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Invited review

# Inventions on keeping properties and non-reactive ingredients in chemical leavening

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**Summary** Bakery foods may be leavened by gas originating from the reaction of specific ingredients in chemical leavening or so-called baking powder. The latter contains alkaline- and acid-reacting compounds that are activated when water is added to make the dough. Care should be taken to prevent premature cross-reaction of active ingredients. The aim of this study was to review keeping properties and non-reactive ingredients in chemical leavening. Information was mainly found in 160 patents, not in the scientific literature. Inventors proposed neutral fillers, anticaking agents and household packaging to control moisture absorption in powders. Chemical leavening carried dough processing aids, nutrients and flavour improvers. Miscellaneous coating materials were introduced to delay gas production in dough refrigerated over prolonged periods. Neutral fillers like corn starch and, more recently, coatings for leavening acids were the most popular solutions for extending the shelf-life of chemical leavening.

**Keywords** Baking powder, chemical leavening, coating, filler, patents, preservation.

## Introduction

Dry chemical leavening preparations may be used to expand the volume of bakery products to get light and spongy texture (Gélinas, 2021). Active ingredients in so-called baking powders are gas-releasing compounds, which are triggered by acid-reacting material. Flour containing baking powder is called self-rising flour. Legally, on food labels, baking powder shall be a combination of sodium or potassium bicarbonate, an acid-reacting material, starch or other neutral material, which may contain an anticaking agent and shall yield not less than 10% of its weight of carbon dioxide, as determined by official method (Minister of Justice of Canada, 2023). A recent in-depth literature review stressed the importance of selecting the right chemical leavening composition according to the nature of bakery food (Russell, 2018a).

Acceptable baking powder activity may extend to about 1 year under optimal storage conditions, including moisture-proof packaging and storage at low temperature in dry environment (Heidolph, 1996). After opening packaging, commercial baking powder retains acceptable gas-forming capacity for 3–6 months (Russell, 2007).

Early baking powders quickly lost strength during storage (Crampton, 1889; Hunt, 1900). Depending on manufacturing, packaging and storage conditions, sodium bicarbonate released variable amounts of gas in powders (Gibson, 1886). A study on commercial baking powders in retail stores in the USA concluded that most products had vastly different gassing power (Mallet, 1888). These results were confirmed by Cornwall (1889). Variability in the activity of chemical leavening preparations was due to the following: (i) variation in the proportion of filling material (starch), (ii) variable character of sodium bicarbonate employed (containing a larger or smaller proportion of true bicarbonate), (iii) greater or less purity of acid-reacting ingredients, (iv) greater or less care in the adjustments to each other in proper proportions of the soda and the acid ingredients, (v) want in due care to insure uniform mixture of the ingredients, (vi) mainly to greater or less absorption of moisture from the air in keeping different degrees of care in drying the materials, and in putting up the powder in packages for sale, (vii) and difference in age of some of the chemical leavening samples (Mallet, 1888). For many early baking powder manufacturers, the sole element of cheapness obscured all other attributes, including healthfulness and keeping properties (Newton, 1889).

The aim of this report is to review keeping properties and non-reactive ingredients in chemical leavening. To our knowledge, this is the first in-depth literature review on this subject matter. Information was mainly found in

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'letters patent for inventions', referred to for short as patents (Bloxam, 1957). Patents protect technical inventions, for example, a product, a process or an apparatus; the owner has to fully disclose the invention (European Patent Office, 2023). Rarely cited in peer-reviewed scientific reviews, patents are a unique source of information, as stressed in companion reviews on chemical leavening (Gélinas, 2021, 2022a,b,c). This article should help food scientists to better understand long-term evolution and future challenges associated with chemical leavening for baking applications.

Solutions for improving the keeping properties of dry chemical leavening preparations mainly include neutral fillers, anticaking agents, coating materials and packaging. During the course of this study, we found that inventors proposed chemical leavening preparations carrying dough processing aids, nutrients and ingredients for reducing off-taste in baked products. Objectives of patented inventions are presented, with historical context and scientific evidence, including more details as Supporting Information (Tables S1–S9; Figs S1 and S2).

