FROZEN DOUGH AND PARTIALLY BAKED BREAD: AN UPDATE

Running title: Frozen dough and part baked bread

Cristina M. Rosell[1], Manuel Gómez[a]

[a] Departamento de Ingeniería Agrícola y Forestal, Tecnología de los Alimentos, E.T.S.Ingenierías Agrarias, Universidad de Valladolid, 34004 Palencia, Spain.

Tel: +34 (9) 79-108359, Fax: +34 (9) 79-108302

[1]Instituto de Agroquímica y Tecnología de Alimentos (IATA-CSIC). POBox 73. Burjasot-46100. Valencia. Spain.

[1]To whom correspondence should be addressed. E-mail: crosell@iata.csic.es

ABSTRACT

The bakery market is growing due to the development of new technologies related with freezing temperatures. In this contribution the state of the art is reviewed, giving special emphasis in the contributions of the last two decades. This review is especially focussing in being a useful guide of the research performed in the application of freezing at different steps of the breadmaking process, giving an overview toward the bakery market is moving on. The raw material requirements, processing conditions and baked bread quality from frozen dough and partially baked bread are reviewed.

Key words: frozen dough, partially baked bread, breadmaking, raw materials, process, quality.

INTRODUCTION

The production of cereals and baked goods has been suffering a continuous transformation promoted by the change in social habits, consumer demands, and the interest of the baked goods producers in saving labours and costs. Initially, the industrialisation of the breadmaking process yielded important savings in time and costs. However, the bread market did not wake up with all those changes and bread consumption underwent a steady decrease till mid-nineties. This decrease was partially due to the short shelf life of the bakery products; their quality is highly dependent on the period of time between baking and consumption. A loss of bread fresness called bread staling produces a loss of consumer acceptance.(1)

A revolutionary change started when low temperatures were applied to the bread market, making possible to eliminate the night work in this industry. The first approach was to frozen the commercial bread, but the successful preservation of freshness was greatly dependent on an adequate control of rates of freezing and defrosting, suitable storage conditions and use of strictly fresh bread.(2) However, frozen bread did not allow extended storage periods without modifying the characteristics of the freshly baked bread.(3) That approach was followed by the development of refrigerated dough that allowed delaying the proofing process.(4) However, the shelf-life of those refrigerated doughs was very short and long distance distribution was not possible. The use of freezing in this market is not new, but in the last years (started from the 80's) a niche market has been converted in a mainstream business. Bread is a food that almost everyone eats, and the bread market was considered a well-established sector with nearly complete penetration, but there were some niches within this market with strong growth potential. Different facts have been encountered for explaining that spectacular growth, among them the diversity of products that keeps consumers interest in the bread market, the health promoting ingredients currently used, the addition of complex flavours and textures that increase bread attractiveness and the expansion of distribution points. The application of low temperatures in breadmaking provides an easy way of processing different types of bread and forms (fresh, refrigerated and frozen) that guarantees a steady rate of growth of this technology.

Research underwent in this subject has followed a parallel trend to the market importance. In figure 1 can be observed that in the last decade the number of research articles increases spectacularly. Due to the growing interest in this subject, an update of it becomes necessary. A simple overview of the research performed in the subject is depicted in Table 1 and 2. Next sections will describe in some detail the use of freezing temperature during the breadmaking process and if special requirements are needed.

FROZEN DOUGH

The production of frozen dough has undergone a great increase in the last decades, due to the variety of products that can be obtained after proofing and baking in the so-called hot points. From the baker's point of view, frozen dough production does not require highly trained people, which means saving costs. Frozen dough is obtained from highly mechanized processes in big companies that can reduce the production costs and manufacturers can supply a product of uniform quality at any time. However the production of frozen dough has moved the breadmaking process to new requirements regarding raw materials, machinery, package and transport. The next sections discussed the technology used for the production of bread from frozen dough and the requirements that should be met for improving the quality of the baked product.[5]

The technology used for the production of frozen dough is known since 1950, although bakers begun to use it in United States in the seventieth. This delay was due to the research and development necessary for setting up the new technology. In fact, initially the baked products from frozen dough had low volume and coarse texture, and shorter shelf life.[6] Nowadays, these problems have been overcomed extending the shelf life of the frozen dough up to six months, and frequently it is only shortened due to fails in the cold chain during transport or temperature fluctuations during storage.

