The Effect of Evaporative Air Chilling and Storage Temperature on Quality and Shelf Life of Fresh Chicken Carcasses

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ABSTRACT The effect of evaporative air chilling on quality of fresh chicken carcasses was compared with air chilling as reference method. Cooling efficiency and total heat loss were significantly higher for evaporative air chilling. The chilling method was of great importance for weight loss. Chicken chilled in cold air lost considerably more weight than chicken cooled by evaporative air chilling; the difference was 1.8%. The chilling method also affected the skin color and the amount of moisture on skin surface. After evaporative air chilling, the chicken carcasses had a lighter color and more water on the back and under the wings. The moisture content in skin and meat, cooking loss, and pH were not affected by chilling method. Odor attributes of raw chicken and odor and flavor attributes of cooked chicken did not show any significant differences between the two chilling methods. The shelf life of chicken stored at 4 and –1 C were not affected significantly by chilling method. Storage time and temperature appeared to be the decisive factors for sensory and microbiological quality of fresh chicken carcasses.

(*Key words*: chicken carcasses, evaporative air chilling, technological and sensory quality, shelf life)

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INTRODUCTION

Quick chilling of poultry carcasses slows the growth of spoilage microorganisms and therefore prolongs shelf life of the product. Furthermore, quick chilling can significantly reduce weight loss. Choice of chilling method is therefore important for the quality of the finished product.

Air chilling is used in Europe in the production of fresh carcasses scalded at 52 C. This low scalding temperature prevents removal of the outer skin layer (epidermis) during plucking. This is important in order to prevent the skin from drying out and to avoid discoloration. Furthermore, the use of air chilling causes a constant weight loss during the chilling process (Veerkamp, 1981). The advantages and disadvantages of various chilling systems have been discussed by several authors (Lillard, 1982; Veerkamp, 1985; Jul, 1986; Ziolecki, 1990; Vranic *et al.*, 1991).

Norwegian poultry slaughterhouses have most commonly used the air chilling as preliminary method for chilling poultry carcasses to be frozen or distributed as fresh. Many Norwegian slaughterhouses use so-called subscalding, in which the temperature of the scald tank is approximately 58 C. Due to this relatively high scalding temperature, the epidermis is removed during plucking, which may cause dry and discolored skin on the carcasses after air chilling. The search for more effective chilling methods has led to installation of equipment for so-called evaporative air chilling at some Norwegian slaughterhouses. Evaporative air chilling was developed as an alternative for immersion chilling of subscalded carcasses (Veerkamp, 1985; Ziolecki, 1990). Using this method, the carcasses are sprayed with a thin water film and cooled by blowing cold air onto them at low temperature (2 to 4 C). Evaporation of the water removes heat from the carcasses, and a quick and effective chilling is achieved. Heat transfer in evaporative air chilling is greater than in air chilling, because water has 30 times greater heat transfer capacity than air. Furthermore, subscalded carcasses (58 C) can be chilled without skin discoloration (Veerkamp, 1981). Another important advantage of this method is that weight loss can be controlled (Veerkamp, 1981, 1986, 1991). Excessive use of water may cause soaking and weight gain in carcasses. Furthermore, during evaporative air cooling, the surfaces of the carcasses are wet at the end of the chilling tunnel, leading to questions about

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Abbreviation Key: CFC = cetrimide-fusidin-cefaloridine agar; NMR = nuclear magnetic resonance; PCA = plate count agar; PS = physiological saline; STAA = streptomycin-thallous acetate-actidione agar VRB = violet red bile agar.

whether this could affect the shelf life and other quality parameters of finished product. Existing information about the influence of air chilling vs evaporative air chilling on quality characteristics of fresh poultry carcasses is not sufficient. The available information mainly contains comparisons between immersion chilling and evaporative air chilling (Ristic, 1996).

The aim of this study was to evaluate the cooling efficiency of air chilling and evaporative air chilling and compare these two chilling methods with regard to physicochemical, sensory, and microbiological characteristics of chicken. Furthermore, we wished to find relationship between chilling conditions, storage temperature and time, and shelf life of fresh chicken carcasses.

MATERIALS AND METHODS

Experiments

The experiments were carried out at a poultry slaughterhouse with installed equipment for evaporative air chilling. Inside the chilling tunnel, the chicken carcasses were sprayed with water in four zones. Two shower leads were installed at the beginning of the chilling tunnel, and a third lead was housed in the corner on the opposite wall. The fourth shower lead was located in the middle of the chilling room. A thermostat and evaporators in the tunnel's ceiling regulated air temperature in the chilling tunnel. The fans forced the air to evaporators, where it was cooled and dispersed through openings in the ceiling over the tunnel. The air velocity between the chicken carcasses was about 0.5 m/s.

