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ScienceDirect
Food Chemistry 101 (2007) 113–119
Food Chemistry
www.elsevier.com/locate/foodchem

Staling of chapatti (Indian unleavened flat bread)

Irshad M. Shaikh, Shalini K. Ghodke, Laxmi Ananthanarayan *

Food Engineering and Technology Department, Institute of Chemical Technology, University of Mumbai, Matunga, Mumbai 400 019, India

Received 7 March 2005; received in revised form 3 January 2006; accepted 3 January 2006

Abstract

Staling in foods is a process, which occurs when starch chains after gelatinization begin to reassociate in an ordered structure. Staling of chapatti results in loss in texture and eating quality of chapatti. Moisture content, water-soluble starch, in vitro enzyme digestibility, enthalpy change (ΔH), texture and sensory quality of chapattis, which are significantly affected during staling both at room and refrigerated temperature storage, were monitored over a storage period of one month. Moisture content, water-soluble starch and in vitro enzyme digestibility were found to decrease steadily during staling of chapattis at both room temperature and refrigerated temperature of storage. Enthalpy change, ΔH, as measured by DSC increased with storage time. The texture of chapattis became progressively harder with storage at both room and refrigerated temperature. A decrease in sensory quality and acceptability of the chapattis was observed with storage. The rate of staling was lower at refrigerated temperature. Most of the staling parameters studied showed good correlation. Texture showed the best overall correlation with all other staling parameters. In general, the correlation obtained at room temperature was better than that at refrigerated temperature.

Keywords: Chapatti; Staling; Water-soluble starch; In vitro enzyme digestibility; Enthalpy change; Texture; Sensory quality

1. Introduction

In India, wheat is one of the daily staples, consumed in different forms of flat breads, such as chapatti, paratha, phulka, tandoori roti and nan. Just as bread is a staple food item in the Western World, chapatti, is a staple food of a majority of the population in many regions of the Indian subcontinent. Almost 90% of the wheat produced in India is consumed in the form of chapatti. Only 10% of the wheat produced in India is consumed in making bread/biscuits/cake and such other products. Chapattis are generally prepared twice a day for lunch and dinner, and unless eaten immediately after preparation, these stale rapidly and become difficult to chew. The most important parameters of chapatti quality are texture and flavour. The former is generally evaluated in terms of tenderness, flexibility and ability to be folded into a spoon shape for eating with curried preparations but the flavour is judged mainly in terms of sweetish taste and fresh typical wheatish aroma.

The increasing demand for convenience food (Raghavan, 1994) because of urbanization and industrialization, has, however, created a need to mechanize the preparation of chapatti for marketing in unit packs, similar to bread. Freshly-baked chapattis are soft, pliable and elastic but when kept at room temperature they stale within few hours and become tough and rigid. Staling of chapattis has not been extensively studied though a few reports are available (Nanjappa, Jagannath, & Arya, 1999). In view of the fact, that chapattis may be manufactured on a large mechanized scale and distributed, the staling of chapattis may become a critical factor for consideration.

Cooking (or processing) normally causes starch gelatinization, i.e. irreversible swelling or even disruption of the starch granules, depending on the severity of the treatment applied. The behaviour of gelatinized starches on cooling and storage, generally termed as retrogradation, is of great

* Corresponding author. Tel./fax: +91 022 24145616.
E-mail address: laxmi@udct.org (L. Ananthanarayan).

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doi:10.1016/j.foodchem.2006.01.015

interest to food scientists and technologists since it profoundly affects quality, acceptability and shelf-life of starch-containing foods (Biliaderis, 1991). Starch molecules in pastes or gels are known to re-associate on aging, resulting in effects such as precipitation, gelation, and changes in consistency and opacity. Crystallites eventually begin to form, and this is accompanied by gradual increase in rigidity and separation between polymer and solvent (syneresis). It is important to distinguish between the short-term development of gel structure via amylose crystallization and long term reordering of amylopectin, which is a much slower process involving recrystallisation of the outer branches (DP = 15) of this polymer (Miles, Morris, Orford, & Ring, 1985; Ring et al., 1987). For common starches containing both amylose and amylopectin, a composite gel network forms, consisting of swollen amylopectin-enriched granules (provided granule integrity is maintained) filling an interpenetrating amylose gel matrix (Miles et al., 1985). During long term storage, amylopectin recrystallizes, thus increasing the rigidity of the swollen granules, which in turn, reinforces the continuous amylose phase. The effect of retrogradation in starch-based products can be desirable or, more usually, undesirable. The undesirability of staled starch is because it results in the formation of hard texture, which directly affects the quality of the final products.

