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Hydrocolloids in wheat breadmaking: A concise review

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ABSTRACT

The present review analyzes the effect of the most common hydrocolloids on diverse aspects of wheat breadmaking. This encompasses exudate gums, gums from seaweeds, modified celluloses, pectins, galactomannans from leguminous seeds and exopolysaccharides from microbial fermentation. Hydrocolloids are employed to improve dough performance, bread characteristics and sensorial quality. They are also added to minimize non desired changes in crumb texture during storage (anstistaling effect). In bake off technologies (frozen dough, par-baked bread) they can help to preserve the structure from damage by freezing thus rendering acceptable products. Finally, nutritional improved mixtures of wheat and other flours can take advantage from hydrocolloids addition in order to compensate a diminished quality.

1. Introduction

Bread is one the most popular and consumed foods in the world. Bread characteristics depend on both flour quality and the breadmaking procedure. High-quality bread from refined WF (white bread) is characterized by a high volume, soft and elastic crumb with uniform appearance, and a relatively extended shelf life. Flour quality is a key factor for achieving an acceptable product and is mainly related to GP quality and quantity. Since deficiencies in flour quality must be compensated to obtain an acceptable product, the addition of flour improvers (oxidizing agents, emulsifiers and enzymes) is a common practice in breadmaking (Stauffer, 1990). In recent years, there has been increasing interest in hydrocolloids due to their natural origin, effects on dough rheology and bread quality. Hydrocolloids have also been satisfactorily used as antistaling agents. Moreover, new technologies such as BOT (baking off technologies) can use these improvers to compensate for the damage by freezing (Selomulyo & Zhou, 2007).

Nutritional trends towards a more healthy diet have promoted the consumption of WG breads and composite breads (mixtures formulated with WF and flours from other sources) that can include high contents of fiber and/or other beneficial components. Despite the increasing interest in these functional foods, the marked sensory differences with respect to standard products continue to be barriers to consumers' acceptance (Heiniö et al., 2016). Among the strategies to enhance acceptance, the use of hydrocolloids can help improve the technological and sensory quality of these breads. The present review summarizes some topics on traditional and new applications of these additives in breadmaking, with a focus on the contributions from recent years (see Table 1).

2. Hydrocolloids as dough and fresh bread improvers

The mechanisms involved in the effect of hydrocolloids on dough and bread characteristics have deserved considerable attention.

The addition of hydrocolloids to WF leads to changes in water absorption. The water absorbing capacity of WF is mainly associated with GP hydration and the development of the gluten network during kneading. Due to their hydrophilic nature, the addition of

Abbreviations: AG, arabic gum; AL, sodium alginate; BG, brea gum; BOT, baking off technologies; κ-CAR, Kappa carrageenan; ι-CAR, Iota carrageenan; λ-CAR, Lambda carrageenan; CH, chitosan; CLSM, confocal laser scanning microscopy; CMC, carboxymethyl cellulose; D, dextran; DSC, differential scanning calorimetry; FOS, fructo-oligosaccharides; GG, guar gum; GOS, gluco-oligosaccharides; GP, gluten proteins; HMP, high methoxyl pectin or high esterified pectin; HPC, hydroxypropyl cellulose; HPMC, hydroxypropylmethyl cellulose; IN, inulin; LBG, locust bean gum; MCC, microcrystalline cellulose; SEM, scanning electron microscopy; Tg, glass transition temperature; TG, tragacanth gum; TSG, tamarind seed gum; WEAX, water-extractable arabinoxylans; WF, wheat flour; WG, whole grain; WUAX, water-unextractable arabinoxylans; XG, xanthan gum.

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gums strongly affects this parameter. Several authors have reported enhanced farinographic water absorption when adding hydrocolloids (AL, k-CAR, XG, MCC, CMC, HPMC, GG, LBG, HMP, D) in a wide range of concentrations (0.1%–5% flour basis-f.b.) (Correa, Añón, Pérez, & Ferrero, 2010; Linlaud, Puppo, & Ferrero, 2009; Maleki & Milani, 2013; Rosell, Rojas, & Benedito, 2001; Tavakolipour & Kalbasi-Ashtari, 2006; Zannini, Waters, & Arendt, 2014). Other methods for evaluating water absorption, such as water imbibing capacity or sedimentation tests, have confirmed this trend (Linlaud et al., 2009). Moreover, linear relationships between hydrocolloid content and water absorption were reported for modified celluloses (Correa et al., 2010; Zannini et al., 2014) and also for other gums such as XG and D (Zannini et al., 2014). Interestingly, the type of hydrocolloid seems to be a more important factor than concentration, as demonstrated by Bárcenas, De la O-Keller, and Rosell (2009), who studied the effect of AG, HPMC and HMP on the hydration properties of gluten-hydrocolloid systems (0.002–0.013 g hydrocolloid/g gluten).

Hydrocolloid interaction with GP does affect the characteristics of the gluten network. León et al. (2000) studied the interactions between different isoforms of carrageenans and GP by IR spectroscopy and SDS-PAGE, and reported that λ-CAR (the most sulfated isoform) could interact better with GP due to its higher hydration capacity and its particular conformation. Furthermore, Ribotta, Ausar, Beltramo, and León (2005) evaluated the interactions between different hydrocolloids (ι-CAR, λ-CAR and κ-CAR, AL, LBG, GG, HMP, XG) and GP by viscosity measurements and electrophoresis. They reported that HMP and λ-CAR have a high ability to form complexes with GP through ionic interactions (through carboxylic and sulfated groups, respectively), which would explain the effect of these gums on dough strength. According to the authors, hydrogen bonding may also play a key role in polysaccharide-GP interactions, which would explain the effects of nonionic gums on dough.

FT-Raman spectroscopy revealed changes in the secondary conformation of GP when hydrocolloids were added to dough (Correa, Ferrer, Añón, & Ferrero, 2014; Linlaud, Ferrer, Puppo, & Ferrero, 2011). The analysis of the amide I band indicated that GG, XG, HPMC and CMC (1%–1.5% f.b.) decreased α-helix conformation, increasing more unfolded, disordered structures. Rosell and Foegeding (2007) studied protein solubility in HPMC-gluten systems and suggested that HPMC could have an interfering role in gluten network formation, reducing cross-linking. Thus, at 85 °C protein extractability decreased, indicating the formation of aggregates but the presence of HPMC promoted protein solubility. By CLSM, Correa et al. (2014) determined that HPMC addition could induce the formation of aggregates, thus leading to a more open gluten network, particularly in the presence of NaCl. On the other hand, the use of CMC led to a more cross-linked network.

Conformational changes in GP were also observed by FT-IR when fiber-rich ingredients containing cellulose and pectin (carob pulp, apple-cranberry, cacao, and oat) were added to dough at 6% (f.b.) (Nawrocka, Miś, & Szymańska-Chargot, 2016). These authors proposed that β-sheets and β-turns located outside the protein complex could form β-like structures between two protein molecules. These changes correlated positively with the increase in the resistance to extension. Nawrocka, Szymanska-Chargot, Mis, Kowalski, and Gruszecki (2016) studied gluten-fiber systems with chokeberry, cranberry, cacao, carrot, oat and flax fibers (3%–9% w/w gluten-fiber mixture basis) by FT-IR. All fibers decreased the α-helix proportion and increased the content of antiparallel β-sheet, suggesting that cellulose, the component present in all of them, could promote these changes. These authors proposed that other changes in the gluten structure related to disulfide bridge conformation and protein folding or aggregation were more dependent on the type of fiber and could be associated with pectin interaction with GP.