## Neutral fillers

Chemical leavening is diluted with large amount of neutral filler to prevent cross-reaction of active reactants, limit moisture absorption and adjust gas-forming capacity. Not less than nineteen types of fillers have been described in patents on baking powder (Table 1); more details are given in Table S1. Inventors had major interest in cereal or starchy by-products like wheat flour, malt flour, potato starch, gluten, cellulose and cob corn meal. Solid fat and dairy products were also popular. Food additives with strong water-absorbing capacity were patent protected, including calcium carbonate, calcium sulphate, diatomaceous earth and fruit peels.

### Objectives

There was a need for cheap, non-reactive and water-absorbing materials that would improve the durability of chemical leavening. Such solution was more convenient than separate packaging for bicarbonates and acids (Walker, 1866). In the 1950s and earlier, alternatives were searched for corn starch, the most popular filler, due to its short supply and prohibitive cost (Barch, 1950; Novitsky, 1957).

### Historical aspects

A Flour. Conant (1842) was the first inventor to mix dry flour with leavening acids such as cream of tartar to protect the acid with flour particles. Turner & Holloway (1853) used rice flour with small amount of arrowroot.

**Table 1** Neutral fillers for chemical leavening, with patent priority date*

| Compound | Priority date; first inventor; patent number |
|---|---|
| 1. Calcium carbonate | 1885; Peters; US 331542<br>1885; Nowell; GB 188512178<br>1947; Barch; US 2532281 |
| 2. Calcium biphosphate; $Ca_2H_2P_2O_8$ | 1901; Kochs; US 673057 |
| 3. Calcium citrate | 1937; Aeckerle; US 2238149 |
| Calcium stearate: see fat, solid | |
| 4. Calcium sulphate (gypsum; plaster) | †<br>1954; Novitsky; US 2793121 |
| 5. Calcium tartrate, neutral | 1928; Weil; GB 304230 |
| 6. Casein; caseinate | 1901; Just; US 692451<br>1903; Teller; US 749643<br>1920; Bleyer; DE 344707 |
| Chalk: see magnesium carbonate | |
| 7. Corn cob meal or cellulose flour | 1943; Tornow; DE 752600 |
| 8. Disodium phosphate, anhydrous | 1913; Holbrook; US 1113632 |
| 9. Fat, solid; lard; calcium stearate; oil-free stearin; hydrogenated oils | †<br>1876; Rosser; US 192716<br>1885; Marsh; US 329419<br>1890; Catlin; US 439267<br>1907; McFarland; US 884606<br>1915; Holbrook; US 1210940<br>1917; Atkinson; US 1264592<br>1962; Stegano; FR 1345671<br>1997; Rodiguez; EP 0882401 |
| 10. Flour (wheat; malt; corn; rice; potato) | †<br>1842; Conant; GB 184510555<br>1845; Jones; GB 184510555<br>1848; Sewell; GB 184812030<br>1884; Carter; GB 188411334<br>1886; Watkins; GB 188605162<br>1901; Oetker; DE 144289<br>1914; Jessop; GB 191424286<br>1922; Rahn; DE 418341<br>1942; Deutsche Mazeina Werke; FR 894472 |
| 11. Fruit peels (lemon or orange) | 1917; Töllner; DE 309712 |
| 12. Gluten | 1905; Kellogg; US 932138<br>1911; Beatty; US 1034677 |
| 13. Kieselguhr; diatomaceous earth; lycopodium | 1928; Schott; US 1952947 |
| 14. Magnesium carbonate; chalk; $MgCO_3$ | 1885; Peters; US 331542<br>1885; Nowell; GB 188512178 |
| 15. Milk powder (skimmed) | 1895; Gregory; US 544975<br>1907; Hooker; GB 190700053 |
| 16. Pyrophosphates, neutral | 1927; Weil; GB 303353 |
| 17. Starch (gelatinised; potato; maize; corn) | †<br>1864; Horsford; US 41815<br>1880; Horsford; US 229705<br>1911; Remington; GB 191118716<br>1912; Strickler; US 1150901<br>1914; Beatty; US 1170474 |

**Table 1** (*Continued*)

| Compound | Priority date; first inventor; patent number |
|---|---|
| | 1918; Berry; GB134987<br>1919; Chemische Fabrik Marienfelde; DE 335474<br>1926; Thornton; US 1689697<br>1929; McCollum; US1771342<br>1942; Lloyd; US 2394791<br>1944; Lee; US 2424992 |
| 18. Strontium carbonate; $SrCO_3$ | 1885; Peters; US 331542 |
| 19. Whey powder | 1944; Lacroix; FR906505 |

*More details in Table S1 (Supporting Information).

