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Weight loss during freezing and the storage of frozen meat

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Abstract

Beef and pork, in sides or quarters, were chilled and then frozen and stored for six months, in stores with different cooling systems, different temperatures and in some cases a covering was used. Some meat was frozen without a previous chilling. The weight loss was determined and the results were statistically analysed by a multiple step-by-step regression. The meat was assessed by sensory analysis. The storage of meat in air-cooled stores resulted in greater weight loss than those resulting from pipe-cooled stores. If the meat is packed, then the former type of store is preferred. Temperature of storage has a highly significant effect upon the weight loss and packing is the most significant variable, being more important in the case of beef. Qualitative changes occurring during frozen storage are not organoleptically detected. © 1999 Published by Elsevier Science Ltd. All rights reserved.

1. Introduction

In many countries, low temperature storage of meat is gradually increasing. Freezing and storage of frozen meat has two major problems:

- the economic aspect, which is mainly related to the resulting weight loss that must be minimized,
- the quality aspect, where organoleptic properties are considered.

As meat is a variable product, we should take into account some differences to what is reported in the specialized literature. Therefore, the goals of this study are to assess weight and quality losses in meat during freezing and long-term storage under different conditions.

2. Materials and methods

Meat sides of recently slaughtered animals were used and chilled by traditional methods Then beef quarters and pork sides were frozen in tunnels and stored for six months at different temperatures, air speed and in different chilling systems.

Some beef sides were deboned after chilling and were placed in cardboard boxes, using polyethylene bags in some of them; then they were frozen and stored.

Other beef quarters and some pork sides were frozen when they were still hot, i.e., without previous chilling. Some were wrapped in polyethylene bags before storing them.

The temperatures were measured by means of Grant, miniature, battery-operated, electronic chart recorders (±1°C).

Air speeds were measured by means of a Wallac battery-operated, direct reading, hot wire anemometer (±0.1 m/s).

Materials

- Beef sides with an average weight of 100 Kg and pork sides with an average weight between 30 and 35 Kg.
- 60 μm thick polyethylene (ρ: 0.910–0.925 g/cm ^{3}).
- 20 Kg capacity waxed cardboard boxes.

The experimental conditions used were:

1. Pilot plant; −20°C and 0.7 m/s during freezing; −13° C and 0.4 m/s during on-shelf storage.
2. Industrial conditions; −24°C and 0.79 m/s during freezing; −10° C and 0.4 m/s storage.
3. Industrial conditions; −20°C and 0.8 m/s during freezing; storage in two pipe-cooled stores, one −13°C and the other −18°C; in both cases, the pieces were hung on hooks.
4. Industrial conditions; −25°C to −30°C and 3 m/s during freezing; −18°C and 0.5 m/s pallet storage.

Average air temperatures are reported.

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The meat was weighed before and after freezing, and monthly during storage. Measurements of weight were made by a 73 kg capacity balance with 20 g divisions. The results of weight losses were statistically analysed by a multiple step-by-step regression.

The main effects pertaining and their second order interactions were included in each case as independent variables. The qualitative variables (type of quarter, with or without polyethylene cover, freezing of pre chilled meat or non-chilled meat freezing) were inserted as dummy variables and their values and their levels, equally spaced in all cases, were codified conveniently in order to assure the orthogonal design:

Forward quarter 0	Chilled meat freezing 0
Hind quarter 1	Non-chilled meat freezing 1
Without polyethylene 0	Stored to −13°C 0
With polyethylene 1	Stored to −18°C 1

Meats were assessed sensorily. Sensory analysis was performed by Difference Tests. Longissimus dorsi muscle samples were taking during storage. Samples were defrosted in air and cooked in a hot air oven at 160°C until the thermel centre reached 75°C. The results were analysed through statistical tables presented by Amerine, Pangborn and Roessler (1965).

3. Results and discussion

Weight losses obtained during freezing in tunnels with temperatures between −20°C and −30°C and air velocities between 0.8 and 3 m/s are presented in Table 1.

The results reported were obtained performing a weighing of average values because there were no significative differences in the weight losses measured for each experiment.

Forward quarters presented the greatest losses as the surface/volume ratio is greater, as also reported by Bailey (1971). Pork sides have lesser losses than beef due to their natural fat covering and skin; Cutting and Malton (1973) also reached similar conclusions.