As the competition of gluten and hydrocolloids for water and the intermolecular interactions between hydrocolloids and GP affect the network structure, the rheological behavior of dough is also affected. Farinograph dough development time (DDT-the time elapsed from the first addition of water to the development of the maximum dough consistency) is related to gluten network formation and can be longer, depending on the type and concentration of gum (Correa et al., 2010; Maleki & Milani, 2013; Rosell et al., 2001; Zannini et al., 2014). The effect on farinograph dough stability (the time elapsed between the moment the top of the curve reaches 500 BU and the moment it falls below 500 BU), a parameter related to flour strength, seems to vary greatly depending on the type and concentration of hydrocolloids, flour characteristics and the presence of other components like NaCl. It has been reported that GG increases stability at 0.25%–1.5% f.b. (Linlaud et al., 2009), but some authors indicated a positive effect only at 0.1% f.b. (Maleki & Milani, 2013). Rosell et al. (2001) reported a high increase in this parameter when XG was added at 0.5% f.b., but a scarce effect was noted by other authors (Linlaud et al., 2009). In the case of modified celluloses, stability seems to depend strongly on the presence of salt (Correa et al., 2010). Stability decreases significantly in dough with HPMC (0.5–1.5% f.b.) and NaCl because salt can promote hydrophobic interactions with GP. On the other hand, the interaction with charged molecules like CMC (0.5%–1.5% f.b.), which reduces stability, seems to be favored in the absence of NaCl, probably due to a screening effect when salt is present. From a microstructural point of view, less stable and softer dough has a more disrupted gluten network, as observed by SEM. Tavakolipour and Kalbasi-Ashtari (2006) reported a decrease in extensograph extensibility and an increase in resistance (R_{50}) for CMC and HPMC added dough (0.1%–0.5% f.b., with salt). Bollaín and Collar (2004) found major effects on extensional parameters by the combined addition of hydrocolloids and emulsifiers (HMP/HPMC, DATEM/HMP and DATEM/HPMC) at maximum addition levels (0.372%, 2.088% and 0.844% f.b. for HPMC, HMP and DATEM, respectively). It can be concluded that hydrocolloid competition with gluten proteins for water is a key factor that affects gluten development. However, the effect on dough rheology will also depend on the particular interactions between hydrocolloids and gluten proteins. A positive interaction would lead to a reinforced dough, but a negative one can produce a disrupted network and a less stable and softer dough.

During baking, starch gelatinizes, protein coagulation takes place and the spongy structure obtained during leavening is fixed, forming the bread crumb. It has been stated that granule swelling can be reduced, leading to a stiffening effect, by the presence of hydrocolloids (particularly in high concentrated systems) that can interact with the molecules lixiviated from starch granules (Biliaderis, Arvanitoyannis, Izydroczyk, & Prokopowich, 1997; Krüger, Ferrero, & Zaritzky, 2003). Thus, due to these interactions, crumb structure and texture are influenced by the presence of gums. However, concerning the starch thermal behavior, at the levels usually used (up to 2% f.b.), hydrocolloids would not have a marked effect on calorimetric parameters (Correa & Ferrero, 2015a; Linlaud et al., 2011). At higher concentrations, hydrocolloids can affect the thermal behavior of dough. Santos, Rosell, and Collar (2008) studied the effects of flour replacement at medium-high levels (6%–34%) by soluble (IN), partially soluble (from sugar beet, pea cell wall), and insoluble (from pea hull) dietary fiber on wheat dough thermal profiles using differential scanning calorimetry (DSC). According to the higher initial and peak gelatinization temperatures, lower end temperature and gelatinization enthalpy (ΔH), these authors concluded that fibers would restrict starch swelling by restricting the availability of water for the remaining

Table 1
Applications on wheat dough, bread and BOT of common commercial hydrocolloids and some novel ones.

