. Baird and G.A. Church, II. 1985. Resistance to flow of oranges in bulk and in cartons. *Transactions of the ASAE* 28(6): 2083 -2088.

Émond, J., M. Bourré, S.O. Sadfa, F. Mercier and A. Gakwaya. 1994. Effects of airflow patterns on precooling efficiency of strawberries. CSAE Paper No. 94-318. Saskatoon, SK: CSAE.

Fraser, H.W. 1992. Sizing and laying out short-term (Summer) refrigerated storage for fruits and vegetables. Agdex 202/732. St. Catherines, ON: Ontario Ministry of Agriculture and Food.

Hackert, J.M., R.V. Morey and D.R. Thompson. 1987. Precooling of fresh market broccoli. *Transactions of the ASAE* 30(5):1489-1493.

Kays, S.J. 1991. *Postharvest Physiology of Perishable Plant Products*. New York, NY: Van Nostrand Reinhold.

Lindsay, R.T., M.A. Neale and H.J.M. Messer. 1975. Cooling produce in large pallet-based boxes. *Journal of Agricultural Engineering Research* 20:235-243.

Mackinnon, I.R. and W.K. Bilanski. 1992. Forced-air precooling of vegetables in bulk. ASAE Paper No. 92-6018. St. Joseph, MI: ASAE.

Mackinnon, I.R., R.K. Prange and P.D. Lidster. 1991. Forced-air spinach precooler. *Applied Engineering in Agriculture* 7(5):593-595.

Mohsenin, N.N. 1980. *Thermal Properties of Foods and Agricultural Materials*. New York, NY: Gordon and Breach.

Rohrbach, R.P., R. Ferrell, E.O. Beasley and J.R. Fowler. 1984. Precooling blueberries and muscadine grapes with liquid carbon dioxide. *Transactions of the ASAE* 27(6):1950-1955.

Salunkhe, D.K., H.R. Bolin and N.R. Reddy. 1991. *Storage, Processing and Nutritional Quality of Fruits and Vegetables. Vol. 1: Fresh Fruits and Vegetables*. Boca Raton, FL: CRC Press.

Sargent, S.A., M.T. Talbot and J.K. Brecht. 1988. Evaluating precooling methods for vegetable packinghouse operations. *Proceedings of Florida State Horticultural Society* 101:175-182.

SAS. 1994. SAS User's Guide: Statistics. Cary, NC: Statistical Analysis System Inc.

Schofer, D.P., J. Anthony, G. Berney and W. Craig. 1992. Portable, inexpensive, farm built, high value crop cooler. ASAE Paper No. 92-6569. St. Joseph, MI: ASAE.

Talbot, M.T., S.A. Sargent, C.D. Baird and J.K. Brecht. 1993. Design and evaluation of a standardized pepper container. ASAE Paper No. 93-6009. St. Joseph, MI: ASAE.

Wood, G. 1994. A descriptive study of Saskatchewan market gardeners with implications for agricultural extension. Unpublished paper. Agricultural Institute of Canada, 74th Annual Conference, Regina, SK.