†Not originally claimed as a patented invention. This neutral filler was known before the 1830's, or prior to the first patent on baking powders that was granted to Whiting (1836).

Flour was not a lasting solution because it contains fat that may combine with oxygen and become rancid (Catlin, 1890). For similar reasons, bran-rich flour had low potential for inclusion in baking powders (Schiller, 1950). Leavening acids like tartrates accelerated flour rancidity (Watts *et al.*, 1949). Between 1910 and 1940, incorporation of flour in chemical leavening was progressively abandoned, partly due to scarcity during war periods in Europe (Fig. S1).

B Starch. Also called maize starch, fat-free corn starch has long been the most popular filler for dry chemical leavening preparations due to its remarkably high degree of lightness (Thatcher, 1890; Mendelsohn, 1939). It was commercially available before 1850 (Bragg, 1850; Civitello, 2017). For example, in 1843, Alfred Bird used corn starch to dilute yeast-free artificial leavening composition containing cream of tartar and sodium bicarbonate and to stabilise the texture of egg-free custard (Cameron, 1898; Page, 2013; Kudos Blends, 2023).

Inventors reported that corn starch was not entirely satisfactory because it was prohibitive and absorbed too much moisture from the air (Catlin, 1890; Novitsky, 1957). Without claiming patent protection and contrary to common belief, Horsford (1856) preferred using wheat flour with a smaller amount of potato starch instead of corn starch, rice flour, gypsum or solid fat.

Most early commercial baking powders contained 32% starch, ranging from 0% to 52% (Crampton, 1889). Fifty years later, mean starch content in baking powders was similar, about 35% (Bailey, 1940). Powders with <10% starch were the least active gas-forming materials and inclusion of more than 30% starch did not translate into better keeping properties (Schiller, 1950). Not an infrequent practice in the past, adding 50–70% filler in chemical leavening was inadequate and associated with falsification (Tillmans & Heublein, 1917).

C Others. Calcium carbonate would be an acceptable neutral filler for baking powders (Brose *et al.*, 2001; Briggs, 2018). Another filler, calcium sulphate, would react with sodium bicarbonate and trigger gas production, allowing the use of more bicarbonate in biscuit dough without leaving an alkaline taste (Patten, 1917). To avoid dust in bakery plants, solid fat was recommended as filler for chemical leavening in the form of a paste (Rodiguez, 1998).

### Scientific evidence

Neutral fillers would have limited effect on the preservation of baking powders, especially those containing very hygroscopic ingredients and stored under high relative humidity conditions (Catlin, 1890; Gallay & Bell, 1936). Often containing much moisture, monocalcium phosphate tends to act spontaneously with bicarbonates (Hunt, 1900; Weil, 1929). Corn starch is an effective protectant against acid reactants despite its low water-absorbing capacity compared to potato starch, which has coarser particles. Small starch particles would efficiently coat and stabilise acid components in baking powders (Gallay & Bell, 1936).

Nowadays, in Canada, neutral fillers in baking powder include only starch and calcium sulphate (Minister of Justice of Canada, 2023). Corn starch is also a very popular excipient or neutral filler in pharmaceutical products (Kurniawansyah *et al.*, 2022). Some individuals have reported allergic reactions to corn starch (Randolph, 1948; Kalikyan, 2020). Alternatives have been searched. For example, resistant starch from sweet potatoes might have some potential as food filler, to increase dietary fibre (Bodjrenou *et al.*, 2023).

