EFFECT OF FREEZING, DEFROSTING, AND STORAGE CONDITIONS ON THE FRESHNESS OF DINNER ROLLS AND CINNAMON ROLLS[1]

K. KULP[2] AND W. G. BECHTEL[2]

ABSTRACT

Freshly baked dinner rolls and cinnamon rolls wrapped in cellophane were frozen at 0°F. (−18°C.) without forced air and at −20°F. (−29°C.) with forced air at 1,000 linear ft. per minute. Defrosting was conducted at 75°F. (24°C.) without forced air and at 115°F. (46°C.) with forced air at 1,000 linear ft. per minute. Freezing and defrosting caused a slight decrease in freshness and increase in firmness, but not as much as when the rolls were stored at 70°F. (21°C.) for 24 hours. Only small differences in freshness and firmness were caused by the variations of the above freezing and defrosting operations. Unwrapped rolls can be frozen at 0°F. (−18°C.) or −20°F. (−29°C.) at air velocities from 0 to 1,000 ft. per minute without serious reduction of moisture. It is undesirable to defrost rolls unwrapped, in view of an appreciable moisture loss. Wrapped dinner rolls and cinnamon rolls can be stored at 0°F. (−18°C.) and at −20°F. (−29°C.) for at least 2 months without critical decrease of freshness. Rapid firming and loss of freshness occurred during storage at 10°F. (−12°C.) or above.

Pence and co-workers have made a thorough study of the effect of wide variations in conditions of freezing, frozen storage, and defrosting on the freshness and firmness of bread (12,14,15). Recently they have reported similar studies on cakes (11,13). While there is great interest in the freezing of sweet yeast-raised products, only a few studies have appeared in the literature, and these have been limited in scope. Arnold (2) reported that the quality of rolls frozen and stored at 0°F. (−18°C.) was satisfactory. Gordon (8) found that sweet yeast-raised products frozen at 8° to 12°F. (−13° to −11°C.) and stored unwrapped were salable for 5 to 6 days. Charles and Van Duyne (7) and Nenninger (10) studied the quality of rolls frozen and stored at −10°F. (−23°C.), while Beattie *et al.* (3) found that coffeecake and butterfly buns frozen at −25°F. (−32°C.) and stored at −15°F. (−26°C.) were satisfactory after 9 months.

It was the purpose of this investigation to study systematically the effect of different conditions of freezing, frozen storage, and defrosting on the freshness and firmness of soft dinner rolls and a typical

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[2] American Institute of Baking, Chicago, Illinois.

sweet yeast-raised product, cinnamon rolls.

Materials and Methods

Dinner Rolls and Cinnamon Rolls. Rolls were prepared in the experimental bakery of the American Institute of Baking. The formulas (see Table I) were selected to produce products intermediate between the lean and rich of commercial practice. Dinner rolls were baked in a pan 7 by 7 by 1½ in., nine rolls per pan. This unit weighed 8 oz. Cinnamon rolls were baked in a pan 8 by 8 by 1¾ in., 12 rolls per pan. The unit weighed 16 oz. Moisture content of the fresh rolls, determined by the vacuum-oven procedure (1), was 33% for dinner rolls and 26% for cinnamon rolls.

TABLE I
FORMULAS OF DINNER ROLLS AND CINNAMON ROLLS

	Dinner Rolls[a]	Cinnamon Rolls[a]
	%	%
Sponge		
Flour	60	76
Water	36	52
Yeast	3	8
Dough		
Flour	40	24
Water	29	0
Salt	2	2.5
Sugar	10	16
Nonfat dry milk	6	6
Eggs	0	16
Shortening	10	16
Raisins	0	20
Cinnamon	0	0.5

[a] Total flour is 100%. Other ingredients are given as percentages of the total flour.

Freezing and Defrosting. Units of the freshly baked products equilibrated at 70°F. (21°C.) were placed in a freezer equipped with variable thermoregulator which maintained a temperature within ± 2°F. (± 1.1°C.) of the setting. Air circulation at rates up to 1,000 linear ft. per minute across the products was provided by an electric blower. This equipment has been described in more detail (9). The time-temperature relationships for freezing and defrosting were also given.