The rate of retrogradation (staling) has been studied by different physicochemical methods. The increase in enthalpy change or shift in endotherm measured by DSC has mostly been used by investigators following bread staling. Other physical changes, such as crumb firmness, loss in flavour, X-ray diffraction and chemical methods, namely starch solubility (iodine affinity), enzyme digestibility, moisture content, have also been used. Chapatti is highly susceptible to staling as compared to bread. Extensive work has been reported on staling of bread. However, the literature on the rate of staling of Indian traditional foods, such as chapatti and phulka, is limited.

The purpose of this study was to investigate the different physicochemical parameters for the evaluation of staling of chapattis. Multiple correlations were established to determine the significance of each parameter in the measurement of staling of chapatti.

2. Materials and methods

2.1. Materials

Branded whole wheat flour (Nature Fresh atta), double-filtered groundnut oil (Dhara), and table salt (Tata salt) were procured from the local market. Preservatives, such as calcium propionate, were procured from CDH Laboratory, Mumbai, India, and potassium sorbate and citric acid were obtained from Hi media, Mumbai, India. Amyloglucosidase was donated by Biocon, Bangalore, India. All the other chemicals used for the analysis were of analytical grade.

2.2. Proximate analysis of atta

The proximate analysis of the branded whole-wheat flour (atta) was carried out as follows:

Moisture content was determined by the AACC (1976) method. Total fat, total ash, acid insoluble ash, crude fibre, dry gluten and protein content were determined by the AOAC method (AOAC, 1975).

2.3. Preparation of chapatti

The whole-wheat flour (100 g) were mixed with 62 ml of water containing 0.2% potassium sorbate, 0.2% calcium propionate, 0.3% citric acid and 2% of salt, all on flour weight basis. This was all kneaded for 5 min to form dough. Then 5% of groundnut oil was added and the dough was again kneaded so that the oil is completely mixed with the dough. The dough was then covered with a wet cloth and allowed to rest for 10 min. It was again kneaded for 1 min. Then 30 g of dough were rolled into a diameter of 15 cm and thickness of approximately 2 mm. The dough was then baked on a preheated griddle under controlled flame on one side for 45 s and the other side for 60 s. It was then puffed directly on a maximum flame for 10 s on both sides. Hot chapatti was then precooled on a hollow wooden stand for about 5 min. Chapatti was then cooled to room temperature and stored in a self-sealing low density polyethylene (LDPE) 60 gauge plastic bag.

2.4. Evaluation of chapatti for staling during storage

2.4.1. General

Chapattis were prepared from whole wheat branded atta, as described earlier, and were periodically evaluated for moisture content, water-soluble starch (WSS), in vitro enzyme digestibility (IVED), enthalpy change (ΔH), texture, colour and sensory analysis during one month of storage at room temperature (29 ± 1 °C) and refrigerated temperature (4 ± 1 °C). In the case of refrigerated chapattis, before analysis, they were brought to room temperature.

2.4.2. Moisture content

Moisture content of chapattis was determined by using a two stage-drying method. In the first stage, 5–7 g of the chapatti sample were taken and kept in an air-oven at 103 °C for 4 h. In the second stage, air-dried samples were ground and 2–3 g of this ground sample were again dried using a first stage drying method (AACC, 1976).