## Anticaking agents

Anticaking additives for food ingredients have been reviewed (Peleg, 2020; Yapıcı *et al.*, 2021). Corn starch would have low anticaking properties in sugar (Irani *et al.*, 1959). According to Ellis (1950):

> It is known that common salt and sugar are both liable to cake on storage and that this objection can be overcome by incorporating in them a small proportion of magnesium carbonate or tricalcium phosphate. Sodium bicarbonate has a slight tendency to form lumps on storage, more particularly when several hundredweight bags are stored on top of one another, and it is not always free flowing. The caking of sodium bicarbonate, however, does not resemble the commonly known caking of

> deliquescent materials; it is rather the formation of lumps from the finally powdered material when stored in warehouses, generally under compression because of the height of the stockpile. For industrial use, especially for mixing with flour for making self-rising flour, it is highly desirable to avoid the formation of lumps and also to have the sodium bicarbonate in a free-flowing form so that the mixing machinery operates uninterruptedly.

Twelve anticaking agents for baking powders have been proposed, mainly targeting sodium bicarbonate and other highly hygroscopic compounds like cream of tartar and monocalcium phosphate (Table 2; Table S2). Nowadays, lumps formation in baking powders may be controlled with calcium silicate, allowed at 5% maximum, a much lower concentration than inert fillers (Minister of Justice of Canada, 2023). Due to very high hydrophilic properties, potassium bicarbonate may be mixed with silicon dioxide, calcium stearate or magnesium oxide (Lubasch *et al*., 2018).

**Table 2** Anticaking agents for chemical leavening, with patent priority date*

| Compound | Priority date; first inventor; patent number |
|---|---|
| 1. Calcium carbonate | 1948; Ellis; GB 635393 |
| 2. Calcium disodium pyrophosphate tetrahydrate | 1961; Stahleber; US 3244478 |
| 3. Calcium hydroxy phosphate | 1948; Ellis; GB 635393 |
| 4. Calcium hyperphosphate; magnesium hyperphosphate | 1961; Stahleber; US 3273960 |
| 5. Calcium silicate, hydrated; $CaSiO_3$[†] | 1958; Miller; US 2933396 |
| 6. Disodium phosphate | 1912; Strickler; US 1037078 |
| 7. Lactose (milk serum; milk sugar) | 1889; Thatcher; US 422464 |
| 8. Magnesium carbonate | 1931; Deutman; US 1913796<br>1948; Ellis; GB 635393<br>1991; Lajoie; US 5153018 |
| 9. Magnesium oxide (MgO) | 1994; Lajoie; US 5552084 |
| 10. Silicon dioxide ($SiO_2$); magnesium silicate | 1991; Lajoie; US 5153018 |
| 11. Starch, potato | 1948; Foster; US 635394 |
| 12. Tricalcium phosphate | [‡] |

*More details in Table S2 (Supporting Information).
[†] Originally claimed as a neutral filler.
[‡] Not originally claimed as a patented invention and cited by Ellis (1950).

## Coatings

Coating materials are a popular solution to protect and delay the activity of chemical leavening agents. To reduce hygroscopicity and delay reaction of bicarbonates in dough, inventors were most interested in solid-fat-like compounds having variable melting properties such as lard, paraffin and wax, as well as miscellaneous ingredients made of cellulose, gums and carbonates (Table 3; Table S3). Compared to bicarbonates, much more coating materials have been proposed for leavening acids, not less than eighteen different types (Table 4; Table S4). For example, as part of the manufacturing process, insoluble glass-like skin may be formed on monocalcium phosphate particles to slow its rate of reaction in dough (Gélinas, 2022b).

## Objectives

Inventors searched for alternatives to inert fillers, which had limited effects on the keeping properties of baking powders. There was a need to delay much gas production in dough so gas would be released only when heated, at the baking step.

