Effect of surfactant and fat on chapati making quality and control of its staling

Hemalatha M.S., U.J.S. Prasada Rao *

Department of Biochemistry, CSIR-Central Food Technological Research Institute, Mysore, India

**ABSTRACT**

Chapati is an unleavened flat baked product and it is prepared using whole wheat flour. One of the problems with chapatis is that they stale rapidly during storage and therefore, they have to be consumed immediately after their preparation. With changing socio-economic conditions and lifestyles, there is an increasing demand for ready to eat chapatis. In the present study, to control staling, chapatis were prepared using whole wheat flours of four different varieties by incorporating additives such as surfactant and fat. The chapatis stored at room temperature for 24 h, 48 h, 72 h and 96 h were evaluated for their quality parameters such as moisture content, chemical properties, sensory attributes, microstructure and amylograph characteristics. The moisture, soluble starch and soluble amylose contents in control chapatis decreased steadily with storage time and at the end of 96 h, the decrease in moisture, soluble starch and soluble amylose contents in chapatis prepared from different varieties were 3–8%, 80–82% and 78–85%, respectively. However, these changes were found to be at a very lesser rate in chapatis prepared from doughs treated with glycerol monostearate (GMS) and fat compared to that of control. Decrease in amylograph paste viscosity was more in control chapatis during storage compared to that of treated chapatis. Scanning electron microscopic studies of chapatis stored up to 96 h revealed that starch granules were uniform in both GMS and fat treated chapatis, when compared to control chapatis. Sensory studies showed that overall quality scores for chapatis prepared from GMS and fat treated doughs did not show any significant differences on storage. Thus, the results suggested that incorporation of surfactant and fat in dough not only improved the overall quality attributes of chapatis but also controlled their staling, during their storage.

1. **Introduction**

Wheat products like bread and chapati stale on storage and staling leads to decreased consumer acceptance (Rathnayake et al., 2018). Staling is a complex phenomena and it is characterized by hardening of bread crumb and softening of crust, due to starch retrogradation (Karim et al., 2000), interactions between gluten proteins and swollen starch granules (Martin and Hoseney, 1991), and migration of water from crust to crumb and starch to gluten (Baik and Chinachoti, 2000). To control these factors, additives like amylases (Lauro et al., 2016) and hydrocolloids (Sciarini et al., 2010) were incorporated into bread dough. Amylases hydrolyze starch into dextrins, which has capacity to hold water resulting in decrease of crystallization of starch (retrogadation) (Lin and Lineback, 1990). On the other hand, hydrocolloids control staling due to their water holding capacity and inhibiting starch-gluten interactions (Gray and Bemiller, 2003).

Surfactants and fat were also incorporated into bread dough to control staling (Orthoefer and Kim, 2019). Fat and surfactants are amphiphilic compounds and they act as emulsifiers. Fats perform as a lubricant contributing to the smoothness of the dough (Canalis et al., 2018). It imparts desirable eating qualities and contributes soft texture and acceptable flavor to baked products (Jacob and Leelavathi, 2007). Surfactants break down the starch-protein interactions by breaking the secondary bonds and also by denaturation of proteins, while fat weaken the protein-starch interactions through formation of starch-lipid complexes (Gray and Bemiller, 2003; Park and Kim, 2021; Smith and Johansson, 2005). Surfactants also control migration of water from starch to gluten during storage by interacting with starch and gluten network (Asghar et al., 2011).

Chapati is a traditional staple food of majority of the people in Indian
As fat and surfactants are less expensive and easy to handle compared to other additives like enzymes, a study on the effect of surfactant and fat was carried out by evaluating quality parameters such as moisture content, rheological properties, sensory attributes and microstructure of fresh and chapati stored up to 96 h at room temperature without any preservatives.

2. Material and methods

2.1. Materials

*Triticum aestivum* wheat varieties, namely GW-322, NI-5439 (good chapati making varieties), MACS-2496 and HD-2781 (poor chapati making varieties) were obtained from Agribank Research Institute, Pune, India. Wheat samples were ground to whole wheat flours (<400 μm) using EGM-467 K disc mill. Glycerol monostearate (GMS) was obtained from M/s Fine Organic Industries, Mumbai and bakery fat (Marvo) was procured locally.

2.2. Preparation of surfactant emulsions

Emulsion was prepared by dispersing 1 part of GMS in 2 parts of water. The mixture was heated with constant stirring at 65 °C and cooled for further use.