2.4.3. Water soluble starch (WSS)

Percentage of total water-soluble starch (WSS) was determined by a modified procedure of Morad and D'Appolonia (1980). Chapatti (200 mg) was extracted with 15 ml of distilled water by agitating the mixture on a shaker for 20 min. The slurry was centrifuged at 5000 rpm for 5 min and the supernatant filtered. The filtrate (10 ml)

was treated with 2 ml of standard iodine solution (2 mg of iodine and 20 mg KI in 100 ml of water) and optical density (OD) was measured using a Hitachi Spectrophotometer at 680 nm. A standard curve was plotted of OD at 680 nm versus concentration of starch (a mixture of 25% amylose and 75% amylopectin) by taking varying amounts of the starch mixture and treating it with standard iodine solution as described above.

2.4.4. In vitro enzyme digestibility (IVED)

IVED of starch in chapatti was determined by a modified procedure of Lucia, Nixcoletta, and Paolo (1995). Chapatti (200 mg) were extracted with 15 ml of 0.1 M Na-acetate buffer (pH 4.75) by agitating the mixture on a shaker for 20 min. The slurry was centrifuged at 5000 rpm for 5 min and the supernatant was filtered. The filtrate (1.9 ml) were taken and heated to 60 °C and 0.1 ml of amyloglucosidase solution (150 mg of the amyloglucosidase in 100 ml of same buffer) was added. After 10 min of incubation at 60 °C, the reaction was stopped with 2 ml of DNSA reagent and the liberated glucose was determined by the DNSA method. A standard curve was plotted of OD at 540 nm versus the concentration of the standard glucose solution. Amount of glucose released was calculated from the standard DNSA curve. IVED was then expressed as % of glucose liberated.

2.4.5. Enthalpy change (ΔH)

Starch molecules in pastes or gels are known to re-associate on aging, resulting in effects such as precipitation, gelation, and changes in consistency and opacity. Crystallites begin to form eventually, and this is accompanied by gradual increase in rigidity and separation between polymer and solvent (syneresis). In DSC, when a thermal transition occurs, the energy absorbed by the sample is replenished by increased energy input to the sample to maintain the temperature balance. Because this energy input is precisely equivalent in magnitude to the energy absorbed in the transition, a recording of this balancing energy yields a direct calorimetric measurement of the energy transition, which is then recorded as a peak. The area under the peak is directly proportional to the enthalpy change (ΔH) and its direction indicates whether the thermal event is endothermic or exothermic. In the case of retrograded starch, the value of ΔH provides a quantitative measure of the energy transformation that occurs during the melting of the recrystallized amylopectin, as well as precise measurements of the transition temperatures (i.e. onset, T_o; peak, T_p; and conclusion, T_c) of the endothermic event.

Change in the enthalpy was determined by using a differential scanning calorimeter (DSC) (TA instruments, USA). The chapatti (5 mg) sample were weighed into the pan. The pan was hermetically sealed by using a sealing machine. Duplicate sample pans were prepared and each was heated at a rate of 10 °C/min from room temperature (25 ± 1 °C) to 200 °C in the Dupont pressure cell with a flow rate of 60 ml/min. The area of all endotherm peaks in DSC plot gives the ΔH value whereas T_g and T_m values give an idea of the proportion of starch molecules involved in the retrogradation process. Fig. 1 shows DSC thermographs of fresh and stored chapatti.

2.4.6. Texture

Texture of the chapattis was analyzed using Stevens LFRA Texture Analyzer with needle probe. The instrument was operated in the normal mode and the speed with which the probe moved was 2 mm/s and it was allowed to penetrate a distance of 10 mm deep in the sample. Texture is expressed as the load in grammes required to penetrate the product.

2.4.7. Colour

The colour of the chapattis under study was measured using a Hunter Lab Colorimeter, model DP-9000 D25 A (Hunter associates laboratory, Reston, VA, USA), in terms of Hunter L (lightness, ranging from 0 to 100, indicating black to white), a ($+a$, redness and $-a$, greenness) and b ($+b$, yellowness and $-b$, blueness).

2.4.8. Sensory analysis

Ten panellists evaluated the chapatti for its texture in terms of very soft, soft, slightly soft, hard and very hard.

