The influence of high freezing rates on the quality of frozen ground beef and small cuts of beef.

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INTRODUCTION

Most of the reports found in the literature on effects of freezing rate on beef quality are concerned with carcasses or large cuts and consequently with moderate or low freezing rates. Only one report has been found in regard to *cooked* fine cuts of beef, and very few reports on the freezing of raw ground beef and small cuts of beef where a relatively large range of freezing rates have been included.

Kondrup and Boldt (1960) presented a comprehensive literature review from which they concluded that very little had been published on the subject after 1950, that the picture was very unclear as far as the effect on sensory quality is concerned, but that there were sufficient indications that freezing rate was not without influence on end quality. Tenderness and drip loss on thawing appeared to improve with increased freezing rate while other sensory qualities were less affected and indications were that juiciness might actually decrease. Important questions to which an answer seemed to be lacking were whether possible effects of freezing rate would be descernable after frozen storage, what lowest freezing rate can be tolerated and how high freezing rate is necessary in order to give a clearly superior product.

In an investigation at the Oklahoma State University reported in 1963 (1963 a, b, c) the effect of freezing temperatures from —9 to —196° C were studied for 1 inch thick steaks of beef. Results obtained showed that meat frozen at temperatures below —18° C became increasingly lighter in colour in the frozen state with freezing rate, and tenderness and general quality were improved. Juiciness was the only quality factor negatively affected.

Andreotti and Ferlenghi (1967) found better retention of sensory quality and less exudation of juices for cooked meat slices frozen at 3—10 cm/h compared with 0.5—1 cm/h. Evaluation of raw meat samples over a period of 2 moths showed consistently lower drip loss on thawing for the higher freezing rate, the difference between methods increasing with storage time.

Brendl and Klein (1967) reported higher water binding ability, as measured by a press method, for ground raw meat frozen at —70° and —190° C compared to freezing at —15° C of 60—80 gram samples in plastic pouches.

Since freezing of ground meat and small cuts of beef is becoming increasingly important both for the institutional and consumer markets, the objective of the present investigation has been to try and clarify the influence of freezing rate on yield and quality for these products over a wide range of freezing rates.

EXPERIMENTAL

Raw material and preparation prior to freezing

Hamburger patties were made on commercial equipment from two different mixes of the approximate compositions given in table 1. The diameter and thickness of the patties were 80 mm and 10 mm respectively and weight about 70 g.

For freezing experiments with fried patties, cooking was done either by deep fat frying at 160° C for 2.5 minutes or pan frying at 175° C pan temperature for 6 minutes. As is seen from the table, differences between the two recipes in water and fat content are considerably smaller after frying.

Table 1. *Water and fat content of raw and cooked hamburger patties. Mean values.*

Mix	*State of preparation*	*fat content* %	*water content* %
1	raw	14.8	61.4
	cooked	13.5	60.4
2	raw	7.9	66.5
	cooked	11.6	57.4

Small cuts of raw beef

Longissumus dorsi muscles were selected from the hind parts of 2 year old heifers, hung at +3° C for 8—10 days after slaughter, and cut into 1.5—2.0 cm slices perpendicular to the fibres immediately before freezing.

EQUIPMENT

Immersion freezing experiments were made in a pilot freezer with programmed frequency and duration of pulsed immersions, or by manual operation in 5 liter Dewar bottles, using the various immersion liquids listed in table 2. In order to permit defined positioning of thermocouple spear probes for temperature recording the samples were placed in small wire baskets with fixtures for the probes.

Spray freezing with liquid nitrogen was made in a conveyorized pilot unit in which conveyor speed, liquid nitrogen spray and precooling conditions could be varied over a fairly wide range.

As reference methods were used freezing in an air blast freezer at —33° C and 5—6 m/s air velocity, and freezing in an insulated box in a freezer without air circulation to simulate the freezing conditions obtained commercially when freezing pallet loads of products packed in cartons.