The slaughtering process was fully automatic; washed chicken carcasses entered the chilling tunnel within 16 min. Both air chilling and evaporative air chilling of carcasses took place in the same chilling tunnel. The difference between the two methods was based on closing the water supply during air chilling. Carcasses cooled by air chilling were the first to be tested (i.e., at the beginning of the production day), because air humidity was lowest at that time. The idea behind this was to "simulate" air chilling as it is done in other processing facilities. After finishing the first part of the experiment, the water supply was opened and evaporative air chilling could begin. Water consumption was approximately 21.5 L/min. Chilling lasted for 50 min for both chilling methods. The experiment was repeated.

Data Recording During the Chilling Processes

Weight and temperature measurements were made on approximately 100 chicken carcasses for each chilling method. The carcasses were randomly selected from the slaughter line just before entering the tunnel, labeled, and weighed before and after chilling in order to calculate percentage weight loss. Core temperature in breast muscle was measured before and after chilling with a digital thermometer.[2] Temperature drop in breast muscles of 12 chicken carcasses from each chilling method was logged on Ebro data loggers.[3] Weight of carcasses just before chilling and differences in temperature caused by the chilling process formed the basis for calculating the total heat loss for each chicken. The following equation was used for calculations:

$$Q = mC(ti - te),$$

where Q = amount of heat (kilocalories); m = weight of the carcass (kilograms); C = specific heat capacity for poultry, i.e., 0.8 kcal/(kg·C); ti = initial core temperature; and te = end core temperature.

Chicken carcasses of average commercial weight (900 g), from each chilling method were randomly selected for further analysis in the laboratory. Chilled carcasses were packed in cardboard boxes lined with plastic, covered with dry ice (CO_2), and transported to the laboratory in a cooler. The chickens were then stored at 4 and –1 C up to 15 and 19 d, respectively. On the day of production, the color of breast and back skin on eight randomly selected carcasses from each chilling method was measured. The next day, the following analyses were made on eight other carcasses from each treatment: moisture on skin surface, moisture content of fat free skin and pH, moisture content, and cooking loss of breast and leg muscles. Moisture on skin surface was measured first. After that, each chicken was divided into two halves. One half was used to determine cooking loss and the other half was used for chemical analysis. As a preparation for chemical analyses, skin was removed from breasts and legs, placed inside an airtight container, and frozen. Meat from breasts and legs was ground separately in a food processor[4] for about 30 s. Moisture content and pH were determined in three parallel samples from each examined chicken. Sensory analysis was performed on raw and cooked chicken by a trained sensory panel.

Methods of Analysis

Color Measurement. Instrumental color analysis was based on measurements of light reflected from chicken surfaces, which were later transformed to values in the CIELAB color space system (C.I.E., 1978). An automatic Minolta colorimeter[5] with an 8-mm measuring cell was used to register the L* (lightness), a* (redness), b*

[2]Yokogawa model 2455,Yokogawa Electronic Corp., 9-32, Nakacho 2-Chrome, Musashino-shi, Tokyo, Japan.

[3]EBI 85, Ebro Electronic GmbH, Peringerstrasse 10, D-85055 Ingoldstadt, Germany.

[4]Masterchef 30, Moulinex S.A., 11 Rue Jules Ferry-F-93170, Bagnolet, France.

[5]Minolta Chroma Meter CR-300, Minolta Camera Co. Ltd., 2-Chome, Azuchi-Machi, Chuo-Ku, Osaka 541, Japan.

(yellowness) values at D- light source. Color on the chicken surface was evaluated on the basis of two measurements taken on breast skin and three measurements taken on back skin for each chicken.

Determination of Moisture on Skin Surface. The amount of moisture on the skin surface was measured after removing the carcasses from storage by determining the increase in weight of a 3 × 3 cm square of Whatman No. 1 filter paper held in contact with the skin for 30 s. The results are given as milligrams per square centimeter. Two measurements were taken on the breast skin and skin under the wings and three measurements were taken on back skin.

Determination of Moisture in Muscle. Three parallel samples of ground meat from chicken leg and breast were dried in a convection oven[6] at 105 C for 16 h. The weight loss was registered as moisture content.

Determination of Moisture in Fat-Free Skin. Frozen chicken skin was cut up into small pieces and homogenized in two steps; first with a food processor[7] for approximately 5 s, and then with another food processor[8] until the desired homogeneity of the test material was achieved. Two 5-g samples of the homogenate were weighed on standardized plastic film[9] and dried for 16 to 18 h at 106 C in a convection oven. After drying and weighing, the moisture content was calculated on the basis of the recorded weight loss. Fat content in the dried samples was determined by Nuclear Magnetic Resonance (NMR).[10] The plastic film with the dried sample was put in NMR tubes, placed in a heating block for 30 min at 70 C, and then immediately after reaching 70 C, the test tubes were placed in the magnet of the NMR. The NMR signal from each sample was proportional to the amount of fat present. On the basis of the registered NMR signals and earlier calibration data from standard fat analysis, the percentage of fat was calculated by means of a computer program based on multiple linear regression.[11] The moisture content of fat-free product was calculated using the following formula:

$$\text{moisture percentage in fat-free product} = \frac{\text{product's real moisture content in percentage} \times 100}{100 - \text{product's real fat content in percentage}}$$

pH-Measurement. Determination of pH directly in ground breast and leg meat was carried out with a Beckman 31 pH meter[12] fitted to a combination insertion electrode.[13]