Packaging. Both kinds of rolls were packaged in 300 MST (moisture proof, heat-sealing, transparent) cellophane and the package was sealed.

Moisture Loss on Freezing and Defrosting. The fresh rolls were cooled to room temperature and weighed. For moisture loss on freezing the rolls were frozen unwrapped. At the end of the freezing time they were wrapped and sealed in waxed paper to prevent further change of

moisture, after which they were defrosted, unwrapped, and weighed. For moisture loss on defrosting, the rolls were cooled and weighed. Then they were wrapped and sealed in waxed paper, frozen, and equilibrated at 0°F. (−18°C.). The wrapper was removed just prior to defrosting, they were then weighed, defrosted to 70°F. (21°C.), and again weighed. Loss of weight was taken as the moisture loss.

Relative Humidity. This was determined by means of a wet- and dry-bulb thermometer in a current of air provided by a small electric fan.

Firmness. The Baker Compressimeter (1) was used. Slices of center crumb 1 by 1 by 1½ in., cut in a miter box, were compressed 2.5 mm. Each value is the average of tests of 20 slices. Freshly baked products were tested 2 hours after removal from the oven.

Freshness. A sensory panel of 20 members was used. Panel members were selected by the method described by Bechtel and Meisner (4), to make sure that they were able to detect the changes generally associated with staling. A symmetrical 8-point rating scale was used, with ratings *very fresh, fresh, moderately fresh, slightly fresh, slightly stale, moderately stale, stale,* and *very stale.* For statistical analysis the rating *very stale* was given the value 1. Successive ratings were given consecutive integers to 8 for *very fresh.* Each result is the average of two panel tests.

Results and Discussion

Effect of Freezing and Defrosting Rates on Firmness and Freshness. The relationship of temperature, air flow, and packaging to the rates of freezing and defrosting of dinner rolls and cinnamon rolls has been reported (9). To study the effect of rates of freezing and defrosting on freshness and firmness the rolls were frozen and defrosted, packaged, at the slowest and most rapid rates previously employed. Freezing conditions were: (a) freezer at 0°F. (−18°C.) without forced air, and (b) −20°F. (−29°C.) with an air flow of 1,000 linear ft. per minute. Defrosting conditions were: (a) defrosting cabinet at 75°F. (24°C.) without forced air, and (b) 115°F. (46°C.) with an air flow of 1,000 linear ft. per minute. The cooling time, the time required to lower the temperature at the center of the unit from 70°F. (21°C.) to 10°F. (−12°C.) was used as an index of the rate of freezing. Defrosting time was that required to raise the temperature at the center of the unit from 0°F. (−18°C.) to 70°F. (21°C.).

The freezing and defrosting times under the above conditions are given in columns 1 and 2 of Table II.

Rolls were defrosted after 20 hours in the freezer, so that very little,

TABLE II

EFFECT OF FREEZING AND DEFROSTING RATES ON THE FRESHNESS AND FIRMNESS OF DINNER ROLLS AND CINNAMON ROLLS

No.	Cooling Time[a]	Defrosting Time[b]	Freshness Rating[c]	S.D.[d]	Firmness Value	S.D.[d]
	minutes	*minutes*			*g/sq in*	
			Dinner Rolls			
1	Freshly baked[e]		7.30	0.80	13.3	1.34
2	55	40	6.55	0.92	13.5	1.20
3	55	145	6.55	1.00	13.9	2.49
4	163	40	6.58	1.34	13.3	2.54
5	163	145	6.68	0.92	16.0	3.78
6	After 24 hours at 70°F. (21°C.)		6.03	1.28	19.0	3.28
			Cinnamon Rolls			
1	Freshly baked[e]		6.90	0.98	17.7	3.20
2	55	27	6.28	1.30	24.3	4.92
3	55	157	6.03	1.33	22.0	7.00
4	130	27	6.10	1.25	22.1	4.85
5	130	157	5.63	1.22	23.4	3.50
6	After 24 hours at 70°F. (21°C.)		4.95	1.33	34.3	5.83

[a] From 70°F. (21°C.) to 10°F. (—12°C.).
[b] From 0°F. (—18°C.) to 70°F. (21°C.).
[c] Rating scale: Very fresh 8, fresh 7, moderately fresh 6, slightly fresh 5, slightly stale 4, moderately stale 3, stale 2, very stale 1.
[d] Standard deviation.
[e] Two hours after baking.