Ingredients

Flour

In breadmaking performance it is necessary to select adequate flour that meet the quality required for the process (Table 1). The freezing and thawing processes exert some stress on the dough that cause a deterioration in the quality of the baked product, because of that wheat flour for these processes must have greater strength than the one used in conventional breadmaking processes.[7] The best results are obtained with wheat varieties of strong gluten,[8,9] thus it is advisable to select specific wheat varieties with strong characteristics as high gluten index and high values of dough deformation energy (W) besides a good value for the curve configuration ratio (P/L) or make appropriated blends for obtaining the desirable strength.[10,11] In the selection of the appropriated flour the protein quality and the gluten strength is more important than the amount of proteins.[8,12] From the different wheat flour compounds, the glutenin fractions play the most important role in the quality of the frozen dough, followed by the fraction of gliadins and the starch.[13]

The scanning electron microscopy analysis of the dough upon freezing and thawing shows a rupture of the gluten network,[14-16] and a progressive dehydration of the gluten.[17] The freezing and thawing processes promote a reduction in the dough resistance to extension measured by the extensograph and that reduction is more intense in the proofed dough than in the unyeasted ones.[18] This effect has been related to the released of certain compounds from dead yeast cells (i.e. glutathione) after freezing and thawing. In fact, doughs subjected to three successive freeze-thaw cycles undergo a reduction in the maximum resistance and an increase in the extensibility measured by the extensograph, besides a change in the high molecular weight glutenins.[19,20] Nevertheless, further studies made in unyeasted bread (parotta) showed a decrease in the consistency peak measured by the farinograph, an increase in the extensograph extensibility, and less intense electrophoresis bands of the high molecular weight proteins.[21] Therefore, the dough weakness observed upon freezing and frozen storage is not only owed to the effect of dead yeast cells.

The causes of those alterations in the dough are not yet clear, although several factors could participate. During freezing and frozen storage, the number of viable yeast cells decreases and as a consequence a reducing compound (glutathione) is released, which can break down the disulphide bonds among proteins leading to a weakening effect on the gluten. Several results confirm this hypothesis; first the addition of oxidants improves the shelf life of frozen dough,[18,22] and secondly the high molecular weight glutenin subunits decrease after frozen storage likely due to the reducing conditions.[19,23] In addition, the hydrophobic interactions play an important role in maintaining the gluten network integrity. Those interactions become weak when the temperature decrease, thus prolonged frozen storage of the dough could yield a steady deterioration of the gluten network. The presence of ice crystals formed during freezing could also produce the rupture of the gluten structure, because of that, the rate of freezing has an important effect on the frozen dough quality.[24,25] Seguchi et al.[26] and Sharadanant et al.[27] reported the relationship between the frozen storage of dough and the water retention capacity, and found that the freezing and thawing processes increase the amount of released liquid, which could be reduced with the addition of salt, sugars or hydrocolloids to the formulation. These authors [28] also found a negative correlation between the water released and the volume of the baked bread. It has been suggested that the watery phase results from the ice crystal formation and the water redistribution in the frozen dough.[29,30] The gluten weakening leads to an increase in the proofing time, a reduction in the oven spring and the dough resistance to stress conditions, resulting in baked breads with a flat surface, crumbs with a coarse texture and great and non-uniform air cells.[10] Therefore, the production of frozen dough requires flour with superior quality than the one used in conventional breadmaking processes.

Yeast

An extensive research (Table 1) has been focused in the development of yeast cells with high tolerance to freezing and frozen storage.[31-33] The commercial baker's yeast shows enough resistance to freezing; however, their behavior changes when yeast is mixed with flour, in this surrounding yeast cells become more sensitive to temperature changes and suffer a rapid loss of the freeze resistance. Despite the reason are not clear, it could be due to the different stability of the yeast cells when latent or metabolically active state.