Determination of Cooking Loss. Cooking loss in chicken breast and leg was evaluated separately. The breast with the upper wing and leg was cut out of a chicken half. The pieces were individually vacuum packed in plastic bags and heat treated in a water bath at 85 C for 50 min. After the heat treatment and cooling in cold water for 5 min to reach approximately 20 to 30 C, the plastic bags were opened and the juices poured out. Excessive fluid was wiped off the meat with paper towels. The difference between the weight before and the weight after cooking was defined as cooking loss and reported as a percentage.

Sensory Analysis. Sensory analysis was performed on raw and cooked chicken according to the international standard methods (ISO 1985a,b, 1988). The trained sensory panel, consisting of 12 judges, carried out a descriptive test without any prior knowledge of the experiment. Before the main test, the sensory panel was calibrated in a pretest, in which each panelist received single half chickens, air chilled and stored at –1 C and evaporative air chilled and stored at 4 C.

Odor of raw chicken from air chilling and evaporative air chilling, stored at both 4 C and –1 C, were judged after 6, 8, and 13 d of storage. On the day of analysis, the chickens were taken out of the refrigerators 4 h before testing. The samples were coded and served in random order to each panelist to avoid position effects during serving. Each judge received a half chicken from each treatment for evaluation of the surface and inside of the carcass. The following odor properties were evaluated on a continuous scale from 0 (lowest intensity) to 9 (highest intensity): odor intensity, chicken odor, fresh, rancid, and off-odor.

Cooked thigh and breast were judged twice during the storage period, i.e., on the 2nd and the 7th d of storage. On the day of analysis, each chicken was divided into breast and thigh, and vacuum packaged separately. Then the pieces were cooked in a water bath at 85 C for 50 min. Each panelist received half a breast and half a thigh for separate evaluation, the samples being kept warm in a steel cup with a lid. Half a breast from evaporative air chilling and storage at 4 C and half a breast from air chilling and storage at –1 C were used for calibration of the panel. Cooked breast and thigh were evaluated with the same attributes as raw chicken: odor and taste intensity, chicken odor and taste, fresh, rancid, and off-odor, and taste. A continuous nonstructured scale was used for evaluation of sensory attributes ranging from the lowest intensity of each attribute (value 1.0) to the highest intensity (value 9.0). Each judge evaluated the samples at individual speed on a computerized system for direct recording of data (CSA, Compusense, Version 4.2, Guelph, ON, Canada).

[6]Termaks type TS 4115, Termaks AS, Lien 79, 5037 Solheimsviken, Norway.
[7]La Moulinette type D 56, Moulinex S.A., 11 Rue Jules Ferry-F-93170, Bagnolet, France.
[8]Krups Speedy type 708, Robert Krups Stiftung and Co. KG., Postfach 190460, D-5650 Solingen 19, Germany.
[9]Mylar A 12-μm polyester film, Du Pont de Nemours Int. S.A., 50–52, route des Acacias, CH-1211 Geneva 24, Switzerland.
[10]Bruker Minispec 120, Bruker Analytische Messtechnik, Am Silberstreifen, D-7512 Rheimstetten 4, Germany.
[11]Internally developed at MATFORSK.
[12]Beckman Instruments Inc., Irvine, CA 92713.
[13]Zerolyt, Mettler-Toledo AG, Process, Im Hackacker 15, 8902 Urdorf, Switzerland.

TABLE 1. Effect of chilling method on weight loss and temperature declines of chicken carcass measured in the slaughterhouse[1]

Variables	Air chilling	Evaporative air chilling	Significance level (*P*)
Initial weight, g	911.7 ± 114.3 (674.6 to 1,194.5)[2]	931.7 ± 118.0 (687.4 to 1,225.4)	NS
Weight loss, %	2.0 ± 0.2 (1.4 to 2.8)	0.2 ± 0.3 (–0.9 to 1.7)	***
Temperature before chilling, C	33.2 ± 3.1 (26.1 to 38.5)	34.9 ± 1.9 (28.7 to 38.6)	***
Temperature after 50 min chilling, C	5.4 ± 1.2 (3.0 to 10.4)	5.0 ± 1.0 (3.5 to 9.2)	***
Total heat loss after 50 min chilling, kcal/kg	20.5 ± 3.5 (13.6 to 28.8)	22.3 ± 3.4 (14.0 to 30.7)	***

[1]Standard deviation is stated after mean value from two experiments (n = 200).

[2]Minimum and maximum values are stated in parenthesis.