Hydrocolloid source	Hydrocolloid	Studied system or topic	Suggested references
seaweeds	Sodium alginate	Dough	Guarda et al. (2004); Ribotta et al. (2005); Rosell et al. (2001); Upadhyay et al. (2012)
		Bread	Guarda et al. (2004); Ribotta et al. (2005); Rosell et al. (2001)
		BOT	Kondacki et al. (2015)
	Agar-agar	Composite breads	Mastromatteo et al. (2015)
	Carrageenans	Dough	Ghodke and Ananthanarayan (2007); Guarda et al. (2004); León et al. (2000); Ribotta et al. (2005); Rosell et al. (2001); Patil and Arya (2016); Smitha et al. (2008)
		Bread	Ghodke and Ananthanarayan (2007); Guarda et al. (2004); León et al. (2000); Patil and Arya (2016); Ribotta et al. (2005); Rosell et al. (2001); Smitha et al. (2008)
		Composite breads	Das et al. (2015); Mamat et al. (2013)
		BOT	Bárcenas et al. (2003); Bárcenas et al. (2004); Morimoto et al. (2015); Sharadanant and Khan (2003a), Sharadanant and Khan (2003b), Sharadanant and Khan (2006),
modified celluloses	MCC	Dough	Correa et al. (2010); Correa et al. (2014)
		Bread	Correa and Ferrero (2015b)
	HPMC	Dough	Bárcenas et al. (2009); Bollaín and Collar (2004), Correa et al. (2010); Correa et al. (2014); Ghodke and Ananthanarayan (2007); Guarda et al. (2004); Maleki and Milani (2013); Patil and Arya (2016); Rosell et al. (2001); Rosell and Foegeding (2007); Smitha et al. (2008); Tavakolipour and Kalbasi-Ashtari (2006); Zannini et al. (2014)
		Bread	Armero and Collar (1996); Armero and Collar (1998); Bárcenas and Rosell (2005); Correa and Ferrero (2015b); Ghodke and Ananthanarayan (2007); Guarda et al. (2004); Maleki and Milani (2013); Rosell et al. (2001); Smitha et al. (2008); Patil and Arya (2016); Tavakolipour and Kalbasi-Ashtari (2006); Zannini et al. (2014)
		BOT	Ahmed et al. (2013); Bárcenas et al. (2003); Bárcenas et al. (2004); Bárcenas and Rosell (2007); Mandala et al. (2007); Mandala et al. (2008); Mandala et al. (2009); Polaki et al. (2010)
	HPC	Composite breads	Mastromatteo et al. (2015)
	CMC	Dough	Correa et al. (2010); Correa et al. (2014); Ghodke and Ananthanarayan (2007); Maleki and Milani (2013); Patil and Arya (2016); Tavakolipour and Kalbasi-Ashtari (2006)
		Bread	Armero and Collar (1996); Armero and Collar (1998); Correa and Ferrero (2015b); Ghodke and Ananthanarayan (2007); Maleki and Milani (2013); Patil and Arya (2016); Tavakolipour and Kalbasi-Ashtari (2006)
		Composite breads	Angioloni and Collar (2008); Angioloni and Collar (2009a); Angioloni and Collar (2009b); Angioloni and Collar (2012); Das et al. (2015); Ho and Noor Aziah (2013); Previtali et al. (2014)
		BOT	Ahmed et al. (2013); Asghar et al. (2007); Morimoto et al. (2015); Sharadanant and Khan (2003a), Sharadanant & Khan (2003b), Sharadanant and Khan (2006)
galacto-mannans	Guar gum	Dough	Ghodke and Ananthanarayan (2007); Ghodke (2009); Linlaud et al. (2009); Linlaud et al. (2011); Maleki and Milani (2013); Ribotta et al. (2005); Smitha et al. (2008); Patil and Arya (2016)
		Bread	Ghodke and Ananthanarayan (2007); Ghodke (2009); Maleki and Milani (2013); Patil and Arya (2016); Ribotta et al. (2005); Smitha et al. (2008)
		Composite breads	Bojňanská et al. (2016); Das et al. (2015); Mastromatteo et al. (2015); Previtali et al. (2014); Sahraiyan et al. (2013)
		BOT	Ahmed et al. (2013); Mandala and Sotirakoglou (2005); Mandala et al. (2007); Mandala et al. (2008); Morimoto et al. (2015); Ribotta et al. (2004); Ribotta and Le Bail (2007); Skara et al. (2011);
	Locust Bean Gum	Dough	Linlaud et al. (2009); Linlaud et al. (2011); Ribotta et al. (2005)
		Bread	Ribotta et al. (2005)
		Composite breads	Angioloni and Collar (2008); Angioloni and Collar (2009a); Angioloni and Collar (2009b)
		BOT	Mandala et al. (2007); Mandala et al. (2008); Mandala et al. (2009); Morimoto et al. (2015); Sharadanant and Khan (2003a), Sharadanant and Khan (2003b), Sharadanant and Khan (2006); Polaki et al. (2010)
exudates	Arabic Gum	dough	Bárcenas et al. (2009); Smitha et al. (2008)
		bread	Pečivová et al. (2013); Smitha et al. (2008)
		BOT	Asghar et al. (2007); Sharadanant and Khan (2003a), Sharadanant and Khan (2003b), Sharadanant and Khan (2006)
	Tragacanth	BOT	Gharaie et al. (2015)
	Brea Gum	Bread	López et al. (2013)
		Composite breads	López and Goldner (2015)
plant cell walls	Pectins	Dough	Bárcenas et al. (2009); Bollaín and Collar (2004); Correa et al. (2012); Correa et al. (2014); Linlaud et al. (2009); Linlaud et al. (2011); Ribotta et al. (2005)
		Bread	Correa et al. (2012); Pečivová et al. (2013); Ribotta et al. (2005)
		Composite breads	Angioloni and Collar (2008); Previtali et al. (2014)
		BOT	Morimoto et al. (2015); Rosell and Santos (2010); Skara et al. (2011)
micro-organisms	Xanthan gum	Dough	Guarda et al. (2004); Linlaud et al. (2009); Linlaud et al. (2011); Maleki and Milani (2013); Ribotta et al. (2005); Rosell et al. (2001); Smitha et al. (2008); Upadhyay et al. (2012); Zannini et al. (2014)
		Bread	Guarda et al. (2004); Maleki and Milani (2013); Ribotta et al. (2005); Rosell et al. (2001); Smitha et al. (2008); Zannini et al. (2014)
		Composite breads	Bojňanská et al. (2016); Das et al. (2015); Ho and Noor Aziah (2013); Shittu et al. (2009)
		BOT	Kondacki et al. (2015); Mandala and Sotirakoglou (2005); Mandala et al. (2007); Mandala et al. (2008); Morimoto et al. (2015); Simsek (2009)
	Dextran	Dough	Zannini et al. (2014)
		Bread	Zannini et al. (2014)
	Gellan gum	BOT	Morimoto et al. (2015)

(*continued on next page*)

Table 1 (*continued*)

Hydrocolloid source	Hydrocolloid	Studied system or topic	Suggested references
others	*L. sativum* gum	Composite breads	Sahraiyan et al. (2013)
	Chitosan	Bread	Kerch et al. (2008)
	Konjac gum	BOT	Morimoto et al. (2015)
	Tamarind seed gum	BOT	Morimoto et al. (2015)

ungelatinized granules.

Bread volume and crumb texture and appearance are the most widely studied characteristics for assessing final product quality. Positive effects of CMC, HPMC, k-and λ-CAR, XG, GG and HMP have been reported, at levels varying from 0.1% to 2.0% f.b. (Bárcenas & Rosell, 2005; Correa & Ferrero, 2015b; Correa, Pérez, & Ferrero, 2012; Guarda, Rosell, Benedito, & Galotto, 2004; León et al., 2000; Maleki & Milani, 2013; Rosell et al., 2001).

Volume and crumb porosity are interrelated parameters, and the size and distribution of gas cells are essential factors for bread quality. By observing the structure of gas cells by Cryo-SEM, Bárcenas and Rosell (2005) reported a more continuous surface with thicker appearance when HPMC was added. Bell (1990) suggested that the improving effect of HPMC could be related to its ability to form a temporal gel at high temperatures that then disintegrates during cooling. This network would strengthen the gas cells (alveoli) in the initial stages of baking and help expansion, leading to a better bread volume. As HPMC would act as a barrier to gas diffusion, it also decreases water vapor losses. Zannini et al. (2014) reported a trend to a positive dose response in wall thickness with D and HPMC, but an opposite one with XG.

Among the novel ingredients containing hydrocolloids, gels from ground chia (*Salvia hispanica*) seed (1%–3% chia f.b.) were also reported to stabilize gas bubbles, rendering higher volume yields (100 g f.b.) than WF alone (Zettel, Krämer, Hecker, & Hitzmann, 2015). However, despite this stabilizing effect, the increase in viscosity of the aqueous medium due to hydrocolloid addition could be an inhibiting factor for bubble growth. Upadhyay, Ghosal, and Mehra (2012) studied the effects of AL and XG (0.5%–3% f.b.) on alveolus development in dough and found that increased modulus values led to smaller bubbles and narrower size distributions.

Hydrocolloids have been assayed in other bread products like pizza, where the addition of HMP (1%–1.5% f.b.) or AG (2.5%–3.75% f.b.) improved overall sensory quality (Pečivová, Dula, & Hrabě, 2013). In flat unleavened breads, such as Indian chapatti, parotta and thepla, the effect of HPMC, CMC, carrageenans, GG, XG and AG (0.25%–1% f.b.) was also studied (Ghodke & Ananthanarayan, 2007; Ghodke, 2009; Patil & Arya, 2016; Smitha, Rajiv, Begum, & Indrani, 2008) and in general, a positive effect of GG on bread quality was reported.

In spite of the extensive available information about the effect of hydrocolloids in different bread formulations, much of the work is essentially descriptive. More basic research is still needed to elucidate the underlying mechanisms of action and the interactions with dough components and other breadmaking additives.

