Humidification of unwrapped chilled meat on retail display using an ultrasonic fogging system

Tim Brown [*a], Janet E. L. Corry [b] and Judith A. Evans [a]

[a] *Food Refrigeration & Process Engineering Research Centre (FRPERC),*

[b] *Division of Farm Animal Science, Department of Clinical Veterinary Science*

University of Bristol, Langford, Bristol, BS40 5DU, UK.

Abstract

The effects of an ultrasonic humidification system on unwrapped meat in a chilled retail display cabinet were assessed. Humidification raised the relative humidity of the cabinet air from a mean of 76.7% to just below saturation at 98.8%. This reduced the mean evaporative weight loss from whole samples of meat after 14 h from 1.68 % to 0.62 % of their initial weight. The rate of deterioration in the appearance of the meat due to dehydration was reduced to the extent that while the un-humidified trial was terminated after 14 h because all samples were judged to be unacceptable, the humidified trial was continued for 24 h without any major changes in appearance.

Levels of presumptive pseudomonas bacteria were relatively high in water samples taken from the humidification system and defrost water during the humidified trial, but *Legionella* spp. were not isolated. Significant increases in the numbers of bacteria on the meat during either trial were only found in one case, that of humidified minced beef. However, some of

[*] *Corresponding author, Fax: +44 (0)117 928 9314, E-mail: Tim.Brown@bris.ac.uk*

the samples had high counts even before display, and this may have masked any effect due to humidification. Differences in levels of air-borne contamination were small and inconsistent.

Air temperatures were raised by humidification by between 1 and 2°C and this was reflected in similarly raised product temperatures. Temperatures of air leaving the evaporator indicated that this was due to icing of the evaporator in the periods leading up to defrosts.

Keywords: Retail Display; Meat; Fogging; Humidification; Weight Loss; Microbiology

1. Introduction

Evaporation of water from unwrapped food during retail display represents a direct loss of the amount of product which can be sold, and in addition limits display life through dehydration and perceived deterioration of quality (Maidment, Missenden, James, Tozer and Bailey, 1999). As lean meat has a high water content and is often displayed with exposed cut surfaces, it is particularly prone to such weight loss. James and Swain (1986) presented a relationship between weight losses per unit area ($g.cm^{-2}$) and changes in appearance of sliced beef to the point where it became un-saleable. The rate at which such losses occurred was found to depend mainly on the relative humidity (RH) of the air surrounding the samples. Maintaining RH at 40% instead of 95% was found to increase weight losses over a 6 h period by a factor of between 14 and 18. Avoidance of low RH is therefore imperative, and use of humidification equipment is one way of achieving this.

Humidification systems for use in food display cabinets aim to increase the amount of water in the air and thereby reduce the difference between water vapour pressures at the surface of the food and in the air. This difference is the driving force behind evaporation. Typically these systems employ ultrasonically excited transducers immersed in baths of water to add

very small water droplets to the air. Using a slightly different approach, misting systems deposit water directly onto the food and replace water lost by evaporation.

Maintaining moist surfaces on food does however have a potential drawback in that it can lead to increased bacterial growth. Many years ago, Scott (1936) and Scott & Vickery (1939) established that the important meat spoilage bacteria are only able to grow on meat at temperatures below 4°C if the surface water activity is greater than 0.96. However, growth is very slow at these temperatures. Previous work on humidification of fruits and vegetables on display found no adverse effects on microbial quality (Brown, Corry and James, 2004), but this may have been due to ozonation of the water supply and cabinet air in the trials. Misting of broccoli in refrigerated storage rooms resulted in reduced bacterial growth (Mohdsom, Spomer, Martin and Schmidt, 1995), an effect attributed to the washing effect of misting or to residual chlorine in the chlorinated tap water used for misting. During un-refrigerated misted display of broccoli and other vegetables for 72 h, bacterial numbers increased by less than one log cycle (Dieckmann and Zache, 1993). When humidification was applied during the chilling of beef carcasses, no significant increases in the surface populations of selected bacterial groups were found (Kinsella, Sheridan, Rowe, Butler, Delagado, Quispe-Ramirez, Blair and McDowell, 2006). However, an isolated outbreak of Legionnaires' disease (Anon, 1990 and Evenson, 1998) was linked to the use of an ultrasonic misting machine in a grocery store, although full details such as the display cabinet temperature were not reported.