These verbal evaluations were then converted into scores where very soft = 9–10, soft = 7–8, slightly hard or slightly soft = 5–6, hard = 3–4, and very hard = 0–2. An average score of 10 judgments was then calculated.

The results of all these evaluations are given in Table 2 (room temperature storage) and Table 3 (refrigerated temperature storage). Table 4 shows the correlation coefficients for various staling parameters for chapattis stored at room temperature. Likewise, Table 5 shows the correlation coefficients for various staling parameters for chapattis stored at refrigerated temperature.

3. Results and discussion

3.1. Proximate analysis of branded whole wheat atta

The proximate composition of the branded atta used in the present work is given in Table 1.

3.2. Evaluation of chapatti for staling during storage

It can be seen from Tables 2 and 3, that when chapattis were stored at room temperature (29 ± 1 °C) and refrigerated temperature (4 ± 1 °C), respectively, staling occurred resulting in decrease in moisture content, water-soluble starch, in vitro enzyme digestibility, sensory score and increase in texture (hardness) and enthalpy change, whereas the color remained relatively unaffected at both room and refrigerated temperatures.

The moisture content of the chapattis stored at room temperature decreased from 32.35% to 16.01% after one

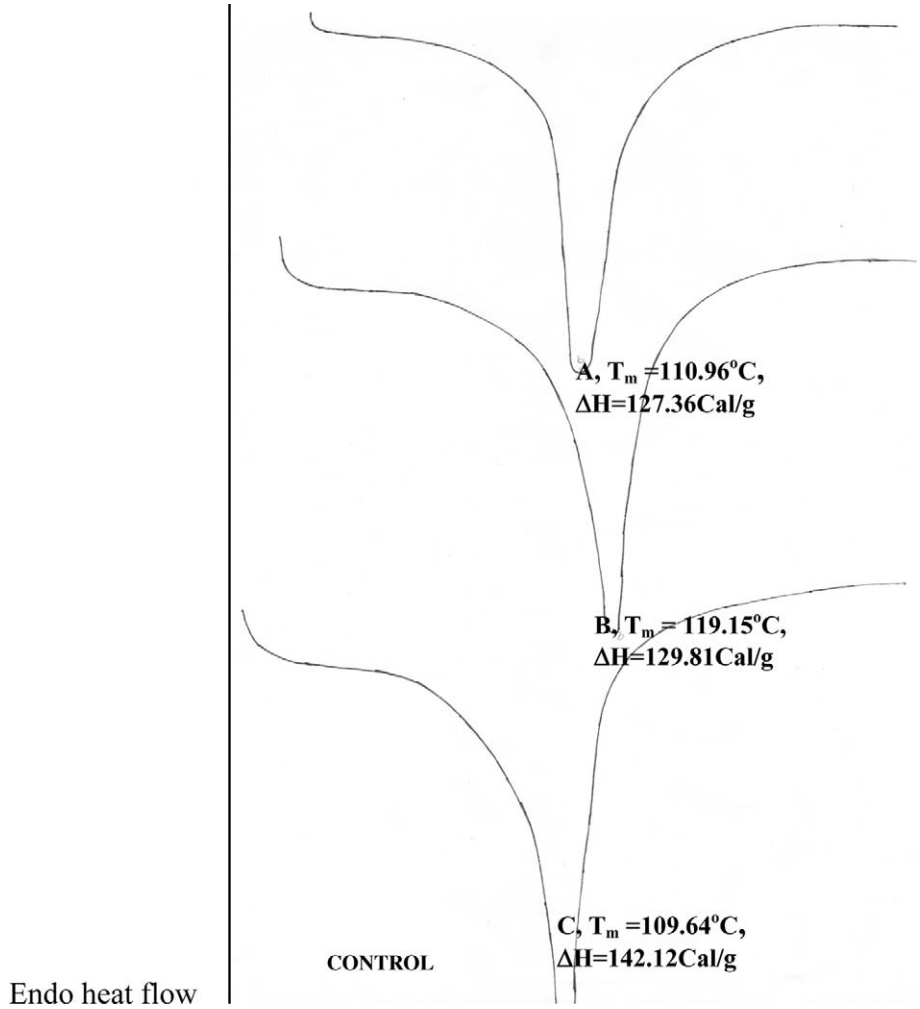

Fig. 1. DSC Thermogram of fresh and stored chapatti (without any anti-staling agents): A = 10th day, refrigerated, B = 0th day storage, temperature C = 10th day, room temperature.