3. Hydrocolloids as antistaling agents

Staling during bread storage is a complex process that involves not only starch retrogradation and moisture losses but also polymer reorganization and water migration (Davidou, Le Meste, Debever, & Becaert, 1996; Schiraldi, Piazza, Brenna, & Vittadini, 1996). Among the strategies for avoiding or minimizing this problem, the addition of "antistaling" agents is well known in bakery. Hydrocolloids (alone or combined with other additives) have been assayed as staling inhibitors.

One of the mechanisms involved in the antistaling effect of gums is the increased moisture retention during storage, thus preserving crumb softness (Bárcenas & Rosell, 2005; Guarda et al., 2004). The structure of crumb is also a key factor. Crumb firming during storage depends mainly on the initial firmness, with lower rates for breads with higher specific volume and softer crumbs. The particular effect of additives on bread specific volume and the interaction with gluten will determine the type of crumb structure where starch retrogradation and moisture distribution occur, thus influencing crumb firming kinetics (Armero & Collar, 1998). Among the factors influencing staling, inhibition of starch-gluten interactions or the development of macromolecular entanglements in the amorphous part of the crumb have been suggested (Davidou et al., 1996). The role of hydrocolloids in the quality of the gas cell structure of crumb was assessed by Bárcenas and Rosell (2005) in breads with HPMC. Cryo-SEM analysis revealed that gas cell walls were smoother and had fewer cavities than in bread without HPMC, thus confirming the close association between the hydrocolloid and the other crumb components.

The effects of hydrocolloids from different sources on staling have been extensively described. Guarda et al. (2004) found that even at low levels (0.1% f.b.) hydrocolloid addition reduced the dehydration rate during storage in breads with AL, XG, k-CAR and HPMC, k-CAR being the hydrocolloid with the lowest water retention capacity.

Modified celluloses CMC and HPMC (0.1%–0.5% f.b.) have been widely reported to be effective in decreasing hardening rate and final crumb firmness values (Armero & Collar, 1996, 1998; Bárcenas & Rosell, 2005; Guarda et al., 2004; Tavakolipour & Kalbasi-Ashtari, 2006). Armero and Collar (1998) found that the effect of CMC and HPMC depended on the type of flour and breadmaking process. For white breads made by the sourdough method, the CMC effect was greater at short storage times, and that of HPMC was more effective at longer ones. HPMC was also effective as crumb softener in the straight dough process. By DSC assays, Bárcenas and Rosell (2005) determined a lower retrogradation index for samples containing HPMC (0.5% f.b.) stored at 4 °C.

Other hydrocolloids that have been reported to inhibit staling are AL (0.1%–0.5% f.b.) (Guarda et al., 2004; Ribotta et al., 2005), carrageenans (0.5% f.b.) (Ribotta et al., 2005), LBG (0.5% f.b.) (Ribotta et al., 2005), GG (0.25%–1% f.b.) (Ghodke, 2009; Ribotta et al., 2005), HMP (0.5%–2% f.b.) (Correa et al., 2012; Ribotta et al., 2005) and among the more novel gums, BG, the exudate of *Cercidium praecox* (López, Pérez, Erramouspe, & Cuevas, 2013). Likewise, Santos et al. (2008) found that the presence of fiber (6%–34% level of replacement) from different origins (IN, and fibers from sugar beet, pea cell wall, pea hull) in wheat bread decreased the enthalpy of amylopectin retrogradation and lowered the retrogradation rate (evidenced by a lower constant k in Avrami equation). Angioloni and Collar (2009a) demonstrated the ability of LBG or CMC, in combination with prebiotic fibers FOS or GOS (at 6%–12% level of replacement), to delay crumb firming during storage. On the other hand, other hydrocolloids do not seem to be as effective, as XG (Guarda et al., 2004; Ribotta et al., 2005) and CH, which exhibited a promoting effect on staling by facilitating water migration from crumb to crust and crumb firming (Kerch et al., 2008).

4. Hydrocolloids used in bake off technologies

Dough freezing and par-baking enable extending the shelf life of bakery products. Partial baking is an interrupted baking process consisting of two baking steps and an intermediate freezing stage. At the first baking stage, the bread structure is set through starch gelatinization and protein coagulation but without crust color development (Roussel & Chiron, 2002). The frozen stage allows for longer storage of the product and finally, at the second baking stage, performed at the delivery points (baking off), crust color develops and consumers can have a “fresh” product at any time.

However, the final quality of frozen stored products is usually lower than that of fresh ones. In the case of bread dough, technological quality diminishes during frozen storage, mainly due to a decrease in yeast viability and to gluten damage due to the loss of cross-linking and depolymerization by ice recrystallization (Ribotta, León, & Añón, 2001; Zhao et al., 2013) and the action of reducing substances from yeasts (Inoué & Bushuk, 1991; Ribotta, León, & Añón, 2003). Structural damage is evidenced by the increase in the air-pore size in the crumbs of breads obtained from frozen doughs and in par-baked breads. This fact was attributed to the damage of the pore walls due to the rigidity of gluten fibrils caused by freezing and to the mechanical stresses developed during cooling (Polaki, Xasapis, Fasseas, Yanniotis, & Mandala, 2010). Besides, the moisture content distribution in the crumbs of breads obtained from frozen dough and par-baked breads is affected by the previous storage process. The highest variation was reported for breads from frozen dough, thus revealing changes in the structure during freezing that result in different mass transfer rates during baking (Mandala, Polaki, & Yanniotis, 2009). The glass transition temperature of the maximally freeze-concentrated matrix in par-baked breads is about −18 °C. Consequently, lower storage temperatures than the usual −18 °C would be necessary to avoid the main processes that occur during storage (starch recrystallization and water diffusion), as reported by Ronda, Caballero, Quilez, and Roos (2011).

Hydrocolloids have been used to prevent the loss of quality in frozen dough. They can minimize gluten damage probably by water immobilization and by preventing large ice crystal formation (Sharadanant & Khan, 2006). Hydrocolloids can also increase the glass transition temperature, as demonstrated by Ribotta and Le Bail (2007) for GG added dough; nevertheless, Tg can remain below commercial freezer temperatures. In addition to their protective effect during frozen storage, gums can retard staling after the full baking of par-baked, frozen stored breads (Bárcenas, Haros, & Rosell, 2003).

The effect of different gums on the breadmaking quality of frozen dough has been reported by several authors, at storage temperatures at or close to commercial freezer temperatures (−18 °C) and periods ranging from days to months. Sharadanant and Khan (2003a, 2003b) found that the addition of AG, CMC or LBG (1%–3% f.b.) to a frozen dough led to lower proof times, higher resistance to extension, and higher specific bread volumes with softer crumbs than the control without gum. CMC and AG (3% f.b.) also showed a positive effect on the sensorial quality of pizza baked from frozen dough (Asghar, Anjum, Butt, Tariq, & Hussain, 2007). When GG, XG or TSG (5% f.b.) were added to frozen dough, higher specific volumes were obtained in comparison with control bread (Morimoto, Tabara, & Seguchi, 2015). TG (1% f.b.) improved sensorial quality and reduced the hardness of breads baked from frozen dough, and also exhibited an antistaling effect (Gharaie, Azizi, Barzegar, & Aghagholizade, 2015).