***$P < 0.001$.

Microbiological Analysis. On each sampling day (1, 3, 5, 7, 9, 11, 13, 15, 17, and 19) three carcasses from each treatment were analyzed by removing 23.8 cm^2 of skin from the breast right up to the neck using a template and a sterile scalpel. Each skin sample was placed in a bag with 15 mL physiological saline (PS) added and treated in a Stomacher[14] for 60 s. A 10-fold dilution series of the mixture was made in PS and two parallel samples of 20 μL each were spread on: Plate Count Agar (PCA)[15] for determination of the total viable numbers; Cetrimide-fusidin-cefaloridine agar (CFC)[16] for determination of *Pseudomonas* spp; streptomycin-thallous acetate-actidione agar (STAA)[17] for determination of *Brochothrix thermosphacta*. One milliliter of the dilution was also added to molten Violet Red Bile agar (VRB)[18] for determination of Enterobacteriaceae in pour plates. The PCA, CFC, and STAA were incubated at 20 C for 96 h, VRB at 37 C for 48 h. Mean values were calculated from the two determinations of the three samples taken from each combination of chilling and storage. Bacterial numbers were reported as $\log_{10}$ colony-forming units per square centimeter.

Statistical Analysis

Results from two experiments carried out 2 mo apart at the same slaughterhouse were collected. Data were subjected to analysis of variance using the General Linear Models procedure of SAS® (SAS Institute, 1990) software to test for significant differences ($P < 0.05$) between air chilling and evaporative air chilling. The factors considered in variance analysis of sensory data from raw chicken were chilling method, storage temperature, and storage time. Data from sensory analysis conducted on cooked chickens were tested with regard to the effect of four factors, i.e., chilling method, storage temperature, storage time, and type of meat (breast and thigh) on chicken odor and flavor properties.

RESULTS AND DISCUSSION

Temperature and Humidity

Average temperature in the chilling tunnel was approximately the same for the two examined systems, i.e., 0.3 C for air chilling and 0.4 C for evaporative air chilling. Air temperature in the cooling tunnel varied between –0.6 C and 2.1 C for air chilling and between –0.5 C and 2.2 C for evaporative air chilling.

Relative air humidity in the tunnel was 2.1% higher during evaporative air chilling than during air chilling. The humidity varied between 94.7 and 100.0% with an average of 97.6%. During air chilling, the relative humidity was lowest (89.6%) in the beginning of the process; as the wet chickens filled the tunnel, humidity increased considerably and reached up to 99.6%.

Weight Loss

Average, range, and standard deviation values for weight loss from two experiments are shown in Table 1. Air chilling lasting 50 min led to significant losses in the carcass weights. The weight loss varied from 1.4 to 2.8% with an average of 2.0%. During 50 min of evaporative air chilling, the reduction in weight was much lower, i.e., 0.2% on average. In some cases a gain in weight of up to 0.9% was observed due to water spraying. Despite the wide variations in weight loss, analysis of variance confirmed the influence ($P < 0.0001$) of chilling system on weight loss during cooling. The current findings are in agreement with data previously published by Veerkamp (1981, 1986, 1991) and confirmed that is possible to control weight loss during evaporative air chilling. Veerkamp

[14]Colworth, Stomacher 400, A. J. Seward, Vac House, Blackfriars Road, London SE1 9U6, U.K.

[15]Difco 0479-01-1, Difco, Difco Laboratories, Detroit, MI 48232-7058.

[16]Oxoid CM 559 + supplement SR 103, Oxoid, Oxoid Ltd., Wade Road Basingstoke, Hampshire RG24 0PW, U.K.

[17]Oxoid CM 881 + supplement SR 1511, Oxoid, Oxoid Ltd., Wade Road Basingstoke, Hampshire RG24 0PW, U.K.

[18]Difco 0012-01-5, Difco, Difco Laboratories, Detroit, MI 48232-7058.

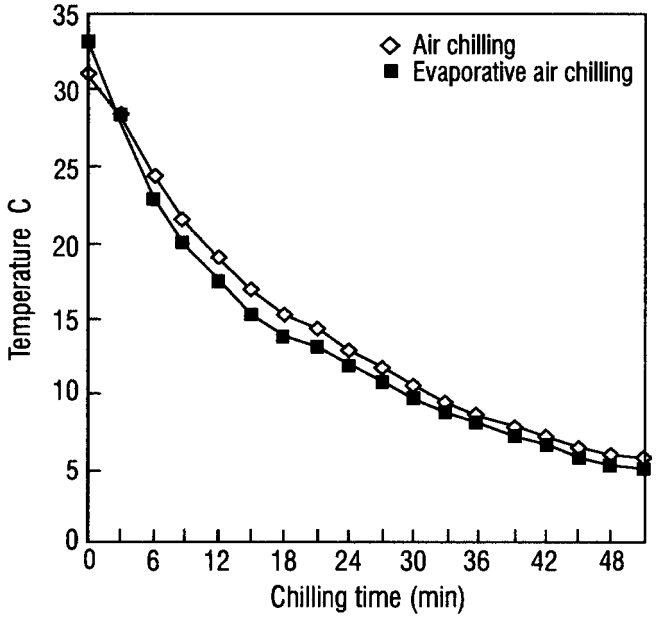

FIGURE 1. Temperature declines in breast muscle of chicken carcasses during evaporative air chilling and air chilling (n = 24).