2.3. Preparation of chapati

Dough was prepared by mixing 200g whole wheat flour with optimum quantity of water in a Hobart mixer (Model N-50) at speed 1 (61 rpm) for 3 min. To prepare dough using additives, 1 g of GMS emulsion was mixed with a standard dough blend. Considering the effect of additives, a study on the effect of surfactant and fat was carried out by evaluating quality parameters such as moisture content, rheological properties, sensory attributes and microstructure of fresh and chapati stored up to 96 h at room temperature without any preservatives.

### Table 1

| Variations | Storage period | Color & Appearance | Tearing Strength | Flakiness | Taste & Aroma | Mouthfeel | Overall Quality |
|------------|----------------|--------------------|-----------------|-----------|--------------|-----------|-----------------|
| Control    | 0 hrs          | 7.6 ± 0.3          | 7.3 ± 0.4       | 7.5 ± 0.6 | 7.1 ± 0.5    | 7.4 ± 0.6 | 7.3 ± 0.4       |
|            | 24 hrs         | 7.2 ± 0.6          | 6.1 ± 0.2       | 6.8 ± 0.3 | 6.6 ± 0.2    | 6.6 ± 0.2 | 6.5 ± 0.2       |
|            | 48 hrs         | 6.9 ± 0.1          | 5.3 ± 0.2       | 6.2 ± 0.3 | 6.2 ± 0.5    | 6.0 ± 0.4 | 6.1 ± 0.2       |
| Surfactant | 0 hrs          | 7.8 ± 0.5          | 7.6 ± 0.2       | 7.8 ± 0.4 | 7.7 ± 0.3    | 7.7 ± 0.5 | 7.8 ± 0.4       |
|            | 24 hrs         | 7.8 ± 0.2          | 7.5 ± 0.2       | 7.5 ± 0.3 | 7.6 ± 0.3    | 7.5 ± 0.4 | 7.6 ± 0.2       |
|            | 48 hrs         | 7.8 ± 0.1          | 7.4 ± 0.3       | 7.4 ± 0.2 | 7.5 ± 0.4    | 7.4 ± 0.4 | 7.4 ± 0.4       |
| Fat        | 0 hrs          | 7.6 ± 0.1          | 7.5 ± 0.2       | 7.6 ± 0.3 | 7.6 ± 0.3    | 7.6 ± 0.2 | 7.6 ± 0.2       |
|            | 24 hrs         | 7.6 ± 0.1          | 7.6 ± 0.2       | 7.6 ± 0.3 | 7.6 ± 0.3    | 7.6 ± 0.2 | 7.6 ± 0.2       |
|            | 48 hrs         | 7.6 ± 0.1          | 7.6 ± 0.2       | 7.6 ± 0.3 | 7.6 ± 0.3    | 7.6 ± 0.2 | 7.6 ± 0.2       |
| MACS-2496  | 0 hrs          | 7.6 ± 0.1          | 7.6 ± 0.2       | 7.6 ± 0.3 | 7.6 ± 0.3    | 7.6 ± 0.2 | 7.6 ± 0.2       |
|            | 24 hrs         | 7.6 ± 0.1          | 7.6 ± 0.2       | 7.6 ± 0.3 | 7.6 ± 0.3    | 7.6 ± 0.2 | 7.6 ± 0.2       |
|            | 48 hrs         | 7.6 ± 0.1          | 7.6 ± 0.2       | 7.6 ± 0.3 | 7.6 ± 0.3    | 7.6 ± 0.2 | 7.6 ± 0.2       |
| HD-2781    | 0 hrs          | 7.7 ± 0.3          | 7.3 ± 0.4       | 7.2 ± 0.5 | 7.2 ± 0.2    | 7.2 ± 0.3 | 6.8 ± 0.3       |
|            | 24 hrs         | 6.9 ± 0.3          | 6.3 ± 0.3       | 6.0 ± 0.2 | 6.5 ± 0.2    | 6.8 ± 0.1 | 6.5 ± 0.1       |
|            | 48 hrs         | 6.9 ± 0.3          | 5.8 ± 0.2       | 5.4 ± 0.3 | 6.1 ± 0.3    | 6.6 ± 0.1 | 6.2 ± 0.2       |
| Surfactant | 0 hrs          | 7.8 ± 0.6          | 7.6 ± 0.6       | 7.7 ± 0.4 | 7.6 ± 0.2    | 7.7 ± 0.3 | 7.8 ± 0.5       |
|            | 24 hrs         | 7.8 ± 0.5          | 7.5 ± 0.4       | 7.5 ± 0.3 | 7.6 ± 0.4    | 7.4 ± 0.4 | 7.7 ± 0.3       |
|            | 48 hrs         | 7.7 ± 0.4          | 7.4 ± 0.3       | 7.5 ± 0.2 | 7.5 ± 0.4    | 7.3 ± 0.3 | 7.6 ± 0.3       |
| Fat        | 0 hrs          | 7.7 ± 0.2          | 7.7 ± 0.2       | 7.5 ± 0.2 | 7.6 ± 0.3    | 7.7 ± 0.2 | 7.9 ± 0.2       |
|            | 24 hrs         | 7.7 ± 0.2          | 7.7 ± 0.2       | 7.5 ± 0.2 | 7.6 ± 0.3    | 7.7 ± 0.2 | 7.9 ± 0.3       |
|            | 48 hrs         | 7.7 ± 0.3          | 7.6 ± 0.3       | 7.4 ± 0.3 | 7.5 ± 0.3    | 7.7 ± 0.2 | 7.8 ± 0.3       |