Initially, it was necessary to minimize the yeast activation and delay the fermentation processes previous freezing,[34,35] but lately, studies revealed that prefermentation before freezing increases the volume of baked bread from frozen dough when freeze tolerant yeasts are used.(36)

The different strains of *Saccharomyces cerevisiae* show a great variation in the sensitivity to freezing damage, likely related to their cytoplasm content.(37,38) The lipid content and its chemical structure seem having effect on the freeze tolerance of the yeast through their influence on the fluidity of the plasma membrane.(39-41) A relationship has also been found between intracellular charged amino acids and proline and the leavening ability of baker's yeasts during frozen dough baking process.(42,43) It has been reported that intracellular L-proline has cryoprotective activity in *S. cerevisiae*, and also, could protect yeast cells from oxidative stress damage (44,45).The endogenous trehalose functions as cryoprotectant,(46-49) as well as the added trehalose.(50,51) A trehalose content of 4-5% seems to be sufficient for avoiding the frozen damage of the yeast; no further protection is obtained with higher content.(52) However, recent results show that, in addition to trehalose, other factors existing in *S. cerevisiae* can enhance general stress resistance.(53)

Many efforts have been focussed in finding freeze tolerant strains, and currently there are special yeast strains for the performance of frozen dough. Among them, there are some selected strains from *Saccharomyces* like *S. fructuum*,(54) and *Torulaspora delbrueckii*.(55-57) In other cases, the freeze tolerance has been improved by directed mutagenesis *of Saccharomyces cerevisiae*.(48-61) The identification of the yeast genes responsible of the freeze tolerance opens a new way for obtaining freeze tolerant yeasts.(31)

There have been described considerable differences of the yeast cell cryotolerance among the commercial samples that indicate the importance of the growing conditions for obtaining uniform cryotolerance.[62] Nevertheless, even with all the research carried out in this subject, some additional work is needed to develop good cryotolerant yeast.

Some losses in the fermentative capacity during freezing and frozen storage are unavoidable even with controlled temperature, quick processing and the use of freeze tolerant yeast. Yeast viability is greatly affected by the freezing and storage temperatures.[63,64] Therefore, in the formulation of frozen dough is necessary to increase the level of yeast between 30 and 100%. A significant loss of activity is produced when using sourdough and poolish for providing flavour to the baked bread. Nevertheless, the use of freeze tolerant yeast improves the performance of frozen dough allowing the increase of the fermentation period before freezing.[65]

Other ingredients

Baked bread from frozen dough made with flour, yeast, salt and water shows the same problem than the ones obtained from conventional process, that is a very short shelf-life. Fats are use to ameliorate that problem extending the shelf life of the baked breads. The addition of fats or oils (0.5-1%) extends the shelf life of the bread up to some weeks. They are usually combined with emulsifiers, due to their effect in reducing the size of cells in the dough making the structure of the dough and of the baked crumb more uniform and "foamy", which has been related to the effect of emulsifiers on surface tension forces in the cells.[66,67] Aibara et al.[68] studied the addition of different fats to the formulation of frozen dough, obtaining large shelf life with fatty acids of short chain and also better bread volume (Table 1). The use of shortenings is also convenient for reducing the fermentation time and improving the quality of the baked breads, although it is necessary to select formulated shortenings for frozen dough.[69]

The addition of gluten (2%) to the formulation of frozen dough improves the volume of the baked breads due to its strengthening effect.[70] It has been also reported that the presence of gluten improves the behaviour of the dough in the freeze-thaw cycles.[71]

Milk products can be also added in the formulation of frozen dough, for instance the addition of sodium caseinate had similar strengthening effect on gluten network than DATEM and ascorbic acid, obtaining better volume and improved texture.[72] The addition of 2-10% sugar and corn syrups also reduces the fermentation time because provide fermentable sugars to the yeasts and increase the crust colour.[73]