Another concern is that the introduction of considerable amounts of water by the humidifier can affect cabinet performance. The extra moisture in the cabinet air tends to condense out onto evaporator surfaces, and this can have an impact on the refrigeration effect and run time of the refrigeration compressor (Brown et al, 2004). If the condensate freezes on the evaporator rather than draining away, it can also lead to increased icing of the evaporator and

consequent deterioration of temperature control. Modification of defrost programmes can correct this, but the use of longer or more frequent defrosts will add more heat to the cabinet.

This investigation was undertaken following enquiries from retail organisations and equipment manufacturers who wished to exploit the advantages of reduced weight loss and longer display life offered by humidification systems, but who were concerned that growth of food spoilage organisms and pathogens might be affected.

2. Materials and method

2.1 Installation of cabinet and humidifier

2.1.1 Installation of cabinet

A 2.44m wide Carter (Birmingham, UK) 55OHD glass-fronted serve-over cabinet was used. A cabinet previously used in a supermarket was used to simulate a worst-case scenario of retro-fitting humidification to a potentially dirty and perhaps contaminated cabinet. No extraordinary cleaning procedures were used and the cabinet was installed in the test chamber within 36 h of its removal from the supermarket. Control settings were checked using an RMS controller supplied with the cabinet but left unchanged for the trials. The temperature of air leaving the evaporator (air off) was set to -9°C and that of air returning to the evaporator (air on) was set to 1°C. The cabinet had been fitted with an electric defrost system, which was set for four defrosts per day (at 0700, 1300, 1700 and 0100). In the un-humidified trial the maximum defrost time was 25 min. As recommended by the humidification equipment supplier, this was extended to 35 min in the humidified trial to counteract additional frosting of the evaporator. The cabinet airflow was checked prior to trials for uniformity across the display area, and was found to be less than $0.5 m.s^{-1}$ in all

positions used for meat samples. The cabinet fittings included fluorescent lights above the display area and these were used during the trial.

The cabinet was placed in a controlled environment test room operating at 25°C and 60% RH (Climate Class III for standard testing as defined in BS EN 441-4:1995) and connected to a remote compressor/condenser pack operating on R404A.

2.1.2 Installation of humidifier

A Lakeside Water Services (LWS, Peterborough, UK) ultrasonic humidification system with a Mistsafe reverse osmosis (RO) filtering and ultraviolet (UV) water treatment unit was installed to supply humidified air to the cabinet. Cold cabinet air was ducted from the back of the display area to the humidifier, and re-introduced through a header bar mounted at the back of the display area. Holes in the header bar extended across the full display width and allowed humid air to mix with air leaving the cabinet evaporator. This mixed, humidified air then passed directly over the meat on display. As recommended by the equipment supplier, the output from the humidifier was set during initial commissioning to maintain the humidity in the cabinet as high as possible without excessive condensation on the cabinet walls. This was intended to maximise any impact on weight loss and shelf life.

2.2 Experimental trials

Two trials were carried out, one with the humidifier switched on throughout the trial and an identical trial with the humidifier switched off. Trial duration was intended to be 24 h unless deterioration of appearance led to earlier termination.

2.3 Merchandising

The cabinet was loaded with the following samples of unwrapped raw meat: bacon (dry cured); beef joints; beef mince; beef steak; beef stewing steak (diced); chicken breasts (skinless); chicken portions; chicken (whole); lamb chops; lamb joints; pork chops; pork joints and pork sausages. Sample positions are shown in Figure 1. All samples were sourced by the equipment supplier and delivered several hours before testing, during which time they were held in a chillroom at 0°C.

2.4 Measurement of temperatures and relative humidities

Previously calibrated copper-constantan thermocouples connected to Measurement Systems (Newbury, UK) Datascan modules were used with PC-based Labtech (Wilmington, USA) data acquisition software to measure and record temperatures at 5-min intervals during each trial. For air temperatures, bare thermocouples were positioned at the right, middle and left of the cabinet in the air leaving the evaporator (air off) and at the back of the cabinet in the air returning to the evaporator (air on). At the front and rear of the cabinet at the right, middle and left (total six), wet and dry bulb temperatures were measured and recorded for accurate determination of relative humidity (RH). To ensure adequate airflow, each wet bulb sensor was positioned in the airflow from miniature 12V fans powered by an external power supply.