## Historical context

According to the earliest patent found on this topic, sodium bicarbonate was sprayed with a solution of magnesium sulphate, forming a dry coating of inert and water-insoluble sodium carbonate; this process prevented the reaction of alkaline bicarbonate with acids in baking powders until water was added to make dough (Horsford & Catlin, 1883). Many early

**Table 3** Coatings for gas-releasing compounds (bicarbonates) in chemical leavening, with patent priority date*

| Compound | Priority date; first inventor; patent number |
|---|---|
| 1. Calcium carbonate | 1882; Horsford; US 270668 |
| 2. Cellulose ether mixture (HPMC) | 1974; Harris; US 3959499[†]<br>1982; Torres-Muñoz Barquin; ES 8401775[†] |
| 3. Fat, liquid (vegetable oils) | 2000; Redding; US 20020064587<br>2003; Domingues; US 20040208957 |
| 4. Fat, solid (stearin; stearic acid; hydrogenated shortening) | 1909; Federer; US 980936[†]<br>1941; Stokes; US 2372402<br>1972; Selenke; US 4022917<br>1976; Yoshitani; JP S5920328[†]<br>2010; Brown; WO 201114151<br>2014; Savary; WO 2016102603<br>2016; Shen; AU 2016102164 |
| 5. Gums (Arabic, carrageenan, xanthan) | 2012; Gaunt; US 20150071979 |
| 6. Magnesium carbonate | 1882; Horsford; US 270668 |
| Starch and other polysaccharides; see gums | |
| 7. Waxes (including beeswax) | 2000; Vaghefi; US 20010044026 |

HPMC, hydroxyl-propyl-methyl cellulose.
*More details in Table S3 (Supporting Information).
[†] Also, for acids (Table 4).

**Table 4** Coatings for acids in chemical leavening, with patent priority date*

| Compound | Priority date; first inventor; patent number |
|---|---|
| 1. Agar-agar | 1907; Craig; GB 190703035 |
| 2. Albumen (egg whites) | 1905; Paul; GB 190605564<br>1905; Best; US856672 |
| 3. Aluminium pyrophosphate | 1941; Cobb; US 2291608 |
| 4. Barrier materials (fat and others) | 1994; Chung; EP 0699392 |
| 5. Calcium acid pyrophosphate | 1939; Cox; 2 263 487<br>1946; Alfred Bird and Sons Ltd.; GB 608708 |
| 6. Calcium glycero-phosphate | 1943; Monsanto Chemical; GB 636209 |
| 7. Calcium lactate | 1943; Monsanto Chemical; GB 636209 |
| 8. Calcium polyphosphate | 1954; Bell; US 2791488 |
| 9. Cellulose (HPMC and others) | 1918; Lange; DE336665<br>1974; Harris; US 3959499[†]<br>1982; Torres-Muñoz Barquin; ES 8401775[†] |
| Dicalcium phosphate (see aluminium pyrophosphate) | |
| 10. Dipotassium phosphate; with magnesium oxide | 2018; Zivkovic; US 20190335763 |
| 11. Fat, solid (ethereal oil; stearin, shortening) | 1904; Lampe; AT 22827<br>1909; Federer; US 980936[†]<br>1919; Blinn; US 1370272<br>1926; Geere; GB 276146<br>1958; Luther; CA 563621<br>1965; Brennan; US 3492128<br>1968; Miyazaki; JP S484541B1<br>1976; Yoshitani; JP S5920328[†]<br>1983; Hayashi; JP H0360141227<br>1986; Katz; US 4792456<br>1999; Wakasugi; JP 2000333591<br>1999; Tamiya; JP 2001045961<br>2000; Uesugi; JP2001286255<br>2001; Pacifico; US 20030031773<br>2001; Domingues; WO 03020044<br>2003; Nukii; JP 2004313185<br>2004; Brinker; WO 2006065134<br>2008; Morris; US 20100015278<br>2009; Maeda; JP 2011067195<br>2013; Arai; JP 2014223042<br>2013; Xu; CN 103461750<br>2016; Arai; JP 2017163887<br>2017; Lubasch; EP 3372086.<br>2019; Hull; US 20210092963 |
| 12. Gelatin | 1931; Fiske; US 1951328 |
| Magnesium oxide (see dipotassium phosphate) | |
| 13. Magnesium pyrophosphate | 1940; Milligan; US 2297630 |
| Magnesium stearate (see fat, solid) | |
| 14. Magnesium sulphate (agglomerated) | 1943; Monsanto Chemical; GB 636209 |
| Paraffin (see waxes) | |
| 15. Potassium oxide | 1938; Schlaeger; US 2160233 |
| 16. Sodium acid pyrophosphate | 1946; Alfred Bird and Sons Ltd.; GB 608708 |
| 17. Sodium lauryl sulphate | 1937; Moss; US2222830 |
| 18. Waxes (paraffin and others) | 1905; Weil; GB 190515667<br>1911; Oetker; GB 191100842<br>1926; C.H. Boehringer Sohn; DE 507399 |

HPMC, hydroxyl-propyl-methyl cellulose.