The combination of hydrocolloids with emulsifiers can also attenuate frozen dough damage (Ribotta, Pérez, León, & Añón, 2004). WF dough with 0.5% GG and 0.5% DATEM (f.b.) was kept at −18 °C for 60 days, and the obtained bread had greater loaf volume than the control one for both nonfrozen and frozen stored dough.

Wang, Tao, Jin, and Xu (2016) investigated the effect of WEAX from rye bran on the quality of Chinese steamed bread dough (0%, 1% and 2% flour replacement). WEAX improved bread characteristics during the 60-day frozen storage, enhancing bread volume and improving texture. The authors related this effect to the stabilization of gas cells by WEAX location in the interfaces and less water crystallization, which decreased yeast losses. However, Kondacki, Ang, and Zhou (2015) did not find a positive effect of AL (0.05%–1%) or XG (0.02%–0.1%) on steamed bread specific volume obtained from frozen dough.

Chilling and refrigeration are other low temperature methods used for dough conservation. The main drawback to the refrigerated storage of dough is water release (syruping) caused by decreased water-holding capacity, probably due to the enzymatic conversion of WUAX to WEAX (Simsek & Ohm, 2009). Simsek (2009) reported that increasing levels of XG (0.1%–1% mixture basis) were inversely correlated with the degree of dough syruping, since the hydrocolloid enhanced water retention.

In par-baked breads, HPMC (0.5% f.b.) improved the specific volume and also reduced crumb hardness and retrogradation index (Bárcenas & Rosell, 2007; Bárcenas, Benedito, & Rosell, 2004). Likewise, Ahmed et al. (2013) reported that HPMC, followed by CMC and GG (0.5%), improved moisture retention and the sensory characteristics in par-baked chapatti bread from whole wheat flour. Pectin (1%) maintained softer crumbs during longer periods in par-baked breads stored at 4 °C or −18 °C (Rosell & Santos, 2010). Mixtures of pectin (0.9–1%), IN (3%) and GG (0.3–0.4%) have also been successfully used in par-baked frozen bread (Skara, Novotni, Cukelj, Smerdel, & Curic, 2011).

On frozen full-baked breads, thawed by microwave heating, Mandala and Sotirakoglou (2005) tested the effect of GG and XG at two different levels (0.16% and 0.65% f.b.). In this case, the increase in gum concentration had negative effects on the specific volume, crumb porosity and crust texture of both fresh and frozen stored breads, especially in breads with GG.

An interesting aspect to highlight is that the hydrocolloid efficiency varies according to the technology used, as stated by Mandala, Kapetanakou, and Kostaropoulos (2008) who compared the effect of different hydrocolloids (XG, HPMC, GG and LBG, 0.2% f.b.) on dough, par-baked and full-baked breads frozen stored (−18 °C) for a week and then baked. Hydrocolloid influence on the final bread characteristics was greater in dough and par-baked breads. Likewise, Mandala, Karabela, and Kostaropoulos (2007) reported that breads from cold stored (24 h at 5 °C) dough containing GG or HPMC (0.2% f.b.) had significantly higher specific volumes than the respective par-baked o full-baked breads, suggesting that the baking stage before storage was more important than the type of hydrocolloid used.

5. Hydrocolloids in composite breads

The use of composite and WG flours to make breads with an increased nutritional value or containing functional components with specific health benefits has become an important trend in bakery in recent years. Despite the recognized benefits of these formulations, the addition of non-wheat flours and WG flours normally leads to a significant loss of technological and sensory quality as compared to refined WF products. In WG breads bitter taste, hard and gritty texture and non appetizing color are barriers to overcome in order to meet consumers' expectations (Arvola et al., 2007; Heiniö et al., 2016).

In composite breads, the lower volume and harder texture have been mainly attributed to the "dilution" of the gluten matrix in the mixture and to protein network disruption (Pérez, Ribotta, Steffolani, & León, 2008). Moreover, it has been stated that the mechanical properties of crumb depend on the physical and chemical characteristics of the cell wall materials (Zghal, Scanlon, & Sapirstein, 2002). In wheat bread, these walls are formed by a bicontinuous system of gluten and gelatinized starch. Comparisons between breads without gluten made from potato or wheat starch indicate that the mechanical parameters will depend on wall thickness and the ability of the different starch granules to be hooked into each other and strengthen these walls (Keetels, Visser, van Vliet, Jurgens, & Walstra, 1996). This suggests that replacement of WF with starch or starch-containing ingredients (such as legume flours) not only would "dilute" the gluten network but also lead to changes in the microstructure of crumb that can also affect bread structure and quality. Besides, fiber-rich ingredients can change gas cell characteristics (Polaki et al., 2010) and influence starch gelatinization and retrogradation due to their water absorption capacity (Santos et al., 2008).

In recent years, several studies on composite and WG breads have confirmed the technological usefulness of hydrocolloids to compensate for quality losses.

Spelt wheat (*Triticum spelt*) is an ancient cereal grain that is attracting growing interest due to the lower cultivation requirements than for common wheat. In order to improve technological quality, Bojňanská, Šmitalová, and Vollmannová (2016) added GG (0.5% f.b.) and XG (0.16% f.b.) to mixtures of WF- spelt WG flour (70:30) and found a positive effect on farinograph dough stability and bread volume.

Legumes are often used in composite breads since they can improve their nutritional value. Previtali et al. (2014) investigated the effect of selected hydrocolloids (CMC, guar seed flour, pectin) at different concentrations (1%–3%) on mixtures of whole durum wheat flour and lentil flour (10%–25% level of WF replacement). Lentil flour addition (25%) negatively affected the textural properties of dough, decreasing maximum and fracture strains and tenacity. The addition of CMC (1%–2%) or guar seed flour (2%) improved dough texture and led to softer crumbs and higher sensorial quality breads. In whole wheat bread from different Italian cultivars, enriched with hydrated and nonhydrated pea flour (5%), the addition of guar seed flour (2%) led to softer crumbs, with interconnected pores and higher scores in sensory analysis (Mastromatteo et al., 2015). Angioloni and Collar (2012) formulated high nutritional wheat breads with replacement (up to 54%) by legume flours (chickpea/pea/soybean) employing gluten plus CMC (6%) as structuring agents.

Doughs with prebiotics have been assessed by Angioloni and Collar (2008). These high-fiber (up to 12%) doughs included different hydrocolloids (CMC, LBG, HMP) blended or not with prebiotic oligosaccharides (IN-FOS and GOS). When 10% WF was replaced with LBG or CMC and prebiotic oligosaccharides, singly and in hydrocolloid/oligosaccharide binary blends (70:30 w/w), a more regular dough structure was observed for LBG/FOS and LBG/GOS, in agreement with the mechanical analysis results (Angioloni & Collar, 2009b).