The least losses were obtained by freezing boneless beef in boxes, and are minimal when the meat is wrapped in polyethylene bags. This was also proven by Washburn (1985). It is necessary, however, to consider the effects of packaging on prolonging the freezing time (Cutting, 1974).

Table 1
% Weight losses during freezing

Sample	% Weight losses[a]
Forward quarter	1.20 (0.55)
Hind quarter	0.90 (0.27)
Cardboard boxes	0.10 (0.003)
Cardboard boxes and polyethylene	0.05 (0.007)
Pork sides	0.70 (0.24)

[a] S.E.

Table 2
% Weight losses during storage (−13°C, 0.4 m/s) [Experiment 1]

Sample	6 months	% Weight losses/month
Forward quarters	5.35	0.89
Hind quarters	5.93	0.98
Forward quarters (polyethylene)	1.40	0.23
Hind quarters (polyethylene)	1.58	0.26
Forward quarters (non-chilled meat freezing)	3.22	0.54
Hind quarters (non-chilled meat freezing)	3.76	0.63
Cartoned boneless beef	4.09	0.68
Cartoned boneless beef (polyethylene)	1.06	0.18
Pork sides	7.36	1.23
Pork Sides (polyethylene)	1.30	0.22

The hot pieces that were frozen had similar losses to the rest of the samples.

In general, the results show greater losses than those reported by other authors such as Lorentzen and Rosvik (1959) and Manev (1983). This is influenced by the freezing conditions that in most of the cases are more severe and besides the quality of carcasses and their fat layers are greater (Cutting, 1974, 1976).

It is well known that evaporation of moisture from the outer layers of food in frozen storage results in significant weight losses (Rutov, 1955).

The percentage weight losses for a six-month period and their monthly averages obtained in Experiment 1 are presented in Table 2.

The effect of packing on weight losses is marked, decreasing it by more than 50%. Bailey (1976) recommended the use of polyethylene less than 0.05 mm thick, and in this case we used a 0.06 mm thick one.

Plank and Kallert (1916) showed weight losses, for six-month storage, in beef quarters and pork sides with a weight similar to the samples used in this work when the temperature was −10°C. In both cases, the reported losses are greater despite being at a storage temperature

Table 3
% Weight losses during storage (−10°C, 0.4 m/s) [Experiment 2]

Sample	6 months	% Weight losses/month
Cardboard boxes	5.4	0.90
Cardboard boxes and polyethylene	2.1	0.35

Table 4
% Weight losses during storage (coils) [Experiment 3]

Sample	Temperature (°C)	6 months	% Weight losses/month
Forward quarters (polyethylene)	−13	1.32	0.22
Hind quarters (polyethylene)	−13	0.50	0.08
Forward quarters	−13	9.12	1.52
Hind quarters	−13	8.59	1.43
Forward quarters (polyethylene)	−18	1.51	0.25
Hind quarters (polyethylene)	−18	0.69	0.11
Forward quarters (non-chilled meat freezing)	−18	4.60	0.77
Hind quarters (non-chilled meat freezing)	−18	3.16	0.53
Forward quarters	−18	3.74	0.62
Hind quarters	−18	2.26	0.38
Pork sides	−13	1.82	0.30
Pork sides	−13	6.20	1.03
Pork sides (polyethylene)	−18	1.43	0.24
Pork sides	−18	1.96	0.33
Pork sides (non-chilled meat freezing)	−18	2.35	0.39

of −13°C. It would be expected to be smaller from the work of Cutting and Malton (1974) on the relationship between the rate moisture evaporation and storage temperature.

Weight losses, in Table 3, present the results obtained in Experiment 2, carried out under industrial conditions. At present, it is considered that packing in cardboard boxes is advantageous, because the shape gives efficient storage and also because they contribute to a reduction in weight loss (Stephen, Creed & Bailey, 1982).

Losses are similar to those obtained in Experiment 1 up to two-month storage, and from then on there was a further increase as a result of a temperature rise in the commercial store which underwent some modification.

Experiment 3 was carried out under industrial conditions, where the studied storage temperatures were −13°C and −18°C, in air-cooled stores. The resulting weight losses are included in Table 4. It can be observed that losses obtained at −13°C are far greater than those of pieces stored at −18°C. If results are compared to those of pieces wrapped in polyethylene, it can be seen that the effect of temperature decreased significantly.

Results obtained in this experiment can be compared to those by Sheffer and Rutov (1970). The ones included in Table 4 are greater.