Table 1
Proximate analysis of branded whole wheat flour

Constituents	Percentage
Moisture	13.2 ± 0.51
Dry gluten	10.2 ± 0.31
Protein	12.3 ± 0.20
Total ash	1.1 ± 0.05
Acid insoluble ash	0.05 ± 0.01
Fat	2.12 ± 0.20
Crude fibre	1.98 ± 0.51

Note: All the values are means ± SD of three values.

month of storage. The water-soluble starch also showed a decrease from an initial value of 5.23% to a value of 0.30% after one month of storage at room temperature. This is because starch molecules in pastes or gels are known to associate on aging, resulting in crystallite formation. Crystallites begin to form eventually, and this is accompanied by gradual increase in rigidity and phase separation between polymer and solvent (syneresis) (Colonna, Leloup, & Bule'on, 1992; Morris, 1990). These crystallites are insoluble in water or their solubility is less than the native starch gel. Thus, during storage, crystallites increase, resulting in a decrease in water-soluble starch. These results are in accordance with those of Kim and D'Appolonia (1977), Morad and D'Appolonia (1980) and Boyacioğlu and D'Appolonia (1994), who reported that the amount of extractable water-soluble starch in bread crumb decreased at faster rate during the first 12 h of storage. The amount of amylose in soluble starch from fresh bread is small; it sharply decreases during first day of storage. Thereafter, the change in amylose is minor, and amylopectin alone controls the retrogradation. The amount of water-soluble starch extractable from bread crumb is known to decrease as the bread is aged. It has been reported that water in bread becomes more bound or immobilized (as observed by nuclear magnetic resonance) during staling (Leung, Magnuson, & Bruinsma, 1983; Wynne-Jones & Blanshard, 1986; Kim-Shin, Mari, Rao, Stengle, & Chinachoti, 1991). The physicochemical changes, suggested to be responsible for such a change, include the increase in water within the amorphous domains, some of which undergo aging or networking, changing hydration behaviour (Kim-Shin et al., 1991).

Further, from Table 2, it can be seen that the IVED of starch in chapattis also decreased from 4.63% to 2.09% in

Table 2
Changes in staling parameters of chapattis stored at room temperature (29 ± 1 °C)