TABLE III

ANALYSIS OF VARIANCE APPLIED TO THE EXPERIMENTS IN TABLE II

		Dinner Rolls		Cinnamon Rolls
Freshness ratings				
Source of variation	D.F.		M.S.	M.S.
Total	119		1.0	1.6
Judges	19		2.3**	3.9**
Treatment	5		3.1**	8.6**
(a) fresh vs. others[a]		1	10.9**	20.4**
(b) 24 hours vs. frozen		1	4.3**	17.8**
(c) slowest vs. other rates		1	0.2 N.S.	4.4*
(d) among fast rates		2		0.3 N.S.
Treatment × Judges	95		0.6	0.8
Firmness values				
Total	119		11.4	59.9
Treatment	5		114.3**	615.3**
(a) fresh vs. others		1	56.4**	942.5**
(b) 24 hours vs. frozen		1	372.5**	2,061.2**
(c) slowest rates vs. others		1	88.8**	24.3 N.S.
(d) among fast-frozen		2	1.9 N.S.	
Residual (error)	114		7.4	35.5

[a] a, No. 1 vs. 2-6 of Table II; b, No. 6 vs. 2-5 of Table II; c, No. 5 vs. 2-4 of Table II; d, Among No. 2-4 of Table II.

if any, of the changes in freshness and firmness can be attributed to time of storage. The processes of freezing and defrosting caused some

loss of freshness and increase in firmness, but the changes were much less than in rolls stored at 70°F. (21°C.) for 24 hours.

As shown in Table II, freshly baked dinner rolls were given a freshness rating between *fresh* and *very fresh* (7.30). After freezing and defrosting this was lowered to between *fresh* and *moderately fresh* (6.55 to 6.68), while after 24 hours at 70°F. (21°C.) the rating was *moderately fresh* (6.03). As shown in Table III, freshly baked dinner rolls were significantly fresher than the others, and the frozen rolls were significantly fresher than those stored 24 hours at 70°F. (21°C.). Within the experimental limits employed, differences in freezing and defrosting times had little effect on freshness as measured by the sensory panel.

Except when both freezing and defrosting were slow, these processes had only a slight effect on firmness of dinner rolls. Slow freezing and defrosting caused a significant increase in firmness over the procedures where at least one of the operations was conducted at a rapid rate. Those stored for 24 hours at 70°F. (21°C.) were significantly firmer than those which had been frozen.

Results of tests of cinnamon rolls in Table II show a somewhat similar relationship. Freezing and defrosting caused a loss of freshness, but that was significantly less (Table III) than that caused by storage for 24 hours at 70°F. (21°C.). Rate of freezing and defrosting had a greater effect on freshness than in the case of dinner rolls. When cinnamon rolls were frozen and defrosted at the slowest rates there was a significant loss of freshness beyond that caused by any of the other combinations of freezing and defrosting rates. The process of freezing and defrosting caused a material increase in firmness, but there was no significant difference in firmness due to the changes in rate of freezing and defrosting. Storage for 24 hours at 70°F. (21°C.) caused a significantly greater increase in firmness than did freezing and defrosting.

Freezing and defrosting caused approximately half the loss of freshness that was caused by 24-hour storage at 70°F. (21°C.); this indicates that there is an advantage to freezing rolls unless they are consumed on the day they are baked. The data show, also, that it is desirable to freeze and defrost these products rapidly to minimize loss of freshness and softness.