* NMS*: Glycerol Monostearate.

1) Data reported as mean ± SD of eight determinations. Means followed by different letters in the same group differ significantly (p<0.05) by Duncan Multiple Range Test.

subcontinent and Asian ethnic communities residing all over the world. As chapati stale swiftly during storage, freshly prepared chapatis are preferred by the consumers. Due to change in lifestyles of consumers, there is an increase in demand for ready to eat chapatis. Although considerable work on the effect of surfactants and fat on bread staling is reported, only few studies on chapatis prepared from dough incorporated with surfactants, hydrocolloids, dextrins and enzymes are available. However, these studies were carried out for limited storage period of 2 days, or storage in refrigeration and in presence of preservatives. Gojral and Gaur (2005) evaluated the extensibility parameter of chapati and reported that glycerol monostearate (GMS) and NaCl showed higher extensibility up to 24h compared to control. Ghodke and Ananthanarayan (2007) reported that chapati dough treated with guar gum had less staling up to 2 days at refrigerated temperature. Later, these workers incorporated sodium stearoyl-2-lactylate(SSL), GMS, propylene glycol, sorbitol, α-amylase, xylanase, maltodextrin and guar gum in presence of preservatives into dough individually as well as in combination, and reported that maltodextrin was more effective, but combination of α-amylase+SSL was more effective at 4 °C due to its synergistic effect (Shaikh et al., 2008).

As fat and surfactants are less expensive and easy to handle compared to other additives like enzymes, a study on the effect of surfactant and fat was carried out by evaluating quality parameters such as moisture content, rheological properties, sensory attributes and microstructure of fresh and chapati stored up to 96 h at room temperature without any preservatives.
Fig. 1. Soluble starch contents of chapatis treated with surfactant and fat.

Fig. 2. Soluble amylose contents of chapatis treated with surfactant and fat.
and 5% of fat were added to whole wheat flour. The dough rested for 30 min at room temperature was divided into small portions (25g). Each portion was sheeted into a thickness of 1.5 mm and was cut into circular shape (12 cm diameter) using a die and baked on hot plate (Haridas Rao et al., 1986). Chapatis were cooled, packed in polypropelene pouches and stored at room temperature until further use.

2.4. Sensory evaluation of chapati

Sensory evaluation of chapatis was done by a panel of eight judges using 10-point scale to assess various sensory attributes. Judges were asked to give maximum scores when chapatis had smooth surface with golden brown color (color and appearance), greater pliability (folding ability), soft texture and easy to tear (tearing strength), little chewiness (mouthfeel), typical wheatish aroma with slight sweetish taste. On the other hand, when chapatis had less pliability, whitish color, leathery texture, excessive chewiness and bland taste the judges were asked to give the lowest scores.