Days	Moisture content[a] (MC)		Water-soluble starch[b]		In vitro enzyme digestibility (IVED)[c]		Enthalpy change[d]			Texture[e] F (g)	Hunterlab colorimeter[f]			Sensory score[g]
	(%)	% reduction in MC	(%)	% reduction in WSS	% of glucose liberated	% reduction in IVED	(ΔH) (cal/g)	T_g (°C)	T_m (°C)		L	a	b	
0	32.35 ± 0.25	–	5.23 ± 0.02	–	4.63 ± 0.05	–	129.81 ± 8.04	108.40 ± 1.59	119.15 ± 0.55	225.13 ± 12.13	59.37 ± 0.02	1.29 ± 0.02	17.78 ± 0.09	9
1	30.32 ± 0.39	–	2.15 ± 0.08	–	4.01 ± 0.01	–	–	–	–	276.19 ± 10.15	59.18 ± 0.09	1.25 ± 0.04	18.27 ± 0.07	7
2	27.89 ± 0.43	13.79	2.00 ± 0.05	61.76	4.00 ± 0.12	13.71	136.48 ± 4.45	104.43 ± 0.09	109.73 ± 0.25	318.12 ± 15.46	59.55 ± 0.03	1.30 ± 0.02	17.98 ± 0.05	6
3	25.65 ± 0.29	–	2.12 ± 0.12	–	3.85 ± 0.11	–	–	–	–	348.94 ± 21.82	59.32 ± 0.09	1.33 ± 0.07	17.54 ± 0.10	4
4	24.19 ± 0.38	–	1.64 ± 0.08	–	3.42 ± 0.08	–	–	–	–	362.20 ± 9.84	59.74 ± 0.06	0.92 ± 0.05	17.61 ± 0.04	4
5	24.57 ± 0.24	24.05	1.30 ± 0.15	75.20	3.33 ± 0.05	28.17	141.12 ± 9.98	102.91 ± 0.04	111.15 ± 0.12	388.18 ± 16.36	59.23 ± 0.02	1.21 ± 0.07	17.42 ± 0.04	3
7	22.19 ± 0.33	–	1.13 ± 0.19	–	3.08 ± 0.16	–	–	–	–	411.44 ± 8.11	59.24 ± 0.09	1.07 ± 0.03	17.41 ± 0.09	1
10	21.79 ± 0.55	32.64	1.11 ± 0.05	78.72	3.05 ± 0.08	34.15	142.12 ± 2.29	102.14 ± 0.25	109.64 ± 0.03	423.19 ± 11.12	59.34 ± 0.12	0.90 ± 0.01	17.88 ± 0.02	1
15	18.37 ± 0.45	–	0.83 ± 0.08	–	2.89 ± 0.06	–	–	–	–	485.46 ± 14.18	59.11 ± 0.32	1.20 ± 0.01	17.34 ± 0.04	1
20	16.25 ± 0.38	49.77	0.42 ± 0.33	91.90	2.33 ± 0.08	49.68	–	–	–	499.32 ± 21.16	59.64 ± 0.03	1.23 ± 0.06	17.56 ± 0.08	1
30	16.01 ± 0.36	50.51	0.30 ± 0.11	94.20	2.09 ± 0.05	54.90	–	–	–	618.20 ± 8.18	59.80 ± 0.07	1.25 ± 0.08	17.54 ± 0.04	1

[a,b,c] Means ± SD of three values.
[d] Means ± SD of two values.
[e,f] Mean ± SD of 12 values.
[g] Mean of 10 values rounded to whole number.

Table 3
Changes in staling parameters of chapattis stored at refrigerated temperature (4 ± 1 °C)