During the trials, a representative sample of each of six product types was chosen at the right, middle and left at the rear and front of the cabinet for temperature measurement, and thermocouples placed at their surfaces and geometric centres.

2.5 Weight loss

Weight loss from the products was assessed using two methods. The first method, described by James and Swain (1986), recorded the initial and subsequent weights of samples placed in

9 cm diameter plastic Petri dishes. In each Petri dish lid, a 7 cm diameter circular section was removed using a hole-cutter attached to an electric pillar drill. This produced a single hole in each lid with a known surface area of 38.48 cm^2. Samples of lamb, pork, beef and mince, chicken with and without skin, bacon and sausages were cut to fit the Petri dishes, which were placed as shown in Figure 1.

The second method involved measuring initial and subsequent weights of each type of meat. Two samples each of meat joints, chops and portions were weighed throughout each trial. For sausages, beef mince and beef stewing steak the weights of full trays were recorded. The positions of the samples were identical in each trial. In both trials, weights were recorded at the beginning of the trial and at 30-min intervals for the first 6 h, at 1-h intervals for the next 6 h and then 2-hourly for the final 12 h.

2.6 Appearance

At the same time intervals as those for weight measurements, the appearance of all products was subjectively assessed in-situ by three experienced laboratory personnel. The assessment concentrated on wet or dry surfaces, light or dark surfaces, colour and overall appearance. The assessors were particularly asked to note the time at which changes in these attributes could be classified as ‘slight’, ‘significant’ and finally ‘unacceptable’.

2.7 Microbiology

2.7.1 Products and air

Microbiological samples were taken before and after each trial from minced beef, chicken breast, lamb chops and pork chops. Samples were taken by excision of 10 cm^2 areas of skin or surface tissue (1-2 mm depth) in duplicate, except for the minced beef were 10 g samples

were removed from the top surface of the mince. The 10 cm^2 samples were homogenised for 1 min with 10 ml quantities of maximum recovery diluent (MRD, Oxoid, Basingstoke) using a Stomacher 80 (Seward, London). The 10 g samples were also homogenised for 1 min, but with 90 ml MRD using a Stomacher 400 (Seward, London). Further decimal dilutions were carried out in MRD and surface-plated.

All counts (in duplicate) were made aerobically on tryptone soy agar with 1% or 0.1% yeast extract (TSYE, Oxoid, Basingstoke) incubated at 25°C for 72 h. Results were expressed as total viable counts and presumptive *Pseudomonas* spp. (counting oxidase positive colonies only), as colony forming units per square centimetre or per gram ($cfu.cm^{-2}$ or $cfu.g^{-1}$).

Settle plates of TSYE agar to monitor microbes in the cabinet air were carefully placed between displayed products at the start of each trial and removed at intervals (at least two plates removed every 2 h). TVCs were reported as colony forming units per square metre per minute ($cfu.m^{-2}.min^{-1}$).

2.7.2 Humidifier and water

In the humidified test, water samples were taken before and after the trials from the humidification unit before the fogging bar (after UV treatment) and from the defrost water leaving the cabinet. Duplicate samples were diluted in MRD and surface plated onto TSYE agar to determine TVCs and numbers of presumptive *Pseudomonas* spp. (as colony forming units per millilitre, $cfu.ml^{-1}$). One litre samples of water were examined by Bristol Scientific Services (Bristol, UK) for *Legionella* spp. using the then current ISO method 11731 (Anon, 1998).

3. Results

3.1 Trial duration

The un-humidified trial was terminated after 14 h as the meat samples were considered dry and unacceptable. The humidified trial was carried out over a full 24-hour test period with no such judgements.