2.5. Chemical analysis of chapati

Moisture content of chapatis was determined by two stage method/oven drying method (AOAC, 2006). Chapatis were cut into small pieces and taken in a petri plate, covered with a sieve and incubated at room temperature for overnight. Chapati pieces were powdered and weighed in an aluminum dish. The dish was kept in an oven maintained at 130 ± 1 °C for 4h and the powder weight was taken after cooling in a desicator. The estimation of soluble starch was done as per the procedure described by Shaikh et al. (2008) and soluble amylose was done as described by Sowbhagya and Bhattacharya (1971). To determine the soluble starch content, chapati powder (200 mg) was soaked in 15 ml of water and stirred for 20 min and centrifuged at 5,000g for 10 min. The supernatant (10 ml) was treated with iodine solution. For soluble amylose estimation, to 0.5g of powder, 10 ml of 0.5N KOH was added and made up to 100 ml with water. To 10 ml of aliquot, 5ml of 0.1N HCl and 0.5 ml of iodine solution were added, made the volume to 50 ml. The absorbance of the blue color formed in these experiments was measured at 625 nm.

2.6. Scanning electron microscopic studies of chapati

Chapatis were cut into small pieces (0.5 cm × 0.5 cm) and freeze dried. These dried pieces were mounted on the sample holder of scanning electron microscope (Model 435VP, UK) with the help of double-sided scotch tape and sputter coated with gold (2 min, 2 mbar). The microscopic observation was done at 15 kV and at a vacuum of 9.75 × 10⁻⁵ torr. Micrographs of appropriate magnifications were selected.

2.7. Amylograph characteristics of chapati

Freeze-dried chapatis were powdered to pass through 400μ sieve. Powder (15 g) was dispersed in 100 ml of distilled water and heated to increase the temperature from 30 to 92 °C at a rate of 5 °C/min, held at 92 °C for 5 min, cooled to 50 °C and then held for 1 min with constant agitation in a Micro-visco-amylograph (Brabender OHG, Duisburg, Germany). Torque was measured at the range of 300 cmg and viscosity was expressed in Brabender Units (BU).
2.8. Statistical analysis and graphical representation

The data were treated statistically by Duncan’s new multiple range test to determine the significance of experimental data (Steel and Torrie, 1980) using the software SPSS (Statistical Products and Service Solution), Statsoft Incorporation, Tulsa, USA. Results were expressed as mean ± standard deviation. A value of p<0.05 was considered to be statistically significant.

3. Results and discussion

3.1. Effect of surfactant and fat on moisture content of chapatis during storage

Moisture contents of freshly prepared control chapatis from wheat varieties viz., GW-322, NI-5439, MACS-2496 and HD-2781 were 30.1%, 30.6%, 31.6% and 29.0%, respectively. However, the moisture content decreased to 24.1%, 26.9%, 28.5% and 21.0%, respectively, upon 96 h of storage. Baik and Chinachoti (2000) reported the decrease in crumb moisture content in bread on storage. The moisture contents in case of chapatis prepared from doughs treated with GMS of these four wheat varieties, upon storage for 96 h, were 29.3%, 29.1%, 30.3% and 28.6%, respectively, showing that decrease in moisture was insignificant.

Similar changes were observed in case of fat treated chapatis showing the moisture contents after storage of 96 h were 26.4%, 28.3%, 29.6% and 25.8%, respectively.

Thus, the percentage reduction in moisture content during storage for 96 h in control chapatis (untreated) of these four varieties was 3–8% moisture, while in case of treated chapatis the reduction in moisture content was very low (0.8–1.5%). Between the two additives, reduction in moisture content was found to be lower in case of chapatis prepared from surfactant treated doughs. Earlier studies on bread indicated that addition of surfactant to dough facilitated the formation of starch-surfactant complexes, which avoided the migration of moisture from crumb to crust (Xu et al., 1992).

3.2. Effect of surfactant and fat on sensory properties of chapatis during storage

There was no significant difference in the color and appearance of the fresh and stored chapatis prepared from dough treated with GMS and fat (Table 1). Good quality chapatis should have wheatish colour spread evenly over the surface with light brown spots (Parimala and Sudha, 2015). On the other hand, control chapatis on storage scored lower values as they were less appealing and tough requiring more strength to tear, whereas, chapatis prepared from surfactant and fat treated dough required less strength to tear.

The values for pliability of control chapatis were between 7.2 and 7.5 and upon storage these values decreased significantly (5.4–6.4). The pliability scores were significantly higher for surfactant (7.3–7.7) and fat (7.4–7.9) treated chapatis upon storage compared to control chapatis. Chapatis prepared from surfactant and fat treated dough had wholesome aroma and taste with sweetish aftertaste, which was found to be highly acceptable. The aroma and taste of control chapatis declined on storage.
compared to that of treated chapatis.