Additives

Emulsifiers can be also used in the performance of frozen dough exerting the same effect than in the conventional process. The rheological properties of wheat dough are markedly influenced by the presence of emulsifiers and the extent of the effect is dependent on the emulsifier properties. The anionic emulsifiers together with the non-ionic (sucrose ester of fatty acids and polysorbate) conferred strength to wheat dough due to the complex formation with gluten proteins.[74] The positive effect of the emulsifiers on the fresh bread characteristics, including volume and crumb texture, can be ensured with long proofing times.[74] Monoglycerides retard the crumb hardening upon baking through the formation of complexes with amylose. The ability of the emulsifiers for forming complexes with amylose varies and thus their effect retarding crumb hardening.[75] Other emulsifiers as sodium stearoyl lactilate (SSL) or diacetyl tartaric ester methyl (DATEM) have a strengthening effect on the gluten network by promoting the protein interactions, which increase the gas retention capacity and in turn the volume of the baked products.[67] According to Stauffer,[76] the majority of the dough strengtheners are anionic emulsifiers and when their hydrophobic side is bond to the proteins the negative charge is incorporated into the complexes leading a net charge close to zero and a dough aggregation. DATEM, SSL, CSL and polysorbate are the dough strengtheners commonly used in baking, due to their effect on proofing, dough machinability, moulding and the early baking. DATEM improves volume and bread texture although does not have any protective effect against freezing damage.[16,22,77]

The addition of egg yolk can also improve the quality of frozen dough and protect the proteins against the unfolding during freezing, frozen storage and thawing.[73]

Oxidants produce a reinforcement of the gluten network by favouring the formation of disulfide bonds, being important its action on frozen dough due to the weakening effect of the freezing. Abd-El-Hady et al.[78] reported that the use of ascorbic acid, alone or blend with potassium bromate or SSL, increases the dough stability during frozen storage. However, the use of potassium bromate is now banned in most countries.

The transglutaminase is an enzyme with good properties for being used in frozen dough. This enzyme catalyzes the transfer reaction between the amine group and the carboxy group of the proteins, creating inter and intramolecular bonds. This reaction allows reinforcing the gluten network and thus minimizes the negative effects of the freezing.[79] In fact, a substantial improvement of pastries and croissants from frozen dough is obtained in the presence of transglutaminase.[80,81]

Other additives, very useful in frozen dough, are the hydrocolloids for their water retention capacity that improves the stability during frozen storage.(82) Ribotta et al.(16,23) obtained better volume of baked bread with the addition of guar gum, even similar to the ones obtained with gluten or DATEM, also improved bread characteristics have been obtained with the addition of locust bean gum, arabic gum and carboxymethylcellulose (CMC).(28) In the conventional processes the hydrocolloids improve dough stability during proofing,(83) and impart a softening effect of the crumb extending the shelf life of the baked breads.(84-88) However, the election of the appropriated hydrocolloid will be crucial since their properties vary according their origin and chemical structure;(89,90) moreover it should be taken into account the interactions with the other ingredients of the formulation, as well as the adjustment of the dough hydration due to the high water adsorption of the hydrocolloids. (91-96)

Processing

Mixing

Nemeth et al.(97) stated the importance of the mixing energy input, type of mixer, water amount in the formulation, presence of oxidants and dough strengtheners, proofing and resting times and freeze-thaw cycles on the baked bread quality from frozen dough.

There are diverse alternatives for ensuring dough temperature, for instance cooling the mixer or delay the yeast addition and sometimes the addition of salt.(98) However, the gluten network should be completely developed at the end of mixing.(99) Loaves baked from frozen dough with a final mixing temperature over 20°C are poorer in both gassing power and overall loaf quality.(100) The negative effect of the high temperatures during mixing is only due to the start of yeasts fermentation. However, some authors found better results with high temperatures at the end of mixing and with a reduction of water content,[77] although differences in results could be ascribed to the diversity of formulations tested.

In the selection of the desirable dough temperature after mixing is also important the time of frozen storage, since prolonged storage increases the yeast damage. In general, low temperatures after mixing and short resting time lead to dough with great quality and stability during frozen storage.[101] The most frequent way to control the mixed dough temperature is through the temperature of the water, using sometimes, chilled water or even ice. In the mixers with a high friction factor is necessary to incorporate a jacket and when this system is not sufficient, cryogenic cooling by using liquid nitrogen or carbon dioxide can be used.[102] The cryogenic agent promotes a fast cooling when is sprayed onto the flour before mixing. This cooling system is more uniform and avoids the presence of too cooled spots that would reduce the quality of the dough.