Days	Moisture content[a] (MC)		Water soluble starch[b]		In vitro enzyme digestibility (IVED)[c]		Enthalpy change[d]			Texture[e] F(g)	Hunterlab colorimeter[f]			Sensory score[g]
	(%)	% reduction in MC	(%)	% reduction in WSS	% of glucose liberated	% reduction in IVED	(ΔH) (cal/g)	T_g (°C)	T_m (°C)		L	a	b	
0	32.35 ± 0.25	–	5.23 ± 0.02	–	4.63 ± 0.05	–	129.81 ± 8.04	108.40 ± 1.59	119.15 ± 0.55	225.13 ± 12.13	59.37 ± 0.02	1.29 ± 0.02	17.78 ± 0.09	9
1	31.34 ± 0.42	–	4.99 ± 0.08	–	4.28 ± 0.16	–	–	–	–	240.19 ± 13.31	59.23 ± 0.08	1.14 ± 0.09	17.27 ± 0.01	9
2	30.97 ± 0.32	4.27	4.90 ± 0.06	6.31	4.18 ± 0.16	9.72	125.46 ± 1.77	102.34 ± 0.21	110.71 ± 0.05	274.19 ± 11.13	59.44 ± 0.05	1.21 ± 0.02	18.32 ± 0.20	9
3	31.89 ± 029	–	3.28 ± 0.12	–	3.32 ± 0.13	–	–	–	–	301.46 ± 14.55	59.41 ± 0.01	0.45 ± 0.10	17.95 ± 0.18	8
4	30.49 ± 0.32	–	3.20 ± 0.02	–	3.40 ± 0.19	–	–	–	–	345.23 ± 18.33	59.32 ± 0.01	1.16 ± 0.11	17.32 ± 0.02	8
5	25.88 ± 0.34	20.00	1.93 ± 0.05	63.10	3.44 ± 0.06	25.70	107.56 ± 7.82	106.84 ± 1.42	112.79 ± 0.78	359.19 ± 12.20	59.18 ± 0.21	1.33 ± 0.05	17.85 ± 0.04	7
7	24.39 ± 0.33	–	1.79 ± 0.01	–	3.41 ± 0.08	–	–	–	–	368.18 ± 13.46	58.90 ± 0.15	1.28 ± 0.03	17.00 ± 0.09	6
10	23.87 ± 0.39	26.21	1.74 ± 0.11	66.73	3.22 ± 0.05	30.45	127.36 ± 9.06	99.96 ± 1.75	110.96 ± 0.32	382.11 ± 20.18	59.90 ± 0.05	0.89 ± 0.05	17.35 ± 0.09	6
15	22.88 ± 0.20	–	1.22 ± 0.08	–	3.06 ± 0.20	–	–	–	–	398.19 ± 7.46	59.15 ± 0.09	0.57 ± 0.01	17.38 ± 0.08	3
20	22.08 ± 0.31	31.75	1.12 ± 0.11	78.59	2.91 ± 0.15	37.15	–	–	–	418.09 ± 13.32	59.32 ± 0.09	1.27 ± 0.01	17.94 ± 0.04	3
30	21.86 ± 0.35	32.43	1.10 ± 0.05	78.97	2.86 ± 0.06	38.23	–..			437.11 ± 16.75	58.88 ± 0.13	1.28 ± 0.01	17.09 ± 0.01	2

[a,b,c] Means ± SD of three values.
[d] Means ± SD of two values.
[e,f] Means ± SD of 12 values.
[g] Mean of 10 values rounded to whole number.

Table 4
Correlation coefficient of storage time, WSS, IVED, ΔH, MC and texture of chapattis stored at room temperature

	Storage period (days)	MC (%)	WSS (%)	IVED (% of glucose liberated)	ΔH (cal/g)	Texture (g)
Storage period (days)	–	–	–	–	–	–
MC (%)	0.808	–	–	–	–	–
WSS (%)	0.470	0.735	–	–	–	–
IVED (% of glucose liberated)	0.837	0.948	0.782	–	–	–
ΔH (cal/g)	0.771	0.962	0.938	0.976	–	–
Texture (g)	0.912	0.932	0.697	0.942	0.989	–

Table 5
Correlation coefficient of storage time, WSS, IVED, ΔH, MC and texture of chapattis stored at refrigerated temperature

	Storage period (days)	MC (%)	WSS (%)	IVED (% of glucose liberated)	ΔH (cal/g)	Texture (g)
Storage period (days)	–	–	–	–	–	–
MC (%)	0.706	–	–	–	–	–
WSS (%)	0.602	0.862	–	–	–	–
IVED (% of glucose liberated)	0.589	0.636	0.883	–	–	–
ΔH (cal/g)	0.025	0.180	0.310	0.240	–	–
Texture (g)	0.709	0.846	0.962	0.905	0.248	–

one month of storage at room temperature. This is because, during storage, more and more amylose and amylopectin recrystallize and thus limited amounts of amylose and amylopectin are available for the enzyme amyloglucosidase to act on, resulting in less glucose liberation. The results are in accordance with Nanjappa et al. (1999), who showed that amyloglucosidase enzyme used in the estimation of IVED is capable of hydrolyzing the amorphous portion of starch to glucose units and is chemically inert to crystallites. As the network of crystallites increases in the amorphous domain or in other words percent crystallinity increases, the IVED decreases.

Also from Table 2, it can be seen that texture values of the stored chapattis increased during storage at room temperature, indicating the increasing hardness of the chapattis; whereas fresh chapatti had the least value of 225.26, indicating that it was soft, the chapattis stored for one month at room temperature showed a value of 618.20.