If we take results from polyethylene packing, the values of losses would be closer to those reported in the literature. Indeed, none of these references specify the weight of pieces used in the experiment.

Experiment 4, carried out in a chamber with an air speed of 0.5 m/s and reported in Table 5 allows a comparison between the weight losses obtained at −18°C. The effect of the increase in air speed is noticeable in increasing weight losses, which is not observed in those pieces packed in polyethylene.

In Table 6, regression coefficients for beef show the significance of the main effects (time, packing, temperature, previously chilled or non-chilled freezing and type of quarter) and are listed together with their interactions in each experiment. The corresponding constants of the regression equation, their correlation coefficients and the F-value in the regression analysis are also listed.

Results show that the longer the storage time, the greater the losses due to evaporation. This effect has a

Table 5
% Weight losses during storage (−18°C, 0.5 m/s) [Experiment 4]

Sample	6 months	% Weight losses/ month
Forward quarters (polyethylene)	0.42	0.07
Hind quarter (polyethylene)	0.42	0.07
Forward quarters	7.50	1.25
Hind quarters	4.56	0.76
Forward quarters (non-chilled meat freezing)	7.62	1.27
Hind quarters (non-chilled meat freezing)	6.30	1.05
Pork sides (polyethylene)	0.18	0.03
Pork sides	2.46	0.41
Pork sides (non-chilled meat freezing)	3.96	0.66

Table 6
Results of multiple regression equation for weight losses during storage of beef (regression coefficients)[a]

Effects	Experiment 1		Experiment 2	Experiment 3	Experiment 4
	Boxes	Quarters	Boxes	Quarters	Quarters
Time	x; 0.1794*	x; 0.1970*	x; 0.2771*	x; 0.2391*	x; 1.6910*
Packing	x; −1.0262*	x; −1.2343*	x; −1.0796*	x; −1.7496*	x; −1.4837*
Quarter	–	x; 0.1386**	–	x; −0.3644*	x
Hot** Chilling	–	x; −0.6120*	–	x; 0.3833***	x; 0.2679**
Temperature	–	–	–	x; −0.7300*	–
Time** Packing	x; −0.0957*	x; −0.1664*	x; −0.082*	x; −0.1506*	x; −.4748*
Time**Quarter	–	x	–	x	x; −0.3625*
Time** Hot	–	x; −0.0852***	–	x	x
Time** Temperature	–	–	–	x; −0.1570*	–
Packing** Quarter	–	–	–	x; 0.2044**	x; 0.5179*
Packing** Temperature	–	–	–	x; 0.7400*	–
Quarter** Hot	–	x	–	x	x; 0.3796*
Quarter** Temperature	–	–	–	x	–
Constant	1.6887*	1.6039*	2.4454*	2.6587*	1.9883*
R (Multiple Correlation Coefficients)	0.9548	0.9397	0.9722	0.9695	0.9776
F (ANOVA)	68.85*	96.81*	172.70*	86.85*	160.48*

[a] x: Effects and interactions studied in the experiments.
* $P < 0.001$.
** $0.01 < P < 0.05$.
*** $0.001 < P < 0.01$.

greater influence in the case where the chamber has a greater air speed (Experiment 4).

Packing resulted in a highly significant effect; the greatest value in Experiment 3 indicates that it has a further importance if the pieces are hung on hooks.

The coefficients related to the quarter factor indicate that the greatest weight losses occur in forward quarters and that stack storage diminishes this effect. This again corresponds to the observations of Bailey (1971) and the higher surface to volume ratio of such quarters.

Non-chilled frozen quarters show greater losses during storage, and this is most significant in the case of hanging storage.

The lesser weight losses occur at lower temperature storage, which is related to the difference between vapour pressure at the surface of the meat and surrounding air (Jasper & Placzek, 1978).

In the study of effects of interactions on weight losses, the use of packing diminishes them in forward quarters and its use has a greater importance if storage time and temperature are higher, and is more significant in chambers with greater air speed and hanging storage.