3.2 Temperature and relative humidity

The mean values and standard deviations (S.D.s) of air leaving and returning to the cabinet evaporator (termed 'air off' and 'air on'), product temperatures and average relative humidities of cabinet air during the trials are shown in Table 1. Humidification raised the temperatures of the air and the products, with differences of between 1 and 2°C. Temperatures of air leaving the evaporator during the humidified trial rose slightly prior to each defrost period, indicating that ice was beginning to form and block the evaporator. This did not happen during the un-humidified trail. Relative humidity was raised by over 22 percentage points to an average value very close to saturation.

3.3 Weight losses

3.3.1 Weight losses per unit area

Weight losses per unit area (average of two values in $g.cm^{-2}$) measured in the un-humidified and humidified trials are shown in Figure 2. The mean loss from humidified samples was 0.005 $g.cm^{-2}$, with individual changes ranging from -0.003 $g.cm^{-2}$ for dry-cured bacon (i.e. a weight gain) to 0.011 $g.cm^{-2}$ for pork flesh. Losses from the un-humidified samples were far higher, with a mean of 0.044 $g.cm^{-2}$ and a range from 0.035 $g.cm^{-2}$ for chicken with skin on to 0.058 $g.cm^{-2}$ for pork flesh.

197 *3.3.2 Weight loss from whole meat samples*

198 Percentage weight losses from whole meat samples (averages of two values) are shown in
199 Figure 3. In all cases samples in the humidified trial lost less weight than samples in the un-
200 humidified trial, although differences between trials were not always as apparent as in the
201 controlled area trials due to differences between sample sizes, shapes and areas of exposed
202 meat surface. Humidified samples lost between –0.32% (i.e. a weight gain, for bacon) and
203 1.59% (whole steak), with a mean loss of 0.62%. Losses from un-humidified samples ranged
204 from 0.92% (sausage) to 3.44% (whole steak), and the mean loss was 1.68%.

205 *3.4 Appearance*

206 Table 2 shows the times at which the assessors noted that samples began to show appearance
207 changes at three levels; slight, significant and totally unacceptable. Slight changes were noted
208 after 1.5 h for all un-humidified samples, but not until 6 h for some samples and in some cases
209 not at all during the 24 h trial for the humidified samples. While all un-humidified samples
210 were judged to be unacceptable after 14 h, no humidified samples were judged unacceptable
211 even after 24 h.

212 *3.5 Microbiology*

213 Results are shown in Table 3.

214 *3.5.1 Products and air*

215 Differences between total viable counts (TVC) and presumptive pseudomonas counts (PP)
216 from meat samples before and after the un-humidified and humidified trials were not
217 consistent and in most instances differed by less than 1 $\log_{10}$ cfu.cm^{-2}. As a general trend, in
218 the humidified trial there was an increase in TVCs (average 0.7 $\log_{10}$ cfu.cm^{-2} or cfu.g^{-1})

whereas in the un-humidified trial there was a slight decrease (average -0.1 $\log_{10}$ cfu.cm^{-2} or cfu.g^{-1}). However, TVCs from samples of minced beef showed a significant increase after the humidified trial (P=0.02). It should be noted that counts on minced beef in both trials and on pork chops in the humidified trial were already high before the display period (>6 $\log_{10}$ cfu.cm^{-2} or cfu.g^{-1}). With such high initial counts, any effect due to humidification may have been masked.

The number of colonies on the settle plates did not change dramatically with time. The results were quite variable, with the number of colonies ranging from 38 to 206 cfu.m^{-2}.min^{-1} (with a mean of 37.3 cfu.m^{-2}.min^{-1}) in the un-humidified trial and between 16 and 51 cfu.m^{-2}.min^{-1} (with a mean of 29.4 cfu.m^{-2}.min^{-1}) in the humidified trial.

3.5.2 Humidifier and water

TVCs and presumptive pseudomonas counts from the water samples were similar, indicating that most bacteria found in the water were presumptive *Pseudomonas* spp.. Both counts were significantly (P<0.01) higher after the humidified trial in water samples taken from just after the humidifier's UV water treatment unit. Conversely, counts from the defrost water decreased significantly (P<0.01) after the trial, although they were still high. Samples taken at the start of the trial showed that TVCs and presumptive pseudomonas counts were significantly higher (P<0.001) in the defrost water than in the water taken after the UV unit. Samples taken after the trial showed no significant difference between samples taken at the two locations. Levels of TVCs and presumptive pseudomonads were relatively high in the defrost water and at the end of the trial after the UV lamp (greater than 4.7 $\log_{10}$ cfu.ml^{-1} in all cases). Checks on the water quality supplied to the UV unit showed that microbial contamination was extremely low (less than 2.5 cfu.ml^{-1}). This indicated that the UV

242 decontamination system was not capable of killing all bacteria. *Legionella* spp. were not
243 isolated.