Concerning the delay in the addition of salt, gluten development is faster in the absence of salt, thus full dough development can be reached with short mixing times and thereby ensure lower dough temperature. The mixing process could be accelerated up to a 25% by delaying the salt addition.[103] The adverse effect of this practice is the pigment oxidation that is usually hindered with salt; hence the color of the resulted baked crumb will be paler.

Sometimes is recommended the delay of yeast addition. During the first 10 minutes of mixing, the yeast is hydrated and becomes active; thus, shortening the time of the yeast in the mixed dough could reduce the degree of fermentation. The delay of the yeasts addition is common in the production of frozen dough, but it is never added simultaneously to the salt because there is a risk of osmotic shock and cell death. The habitual practice is to add the yeast at the middle of the mixing and the salt near the end.

Post mixing operations before freezing

Dough used for freezing has greater consistency than the conventional dough because the water amount is reduced.[77,104] This consistency will affect the subsequent operations like kneading, dividing and forming, although no especial machines are used for frozen doughs. After mixing, dough is divided, kneaded, rounded, sheeted, rolled and transported to the freezer in a short period of time for minimizing the yeast activation. All the steps performed for the dough making up modify the structure of the gas cells, and contribute to dough development.[105] Small batches are usually recommended in order to reduce the time needed for making up the dough before freezing.[106] Sheeting-molding conditions have not significant effect on the stability of frozen-thawed dough, but dough shape affects the resulting bread volume, in fact sheets and cylinders lead to breads with high volume than the one obtained from ball-shaped dough pieces.[107]

Freezing and frozen storage

Freezing and frozen storage conditions have a great influence on the quality of baked breads.[17,28,108] The fermentation time increases with the frozen storage. No significant dough differences were observed among the freezing methods during the first 11 weeks of frozen storage, but after that time the samples stored at –20°C showed a rapid deterioration.

Havet et al.[25] showed that rapid cooling velocity produces a great damage in yeast activity and gluten structure. During freezing, a disruption of the gluten structure is produced due to ice crystal formation and water migration, ultimately to the extent that starch granules appear no longer associated to gluten network.[109] The temperature oscillations during storage and the duration of the frozen storage are determinant on the frozen bread dough baking performance [25,110] and –prolonged storage increases the crumb firmness of the baked breads.[111] When the core of the product reaches –20°C the temperature fluctuations should be controlled for avoiding water migration and changes in osmotic pressure. Those temperature fluctuations lead to a significant deterioration of the product quality.[110]

Ribotta et al.,[112] when analyzing the frozen dough storage by differential scanning calorimetry (DSC), obtained an increase in the gelatinization enthalpy of the starch after 150 days of frozen storage at –18°C. At 230 days of frozen storage it was detected a decrease in the gelatinization temperature and a reduction of the temperature range. The resulting baked breads had higher retrogradation enthalpy of amylopectin during staling than their counterparts from conventional process.

The transportation of frozen dough and the storage in the retail bakeries constitute a crucial point for keeping the quality of the product. The temperature of the frozen dough should be kept constant without temperature fluctuations when the product is transferred from the freezer to the truck and then to the bakery.[109]

Thawing and baking

Frozen dough should be thawed and fermented before baking. Proofing of thawed dough should be performed as in the conventional practices; the unique difference is that the relative humidity of the proofing cabined should be reduced to 75% for the thawed doughs, otherwise condensation spots could appear on the surface bringing dark spots in the baked breads. Thawed dough should not be sheeted and molding before proofing because the reduction in the fermentative capacity and the softening of the gluten network are irreversible.(103)