In the study on pork, the main effects considered were time, packing, temperature, non-chilled freezing and their interactions. Results are reported in Table 7. Regression coefficients for factors such as time, packing and

Table 7
Results of multiple regression equation for weight losses during storage of pork (regression coefficients)[a]

Effects	Experiment 1	Experiment 3	Experiment 4
Time	x; 0.2656*	x; 0.2253*	x; 0.0840*
Packing	x; −2.0350*	x; −0.5731*	x; −08094*
Hot** Chilling	–	x	x; 0.5981*
Temperature	–	x; −0.5610*	–
Time** Packing	x; −0.1681***	x; −0.0943***	x; −0.0725***
Time** Hot	–	x	x
Time** Temperature	–	x; −0.0770***	–
Packing** Temperature	–	x; 0.3452*	–
Constant	2.8100*	1.4590*	1.5865*
R (Multiple Correlation Coefficients)	0.9914	0.9553	0.9508
F (ANOVA)	382.97*	40.07*	129.60*

[a] x: Effects and interactions studied in the experiments.
* $P < 0.001$.
** $0.01 < P < 0.05$.
*** $0.001 < P < 0.01$.

Table 8
Sensory analysis of beef (25 judges) [Experiment 1. Minimum significant number of agreeing scores: 18 ($P < 0.05$)]

Variable	Number of judges that preferred some sample									Number of judges that did not find any difference		
	Polyethylene			Without polyethylene			Without polyethylene and non-chilled meat freezing					
Storage time (months)	2	4	6	2	4	6	2	4	6	2	4	6
Color	9	10	12	12	13	8	–	–	–	4	2	5
Taste	10	11	10	14	8	10	–	–	–	1	6	5
Odor	12	9	10	7	9	10	–	–	–	6	7	5
Toughness	–	–	–	14	17	19	9	5	6	2	3	–
Storage conditions	Number of judges that found rancidity						Number of judges that did not find rancidity					
	2		4		6		2		4		6	
−13°C Polyethylene	2		2		1		23		23		24	
−13°C	2		–		2		23		25		23	

Table 9
Sensory analysis, cartoned boneless beef (40 judges) [Experiment 2. Minimum significant number of agreeing scores: 26 ($P < 0.05$)]

Variable	Number of judges that preferred some sample				Number of judges that did not find any difference	
	Polyethylene		Without polyethylene			
Storage time (months)	3	6	3	6	3	6
Color	15	12	12	17	13	11
Taste	12	10	14	15	14	15
Odor	17	15	15	18	8	7
Storage conditions	Number of judges that found rancidity			Number of judges that did not find rancidity		
	3		6	3		6
−10°C, boxes	3		7	37		33
−10°C , boxes and polyethylene	4		4	36		36

Table 10
Sensory analysis of beef over six months storage [Experiment 3]

First Test (29 judges). Minimum significant number of agreeing scores: 21 ($P<0.05$)

Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
Storage conditions	−13°C (Polyethylene)	−18°C (Polyethylene)	
Color	15	12	2
Taste	13	13	3

Storage conditions	Number of judges that found rancidity	Number of judges that did not find rancidity
−13°C Polyethylene	5	24
−18°C Polyethylene	3	26

Second Test (20 judges). Minimum significant number of agreeing scores: 15 ($P<0.05$)

Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
Storage conditions	−13°C (Polyethylene)	−13°C	
Color	6	13	1
Taste	9	9	2

Storage conditions	Number of judges that found rancidity	Number of judges that did not find rancidity
−13°C Polyethylene	3	17
−13°C	2	18

Third Test (25 judges). Minimum significant number of agreeing scores: 18 ($P<0.05$)

Variable	Number of judges that preferred some sample			Number of judges that did not find any difference
Storage conditions	−18°C (polyethylene)	−18°C	−18° C (non-chilled meat freezing)	
Color	15	8	–	2
Taste	15	8	–	2
Toughness	–	14	10	1

Storage conditions	Number of judges that found rancidity	Number of judges that did not find any rancidity
−18°C Polyethylene	3	22
−18°C	5	20

Fourth Test (20 judges). Minimum significant number of agreeing scores: 15 ($P<0.05$)

Variable	Number of judges that preferred some sample			Number of judges that did not find any difference
Storage conditions	−13°C	−18°C	−18°C non-chilled meat freezing	
Color	13	6	–	1
Taste	10	6	–	4
Toughness	–	19	1	–

Storage conditions	Number of judges that found rancidity	Number of judges that did not find rancidity
−13°C	3	17
−18°C	3	17

temperature were highly significant. The highest times and greater temperatures have the greatest weight losses.

The use of packing diminishes losses. The highest value in Experiment 1 is related to storage conditions, higher temperatures (−13°C) and forced air circulation. When comparing with the coefficients obtained for beef, it can be observed that packing is less important in the case of pork weight losses.