244 **4. Discussion**

245 The benefits of reduced weight loss and extended display life offered by humidification,
246 previously reported for fruits and vegetables (Brown et al, 2004), were confirmed by these
247 limited trials for meat. However, these benefits were not achieved without some attendant
248 risk of increased bacterial growth. This was probably due primarily to maintenance of moist
249 surfaces on the meat but raised temperatures in the humidified trial may also have had an
250 effect. In the work on fruits and vegetables, ozone was used as an added precaution against
251 increased bacterial growth. Similar measures may be advisable in meat display situations.

252 The relatively slight rise in temperatures in the humidified trial would have far less effect on
253 product weight loss than changes in relative humidity or air velocity (James and Swain, 1986).
254 They do however indicate either higher loads on the cabinet refrigeration system or reduced
255 ability to remove heat (or a combination of both). Further analysis of air temperatures
256 measured during the humidified trial indicated that ice may have been forming on the
257 evaporator for periods of up to an hour before each defrost, and it is likely that this and the
258 extra heat added by longer defrosts caused the higher product temperatures seen in this trial.

259 The relative humidity of the cabinet air was raised to just below saturation, as recommended
260 by the equipment supplier to maximise weight loss reductions and extensions to display life.
261 However the average RH in the un-humidified cabinet was already quite high at 76.7%. This
262 is higher than any of the RHs found in cabinets during visits to retail stores reported by James
263 and Swain (1986). It should be noted therefore that the benefits to be gained by using

264 humidification in more typical (drier) cabinets would be greater than those achieved in this
265 trial.

266 The weight loss results from the controlled area samples can be compared to determine the
267 reduction achieved by humidification. They can also be used to assess the extent to which
268 dehydration affected appearance, using the scale developed by James & Swain (1986). This
269 scale suggested that with evaporative losses of up to 0.01 $g.cm^{-2}$, meat will still be red,
270 attractive and wet, although it may have lost some brightness. This level of weight loss
271 corresponded to the first noticeable changes in product appearance observed in the current
272 trials. The maximum losses from the humidified samples exceeded this level only towards the
273 end of the 24 h trial. For the un-humidified samples, losses after 4 h were beginning to enter
274 the range 0.015 to 0.020 $g.cm^{-2}$. This level of weight loss was described by the scale as
275 resulting in some surface drying and darkening and corresponded to the samples described as
276 having changed significantly. Further weight losses of 0.025 to 0.035 $g.cm^{-2}$ were described
277 by the scale as resulting in dry and leathery meat with obvious darkening. Most of the un-
278 humidified samples had reached this level by between 6 and 9 h, by which time most were
279 beginning to be described as unacceptable. Further weight losses in the region of 0.05 to 0.10
280 $g.cm^{-2}$ were described as resulting in black appearance by the scale. After 14 h in the un-
281 humidified trial all samples had lost between 0.40 and 0.60 $g.cm^{-2}$ and all had been described
282 as unacceptable.

283 Weight losses as percentages of initial weight, i.e. from whole joints and pieces of meat,
284 showed more variation than the controlled area losses. This was due to slight differences
285 between shape, size and position of samples in the two trials. In all cabinets, samples in the
286 humidified trial lost less weight over the trial period than equivalent samples in the un-
287 humidified trial, with reductions ranging from 0.3% to 2.1% of initial weight. While such

savings are significant, they would perhaps be less important to a retail operation than extended display life, which would avoid disposal of dehydrated meat before sale.