(1981) reported no weight loss when carcasses were sprayed with approx. 0.5 L water, divided between seven spraying operations. In contrast, an average of 1.3% weight gain of chicken carcass was noted during 45 min air evaporative chilling with four spraying locations (Ziolecki *et al.*, 1997).

Efficiency of the Chilling Methods

The internal temperature of the chickens, measured in breast muscle, at the beginning of the chilling process varied from 26.1 to 38.6 C for all the examined carcasses (Table 1). It was observed that average temperature before air chilling was significantly lower (1.7 C) than for those before evaporative air chilling ($P < 0.0001$). A possible explanation could be that the air chilled chickens were slaughtered first at the beginning of the work day.

Final temperatures in chicken breast were on average just above 5 C for the two experiments carried out 2 mo apart (Table 1). Chickens cooled by cold air had small but significantly higher temperatures (0.4 C; $P < 0.001$); however, the differences would be of no practical concern.

Figure 1 shows the course of average temperature in chicken breast muscle from the two chilling methods. After the first 6 min, the carcasses sprayed with water had slightly lower temperatures than the air chilled carcasses but the differences were of no practical importance. Efficiency of the evaporative air chilling in our experiments was larger that the results obtained by Ziolecki *et al.* (1997), who observed a temperature decrease in chicken carcasses from 34.8 to 8.1 C during 45 min of evaporative air chilling. A slightly higher final temperature, i.e., 12 C, was noticed after 27.5 min of evaporative air chilling (Mulder and Veerkamp, 1990).

TABLE 2. Effect of chilling method on chicken skin color measured on the day of production[1]

Color parameters	Air chilling	Evaporative chilling	Significance level (*P*)
Breast skin			
Lightness (L*)	66.2 ± 2.8	70.8 ± 2.3	***
Redness (a*)	1.5 ± 1.0	1.0 ± 1.0	NS
Yellowness (b*)	6.6 ± 2.4	2.1 ± 2.5	***
Back skin			
Lightness (L*)	76.1 ± 1.7	77.2 ± 1.7	*
Redness (a*)	5.8 ± 1.3	5.2 ± 1.3	NS
Yellowness (b*)	12.6 ± 1.8	10.2 ± 1.7	**

[1]Standard deviation is stated after mean value from two experiments (n = 16).

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

Temperature differences during chilling and the weight of carcasses were used to calculate total heat loss. The differences in temperature of breast muscles from the beginning to the end of the chilling process were larger for chicken carcasses cooled by evaporative air chilling (29.8 C) than for those cooled in air only (27.8 C). Hence, the total heat loss during 50 min evaporative air chilling was 1.8 kcal/kg greater ($P < 0.001$) than during the same time of air chilling (Table 1).

Color

The chilling method had great influence on the skin color of chicken breast (Table 2). Significantly ($P < 0.001$) lower values of L* and higher values of b* indicate that chicken cooled in cold air had a darker and more intense yellow color than chicken cooled by the evaporative air chilling method. Water spraying during evaporative air chilling prevented the surface from dehydrating and ensured a lighter color. Although the color of the back skin was lighter and more intense than the color of the breast (higher a* and b* values), this would not necessarily have been the case had the measurements been taken away from the backbone region. Collected data from objective color measurements (L*, a*, b*) confirm visual observa-

TABLE 3. Amount of surface moisture on chicken skin measured 1 d after slaughter[1]

Measure point	Air chilling	Evaporative air chilling	Significance level (*P*)
	——— (mg/cm^2) ———		
Back	2.0 ± 0.9	3.4 ± 0.7	*
Under wings	1.2 ± 0.5	2.2 ± 0.9	**
Breast	1.1 ± 0.6	1.6 ± 1.0	NS

[1]Standard deviation is stated after mean value from two experiments (n = 16).

*$P < 0.05$.

**$P < 0.01$.

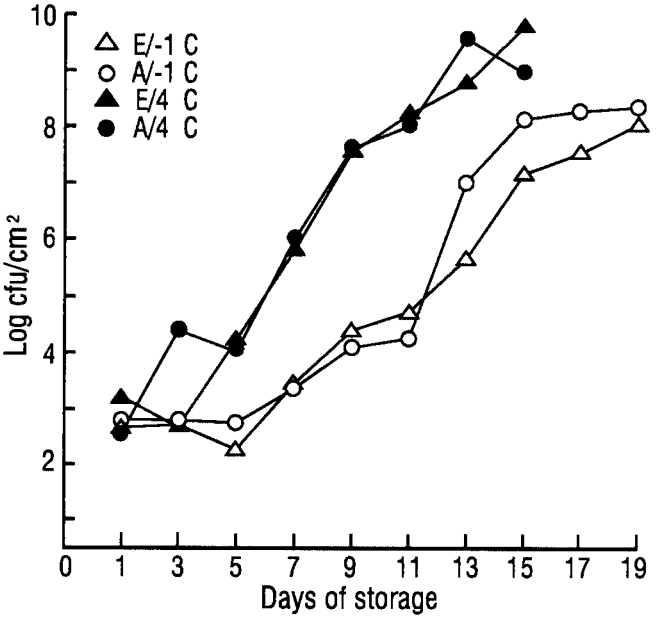

FIGURE 2. Effect of chilling method and storage temperature on growth of total aerobic flora on chicken skin (n = 6). Chickens were chilled by evaporative air (E) or air (A) method and stored at –1 (open symbols) or 4 C (filled symbols).