Mouthfeel scores correlate to chewing and other textural properties of food products (Sim et al., 2020). Sensory scores of control chapatis for mouthfeel ranged between 7.2 and 7.4 and decreased on storage (6.0–6.6). Chapatis prepared from GMS treated doughs on storage had sensory scores of 7.0–7.5, while for fat treated doughs, they were 7.6–7.9. The mouthfeel values for control chapatis were significantly lower than that of the treated chapatis (Table 1). Knightly (1988) reported that GMS forms a complex between monoglycerides and amylose contributing to decrease in firming.

Overall sensory quality of chapatis is attributed by all the above parameters, showing an improving effect when doughs were treated with surfactants and fats. The sensory properties of chapatis prepared from all the wheat varieties improved on treating with surfactant and fats during storage. Thus, treatment of dough with surfactant and fat in chapati preparation improves the overall quality of product and also decreases the rate of staling.

3.3. Effect of surfactant and fat on chemical characteristics of stored chapatis

Changes in starch characteristics during storage may contribute to staling of chapatis. As shown in Figs. 1 and 2, changes in soluble starch and soluble amylose contents were observed in control and treated chapatis. The soluble starch and soluble amylose contents in control chapatis significantly decreased on storage. Fresh chapatis prepared from dough treated with GMS and fat had higher content of soluble starch and soluble amylose compared to control chapatis. Although there was a significant decrease in the content of these components during storage, the decrease observed was significantly very low in case of treated chapatis stored for 96h. Surfactant has both hydrophilic and hydrophobic moieties in their molecular structure and it was reported that surfactants form complexes with amylose as well as amyllopectin fractions (Gomez et al., 2004). Therefore, the changes in the contents of these components may influence the product quality.

3.4. Scanning electron microscopic studies of chapatis during storage

During baking, starch granules gets gelatinized and gelatinized starch (GS) forms into continuous starch net work. Partially GS particles were observed in control chapatis prepared from wheat varieties having good chapati making properties (GW-322 and NI-5439) (Figs. 3 and 4), while in wheat varieties having poor chapati making properties (MACS-2496 and HD-2781), less number of GS particles were observed. With respect to proteins matrix, protein aggregation (PA) was also less in good varieties, while PA was more prominent in poor chapati making varieties (Figs. 5 and 6). With the increase in storage time, increase in PA and further decrease in GS particles was observed. Earlier SEM studies, on bread also revealed continuous GS network in fresh breads and rigidity of starch particles on staling (Błaszczyk et al., 2004).

In case of chapatis prepared from GMS treated doughs of all the wheat varieties, GS particles were distributed all over the area focused (Figs. 3–6). Thin protein (TP) film formed around the concentrated GS particles, which was contemplated by a glossy structure enfolded in a...
circular shape delineating the starch granule. On storage for 24 h, there was no change observed in the microstructure. On further storage for 48 h, the microstructure showed slight difference in the matrix of protein conjugation. However, uniformity in starch structure was observed in fresh and stored GMS treated chapatis.

In the microstructure of fat treated chapatis, GS granular structure and protein network with glossy structure covered with TP around starch particles were observed (Figs. 3–6). There was slight difference in

PA - Protein aggregation GS - Gelatinized starch TP - Thin protein

Table 2
Amylograph paste viscosity of chapatis treated with surfactant and fat.