Numbers of microbes were higher in all varieties of meat at the start of the humidified trial. The reason for such large differences was not obvious, as the meat was sourced from the same supplier and had been similarly handled. There were no significant increases in bacterial counts on the meat during either trial except in the case of TVCs from minced beef, which showed a small but significant increase after the humidified trial but remained almost stable during the un-humidified trial. However, counts from minced beef samples from both trials and from pork chops from the humidified trial were high even before the display periods. For minced beef such counts might result from extra handling etc. but for pork this suggests poor initial quality, relatively old samples or temperature abuse prior to delivery. In either case the samples were near the end of their microbiological shelf life even before display. With such high initial numbers it is possible that any increased growth due to humidification could have been masked.

The numbers of colonies found on the settle plates varied slightly but did not indicate any increase in microbes in the air during either trial.

Legionella spp. were not found in the humidified trial in the water leaving the humidifier's UV water treatment unit or in the defrost water leaving the cabinet. However, water samples taken from these locations contained relatively high levels of presumptive pseudomonas bacteria. The same levels were not found in the supply water, where numbers were extremely low, and therefore the source of contamination was not from the supply water. The relatively poor microbiological quality of the water in the humidification system gives cause for concern because, although the bacteria were mostly pseudomonads in this trial, the conditions could also support psychrotrophic pathogens such as *Listeria monocytogenes*,

312 which could contaminate product in the cabinet. The humidification equipment in these trials
313 utilised reverse osmosis filtering and ultraviolet water treatment, but it may be that further
314 measures such as ozonation could offer more effective protection against contamination
315 (Brown et al, 2004).

316 **5. Conclusions**

317 This study confirms that humidification can improve the economics of retailing unwrapped
318 meat in two ways. The most obvious is by slowing the rate of evaporation from the product
319 and retaining its weight for sale. The second, and most important in this work, is by
320 minimising dehydration and the deterioration in appearance that it produces. This offers
321 greatly extended display life.

322 However, the study also found that the risk of increased bacterial growth due to maintenance
323 of moist product surfaces can not be ignored, particularly as air and product temperatures
324 were found to be raised by humidification. Although the majority of bacterial counts were
325 not raised by humidification, those from samples of minced beef were. During the humidified
326 trial, numbers of bacteria in water samples taken after the humidifier's UV treatment unit and
327 from the defrost water were also relatively high, but *Legionella* spp. were not isolated. This
328 would suggest that further preventative measures should be considered to better protect
329 against increased growth of food spoilage and pathogenic bacteria.

330 Air and product temperatures in the humidified trial were slightly higher than in the
331 un-humidified trial and this was probably due to some icing of the evaporator and increased
332 defrost times.

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Figure 1

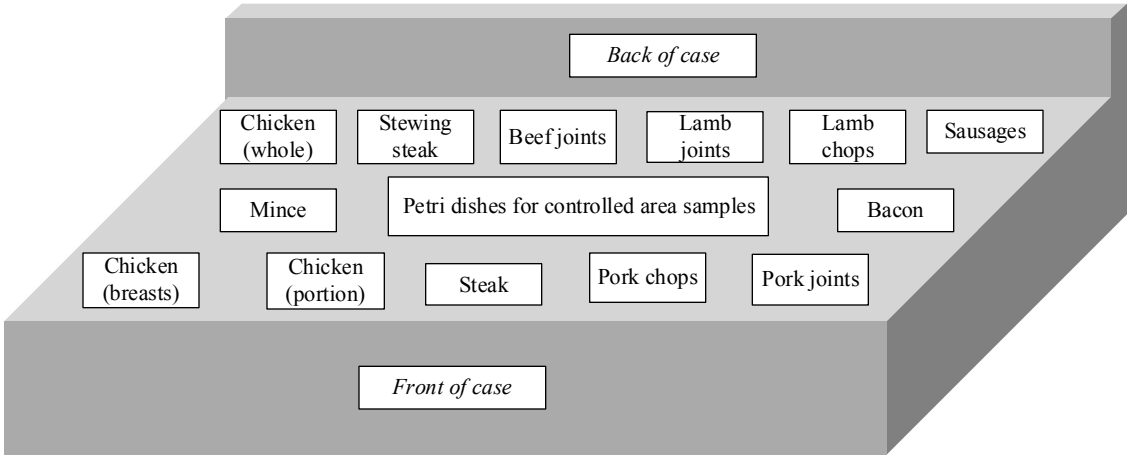

Figure 1. Product merchandising positions in the cabinet.