Moisture Loss on Freezing and Defrosting Unwrapped Rolls. During freezing, unwrapped rolls were exposed to the atmosphere of the freezer for the time required for the temperature at the center of the unit to fall from 70°F. (21°C.) to a temperature 10°F. (5.6°C.) above that of the freezer. Freezer temperatures of 0°F. (−18°C.) and −20°F. (− 29°C.) were employed, with air flow of 0, 150, 500, and 1,000 linear ft. per minute. The exposure times of dinner rolls were from 68 min-

utes to 162 minutes, depending on temperature and air flow rate. Those of cinnamon rolls were from 48 minutes to 173 minutes.

No relationship was found between moisture loss and freezer temperature or rate of air flow. The 8-oz. unit of dinner rolls lost an average of 0.5% of its initial weight, with a range of 0.2 to 0.8%. The 16-oz. unit of cinnamon rolls lost an average of 0.3% of its initial weight, with a range of 0.1 to 0.4%.

On defrosting, the unwrapped rolls were exposed for the time required for the temperature at the center of the unit to rise from 0°F. (−18°C.) to 70°F. (21°C.). Defroster temperatures of 75°F. (24°C.), 95°F. (35°C.), and 115°F. (46°C.) were used and at each temperature air flow rates were 0, 150, 500, and 1,000 ft. per minute. The average moisture loss from dinner rolls was 1.4%, with a range from 0.6 to 2.44%. The average moisture loss from cinnamon rolls was 1.0%, with a range from 0.6 to 1.6%. Analysis of variance showed no significant relationship between moisture loss and either defroster temperature or rate of air flow.

During freezing the surface layers of the product are cooled rapidly and the rate of evaporation of moisture is diminished because of the lowered moisture vapor pressure. On defrosting the reverse is true, and as the product is warmed evaporation of moisture becomes greater. The moisture losses on freezing were not high, and it appears feasible to freeze rolls prior to wrapping if this is desirable from other points of view. The combined moisture loss due to freezing and defrosting averaged 1.9% for dinner rolls and 1.3% for cinnamon rolls. These were the result of minimum exposure to the atmosphere of the freezer and defroster and do not include losses which would occur during frozen storage, nor those which would occur if the rolls were allowed to remain longer than the minimum time in the defroster. It has been shown (5) that a loss of 2% moisture from bread results in significant lowering of its freshness. It seems probable that such a moisture loss would affect the freshness of rolls in a similar manner. It therefore appears undesirable to defrost rolls unwrapped.

Effect of Storage Temperature on Freshness and Firmness. The importance of freezer temperature to the maintenance of freshness and softness of dinner rolls is shown in Table IV. The rolls were frozen in 55 minutes and defrosted in 145 minutes. It was shown in Table II that rolls treated in this manner were given the freshness rating 6.55 and had a firmness of 13.9 g. per sq. in. During the first week of storage there was a decrease in freshness and an increase in firmness at all temperatures. Except for the rolls stored at 20°F. (−7°C.), the loss of freshness was not great. At 20°F. (−7°C.) the freshness rating after 1

week was 4.85, a value below *slightly fresh*. This was approximately the same as that of rolls stored at 10°F. (−12°C.) for 3 weeks. At these two higher temperatures there was a substantial increase in firmness within 1 week and a further increase on longer storage.

TABLE IV

EFFECT OF STORAGE TIME AND TEMPERATURE ON THE FRESHNESS AND FIRMNESS OF DINNER ROLLS[a]

Storage Temperature		Time of Frozen Storage					
		1 Week		2 Weeks		3 Weeks	
		Freshness Rating[b]	S.D.[c]	Freshness Rating[b]	S.D.[c]	Freshness Rating[b]	S.D.[c]
°F	°C						
20	(− 7)	4.85	1.24	4.25	1.13	4.15	1.49
10	(−12)	6.28	0.89	5.98	1.97	4.60	1.57
0	(−18)	6.05	1.29	5.95	1.05	6.08	1.05
−20	(−29)	5.93	1.40	6.20	1.13	5.78	1.24
		Firmness					
		g/sq in	*S.D.*	*g/sq in*	*S.D.*	*g/sq in*	*S.D.*
20	(− 7)	32.8	5.94	31.2	3.04	39.8	3.02
10	(−12)	29.2	3.43	33.9	5.99	46.7	6.12
0	(−18)	28.5	3.15	20.7	2.47	22.1	2.62
−20	(−29)	21.9	5.93	21.7	4.36	17.8	3.09