In other nonconventional formulations, hydrocolloids have been tested with dissimilar results. Ho and Noor Aziah (2013) studied the effect of XG and CMC (0.8% f.b.) on mixtures of WF-banana pseudostem flour (90:10) and found reduced farinograph stability even in the presence of gums. Das, Raychaudhuri, and Chakraborty (2015) used different hydrocolloids (CAR, CMC, GG, XG, 0.25%–1%, f.b.) in WF-coriander breads (3% coriander leaf powder, f.b.). In general, the specific volume and crumb grain characteristics of fresh bread improved. Moreover, crumb firming kinetics during storage slowed down with GG and CMC addition. Shittu, Aminu and Abulude (2009) analyzed the effect of XG (1%, 2% f.b.) on blends of WF-cassava flour (90:10). The addition of XG increased the specific volume and softness and improved crust appearance, taste and overall acceptability.

There is also increasing research on novel gums with potential ability as bread improvers in composite formulations. BG was used in wheat breads with lupine protein isolate (90:10) at a level of 0.5% mixture basis (López & Goldner, 2015). Although this gum did not improve bread volume, crumb moisture was higher, and breads were more cohesive and springy, and with a more extended sensory shelf life. The combined effect of GG and *Lepidium sativum* seed (garden cress seed) gum (0.3%, 0.6% and 1% mixture basis) on composite formulations of WF-rice flour (80:20) was reported by Sahraiyan, Naghipour, Mahdi Karimi, and Davoodi (2013). Water absorption, DDT and dough stability increased with the addition of hydrocolloids alone or in combination. The samples with the maximum level of *L. sativum* seed gum showed the highest resistance to extension, lower crumb firmness, and higher cohesiveness and resilience. The red seaweed *Kappaphycus alvarezii* is one of the main sources of carrageenans. Mamat et al. (2013) reported that the replacement of WF with dried ground seaweed (2%–8%) increased farinograph water absorption, DDT and stability, and reduced dough stickiness. However, breads obtained with seaweed composite flour had lower volumes and harder crumbs.

So far, most of the studies on composite formulations containing hydrocolloids have focused mainly on their breadmaking performance and the final product quality, which is certainly of technological interest. However, more microstructure studies on these complex systems could allow us to understand the dissimilar results obtained and help to design enriched breads.

6. Conclusions

Hydrocolloids have proved to be effective, versatile and safe additives in wheat breadmaking. Hydrocolloids generally increase water absorption of WF. Through specific interactions, particularly with gluten proteins, they can positively or negatively modify dough rheology, which depends on their structure, concentration and the interactions with other components. Hydrocolloids can improve bread volume, crumb porosity and texture, leading to products with enhanced technological quality. They can be effective in inhibiting staling through concurrent mechanisms. Moisture retention and water mobility, and the structure of the particular matrix where staling occurs are influenced by the addition of gums and seem to be determinant factors. Hydrocolloids can reduce syruping in refrigerated dough and damage in frozen dough and par-baked bread, as well as staling in full baked breads obtained from them. In composite formulations where refined or whole wheat flours are blended with other flours (i.e., from legumes), fiber-rich ingredients, or protein isolates for nutritional purposes, hydrocolloids contribute to improving the product quality.

Despite the considerable number of reports about the effects of hydrocolloids on dough and bread, the mechanisms involved in their interaction with dough components still deserve considerable attention. This topic as well as the characterization and performance of novel gums suitable for breadmaking continue to be promissory research areas.