tions noticed earlier by industry personnel and scientists (Veerkamp, 1981, 1985; Ziolecki, 1990) that air chilling causes discoloration of the skin.

Water Uptake

Surface moisture measured 1 d after slaughter varied depending on where the measurement was taken (Table 3). Most of moisture was detected on the back skin, whereas breast skin had the least surface moisture. These differences are related to the storage of the chickens, as they were lying on their backs in boxes with plastic film on the bottom. The chickens were in close contact with the condensed water, which, after some time, accumulated on the bottom of the boxes. The chickens sprayed with water during chilling had significantly greater amounts of moisture on the back ($P < 0.05$) and under the wing ($P < 0.01$) than the chickens chilled in cold air. The greatest difference between air chilled and evaporative air chilled chickens was found on the back skin (1.4 mg/cm^2). Chicken cooled by evaporative air chilling had on average 0.5 mg/cm^2 more water on breast skin than chicken cooled by air, but the difference was not significant ($P < 0.2163$).

The moisture content of chicken skin is typically inversely proportioned to the fat content. In the present experiments, moisture content in the skin of the examined chicken varied between 29.1 and 50.5%, whereas the fat content was between 39.1 and 62.7%. It was therefore necessary to determine the content of moisture in fat-free skin. The chilling method did not have an influence on moisture in fat-free skin. Breast and leg contained on average for both chilling methods 82.3 and 79.8% moisture, respectively, in fat-free skin.

Mean values for moisture content in breast and leg meat were on average 74.9% and 70.9%, respectively. Analysis of variance revealed that the chilling method had no influence on the moisture content in the skin or in the meat. This result means that gentle water spraying during evaporative air chilling should not involve a risk of increasing the extraneous water in the carcasses under these conditions.

pH and Cooking Loss

There were no significant differences in final pH between the chilling methods measured after 24 h, either for breast meat ($P < 0.8430$) or for leg meat ($P < 0.1788$). Final pH in breast meat and leg meat were 5.8 and 6.5, respectively. Breast meat lost about 15.5% of its original weight during cooking, whereas leg meat had, on average, 13.0% cooking loss. Higher pH and greater fat content were the reasons that leg meat had better water retention. No significant differences in cooking loss between the examined chilling methods were detected for either breast or leg meat, which indicated that the meat did not take up any water during evaporative air chilling.

Microbiological Analysis

There were no substantial differences in the growth rate or in the numbers of bacteria between evaporative and air chilled chicken (Figure 2). As expected, bacterial growth rate was higher, and the shelf life shorter, for chickens stored at 4 C than those stored at –1 C. In both storage

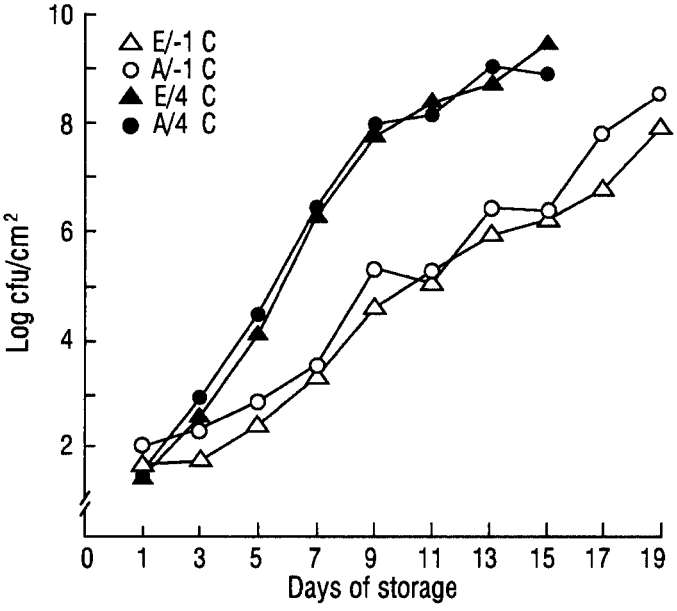

FIGURE 3. Effect of chilling method and storage temperature on growth of *Pseudomonas* spp. on chicken skin (n = 6). Chickens were chilled by evaporative air (E) or air (A) method and stored at –1 (open symbols) or 4 C (filled symbols).