In all freezing experiments surface and centre temperatures of samples were determined by copper-konstantan thermocouple spear sensors and a potentiometric recorder.

In some of the heating experiments with frozen, precooked meat samples a continuous 5 kW microwave tunnel module made by the Husqvarna company was used, operating at a frequency of 2450 MHz.

Packaging. In the preliminary experiments where freezing rate was determined for immersion freezing, impermeable packaging had to be used for the liquids where direct contact with foods is not permissable, while experiments were made both with and without individual packaging for the liquified gases.

In the main multifactorial experiments individual freezing was done without packaging, except at the slowest freezing rate where a saran-cellophane-polyethylene laminate was used. This type of packaging material of low oxygen permeability was also used for after freezing packaging in all storage tests.

EXPERIMENTAL METHODS

Freezing: In the immersion freezing experiments in refrigerated liquids, these were stirred by moving the sample holder up and down at a given frequency. In the liquified gases patties were frozen by constant immersion and removed before centre temperature reached such values that cracking might occur when using liquid nitrogen. For sliced, raw meat pulsed immersion had to be used to avoid cracking.

For liquid nitrogen spray freezing a technique was worked out where total treatment time, including the precooling section, was 8 minutes and actual time in the spraying zone 1—2 minutes. Final centre temperature at the exit end was —15° C corresponding to a temperature after equilibration between surface and centre of about —25°C.

Table 2. Freezing rates for hamburger patties and slices of beef by different freezing methods.

Product	*Freezing method and medium*	*Freezing temp. ° C*	*Packaging*	*Weight grams*	*Sample Dimensions (mm)*	*Freezing time (+4 to −25° C)*	*Freezing rate cm/hr (0 to −10° C centre temp.)*
raw hamburger patties	immersion freezing in liquid nitrogen(LN_2)	−196	unwrapped	70	Ø 80, thickn. 10	40 sec.	250
»	»	−196	mylar lam.	70	»	45 sec.	150
»	in methanol-water (65%)	− 50	saran-cellophane-polyethylene	70	»	3.2 min.	27
»	»	− 40	»	70	»	3.7 min.	17
»	in $CaCl_2$-brine (29.8%)	− 50	»	70	»	2.7 min.	25
»	»	− 40	»	70	»	3.4 min.	18
»	in Freon 12	− 50	»	70	»	2.2 min.	33
»	»	− 30	»	70	»	4.8 min.	13
»	»	− 30	saran-paperpoly-ethylene	70	»	4.1 min.	16
»	»	− 30	unwrapped	70	»	4.0 min.	16
»	in propyleneglycol	− 40	saran-cellophane-polyethylene	70	»	4.9 min.	12
»	in NaCl-brine (22 %)	− 20	»	70	»	6.5 min.	8
»	in $CaCl_2$-brine (22.8%)	− 20	»	70	»	6.5 min.	8
»	air plast tunnel	− 33	unwrapped	70	»	31 min.	1.6
»	simulated in package-pallet freezing	− 20	wrapped	70	»	18 hr	0.03
hot cooked hamburger patties	air blast tunnel	− 33	unwrapped	60	Ø 75, thickn. 10	60 min.	1.2
slices of beef	spray with LN_2	−196	»	100	thickness 15	3−4 min.	15−20
»	immersion in LN_2	−196	»	»	»	2.5 min	50
»	air blast tunnel	− 33	»	»	»	50 min.	1.4
»	immersion in LN_2	−196	»	125	thickness 20	2.5 min.	100
»	simulated in package-pallet freezing	− 20	wrapped	»	»	40 hr	0.03

Storage: Frozen samples were stored in moisture and oxygen tight packaging at —20° or —30°C for periods varying from one week to 6—7 months before testing.

Preparation after storage: Cooking of *raw patties* was done directly from the frozen condition by pan frying in margarine for 12 minutes at a pan temperature of 170°C to a final centre temperature of 65°C. Frozen raw beef slices were thawed at +20°C and cooked by pan frying in margarine for 10 minutes at 175°C. Precooked patties were also heated directly from the frozen condition, using a pan temperature of 160°C and a heating time of 8 minutes in comparison with continuous microwave heating for 1—2 minutes.