[a] Values 2 hours after baking: freshness, 7.00 (S.D. 0.75); firmness 15.8 g. per sq. in. (S.D. 2.42).
[b] Based on the rating scale: 8, very fresh; 7, fresh; 6, moderately fresh; 5, slightly fresh; 4, slightly stale; 3, moderately stale; 2, stale; 1, very stale.
[c] Standard deviation.

At freezer temperatures of 0°F. (−18°C.) or below, there was no evidence of staling or firming from the first to third week of storage. The study at 0°F. (−18°C.) was continued for a total storage time of 8 weeks. The freshness rating after the eighth week was 6.35 and the firmness was 21.9 g. per sq. in., showing that no further deterioration in quality had occurred.

As shown in Table V, freshness and firmness values at 20°F. (−7°C.) were significantly below those at lower temperatures, while the values at 10°F. (−12°C.) were significantly below those at 0°F. (−18°C.). If dinner rolls are to be frozen and stored for more than a few days a temperature of 0°F. (−18°C.) or below is required to maintain freshness and softness.

Cinnamon rolls were frozen in 55 minutes and defrosted in 157 minutes. This treatment reduced the freshness to 6.03 or *moderately fresh*, and increased the firmness to 22.0 g. per sq. in. (Table II). Data in Table V show that after storage for 1 week at 20°F. (−7°C.) the rolls were rated 4.28, or *slightly stale*, and the firmness had increased to 40.0 g. per sq. in. These values are appreciably poorer than those in Table

II for cinnamon rolls stored 24 hours at 70°F. (21°C.). A further loss of freshness and increase in firmness occurred during the following 2 weeks.

The deterioration of cinnamon rolls at 10°F. (−12°C.) was rather rapid. At the end of the first week they were rated 5.13 in freshness *(slightly fresh)*. Firmness had increased to 33.2 g. per sq. in. These values are approximately the same as for rolls stored at 70°F. (21°C.) for 24 hours. During the next two weeks freshness continued to decrease to a value not appreciably better than that of the rolls at 20°F. (−7°C.).

TABLE V

EFFECT OF STORAGE TIME AND TEMPERATURE ON THE FRESHNESS AND FIRMNESS OF CINNAMON ROLLS[a]

Storage Temperature		Time of Frozen Storage					
		1 Week		2 Weeks		3 Weeks	
		Freshness Rating[b]	S.D.[c]	Freshness Rating[b]	S.D.[c]	Freshness Rating[b]	S.D.[c]
°F	°C						
20	(− 7)	4.28	1.07	3.60	1.58	3.75	1.40
10	(−12)	5.13	1.23	4.83	1.45	3.88	1.38
0	(−18)	6.45	1.22	5.90	1.02	5.55	1.65
−20	(−29)	5.90	1.60	5.70	1.30	5.60	0.99
		Firmness					
		g/sq in	*S.D.*	*g/sq in*	*S.D.*	*g/sq in*	*S.D.*
20	(− 7)	40.0	11.27	48.7	14.96	63.8	18.18
10	(−12)	33.2	5.97	32.4	7.74	44.5	8.16
0	(−18)	15.8	4.17	18.1	5.09	20.8	5.08
−20	(−29)	14.6	5.20	16.6	3.75	15.4	3.40

[a] Values 2 hours after baking: freshness 6.90 (S.D. 0.98); firmness, 14.2 g. per sq. in. (S.D. 2.86).
[b] Based on the rating scale: 8, very fresh; 7, fresh; 6, moderately fresh; 5, slightly fresh; 4, slightly stale; 3, moderately stale; 2, stale; 1, very stale.
[c] Standard deviation.