*More details in Table S4 (Supporting Information).

[†] Also, for bicarbonates (Table 3).

coating materials gave disappointing results because coating dissolved too late in the process, especially in stiff or under-hydrated dough. Bread was often spotted, resulting from local action of acid and soda particles coated with solid fat, for example (Catlin, 1890). Caking was likely to result when powders mixed or coated with fat-based ingredients were exposed to ordinary maximum temperature and cooled. It was difficult to control the thickness of fat-based coatings. If coating was too thin, this resulted in premature gas production in dough. Many authors considered that coating was too expensive compared to the manufacturing cost of acid components in chemical leavening (Toy, 1976).

## Scientific evidence

New barrier materials for chemical leavening were mainly introduced in patents. Before the 1990s, no research data were available on encapsulation of active ingredients for chemical leavening (Dorko & Penfield, 1993). The latter situation contrasts much with intense peer-reviewed research and development activities on the preservation of active dry yeast (Gélinas, 2019).

Benefits of microencapsulation for specific baking applications are described in Lenz *et al.* (2018). According to Lakkis (2007), chemical leavening agents should preferably be coated with large amounts of coating, up to 95%, which is much more than other food applications. Particles should be very narrow in sizing, preferably ranging between 50 and 100 µm (Pacifico, 2003). For coating sodium bicarbonate, it is recommended to use hard fats with fine grain sizing (≦15 µm), provided that no lump or agglomerate is formed (Bouchain, 2014). The most popular encapsulation techniques include fluid bed, bottom spray (Würster Process), tangential spray (rotor process) and spray-chilling/cooling (Hull & Campanella, 2021).

Without acidulants, encapsulated sodium bicarbonate would be the best solution when gas release is highly controlled and fully delayed during long storage periods, for example, in frozen cookie dough (Book & Livvix, 2018). Co-encapsulation of baking powders with solid-fat-like butter oil would be difficult to control and might result in major losses of leavening activity (Onwulata *et al.*, 1997). As mentioned above, agglomerates of bicarbonates, those that do not dissolve completely, result in increases in pH and undesirable discoloration spots in the crumb. Cakes with a denser texture may be obtained with encapsulated bicarbonates if gas production is delayed too much, especially with slow-acting leavening acids like GDL (Diez-Sánchez *et al.*, 2020).

Nowadays, major problems with coating materials appear to have been solved so many encapsulated leavening acids are now available (Book & Livvix, 2018). For example, sodium bicarbonate may be coated with glycerol monostearate and konjac glucomannan (Ding *et al.*, 2018a). Ammonium bicarbonate may be protected with a coat of palm stearin and carnauba wax (Ding *et al.*, 2018b). In general, coating of dry chemical leavening particles would mainly apply to very specific baking applications, to prevent premature gas build-up and dough expansion in thawed and refrigerated dough.

## Storage devices

For about 65 years, in particular, between 1871 and 1936, inventors proposed miscellaneous vessels for storing and handling baking powders for home baking, to exclude air and moisture while allowing easy measuring (Table S5).

### Objective

There was a need for household storage devices that prevented moisture absorption of hygroscopic materials such as baking powder and coffee.

### Historical context

As reported by Bartlett (1894), baking powder rapidly deteriorated when exposed to air and metal. Inventors designed boxes, including closing devices, made of pasteboard with the smallest amount of metal ends. To avoid premature reaction, alkalis and leavening acids were placed in separate packages in quantities suited to the given weight of flour, as patented or recommended by many inventors (Horsford, 1864a,b; Walker, 1866; Ripley, 1871; Adair, 1904; Whitelaw, 1915; Umina & Westcott, 1972). It was desirable to obviate the necessity of using separate packaging, for the sake of economy (Catlin, 1890). Alkalis and acids were also stored in separate compartments of the same vessel, as first proposed by Wilson (1871), and later adapted by Clotworthy (1891), as shown in Fig. S2.