Bread loaves from frozen dough have lower volume than the ones from straight process, and their crumb firmness increases with the time of frozen storage.(23) In addition, their crumb is characterized by thick network walls and a thick crust with a rough surface;(65) moreover crumbs have large pores with a non-uniform distribution.(113) Those breads also show high staling rate due to a decrease of loaf volume and a disruption of the protein structure.(111,114) However, it is possible to improve the quality of those loaves adding gluten, emulsifiers and hydrocolloids.(23)

PARTIALLY BAKED BREAD

Frozen dough still has several requirements related to wheat flour quality, freezing and thawing conditions and thawed dough handling.(7) Because of that the market is moving from frozen dough to partially baked bread (part-baked, par baked bread or pre baked bread) (Table 2). This product was initially developed for improving the bread quality.(115-117) Bread from partially baked is made following the conventional process, with the exception of baking. The partial baking or interrupted baking method consists in baking the bread dough till the structure is fixed; thus the partially baked bread has the crumb structure of the baked bread without a crunchy crust. In the retail bakery the partially baked bread is only baked for a very short time. The market of the partially baked bread is rapidly growing because the product is already sized, shaped and partially baked, reducing the preparation of the baked bread.

Several studies have been conducted for determining the effect of the proving conditions[118], the optima time and temperature for partially baking,[115,119-122], and also the chilling condition after partial baking and the freezing condition on the partially baked bread.[118] Short prebaking times at high temperatures leads to more open structure of the crumb.[115,123] In general, the optimum prebaking time is approximately two thirds of the time required for full baking.[121] High steam is recommended for improving the crust.[117] One of the quality problems of the fresh bread obtained from partially baked bread is the crust flaking resulting from the detachment of some part of the crust.[124] This phenomenon has been ascribed to two different processes: the concentration of water ice under the crust due to the presence of the freezing front and the interface differences between the crust and crumb associated to the tensile forces and stresses induced by the thermomechanical shock.[124] Le Bail et al [118] reported that chilling conditions after partial baking are the most determinant parameter on the crust flaking followed by the proving conditions. In general high air humidity during those processes tends to reduce the crust flaking.

Partially baked bread has a very short shelf life due to the absence of crust and its high moisture content,[123,125] which increase the susceptibility to microbial growth. In fact, it has been described the growth of spoilage bacteria such as *Bacillus strains*.[126] Different approaches have been proposed for extending the shelf life of the partially baked breads. The package either in a modified atmosphere containing 40% CO_2 and 60% N_2,[127] or in polyethylene-polyamide-polyethylene vinyl alcohol bags containing 70% CO_2,[128] considerably prolongs the shelf life of partially baked bread. Even the use of low temperatures (2-6°C) have been successfully used for extending the shelf life of the partially baked bread till ten days.[85,129] However the most extended practice is to keep the partially baked bread frozen during the storage period up to its final baking. The hygienic conditions in the bakeries should be carefully controlled, because, although the microorganisms do not grow at frozen temperatures, the final baking is not sufficient to inactivate microorganisms, particularly *B. licheniformis* spores.[126]

Bread obtained by the partially baking process has sensory and textural properties close to those of the bread obtained by a conventional method,[119,121] although crumb hardness increase with the time of frozen storage.[130]

Concerning the staling behaviour during storage, it should be distinguished between the storage of partially baked bread and the bread after rebaking. Barcenas et al [130] did not detect retrogradation of amylopectin during frozen storage of partially baked bread. Nevertheless, when analyzing the aging of the rebaked samples, the time of frozen storage produces a progressive increase of the retrogradation temperature range of the amylopectin, and also great energy is required for amylopectin melting at longer storage period, indicating that structural changes of amylopectin are produced during frozen storage. Crumb hardness results of the fresh bread and also DSC studies indicate that some changes are produced during the frozen storage. Hence, freezing-thawing cycles produce dramatic effects on the bread properties even in the case of partially baked bread which has already fixed the crumb structure.[130] Nonetheless, the crumb hardness could be reduced by modifying the bread formulation, for instance the use of high dosage of yeast, the addition of vegetal fats[131] or the addition of hydrocolloids.[92,129,132]

It has been reported that hydroxypropylmethyl cellulose (HPMC) increases the specific volume and the moisture retention of the bread from partially baked, moreover reduces the crumb hardness and inhibits the effect of the frozen storage on the bread staling.[85,92,129,132]