ANALYTICAL METHODS

Moisture content was determined as weight loss on freeze dehydration, and fat content was determined on the dried material by Soxhlet extraction with petroleum ether.

Thaw drip was determined as weight loss during thawing to a final temperature of 20°C for meat samples placed on a wire mesh inside a moisture tight plastic pouch.

A measure of water holding ability was obtained by centrifuging 10 g samples of hamburger patties at 1200 g in a refrigerated centrifuge, and 2 g samples of whole cuts of meat.

Sensory evaluation was made by a 5 member panel for visual appearance, taste, juiciness and texture or tenderness, using 9-point hedonic scales, where 1 corresponds to extremely poor (low) and 9 to extremely good (high).

Cooking and reheating losses as well as evaporative losses on freezing were determined by weighing.

RESULTS

1. Comparison of freezing rates for different methods and media

The various freezing methods and freezing media compared are listed in table 2 together with freezing times and rates obtained for meat patties and sliced raw beef.

The technically most useful media for immersion freezing at moderate freezing temperatures appeared to be freon and methanol-water solution, of which liquid Freon is by far the most expensive unless a very efficient recirculation system can be used.

Spray freezing with liquid nitrogen gave about equivalent freezing rates to immersion freezing in methanol solution at —40°C or in liquid Freon at —30°C, while air blast freezing at —33°C gave about 10 times lower freezing rate, and simulated in package pallet freezing nearly 500 times lower freezing rate.

2. *Influence of freezing rate for raw hamburger patties*

Sensory quality after immersion freezing at different freezing rates and short time frozen storage is reported in table 3, and sensory quality, cooking losses and water holding ability for liquid nitrogen immersion freezing, air blast freezing and simulated in package pallet freezing after different storage time and temperatures for one of the recipes investigated in table 4.

Table 3. *Immersion freezing experiments with raw hamburger patties, recipe no 1. Evaluation after 1 week frozen storage at −20° C. Mean scores for 4—16 determinations.*

Quality aspect	*Immersion freezing conditions*					
	NaCl-brine 8 cm/hr	*Methanol solution 22 cm/hr*	*Freon 12 wrapped*	*Freon 12 15 cm/hr unwr.*	*Liquid nitrogen wrapped 150 cm/hr*	*Liquid nitrogen unwr. 250 cm/hr*
Appearance	6.4	6.7	6.0	6.8	6.3	6.3
Taste	6.3	6.3	6.5	6.8	6.0	5.8
Juiciness	6.0	6.2	6.0	5.5	5.8	4.8
Texture	6.4	6.5	6.0	6.7	6.3	6.3

The only apparent difference in this experiment is in juiciness, indicating lower juiciness for immersion of unwrapped samples in the liquified gases.

In table 4 water holding ability, as reflected by the centrifugation test, was higher for the liquid nitrogen frozen product. For cooking losses a trend is observed towards higher values for very slowly frozen patties. No significant differences were obtained in sensory qualities after cooking. Visual appearance and taste scores clearly decrease with increasing storage time, as did texture scores for recipe no 1.

For both series of experiments very rapid freezing resulted in an unnaturally pale or whitish colour in the frozen state which again disappeared on thawing. The reason is believed to be due to the formation of very small ice crystals. Air blast freezing gave the best frozen state appearance, while very slow freezing resulted in darker colour and the formation of ice on the product surface.