| Wheat Varieties | Hours | Maximum Paste Viscosity (BU) | Cold Paste Viscosity (BU) |
|-----------------|-------|------------------------------|--------------------------|
|                 |       | Control | Surfactant | Fat  | Control | Surfactant | Fat  |
| GW-322          | 0     | 386     | 514       | 333  | 627     | 815       | 573  |
|                 | 24    | 294     | 508       | 284  | 539     | 808       | 483  |
|                 | 48    | 211     | 498       | 255  | 312     | 800       | 391  |
|                 | 72    | 139     | 484       | 202  | 206     | 780       | 345  |
|                 | 96    | 112     | 471       | 184  | 155     | 779       | 274  |
| NI-5439         | 0     | 390     | 463       | 379  | 690     | 740       | 661  |
|                 | 24    | 301     | 431       | 293  | 530     | 667       | 497  |
|                 | 48    | 273     | 314       | 202  | 497     | 595       | 340  |
|                 | 72    | 242     | 285       | 187  | 413     | 473       | 303  |
|                 | 96    | 212     | 264       | 176  | 345     | 423       | 287  |
| MACS-2496       | 0     | 232     | 326       | 137  | 369     | 471       | 256  |
|                 | 24    | 135     | 256       | 121  | 222     | 396       | 202  |
|                 | 48    | 119     | 188       | 109  | 194     | 259       | 119  |
|                 | 72    | 103     | 163       | 97   | 145     | 212       | 109  |
|                 | 96    | 85      | 112       | 81   | 123     | 185       | 98   |
| HD-2781         | 0     | 332     | 422       | 206  | 601     | 757       | 432  |
|                 | 24    | 245     | 414       | 180  | 427     | 743       | 414  |
|                 | 48    | 109     | 403       | 165  | 229     | 738       | 362  |
|                 | 72    | 99      | 392       | 143  | 165     | 731       | 345  |
|                 | 96    | 82      | 384       | 124  | 143     | 726       | 312  |

Data reported are as-is basis and expressed as means of two determinations.
protein matrix with partial PA on storage and uniformity in starch structure was observed in fresh and stored chapatis prepared from fat treated doughs of all the wheat varieties.

3.5. Effect of surfactant and fat on amylograph characteristics of stored chapatis

Amylograph studies reveal the changes in viscosities during the complete process of gelatinization and retrogradation of starch (Zeng et al., 1997). The paste viscosities and cold paste viscosities of Control chapatis decreased on storage (Table 2) indicating the retrogradation of starch in chapati. During staling starch retrograde and form rigidity in starch granules. In confirmation with the present study, amylograph studies on bread crumb during storage showed a decrease in paste viscosity (Xu et al., 1992). The substantial binding of water on ageing causes rigidity in starch granules due to configuration of cross-linkages of starch molecules through hydrogen bonds (Redgwell et al., 2001). In the present study, paste viscosity was not significantly different on storage in treated chapatis. The decrease in paste viscosities of chapatis prepared from glycerol monostearate treated dough is around six times lesser than that of control chapatis on storage (Table 2). Surfactants are reported to delay pasting characteristics of bread (Gray and Bemiller, 2003).

The paste viscosities of fat treated chapatis were less in comparison with control and GMS treated fresh and stored chapatis. The paste viscosities of bread crumbs treated with shortenings are also known to give lower viscosities (Xu et al., 1992). The fat added do not form an inclusion complex with amylose, hence the lubrication between granules decrease. Amylose and amyllopectin molecules entangle with each other and among themselves disassociating the lipids in which state lower paste viscosities are exhibited (Xu et al., 1992). However, the paste viscosities of fat treated chapatis did not decrease significantly on storage.

4. Conclusions

Staling of chapatis was controlled upon treating the doughs with additives, viz., surfactant and fat. These additives improved the overall quality attributes of chapatis. These quality enhancements are due to alterations in rheological properties of dough as well as microstructure of chapatis. As surfactant and fat are less costly and easier to handle compared to other additives like different enzymes, these compounds become more popular additives to control chapati staling.

Acknowledgements

The authors thank Director, CSIR-Central Food Technological Research Institute for constant support and encouragement in carrying out the study.