Developed before 1936, these inventions were for household applications. In the USA, especially in the South, baking powder was extremely popular for home baking, being extensively used by 91% of families, with an average annual consumption of 2.6 kg (General Foods Corporation, 1934). Storage cans, measuring vessels and grinding devices could also eliminate lumps in chemical leavening. A unique mixer for homemade baking powder was patented to get insured that the resultant mixture was free of starch or alum or other adulterants (Table S5).

### Scientific evidence

No comprehensive scientific report was found on phenomena associated with the degradation of individual active ingredients in chemical leavening according to packaging conditions.

## Other methods of the preservation of chemical leavening

Besides the latter innovations on neutral fillers, coating materials and storage devices, a few other techniques were proposed to check and improve the keeping properties of chemical leavening (Table S6). Catlin (1892) introduced granular phosphate-based acids to limit exposition of active material to moisture. To expel moisture, Johnson (1922) centrifuged cake mixes at elevated temperatures. Particles of acid and alkaline reactants were rendered mutually repellent when charged separately with high-intensity electrostatic charge of like sign, preferably of a positive sign (Fiske, 1938a, 1938b).

Kiely (1909) patented a test to determine the activity of baking powders based on a gas-measuring vessel in which water was displaced, corresponding to the amount of gas generated. Earlier techniques were described in the scientific literature (Catlin, 1893; Page, 2017). Official methods have been adopted in the 1920s (Page, 2017; Russell, 2018b).

## Dough improvers

Inventors proposed baking powders carrying processing aids, like gums, to improve gas retention in dough (Table S7). According to Mendelsohn (1939), dehydrated egg whites were often compounded in early baking powders. An uncommon practice nowadays, colouring matter

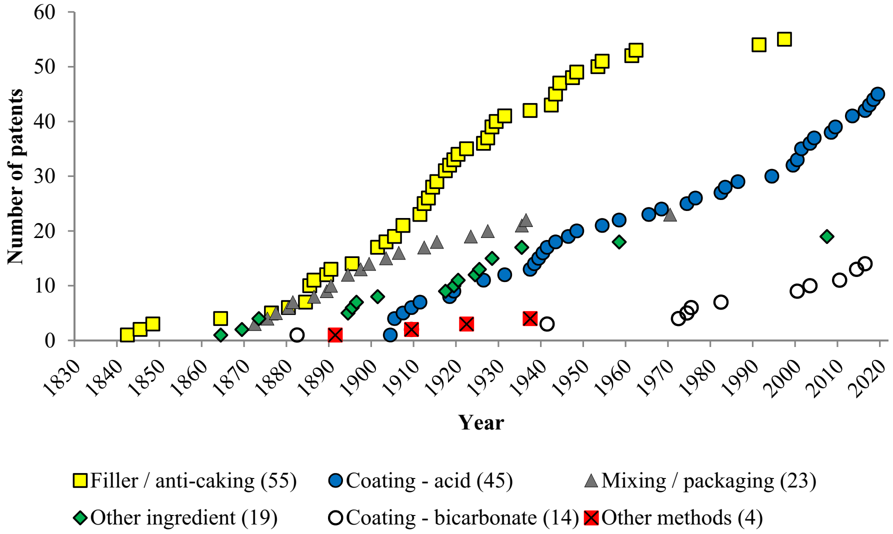

**Figure 1** Evolution over time of patent applications on keeping properties and non-reactive ingredients in chemical leavening.

was added to baking powder sold as an egg substitute to help cake batter expand (Bolm, 1918).

Baking powders carrying nutrients were also proposed to improve bread's nutritive value with minerals (potassium and phosphorus) and protein (milk, egg and blood) or supplemented with amylase to improve starch digestibility (Table S8). It is not clear if food nutritive value was much improved considering low level of additional nutrients in baking powder and dough. Inactive yeast-based preparations were patented to mask off-taste, a major problem associated with baking powder (Table S9).