Coefficients for the effect of non-chilled or previously chilled freezing indicate that weight losses during storage are greater for non-chilled sides.

The most important result in the study of interactions was that the use of packaging is more important if time and storage temperatures are higher.

The adequacy of the models obtained is evident by observing the values of multiple correlation coefficients

Table 11
Sensory analysis of pork (25 judges) [Experiment 1. Minimum significant number of agreeing scores: 18 ($P < 0.05$)]

Variable	Number of judges that preferred some sample						Number of judges that did not find any difference		
	Polyethylene			Without Polyethylene					
Storage time (months)	2	4	6	2	4	6	2	4	6
Color	12	11	7	7	11	9	6	3	9
Taste	16	7	7	7	13	13	2	5	5
Odor	11	4	6	7	12	10	7	9	9
Storage conditions (months)	Number of judges that found rancidity				Number of judges that did not find rancidity				
	2	4	6		2		4		6
−13°C Polyethylene	1	2	2		24		23		23
−13°C	2	4	3		23		21		22

in each case and can also be checked by the analysis of residuals.

The results of the sensory assessment do not indicate quality losses which could be organoleptically detected. Moreover, rancidity was not found in any case, and there were not significant differences among the different storage conditions with regard to colour, flavour and odour.

When comparing the toughness between non-chilled meats and previously chilled frozen meat, the toughest was non-chilled frozen beef. This can be explained by the phenomenon known as cold shortening (Taylor, Chrystall & Rhodes, 1972; Calvello, 1981; Mackie, 1993).

In the case of pork, this phenomenon was not recorded due to the fast decrease in pH after slaughter compared to beef (Bendall, 1972).

Sensory analysis results for beef are presented in Tables 8–10. The results for pork are presented in Tables 11 and 12.

Different storage temperatures, use or not of wrapper and non-chilled or pre-chilled meat were compared.

There were no significant differences between different storage conditions with regard to colour, taste and odour in any experiment.

Table 12
Sensory analysis of pork over six months storage [Experimental 3]

First Test (13 judges). Minimum significant number of agreeing scores: 11 ($P<0.05$)			
Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
Storage conditions	−18°C (polyethylene)	−18°C	
Color	5	7	1
Taste	7	5	1
Storage conditions	Number of judges that found rancidity	Number of judges that did not find rancidity	
−18°C Polyethylene	1	12	
−18°C	0	13	
Second Test (13 judges). Minimum significant number of agreeing scores: 11 ($P<0.05$)			
Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
Storage conditions	−13°C (polyethylene)	−18°C (polyethylene)	
Color	9	4	0
Taste	2	9	2
Storage conditions	Number of judges that found rancidity	Number of judges that did not find rancidity	
−13°C Polyethylene	6	7	
−18°C Polyethylene	0	13	
Third Test (15 judges). Minimum significant number of agreeing scores: 12 ($P<0.05$)			
Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
Storage conditions	−13°C (polyethylene)	−13°C	
Color	6	7	2
Taste	9	4	2
Storage conditions	Amount of judges that found rancidity	Amount of judges that did not find rancidity	
−13°C polyethylene	5	10	
−13°C	1	14	
Fourth Test (20 judges). Minimum significant number of agreeing scores: 15 ($P<0.05$)			
Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
Storage conditions	−18°C	−18°C, non-chilled meat freezing	
Toughness	8	9	3

Table 13
Sensory analysis of beef (56 judges) [Experiment 4. Minimum significant number of agreeing scores: 35 ($P < 0.05$)]

Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
	Meat frozen and stored	Chilled meat	
Color	18	34	4
Taste	23	33	–
Toughness	25	31	–
	Number of judges that found rancidity	Number of judges that did not find rancidity	
Meat frozen and stored	9	47	
Chilled meat	7	49	

Table 14
Sensory analysis of pork (52 judges) [Experiment 4. Minimum significant number of agreeing scores: 33 ($P < 0.05$)]

Variable	Number of judges that preferred some sample		Number of judges that did not find any difference
	Frozen and stored meat	Chilled meat	
Color	20	25	7
Taste	19	28	5
Toughness	20	26	6
	Number of judges that found rancidity	Number of judges that did not find rancidity	
Frozen and stored meat	14	38	
Chilled meat	2	50	

Moreover, rancidity was not found to be significant in any case although it is known that one of the fundamental alterations in stored meat at temperatures below the frozing point is rancidity and it is more frequent in pork meat owing to larger susceptibility of their oils.