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References

Ahmed, A., Anjum, M., Ahmad, A., Khalid, N., Randhawa, M. A., Ahmad, Z., et al. (2013). Effects of hydrocolloids on partial baking and frozen storage of wheat flour chapatti. *Food Science and Technology Research, 19*, 97–103.
Angioloni, A., & Collar, C. (2008). Functional response of diluted dough matrixes in high-fibre systems: A viscometric and rheological approach. *Food Research International, 41*, 803–812.
Angioloni, A., & Collar, C. (2009a). Gel, dough and fibre enriched fresh breads: Relationships between quality features and staling kinetics. *Journal of Food Engineering, 91*, 526–532.
Angioloni, A., & Collar, C. (2009b). Significance of structuring/prebiotic blends on bread dough thermo-mechanical profile. *European Food Research and Technology, 229*, 603–610.
Angioloni, A., & Collar, C. (2012). High legume-wheat matrices: An alternative to promote bread nutritional value meeting dough viscoelastic restrictions. *European Food Research and Technology, 234*, 273–284.
Armero, E., & Collar, C. (1996). Antistaling additive effects on fresh wheat bread quality. *Food Science and Technology International, 2*, 323–333.
Armero, E., & Collar, C. (1998). Crumb firming kinetics of wheat breads with antistaling additives. *Journal of Cereal Science, 28*, 165–174.
Arvola, A., Lähteenmäkia, L., Dean, M., Vassallo, M., Winkelmann, M., Claupein, E., et al. (2007). Consumers' beliefs about whole and refined grain products in the UK, Italy and Finland. *Journal of Cereal Science, 46*, 197–206.
Asghar, A., Anjum, F. M., Butt, M. S., Tariq, M. W., & Hussain, T. (2007). Rheological and storage effect of hydrophillic gums on the quality of frozen dough pizza. *Food Science and Technology Research, 13*, 96–102.
Bárcenas, M. E., Benedito, C., & Rosell, C. M. (2004). Use of hydrocolloids as bread improvers in interrupted baking process with frozen storage. *Food Hydrocolloids, 18*, 769–774.
Bárcenas, M. E., De la O-Keller, J., & Rosell, C. M. (2009). Influence of different hydrocolloids on major wheat dough components (gluten and starch). *Journal of Food Engineering, 94*, 241–247.
Bárcenas, M. E., Haros, M., & Rosell, C. M. (2003). An approach to studying the effect of different bread improvers on the staling of pre-baked frozen bread. *European Food Research and Technology, 218*, 56–61.
Bárcenas, M. E., & Rosell, C. M. (2005). Effect of HPMC addition on the microstructure, quality and aging of wheat bread. *Food Hydrocolloids, 19*, 1037–1043.
Bárcenas, M. E., & Rosell, C. M. (2007). Different approaches for increasing the shelf life of partially baked bread: Low temperatures and hydrocolloid addition. *Food Chemistry, 100*, 1594–1601.
Bell, D. A. (1990). Methylcellulose as a structure enhancer in bread baking. *Cereal Foods World, 35*, 1001–1006.
Biliaderis, C. G., Arvanitoyannis, I., Izydroczyk, M. S., & Prokopowich, D. J. (1997). Effect of hydrocolloids on gelatinization and structure formation in concentrated waxy maize and wheat starch gels. *Starch/Staerke, 49*, 278–283.
Bojňanská, T., Šmitalová, J., & Vollmannová, A. (2016). Effect of the addition of hydrocolloids on the rheological and baking properties of the products with added spelt flour (*Triticum spelta l.*). *Potravinarstvo, 10*, 157–163.
Bollaín, C., & Collar, C. (2004). Dough viscoelastic response of hydrocolloid/enzyme/surfactant blends assessed by uni- and bi-axial extension measurements. *Food Hydrocolloids, 18*, 499–507.
Correa, M. J., Añón, M. C., Pérez, G. T., & Ferrero, C. (2010). Effect of modified celluloses on dough rheology and microstructure. *Food Research International, 43*, 780–787.
Correa, M. J., Ferrer, E., Añón, M. C., & Ferrero, C. (2014). Interaction of modified celluloses and pectins with gluten proteins. *Food Hydrocolloids, 35*, 91–99.
Correa, M. J., & Ferrero, C. (2015a). Thermal behaviour of wheat starch and flour at different water levels: Effect of pectins, modified celluloses and NaCl. *Starch/Stärke, 67*, 338–347.
Correa, M. J., & Ferrero, C. (2015b). A comparative study of commercial modified celluloses as breadmaking additives. *International Journal of Food Properties, 18*, 849–861.
Correa, M. J., Pérez, G. T., & Ferrero, C. (2012). Pectins as breadmaking additives: Effect on dough rheology and bread quality. *Food and Bioprocess Technology, 5*, 2889–2898.
Das, L., Raychaudhuri, U., & Chakraborty, R. (2015). Effects of hydrocolloids as texture improver in coriander bread. *Journal of Food Science and Technology, 52*, 3671–3680.
Davidou, S., Le Meste, M., Debever, E., & Becaert, D. (1996). A contribution to the study of staling of white bread: Effect of water and hydrocolloid. *Food Hydrocolloids, 20*, 375–383.
Gharaie, Z., Azizi, M. H., Barzegar, M., & Aghagholizade, R. (2015). Effects of hydrocolloids on the rheological characteristics of dough and the quality of bread made from frozen dough. *Journal of Texture Studies, 46*, 365–373.
Ghodke, S. K. (2009). Effect of guar gum on dough stickiness and staling in Chapatti—An Indian unleavened flat bread. *International Journal of Food Engineering, 5*. Article 7.
Ghodke, S. K., & Ananthanarayan, L. (2007). Influence of additives on rheological characteristics of whole-wheat dough and quality of Chapatti (Indian unleavened flat bread) Part I- hydrocolloids. *Food Hydrocolloids, 21*, 110–117.
Guarda, A., Rosell, C. M., Benedito, C., & Galotto, M. J. (2004). Different hydrocolloids as bread improvers and antistaling agents. *Food Hydrocolloids, 18*, 241–247.
Heiniö, R. L., Noort, M. W. J., Katina, K., Alam, S. A., Sozer, N., de Kock, H. L., et al. (2016). Sensory characteristics of wholegrain and bran-rich cereal foods - a review. *Trends in Food Science and Technology, 47*, 25–38.
Ho, L. H., & Noor Aziah, A. A. (2013). Dough mixing and thermal properties including the pasting profiles of composite flour blends with added hydrocolloids. *International Food Research Journal, 20*, 911–917.
Inoué, Y., & Bushuk, W. (1991). Studies on frozen doughs. I.Effects of frozen storage and freeze-thaw cycles on baking quality and rheological properties. *Cereal Chemistry, 68*, 627–631.
Keetels, C. J. A. M., Visser, K. A., van Vliet, T., Jurgens, A., & Walstra, P. (1996). Structure and mechanics of starch bread. *Journal of Cereal Science, 24*, 15–26.
Kerch, G., Rustichelli, F., Ausili, P., Zicans, J., Merijs Meri, R., & Glonin, A. (2008). Effect of chitosan on physical and chemical processes during bread baking and staling. *European Food Research and Technology, 226*, 1459–1464.
Kondacki, T., Ang, A. M. Y., & Zhou, W. (2015). Impact of sodium alginate and xanthan gum on the quality of steamed bread made from frozen dough. *Cereal Chemistry, 92*, 236–245.
Krüger, M. A., Ferrero, C., & Zaritzky, N. E. (2003). Modelling corn starch swelling in batch systems: Effect of sucrose and hydrocolloids. *Journal of Food Engineering, 58*, 125–133.
León, A. E., Ribotta, P. D., Ausar, S. F., Fernandez, C., Landa, C. A., & Beltramo, D. M. (2000). Interactions of different carrageenan isoforms and flour components in breadmaking. *Journal of Agricultural and. Food Chemistry, 48*, 2634–2638.
Linlaud, N. E., Ferrer, E., Puppo, M. C., & Ferrero, C. (2011). Hydrocolloid interaction with water, protein and starch in wheat dough. *Journal of Agricultural and Food Chemistry, 59*, 713–719.
Linlaud, N. E., Puppo, M. C., & Ferrero, C. (2009). Effect of hydrocolloids on water absorption of wheat flour and farinograph and textural characteristics of dough. *Cereal Chemistry, 86*, 376–382.
López, E. P., & Goldner, M. C. (2015). Influence of storage time for the acceptability of bread formulated with lupine protein isolate and added brea gum. *LWT – Food Science and Technology, 64*, 1171–1178.
López, E., Pérez, G., Erramouspe, P. J. de, & Cuevas, C. (2013). Effect of Brea Gum on the characteristics of wheat bread at different storage times. *Food Science and Technology, 33*, 745–752.
Maleki, G., & Milani, J. M. (2013). Effect of guar gum, xanthan gum, CMC and HPMC on dough rhealogy and physical properties of barbari bread. *Food Science and Technology Research, 19*, 353–358.
Mamat, H., Matanjun, P., Ibrahim, S., Amin, S. F. Md, Abdul Hamid, M., & Rameli, A. S. (2013). The effect of seaweed composite flour on the textural properties of dough and bread. *Journal Applied Phycology, 26*, 1057–1062.
Mandala, I., Kapetanakou, A., & Kostaropoulos, A. (2008). Physical properties of breads containing hydrocolloids stored at low temperature: Ii-effect of freezing. *Food Hydrocolloids, 22*, 1443–1451.
Mandala, I., Karabela, D., & Kostaropoulos, A. (2007). Physical properties of breads containing hydrocolloids stored at low temperature. I. Effect of chilling. *Food Hydrocolloids, 21*, 1397–1406.
Mandala, I., Polaki, A., & Yanniotis, S. (2009). Influence of frozen storage on bread enriched with different ingredients. *Journal of Food Engineering, 92*, 137–145.
Mandala, I. G., & Sotirakoglou, K. (2005). Effect of frozen storage and microwave reheating on some physical attributes of fresh bread containing hydrocolloids. *Food Hydrocolloids, 19*, 709–719.
Mastromatteo, M., Danza, A., Lecce, L., Spinelli, S., Lampignano, V., Laverse, J., et al. (2015). Nutritional and physicochemical characteristics of wholemeal bread enriched with pea flour. *International Journal of Food Science and Technology, 50*, 92–102.
Morimoto, N., Tabara, A., & Seguchi, M. (2015). Effect of xanthan gum on improvement of bread height and specific volume upon baking with frozen and thawed dough. *Food Science and Technology Research, 21*, 309–316.
Nawrocka, A., Miś, A., & Szymańska-Chargot, M. (2016). Characteristics of relationships between structure of gluten proteins and dough rheology – influence of dietary fibres studied by FT-Raman spectroscopy. *Food Biophysics, 11*, 81–90.
Nawrocka, A., Szymańska-Chargot, M., Miś, A., Kowalski, R., & Gruszecki, W. (2016). Raman studies of gluten proteins aggregation induced by dietary fibres. *Food Chemistry, 194*, 86–94.
Patil, S. P., & Arya, S. S. (2016). Influence of additives on dough rheology and quality of thepla: An Indian unleavened flatbread. *Food Measure, 10*, 327–335.
Pečivová, P., Dula, P., & Hrabě, J. (2013). The influence of pectin from apple and gum arabic from acacia tree on the quality of pizza. *International Journal of Food Properties, 16*, 1417–1428.
Pérez, G. T., Ribotta, P. D., Steffolani, M. E., & León, A. E. (2008). Effect of soybean proteins on gluten depolymerization during mixing and resting. *Journal of the Science of Food and Agriculture, 88*, 455–463.
Polaki, A., Xasapis, P., Fasseas, S., Yanniotis, S., & Mandala, I. (2010). Fiber and hydrocolloid content affect the microstructural and sensory characteristics of fresh and frozen stored bread. *Journal of Food Engineering, 97*, 1–7.
Previtali, A. S., Mastromatteo, M., De Vita, P., Ficco, D. B., Contel, A., & Del