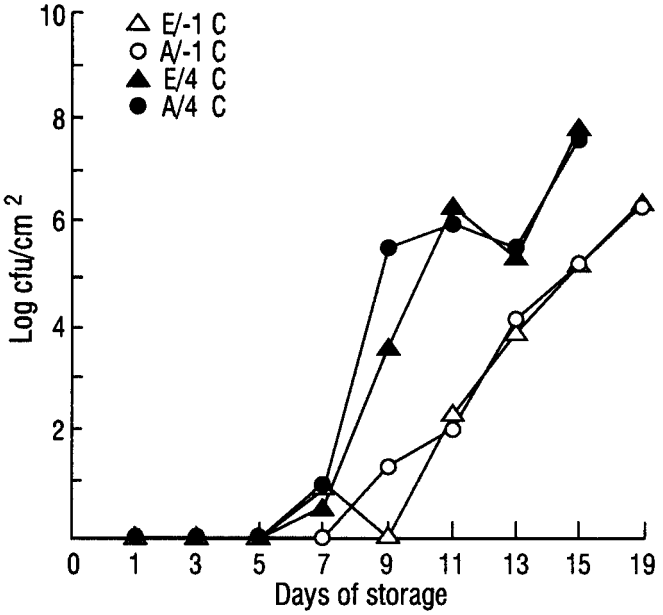

FIGURE 4. Effect of chilling method and storage temperature on growth of *Brochothrix thermosphacta* on chicken skin (n = 6). Chickens were chilled by evaporative air (E) or air (A) method and stored at –1 C (open symbols) or 4 C (filled symbols). Counts in samples from all treatments at Days 1, 3, and 5 were below the detection limit.

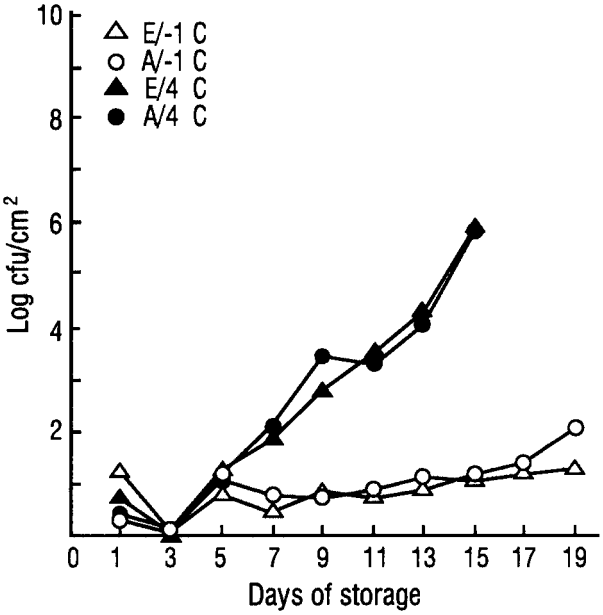

FIGURE 5. Effect of chilling method and storage temperature on growth of Enterobacteriaceae flora on chicken skin (n = 6). Chickens were chilled by evaporative air (E) or air (A) method and stored at –1 C (open symbols) or 4 C (filled symbols). Counts in samples from all treatments at Day 3 were below the detection limit.

experiments, *Pseudomonas* spp. dominated the flora on the skin samples from evaporatively and air chilled chicken stored at 4 or –1 C (Figure 3). In all samples, there was growth of *Brochothrix thermosphacta* (Figure 4), but their maximum numbers were 100-fold less than those of *Pseudomonas* spp. There was also significant growth of Enterobacteriacea on chicken stored at 4 C both for air chilled and evaporatively chilled chicken (Figure 5). Development of such flora is typical for chicken subjected to cold air storage (Barnes and Thornley, 1966; Barnes, 1976; Marenzi, 1985). Unpleasant odor was detected when the total number of bacteria reached 10^7 to 10^8 bacteria per square centimeter in samples taken from both chilling methods. Therefore, it can be concluded that chilling method had no effect on the shelf life of chicken carcasses.

Sensory Analysis

The first sensory evaluation of odor of raw chicken stored at 4 and –1 C was performed 6 d after slaughtering. The chickens were thereafter evaluated after 8 and 13 d of storage. Mean values for odor attributes based on results

TABLE 4. Effect of chilling method and storage temperature on odor attributes assessed on surface and inside of raw chicken carcasses[1]