The freshness rating of cinnamon rolls after 1 week at 0°F. (−18°C.) appears to be abnormally high compared to the value for the frozen and defrosted rolls in Table II. This may reflect some variation in the characteristics of the different lots of rolls, together with the normal day-to-day variation to be expected of the panel. If one uses the rating approximately 6.0, which seems reasonable from Table II and from the value at −20°F. (−29°C.) after 1 week, then cinnamon rolls showed no loss of freshness (beyond that caused by freezing and defrosting) during the first 2 weeks. The small increase in firmness was negligible. There was apparent deterioration in freshness during the third week and the study was continued for a total of 8 weeks to determine if staling would continue. Tests were made at 2-week intervals. A further loss of freshness was observed at each test until, after 8 weeks, the

rolls were rated *slightly stale* (4.05). Since the firmness after 8 weeks was only 23.4 g. per sq. in., it seems unlikely that firming was involved to any great extent in the loss of freshness. During the 3-week storage study at −20°F. (−29°C.) this temperature appeared to offer no advantage over 0°F. (−18°C.) in maintaining freshness, although it prevented any firming.

The analysis of variance in Table VI shows that deterioration at 20°F. (−7°C.) was significantly greater than at the lower temperatures and that the loss of freshness and increase in firmness at 10°F. (−12°C.) were significantly greater than those at 0°F. (−18°C.) and −20°F. (−29°C.). There was no significant difference between the results at the last two temperatures.

TABLE VI

ANALYSIS OF VARIANCE APPLIED TO THE EXPERIMENTS IN TABLES IV AND V

		Dinner Rolls	Cinnamon Rolls
Freshness ratings			
Source of variations	D.F.	M.S.	M.S.
Total	319	2.5	2.5
Storage time (S)	3	104.2 **	79.9 **
Judges (J)	19	3.8 **	4.3 **
Temperature (T)	3	25.0 **	43.2 **
+20° vs. −20°, 0° and 10°F.	1	69.1 **	82.3 **
−20° vs. 0°F.	1	0.1 N.S.	1.2 N.S.
−20° & 0°F. vs. +10°F.	1	5.9 **	46.3**
S × J	57	1.3 N.S.	1.3 N.S.
T × J	57	1.4 N.S.	0.6 N.S.
S × T	9	5.2 **	5.8 **
S × T × J	171	0.9	1.0
Firmness values			
Total	319	130.4	289.9
Storage time	3	3,731.1 **	6,669.9 **
Temperature	3	2,838.7 **	12,393.5 **
+20° vs. −20°, 0° and 10°F.	1	1,978.0 **	25,235.4 **
−20° vs. 0°F.	1	245.0 N.S.	164.0 N.S.
−20° & 0°F. vs. +10°F.	1	6,293.0 **	11,781.0 **
Residual	313	69.9	112.7

Bergholz (6) observed that when raisin bread is stored at room temperature, moisture migrates from the crumb to the raisins. A similar change occurs in cinnamon rolls, even during frozen storage. This is evident from the results in Table VII.

After 3 weeks of storage the moisture gain of raisins was 11.5% at +20°F. (−7°C.), 8.6% at 0°F. (−18°C.), and 3.4% at −20°F. (−29°C.). Part of this moisture change undoubtedly occurred during the freezing and defrosting operations, but at 0°F. (−18°C.) and +20°F. (−7°C.) it was too high to be accounted for by this effect only. It is concluded, therefore, that moisture migration is not arrested entirely in the freezer and is at least partly responsible for the relatively low stability of this

TABLE VII

MOISTURE REDISTRIBUTION IN CINNAMON ROLLS DURING STORAGE

CONDITION OF STORAGE	MOISTURE	
	In Raisins	In Crumb
	%	%
Freshly baked	21.0	25.1
72 hours at 70°F. (21°C.)	30.6	22.0
3 weeks at 20°F. (−7°C.)	32.5	21.1
3 weeks at 0°F. (−18°C.)	29.6	22.1
3 weeks at −20°F. (−29°C.)	24.4	23.0

product. This phenomenon would probably be a factor in the stability during frozen storage of other bakery foods containing raisins, or of bakery foods consisting of more than one phase, one of which differs in hygroscopicity or freezing point from the other.

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