Nobile, M. A. (2014). Effect of the lentil flour and hydrocolloids on baking characteristics of wholemeal durum wheat bread. *International Journal of Food Science and Technology, 49*, 2382–2390.

Ribotta, P. D., Ausar, S. F., Beltramo, D. M., & León, A. E. (2005). Interactions of hydrocolloids and sonicated-gluten proteins. *Food Hydrocolloids, 19*, 93–99.

Ribotta, P., & Le Bail, A. (2007). Effect of additives on the thermo-mechanical behaviour of dough systems at sub-freezing temperatures. *European Food Researchand Technology, 224*, 519–524.

Ribotta, P. D., León, A. E., & Añón, M. C. (2001). Effect of freezing and frozen storage of doughs on bread quality. *Journal of Agricultural Food Chemistry, 49*, 913–918.

Ribotta, P. D., León, A. E., & Añón, M. C. (2003). Effects of yeast and freezing in frozen dough. *Cereal Chemistry, 80*, 454–458.

Ribotta, P. D., Pérez, G. T., León, A. E., & Añón, M. C. (2004). Effect of emulsifier and guar gum on micro structural, rheological and baking performance of frozen bread dough. *Food Hydrocolloids, 18*, 305–313.

Ronda, F., Caballero, P. A., Quilez, J., & Roos, Y. (2011). Staling of frozen partly and fully baked breads. Study of the combined effect of amylopectin recrystallization and water content on bread firmness. *Journal of Cereal Science, 53*, 97–103.

Rosell, C. M., & Foegeding, A. E. (2007). Interaction of hydroxypropylmethylcellulose with gluten proteins: Small deformation properties during thermal treatment. *Food Hydrocolloids, 21*, 1092–1100.

Rosell, C. M., Rojas, J. A., & Benedito, C. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids, 15*, 75–81.

Rosell, C. M., & Santos, E. (2010). Impact of fibers on physical characteristics of fresh and staled bake off bread. *Journal of Food Engineering, 98*, 273–281.

Roussel, P., & Chiron, H. (2002). *Les pains français*. Evolution, qualité, production. Mae Erti Ed. Vesoul.

Sahraiyan, B., Naghipour, F., Mahdi Karimi, M., & Davoodi, M. G. (2013). Evaluation of *Lepidium sativum* seed and guar gum to improve dough rheology and quality parameters in composite rice wheat bread. *Food Hydrocolloids, 30*, 698–703.

Santos, E., Rosell, C. M., & Collar, C. (2008). Gelatinization and retrogradation kinetics of high-fiber wheat flour blends: A calorimetric approach. *Cereal Chemistry, 85*, 455–463.

Schiraldi, A., Piazza, L., Brenna, O., & Vittadini, E. (1996). Structure and properties of bread dough and crumb. Calorimetric, rheological and mechanical investigations on the effects produced by hydrocolloids, pentosans and soluble proteins. *Journal of Thermal Analysis, 47*, 1339–1360.

Selomulyo, V. O., & Zhou, W. (2007). Frozen bread dough: Effects of freezing storage and dough improvers. *Journal of Cereal Science, 45*, 1–17.

Sharadanant, R., & Khan, K. (2003a). Effect of hydrophilic gums on frozen dough. I. Dough quality. *Cereal Chemistry, 80*, 764–772.

Sharadanant, R., & Khan, K. (2003b). Effect of hydrophilic gums on frozen dough. II. Bread characteristics. *Cereal Chemistry, 80*, 773–780.

Sharadanant, R., & Khan, K. (2006). Effect of hydrophilic gums on the quality of frozen dough: Electron microscopy, protein solubility, and electrophoresis studies. *Cereal Chemistry, 83*, 411–417.

Shittu, T. A., Aminu, R. A., & Abulude, E. O. (2009). Functional effects of xanthan gum on composite cassava-wheat dough and bread. *Food Hydrocolloids, 23*, 2254–2260.

Simsek, S. (2009). Application of xanthan gum for reducing syruping in refrigerated doughs. *Food Hydrocolloids, 23*, 2354–2358.

Simsek, S., & Ohm, J. B. (2009). Structural changes of arabinoxylans in refrigerated dough. *Carbohydrate Polymers, 77*, 87–94.

Skara, N., Novotni, D., Cukelj, N., Smerdel, B., & Curic, D. (2011). Combined effects of inulin, pectin and guar gum on the quality and stability of partially baked frozen bread. *Food Hydrocolloids, 30*, 428–436.

Smitha, S., Rajiv, J., Begum, K., & Indrani, D. (2008). Effect of hydrocolloids on rheological, microstructural and quality characteristics of parotta – an unleavened indian flat bread. *Journal of Texture Studies, 39*, 267–283.

Stauffer, C. E. (1990). *Functional additives for bakery foods*. London: Chapman & Hall.

Tavakolipour, H., & Kalbasi-Ashtari, A. (2006). Influence of gums on dough properties and flat bread quality of two persian wheat varieties. *Journal of Food Process Engineering, 30*, 74–87.

Upadhyay, R., Ghosal, D., & Mehra, A. (2012). Characterization of bread dough: Rheological properties and microstructure. *Journal of Food Engineering, 109*, 104–113.

Wang, P., Tao, H., Jin, Z., & Xu, X. (2016). Impact of water extractable arabinoxylan from rye bran on the frozen steamed bread dough quality. *Food Chemistry, 200*, 117–124.

Zannini, E., Waters, D. M., & Arendt, E. K. (2014). The application of dextran compared to other hydrocolloids as a novel food ingredient to compensate for low protein in biscuit and wholemeal wheat flour. *European Food Research and Technology, 238*, 763–771.

Zettel, V., Krämer, A., Hecker, F., & Hitzmann, B. (2015). Influence of gel from ground chia (Salvia hispanica L.) for wheat bread production. *European Food Research and Technology, 240*, 655–662.

Zghal, M. C., Scanlon, M. G., & Sapirstein, H. D. (2002). Cellular structure of bread crumb and its influence on mechanical properties. *Journal of Cereal Science, 36*, 167–176.

Zhao, L., Li, L., Liu, G.-Q., Chen, L., Liu, X., Zhu, J., et al. (2013). Effect of freeze-thaw cycles on the molecular weight and size distribution of gluten. *Food Research International, 53*, 409–416.