References

Aoac, 2006. AOAC. Official Methods of Analysis, seventeenth ed. Association of Official Analytical Chemists, Washington DC.
Asghar, A., Anjum, F.M., Allen, J.C., 2011. Utilization of dairy byproduct proteins, surfactants, and enzymes in frozen dough. Crit. Revs. in Food Sci. and Nutr. 51 (4), 374-382.
Baik, Chinchoti, 2000. Moisture Redistribution and Phase Transitions During Bread Staling. Cereal Chem. 77, 484–488.
Błaszczak, W., Sadowska, J., Rosell, C.M., Formal, J., 2004. Structural changes in the wheat dough and bread with the addition of alpha-amylases. Europ. Food Re. Technol. 219, 348–354.
Canalis, M.S.B., Valentinuzzi, M.C., Acosta, R.H., Leon, A.E., Ribotta, P.D., 2018. Effects of fat and sugar on dough and biscuit behaviours and their relationship to protein mobility characterized by TD-NMR. Food Bioprocess Technol. 11, 953–965.
Ghodke, K.S., Ananthanarayan, L., 2007. Influence of additives on rheological characteristics of whole-wheat dough and quality of Chapati (Indian unleavened flat bread) Part I—hydrocolloids. Food Hydrocolloids 21 (1), 110–117.
Gomez, M., Real, S.D., Rosell, C.M., Ronda, F., Blanco, C.A., Caballero, P.A., 2004. Functionality of different emulsifiers on the performance of breadmaking and wheat bread quality. Europ. Food Re. Technol. 219, 145–150.
Gray, J.A., Bemiller, J.N., 2003. Bread staling: molecular basis and control. Compr. Rev. Food Sci. Food Saf. 2, 1–21.
Gujral, H.S., Gaur, S., 2005. Instrumental texture of chapati as affected by barley flour, glycerol monostearate and sodium chloride. Int. J. Food Prop. 8 (2), 377–385.
Haridas Rao, P., Leelavati, K., Shurpalekar, S.R., 1986. Test baking of chapati—flat bread) Part I—hydrocolloids. Food Hydrocolloids 21 (1), 36–40.
J. Food Eng. 79 (1), 299–305.
Karin, A.A., Norizah, M.H., Seow, C.C., 2000. Methods for the study of starch retrogradation. Food Chem. 71, 9–36.
Knightly, W.H., 1988. Surfactants in baked foods. Current practices and future trends. Cereal Foods World 33, 405–412.
Lauro, R., Spina, A., Pasqualone, A., Auditore, L., Puglisi, L., Puglisi, G., 2016. A novel α-amylase-lipase formulation as anti-staling agent in durum wheat bread. LWT-Food Sci. Technol. 65, 381–389.
Lin, W., Lineback, D.R., 1990. Changes in carbohydrate fractions in enzyme-supplemented bread and the potential relationship to staling. Starch Stärke 42, 385–394.
Martin, M.L., Hoseney, R.C., 1991. A mechanism of bread firming. II. Role of starch hydrolyzing enzymes. Cereal Chem. 68, 503–507.
Orthofer, F., Kim, D., 2019. Applications of Emulsifiers in Baked Foods. Food Emulsifiers and Their Applications, pp. 299–321.
Parimala, K.R., Sudha, M.L., 2015. Wheat-based traditional flat breads of India. Crit. Rev. Food Sci. Nutr. 55 (1), 67–81.
Park, S., Kim, Y., 2021. Clear label starch: production, physicochemical characteristics, and industrial applications. Food Sci.Biotechnol. 30 (1), 1–17.
Rathnayake, H.A., Navaratne, S.B., Navaratne, C.M., 2018. Porous crumb structure of leavened baked products. Intern. J. Food Sci. Article ID 8187318 (2018).
Redgwell, R.J., Michieli, J.H., Fischer, M., Reynold, S., Nicolas, P., Siveert, D., 2001. Xylanase induces changes to water and alkalai extractable arabinoxylans in wheat flour: their role in lowering batter viscosity. J. Cereal. Sci. 33, 83–96.
Scriarini, L.S., Ribotta, P.D., Leon, A.D., Perez, G.T., 2010. Effect of hydrocolloids on gluten-free batter properties and bread quality. Int. J. Food Sci. Technol. 45, 2306–2312.
Shaikh, I.M., Ghodke, S.K., Ananthanaryan, L., 2008. Inhibition of staling of chapati (Indian unleavened flat bread). J. Food Process. Preserv. 32, 378–402.
Sim, E., Park, E., Mo, F., Baik, B., Ponseca, J.M., Delviche, S.R., 2020. Sensory and physicochemical properties of whole wheat salted noodles under different preparations of bran. J. Cereal Sci. 96, 103–112.
Sowbhagya, C.M., Bhattacharya, K.R., 1971. A simplified colorimetric method for determination of amylose content in rice. Starch/Starke 23, 53–56.
Steel, G.D., Torrie, J.H., 1980. Principles and Procedures of Statistics. McGraw Hill, New York, USA.
Xu, A., Chung, K., Pinto, G.J., 1992. Bread crumb amylograph studies. I. Effects of storage time, shortening, flour lipids, and surfactants. Cereal Chem. 69, 495–501.
Zeng, M., Morris, C.F., Batey, I.L., Wrigley, C.W., 1997. Sources of variation for starch gelatinization, pasting, and gelation properties in wheat. Cereal Chem. 74, 63–71.