Table 4. *Freezing of raw patties of recipe no 1. Evaluation after 1 week to 5 months' frozen storage. Mean scores for 10 determinations*

Quality aspect	Immersion in liquid nitrogen 250 cm/hr			Air blast freezing 1.6 cm/hr			Slow freezing 0.03 cm/hr		
	—20° C 1 week	—20° C 3 months	—30° C 5 months	—20° C 1 w.	—20° C 3 m.	—30° C 5 m.	—20° C 1 w.	—20° C 3 m.	—30° C 5 m.
Appearance	5.0	4.8	4.2	5.2	4.8	4.4	5.6	5.3	4.3
Taste	5.2	4.5	4.7	4.8	4.9	4.3	5.4	4.8	4.4
Juiciness	5.6	5.4	5.6	6.0	5.9	5.5	5.8	5.5	5.7
Texture	6.4	5.0	4.5	5.8	5.4	4.4	5.6	5.0	5.0
Cooking loss %	15.9	18.5	16.9	15.8	18.8	17.9	19.7	22.3	19.7
Centrifugation loss %	7.8	8.9	8.9	11.0	11.5	9.3	9.3	12.4	11.5

3. *Influence of freezing rate for cooked hamburger patties*

In one factorial experiment immersion freezing in liquid nitrogen was compared with air blast freezing at —33°C and simulated pallet freezing for two recipes after 1 week to 5 months' frozen storage. In a second experiment spray freezing with liquid nitrogen was compared with air blast freezing over the same storage period but using a microwave tunnel for heating to eating temperature. The results from the first experiment and recipe no 1 are given in table 5.

Table 5. *Freezing of cooked patties of recipe no 1. Evaluation after 1 week to 5 months' frozen storage. Mean scores for 10 determinations.*

Quality aspect	Immersion in liquid nitrogen 250 cm/hr			Air blast freezing 1.2 cm/hr			Slow freezing 0.03 cm/hr		
	—20 ° C 1 week	—20° C 3 months	—30° C 5 months	—20° C 1 w.	—20° C 3 m.	—30° C 5 m.	—20° C 1 w.	—20° C 3 m.	—30° C 5 m.
Appearance	4.8	4.6	4.8	6.2	4.7	5.4	6.0	4.9	5.0
Taste	4.8	4.1	4.9	5.4	5.0	4.8	6.2	5.2	4.4
Juiciness	5.2	4.7	5.1	5.4	5.3	4.9	5.6	5.1	4.9
Texture	6.0	5.3	5.0	5.6	5.0	5.1	5.8	5.4	4.6
Reheating loss %	7.8	3.4	6.5	12.3	3.6	8.9	10.6	5.6	5.6
Centrifugation loss %	12.3	11.5	16.9	13.9	18.0	16.5	19.0	21.8	22.7

The observations on water holding ability and drip loss and on visual colour and appearance in the frozen state agreed with those for raw patties. Reheating loss tended to increase with lower freezing rate. Otherwise the influence of freezing rate on sensory quality was variable and uncertain and no statistically significant differences were obtained for either method of reheating. Some tendency towards lower juiciness and visual appearance for samples frozen by immersion in liquid nitrogen was observed, and sensory quality seemed to decrease more rapidly for the very slowly frozen samples.

4. Influence of freezing rate for raw, sliced beef

The results from two factorial experiments are given in table 6, involving freezing of slices of longissimus dorsi muscle by liquid nitrogen immersion and spray, air blast freezing at —33°C and simulated in package pallet freezing, with evaluation after frozen storage from 2 weeks to 6 months. The two experiments involved meat from separate animals and different slice thickness.