	Air chilling		Evaporative air chilling		Significance level (*P*)	
Sensory attributes	–1 C	4 C	–1 C	4 C	Methods	Temperature
Carcasses surface						
Odor intensity	4.5 ± 1.2[2]	6.3 ± 1.7	4.5 ± 1.1	6.2 ± 1.8	NS	***
Odor of chicken	6.4 ± 1.4	4.1 ± 2.2	6.4 ± 1.6	4.1 ± 2.3	NS	***
Fresh odor	6.2 ± 1.5	3.7 ± 2.2	6.2 ± 1.6	3.9 ± 2.4	NS	***
Rancid odor	1.6 ± 1.1	3.1 ± 2.6	1.6 ± 1.3	3.2 ± 2.8	NS	**
Off-odor	2.6 ± 1.5	5.2 ± 2.2	2.4 ± 1.4	4.6 ± 2.7	NS	***
Carcasses, inside						
Odor intensity	4.5 ± 1.1	6.8 ± 1.4	4.7 ± 1.0	6.3 ± 1.9	NS	***
Odor of chicken	6.4 ± 1.6	3.5 ± 2.1	6.4 ± 1.5	4.1 ± 2.5	NS	***
Fresh odor	6.1 ± 1.7	3.2 ± 1.8	6.3 ± 1.6	3.8 ± 2.4	NS	***
Rancid odor	1.6 ± 1.0	3.1 ± 2.8	1.6 ± 1.1	2.8 ± 2.8	NS	***
Off-odor	2.8 ± 1.6	5.6 ± 2.3	2.4 ± 1.4	4.7 ± 2.6	NS	***

[1]Continuous scale for sensory attributes ranges from value 1.0 (the lowest intensity) to value 9.0 (the highest intensity).

[2]Standard deviation is stated after mean value from two experiments (n = 72).

**$P < 0.01$.

***$P < 0.001$.

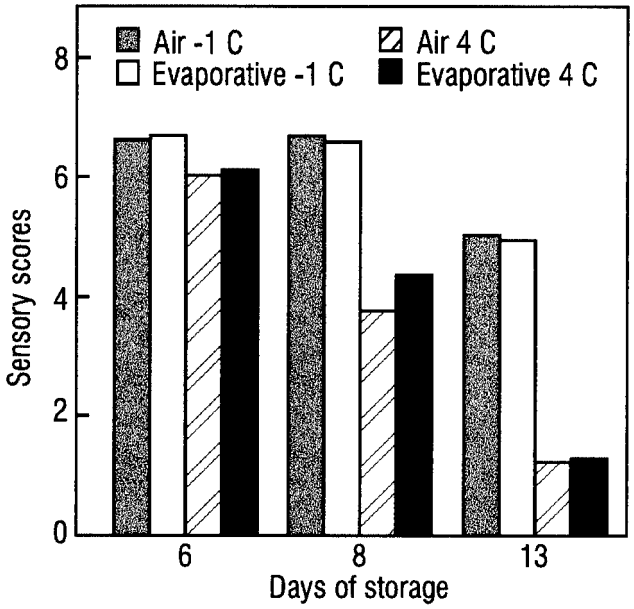

FIGURE 6. Effect of chilling method (air versus evaporative air) and storage temperature (–1 vs 4 C) on fresh odor assessed on surface of raw chicken carcasses (n = 24). Continuous scale for sensory attributes ranges from value 1.0 (the lowest intensity) to value 9.0 (the highest intensity).

from the three storage periods are shown in Table 4. There were no qualitative or quantitative differences in odor characteristics between the surface and inside of the chickens. The results of sensory analysis indicated that chilling method had no influence on odor parameters of raw chicken, whereas storage temperature was of great importance (Figure 6). In chicken stored at –1 C, the odor of the surface and the inside remained unchanged for 8 d, whereas chicken stored at 4 C had more noticeable off-odors after 8 d than after 6 d of storage. During the next 5 d, the odor was significantly exacerbated, especially in chicken stored at 4 C. Ziolecki *et al.* (1997) reported similar results from storage experiment on chicken carcasses chilled by the evaporative air method. They detected the first symptoms of odor deterioration in the carcasses after 6 d storage at 4 C, whereas carcasses stored at 0.0 ± 1 C maintained their freshness until 12 d.

In the heat-treated chickens both taste and odor were evaluated on legs and breasts. No differences were found between scores given for sensory attributes of cooked chicken assessed on the second and seventh day after slaughter. Results showed that none of the examined factors, i.e., chilling method, storage temperature, storage time and type of meat, had any influence on sensory qualities in the chicken stored for 1 wk.

Conclusions

Evaporative air chilling was somewhat more effective in cooling chicken carcasses but the difference was of no practical significance. Satisfactory final temperatures of the chickens were achieved by both methods. Chicken cooled to approximately 5 C in the chilling process was suited for packing and further storage in fresh state.

Results from the experiments indicate the great importance of chilling method for weight loss during cooling. Differences in cooling loss in the region of 1.8%, during 1 d of production, represents a large loss of product in a processing plant. Application of evaporative air chilling can therefore be an economic benefit for slaughterhouses. It is important to be aware that excessive spraying with water may cause weight gain due to added water absorption. The significantly larger amount of surface moisture on the back and under the wings had no influence on the chicken's shelf life or its sensory properties. Microbiological and sensory qualities depended on storage time and temperature and not on the method of cooling. Advantages of using evaporative air chilling were also observed with regard to skin color. Chicken cooled by this method had a lighter color than air chilled chicken. This confirms that spraying with water prevents discoloration and in that way improves the chickens' appearance.

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