Figure 2

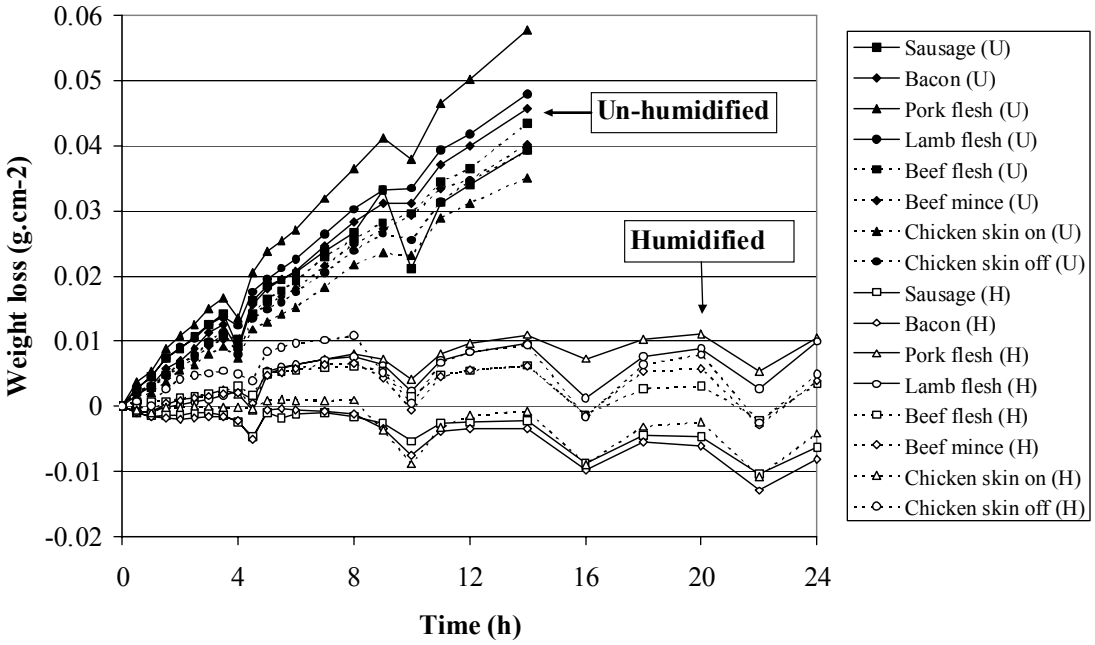

Figure 2. Weight losses per unit area.

Figure 3

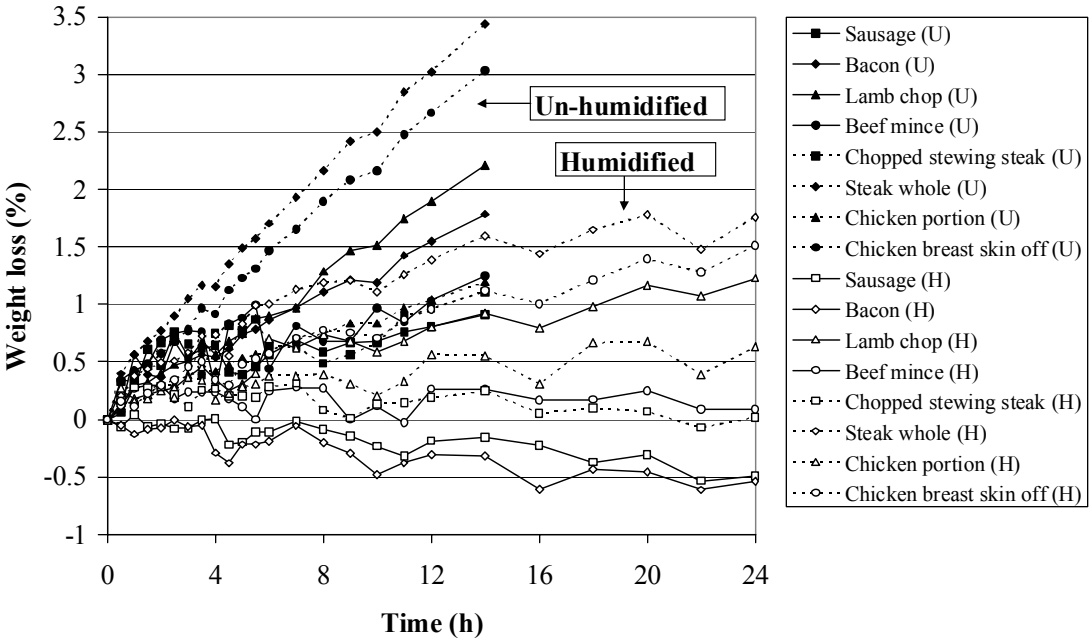

Figure 3. Weight losses as percentages of initial weight.