## Conclusions

To our knowledge, this is the first complete literature review on keeping properties and non-reactive ingredients in chemical leavening. Barely addressed in the scientific literature, such information was mainly found in 160 patents issued over about 200 years. This confirms that 'letters patent for inventions' contain much knowledge. Many innovative solutions were proposed to improve the durability of chemical leavening, as summarised below.

1. Early baking powder preparations were very difficult to keep and became lumpy under ordinary storage conditions. As an alternative to separate packaging, inventors proposed techniques to combine acids and bases in chemical leavening preparations and dilute the latter active ingredients with non-reactive ingredients. This was a difficult challenge.
2. Not less than nineteen types of neutral filler were proposed. Introduced in the 1840s, starch, especially corn starch, is still the main neutral filler for baking powders, giving excellent results compared to wheat flour, solid fat or gypsum, for example. Potential alternatives to corn starch might target resistant starch for fibre enrichment of bakery foods.
3. Nowadays, inventors have lost interest in neutral fillers and household storage devices and stopped adding nutrients and dough-processing aids to baking powders. Besides the dilution of active ingredients, neutral fillers had limited impact on the durability of chemical leavening, especially those containing highly hygroscopic materials such as tartrates, lactates and early phosphate-based leavening acids (Gélinas, 2022b, 2022c). It was not until the 1930s that more stable leavening acids such as coated monocalcium phosphate and sodium acid pyrophosphate were commercially available, which is about the same period as acceptable dry baker's yeast but much later than compressed yeast (Gélinas, 2017, 2019).
4. In more recent years, coatings for leavening acids have been the most popular solutions to improve the durability of chemical leavening, especially to delay reaction in dough stored under refrigeration (Fig. 1). Not less than eighteen types of coating materials were proposed for leavening acids, that is much more than seven types recommended for bicarbonates. Better encapsulation techniques now allow timely control of reaction rates of acids and alkalis, including specific fat composites melting at different temperatures. For example, highly stable leavening acids like glucono-delta-lactone may be coated so non-expanded dough may be stored for very long periods.

5 Based on information disclosed in patent specifications, it may be difficult to select the best coating materials for chemical leavening. Supplementary assays must be performed to better suit individual needs. Future research avenues include the development of better techniques to evaluate the potential of coating materials in different bakery formulations. Reasons for loss of activity in coated acids and bicarbonates should be addressed, possibly based on lessons learned with active dry baker's yeast.

To sum up, improving the durability of chemical leavening would likely optimise the concentrations of its active ingredients, also contributing to the reduction of off-flavours in bakery products. More attention should be given to the nutritive value of neutral fillers in baking powders.

## Author contributions

**Pierre Gélinas:** Conceptualization (lead); data curation (lead); formal analysis (lead); investigation (lead); validation (lead); writing – original draft (lead); writing – review and editing (lead).

## Conflict of interest

There is no conflict of interest to declare.

## Ethical approval

Ethics approval was not required for this research.

## Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.16451.

## Data availability statement

Data sharing is not applicable as no new data was generated, or this article describes entirely theoretical research.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Figure S1.** Evolution over time of inert fillers for chemical leavening, as mentioned in specifications of 494 patents introduced by Gélinas (2021).

**Figure S2.** Drawing accompanying US Patent 462109 entitled "Packing baking-powder".

**Table S1.** Neutral fillers in chemical leavening, with patent priority date – Extended version.

**Table S2.** Anticaking agents for chemical leavening, with patent priority date – Extended version.

**Table S3.** Coatings for gas-releasing agents (bicarbonates) in chemical leavening, with patent priority date – Extended version.

**Table S4.** Coatings for acids in chemical leavening, with patent priority date – Extended version.

**Table S5.** Mixers and packaging to improve keeping properties of chemical leavening, with patent priority date – Extended version.

**Table S6.** Other methods to determine and improve the keeping properties of chemical leavening, with patent priority date – Extended version.

**Table S7.** Dough processing aids in chemical leavening, with patent priority date – Extended version.

**Table S8.** Nutrients in chemical leavening, with patent priority date – Extended version.

**Table S9.** Flavour improvers in chemical leavening, with patent priority date – Extended version.