As seen from Table 2, the sensory score decreased with time of storage at room temperature, which reflects the loss in acceptability of chapattis. Colour as measured by Hunterlab colorimeter, did not show any predictable trend or change with storage at room temperature.

Further, Table 2 shows an increase in the enthalpy values with increase in the storage period. In the case of retrograded starch, the value of ΔH provides a quantitative measure of the energy transformation that occurs during the melting of recrystallized amylose and amylopectin. In Fig. 1, the thermograms show a staling endotherm peak (SEP) at about 100–120 °C, which is due to the retrograded amylose fraction and retrogradation of amylose takes place immediately in chapatti on being cooled to room temperature. While amylose appears to dominate the initial stages of retrogradation, long term changes in rigidity and crystallinity of starch gels are generally attributed to amylopectin. Chapatti is highly susceptible to staling (Sidhu, Wilflled, & Dietrich, 1990). This may be due to the compact structure (less free volume) of these products compared to bread (Swyngedau, Nussinovitch, Roy, Peleg, & Huang, 1991). Staling (firming) of cereal products increases the T_g from sub zero to ambient temperature due to development of crystallites forming a network (Slade & Levine, 1991).

From Table 3, it can be seen that chapattis stored at refrigerated temperature showed the same pattern of change with respect to moisture content, water-soluble starch, IVED, texture and sensory scores as do chapattis stored at room temperature. However, the reductions in moisture content, WSS and IVED of chapattis stored at refrigerated temperature were less than those of chapattis stored at room temperature. Also, the increase in enthalpy change, ΔH, and texture (force in g) was much less than in chapattis stored at room temperature. Sensory score decreased with time of storage at refrigerated temperature, which reflects the loss in acceptability of chapattis. Colour as measured by Hunterlab colorimeter, did not show any predictable trend or change with storage at refrigerated temperature. This showed that staling occurred, even when chapattis were stored at refrigerated temperature, but to a lesser extent.

From Table 3, it can be seen that the ΔH value decreased initially (up to 5 days) and thereafter it again increased. This may be because, during storage at low temperatures (4° ± 1 °C), gelatinized starch molecules re-associate, but in less ordered and hence less perfect or stable forms than those existing in the native granules (Cooke & Gidley, 1992; Nakazawa, Noguchi, & Takahashi, 1985; Shi & Sheib, 1992; Yaung & Thomson, 1998). Therefore, less energy is required to melt these crystals (Maurice, Slade, Siretto, & Page, 1985; Nakazawa, Noguchi, Takahashi, & Takada, 1984; Wirakarta Kusumah, 1981).

The correlation between various staling parameters of chapatti stored at room temperature is shown in Table 4. Similarly, the correlation coefficients for all the staling parameters of chapatti stored at refrigerated temperature, are listed in Table 5. On comparing Tables 4 and 5, it can be seen that the correlation coefficient for ΔH w.r.t. other parameters was found to be very poor for refrigerated storage as compared to room temperature storage. Most of the other staling parameters showed good correlation. Texture showed the best overall correlation with all other staling parameters. In general, the correlation obtained at room temperature was better than that at refrigerated temperature.

4. Conclusion

The present study on staling of chapattis has established some new findings. Staling in chapatti occurs both at room temperature and refrigerated temperature storage, as is evident from various staling parameters monitored, but the rate of staling is less at refrigeration temperature (4 ± 1 °C) than that at room temperature (29 ± 1 °C) storage. Initial rate of staling is higher and possibly amylose is responsible for this process, as is evident from the DSC thermograms, where the melting of the crystallites occurs in the range 100–120 °C. Good correlation was observed among various staling parameters monitored, particularly for room temperature storage. Texture gave the best overall correlation. Though the mechanism of bread staling and factors affecting it are well understood, further investigations are necessary in order to understand and minimize staling in traditional (Indian) food products, particularly chapatti.

Acknowledgements

The authors thank Prof. J.S. Pai, Head, Food and Fermentation Technology Division, U.I.C.T., Mumbai, for allowing the use of various facilities in the Division, particularly DSC.

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