Table 1

Table 1. Means and standard deviations (*S.D.*) of air and product temperatures and average* relative humidity of cabinet air.

Measurement	Un-humidified		Humidified	
	Mean / average	*S.D.*	Mean / average	*S.D.*
Air-off temperature (°C)	-7.7	*1.4*	-6.0	*0.6*
Air-on temperature (°C)	-0.5	*0.9*	1.9	*1.3*
Product temperature (°C)	0.7	*0.9*	2.4	*0.8*
Relative humidity (%)	76.7		98.8	

**Relative humidities expressed as averages rather than means as individual values are capped at 100%.*

Table 2

Table 2. Times at which changes in the appearance of samples was noted.

Times (h) to change	Un-humidified			Humidified		
	Slight	Significant	Unacceptable	Slight	Significant	Unacceptable
Bacon	1.5	2	12	22	>24	>24
Beef joints	1.5	2	12	>24	>24	>24
Beef mice	1.5	2.5	12	18	>24	>24
Beef steak	1.5	3	4.5	22	>24	>24
Beef stewing steak	1.5	2.5	3	22	>24	>24
Chicken breasts	1.5	7	12	6	>24	>24
Chicken portions	1.5	2.5	14	6	22	>24
Chicken whole	1.5	11	12	6	22	>24
Lamb chops	1.5	14	14	6	22	>24
Lamb joints	1.5	7	12	6	22	>24
Pork chops	1.5	11	14	5	18	>24
Pork joints	1.5	2.5	12	5	18	>24
Pork sausages	1.5	11	12	>24	>24	>24

>24 denotes no change noted at the end of the trial.

Table 3

Table 3. Microbiological results from meat, water and air sampling.

	Un-humidified			Humidified		
	Before display	After display	*Difference (Aft.-Bef.)*	Before display	After display	*Difference (Aft -Bef.)*
Meat sampling						
TVCs (log_{10} cfu.cm^{-2})						
Chicken	4.3	4.5	*0.1*	4.8	5.0	*0.2*
Lamb	3.9	4.7	*0.8*	5.0	5.8	*0.8*
Pork	4.7	5.1	*0.4*	6.7	7.7	*1.0*
Beef (log_{10} cfu.g^{-1})	6.9	6.8	*-0.1*	7.0	7.6	*0.7*
PPs (log_{10} cfu.cm^{-2})						
Chicken	3.1	3.5	*0.4*	4.4	4.8	*0.4*
Lamb	3.1	4.5	*1.3*	4.7	5.8	*1.1*
Pork	4.2	4.8	*0.6*	6.4	7.5	*1.2*
Beef (log_{10} cfu.g^{-1})	6.7	6.6	*-0.1*	6.7	7.2	*0.5*
Water sampling *(humidified trial only)*						
TVCs (log_{10} cfu.ml^{-1})						
After UV unit				3.5	6.0	*2.5*
Defrost water				6.6	5.5	*-1.1*
PPs (log_{10} cfu.ml^{-1})						
After UV unit				2.9	6.0	*3.1*
Defrost water				6.5	5.2	*-1.3*
Legionella spp.						
After UV unit				Not found	Not found	
Defrost water				Not found	Not found	
Air sampling *(2h intervals)*	Mean	*S.D.*		Mean	*S.D.*	
TVCs (cfu.m^{-2}.min^{-1})						
Settle Plates	37.3	*23.9*		29.4	*11.5*	

Meat and water sampling in duplicate, air reported as mean of multiple samples.

TVC denotes Total Viable Count, PP denotes Presumptive Pseudomonas spp..