Table 6. *Freezing of raw, sliced beef. Mean fo 12 determinations.*

Quality aspect	*Frozen storage time at —30° C*	*Immersion in liquid nitrogen 50—100 cm/hr*	*Liquid nitrogen spray 15—20 cm/hr*	*Air blast 1.4 cm/hr*	*Slow freezing 0.03 cm/hr*
Series A. 20 mm slice thickness					
Taste	overall	6.0	—	6.3	6.0
Juiciness	2 weeks	5.9	—	6.8	6.7
	3 months	5.4	—	6.5	6.2
	5 months	5.4	—	5.1	5.4
Tenderness	2 weeks	6.0	—	5.9	5.8
	3 months	6.2	—	6.2	5.4
	5 months	4.8	—	5.8	5.1
Drip loss %	overall	1.5	—	2.2	4.3
Centrifugation loss %	overall	21.8	—	23.2	21.8
Cooking loss %	overall	26.8	—	23.9	24.7
Series B. 15 mm slice thickness					
Taste	2 months	7.3	6.6	7.1	—
	6 months	5.8	6.0	5.4	—
Juiciness	2 months	6.3	6.2	6.5	—
	6 months	4.6	4.9	4.8	—
Tenderness	overall	3.6	3.7	3.6	—
Drip loss %	overall	0.5	0.6	1.6	—
Centrifugation loss %	overall	23.1	25.5	24.2	—
Cooking loss %	overall	27.2	23.4	24.9	—

Very rapid freezing by liquid nitrogen resulted in a slightly lighter and brighter red colour after defrosting while appearance in the frozen condition was markedly paler and more whitish in colour. Drip loss decreased with increasing freezing rate. Cooking losses were higher for liquid nitrogen immersion freezing so that difference in total weight loss (freezing, thawing, cooking) was rather insignificant from slower freezing methods. Difference in sensory quality after cooking between freezing rates were not statistically significant, but a tendency towards lower juiciness for very rapidly frozen samples could be seen.

DISCUSSION AND CONCLUSIONS

A wide range of freezing rates has been covered in the present investigation of raw and cooked hamburger patties and sliced raw beef, from over 200 cm/hr for liquid nitrogen immersion to 0.03 cm/hr for simulated in package pallet freezing. Over this range of freezing rates, differences observed in sensory quality after cooking or reheating are surprisingly small, suggesting that raw material and preparation, packaging and frozen storage conditions are probably more important factors than freezing rate for these products. A general tendency towards lower juiciness for very rapidly frozen samples was observed, in agreement with earlier reports. For cooked samples frozen by immersion in liquid nitrogen visual appearance was often marred by surface cracks appearing during reheating. On the other hand sensory quality for cooked patties seemed to decrease more rapidly during storage for very slowly frozen products.

In contrast, *visual appearance* in the frozen state differed considerably with freezing rate, in that higher freezing rate gave increasingly more whitish and pale surface colour, probably requiring supplementary surface heat treatment to recrystallize the surface ice. After thawing, these differences disappeared, and surface colour tended to be slightly brighter for the flash frozen raw meat and darker for the slowly frozen meat, still in agreement with scattered observations in the literature.

For sliced, raw meat increasing freezing rate resulted in gradually decreasing *drip loss* on thawing in agreement with Andreotti and others but in disagreement with the investigations at the Oklahoma State University. The differences obtained were considerably lower than claimed in many articles of a popular nature but still of practical significance.

Cooking losses were, however, higher for nitrogen immersion freezing so that total weight loss showed only marginal difference from lower freezing rates. This is in fair agreement with a report by Moiseva and Piskareva (1959), reviewed by Kondrup, according to which liquid nitrogen immersion freezing of small pieces of beef resulted in lower drip loss but higher cooking losses.

For raw and cooked patties *water holding ability*, as estimated by centrifugation, was better for very rapid freezing, (equal to unfrozen meat). Cooking losses or *reheating* losses tended to increase for very slowly frozen samples. With patties no drip loss was obtained for any freezing method, probably because of the binding agents present in the recipes.

In our data there is indication of a slight quality advantage for liquid nitrogen spray freezing over direct immersion freezing inspite of the considerably lower freezing rate. Comparison between immersion freezing with and without packaging in plastic pouches also indicate a disadvantage for direct immersion. The possibility of some optimum freezing rate in between the freezing rates investigated should not be disregarded entirely, but is not considered likely.

Comparing quality and yield for raw and for cooked hamburger patties after frozen storage and preparation or reheating, indications are that quality is about equivalent. For one recipe total yield was the same, but for the other total yield was lower when freezing in the raw condition.

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