CONCLUSION

Frozen storage of bread dough or partially baked bread allows to have almost ready products at any time of the day, and the retails should only give a special touch for differentiating their products from the more commercial ones. From the previous information it can be extracted that this market is still going to increase supported by the improvement of these products quality and the development of new products based in this technology. This change in the bakery market could be very advantageous in the case of special breads, like gluten free bread or rich fiber bread. These type of products are addressed to small groups and sometimes it is very difficult to find them in the conventional bakeries, thus the use of frozen either dough or partially baked bread could overcome those problems and provide a wide range of products.

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Table 1. Overview of the research performed in the development of frozen doughs.

Formulation		(51,97,99)
Flour		(7,8,9,12,13,133)
Yeast	Selection	(31,42,43,44,45,49,55,60,61,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149)
	Stability	(48,52,54,57,62,102,150,151,152)
Other ingredients	Gluten	(51,70,71,153,154,155)
	Egg and sugars	(73)
	Milk derivates	(72)
Additives	Hydrocolloids	(16,27,28,156)
	Emulsifiers	(22,77,157)
	Shortenings	(68,69,131)
Processing	Make up	(99,100,101,104,107,158,159)
	Freezing	(25,112)
	Frozen storage	(7,13,17,18,20,63,110,111,160,161,162,163)
	Thawing	(19)
	Dough structure	(15,109,164,165,166)
Bread quality		(23,28,167)
	Safety	(5)
	Structure	(65,113)
	Staling	(114)

Table 2. Overview of the research performed in the development of partially baked breads.

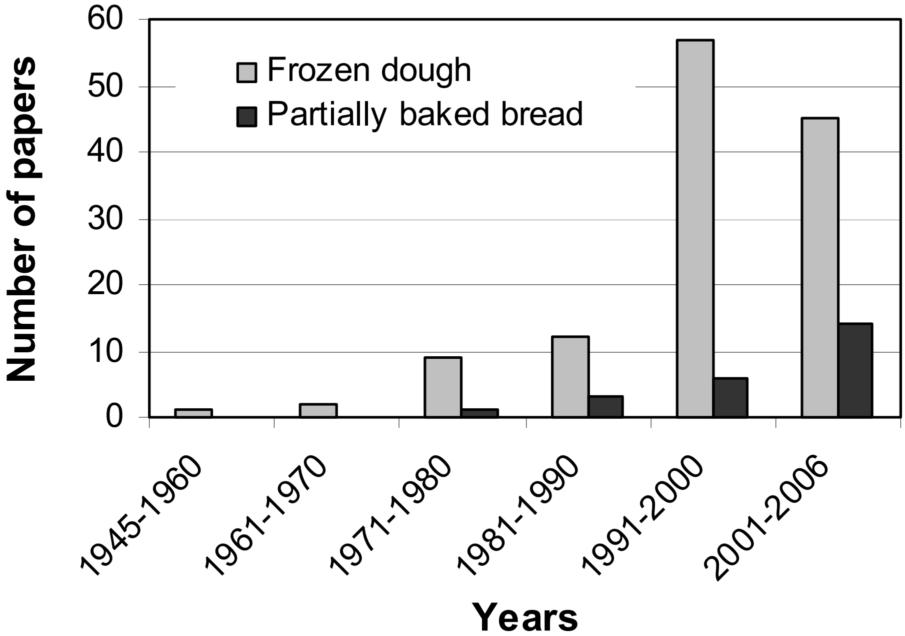
Ingredients	(131)
Additives	(84,130,132)
Processing	(117,118,119,120,121,123,124,125)
Partially baked storage	(126,127,128,129,168,169)
Bread quality	(85,92,125)

FIGURE CAPTIONS

Figure 1. Trend of research manuscripts included in the Science Citation Index related to frozen dough and partially baked bread.

Figure 1

4



60
50
40
30
20
10
0
Number of papers
Frozen dough
Partially baked bread
1945-1960
1961-1970
1971-1980
1981-1990
1991-2000
2001-2006
Years