When comparing toughness between non-chilled meats and previously chilled frozen meat, it could be observed for beef in Experiment 1 (Table 8) that in the second month 14 judges found toughness in the frozen meat without previous chilling. Nevertheless, this was not significant because a minimum of 18 concurring scores are necessary for significance.

The judges preferred the toughness of previously chilled frozen meat at 2 and 4 months storage. After 6 months, 19 judges detected toughness in the non-chilled frozen meat, this result being significant.

Likewise in Experiment 3 (Table 10), in the 4th Test, the results of comparing toughness were the following: 19 of the 20 judges detected the largest toughness in non-chilled meat freezing.

This sensory analysis results can be explained by the phenomenon known as cold shortening (Taylor et al., 1972; Calvello, 1981; Mackie, 1993; Bailey, 1976) thus limiting the use of rapidly lowering temperature in order to minimize weight loss. These results indicated that the conditions for this phenomenon to occur were present. To avoid cold shortening, the meat should not reach 10°C before pH falls to 6.2, after slaughter.

When comparing toughness between non-chilled meats and previously chilled frozen meats, in the case of pork meat, significant differences were not found. These results agreed with most of the previous investigators, who have reported that cold shortening was not recorded in pork meat due to the fast decrease in pH after slaughter compared to beef (Bendall, 1972).

In the sensory evaluation, Experiment 4 (Tables 13 and 14) chilled meat and frozen meat stored during 6 months were compared. The results did not indicate quality losses which could be organoleptically detected.

References

Amerine, M., Pangborn, R., & Roessler, E. (1965). *Principles of sensory evaluation of foods*. New York: Academic Press.

Bailey, C. (1971). Inadequate meat refrigeration systems. *Meat*, *44*(8), 16–20.

Bailey, C. (1976). The Chilling of Beef Carcasses. Meat Chilling: Why and How. 13.1–13.11. M.R.I., Symposium No. 2, Langford.

Bendall, J. (1972). The Influence of Rate of Chilling on the Development of Rigor and Cold shortening. Meat Chilling: Why and How. M.R.I., Symposium No. 2, Langford.

Calvello, A. (1981). Recent studies on meat freezing. In: R. Lawrie. London: Developments in Meat Science Publishers.

Cutting, C. (1974). Weight Losses in Meat ,Some Significant Factors. Meat Research Institute. Memorandum No. 4, Langford.

Cutting, C., & Malton, R. (1973). Evaporative losses. Proceedings of the M.R.I. Symposium No. 3. Meat Freezing: Why and How. Langford, p. 36.1.

Cutting, C., & Malton, R. (1974). Freezing times and weight losses of meat in comercial cold stores. Proceedings of the M.R.I. Symposium No. 4. Meat Freezing:Why and How.

Cutting, C. (1976). Refrigeration Techniques in Developing Countries. Bull. I.I.F., París.

Jasper, W., & Placzek, R. (1978). Conservación de la carne por Frío. Editorial Acribia, Zaragoza, España.

Lorentzen, G., & Rosvik, S. (1959). Investigation of Heat Transfer and Weight Loss During Freezing of Meat. Institute Internacional of Refrigeration. Proceedings of 10th International Congress 3, 120–125.

Mackie, I.M. (1993). The effects of freezing in flesh proteins. *Food Rev. Int.*, *9*(4), 575–610.

Manev, G. (1983). La Carne y su Elaboración. Editorial Científico-Técnica. Ciudad Habana, Cuba.

Plank, R., & Kallert E. (1916). Treatment and Manipulation of frozen meat. Abhandlungen, Volksernahrung, H. 6. Berlin. Ed .d . Zentral-Einkaufsges.

Rutov, D. (1955). The diminishing of weigth losses in frozen meat during storage. Proceedings of the IXth International Congress Refrigeration, p. 98.

Sheffer, A., & Rutov, D. (1970). Bull. Institut International du Froid. *Anexo*, *3*, 143–150.

Stephen, J., Creed, P., & Bailey, C. (1982). Determination of Boxed Meat Blocks Freezing, Time. Meat Processing, 56–58.

Taylor, A., Chrystall, B., Rhodes, D. (1972). Toughness in Lamb Induced by Rapid Chilling. *Journal of Food Technology, 7*, 251–258.

Washburrn, M. W. (1985). Frozen Meat Technology-Freezing System. Proceeding of the Meat ProcessingConference. University of California, Davis.