United States Department of Agriculture
Agricultural Marketing Service | National Organic Program
Document Cover Sheet
https://www.ams.usda.gov/rules-regulations/organic/petitioned-substances

Document Type:

☐ **National List Petition or Petition Update**

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

☒ **Technical Report**

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Ammonium Bicarbonate and Carbonate

Handling/Processing

Identification of Petitioned Substance

Chemical Names:
ammonium carbonate $(NH_4)_2CO_3$
- ammonium sesquicarbonate
- carbonic acid, diammonium salt
- diammonium carbonate

ammonium bicarbonate (NH_4HCO_3)
- ammonium acid carbonate
- ammonium hydrogen carbonate
- carbonic acid, monoammonium salt
- monoammonium carbonate

Other Names:
AmBic; baker's ammonia; bicarbonate of ammonia; bicarb; hartshorn; salt of hartshorn; sal volatile; smelling salts

Trade Names:
Sold as baker's ammonia or ammonium carbonate/bicarbonate

CAS Numbers:
ammonium carbonate: 506-87-6
Mixture of ammonium bicarbonate and ammonium carbamate: 8000-73-5
ammonium bicarbonate: 1066-33-7

Other Codes:
ammonium carbonate:
- EC number: 233-786-0
- E number: E503(i)
- UNII: PDP691CN28 (NJ5VT0FKLJ when a mixture of ammonium bicarbonate and ammonium carbamate)

ammonium bicarbonate:
- EC number: 213-911-5
- E number: E503(ii)
- UNII: 45JP4345C9

Summary of Petitioned Use

This full scope technical report provides information to the National Organic Standards Board (NOSB) to support the sunset review of ammonium bicarbonate, listed at 7 CFR 205.605(b)(4), and ammonium carbonate, listed at § 205.605(b)(5). This report focuses on the uses of these materials in organic processing and handling, as leavening agents only (per the substances' annotations).

In 1995, a Technical Advisory Panel (TAP) developed a report for the NOSB on ammonium bicarbonate and carbonate (NOSB, 1995). No technical reports have been written for these materials since. These substances were included on the National List of Allowed and Prohibited Substances (hereafter referred to as the "National List") with the first publication of the National Organic Program (NOP) Final Rule (65 FR 80548, December 21, 2000). The NOSB has recommended their renewal in 2005, 2010, 2015, and 2020 (NOSB, 2009; NOP, 2010; NOSB, 2015, 2020).

As ammonium bicarbonate and carbonate are both listed at § 205.605(b), synthetic forms are allowed. The annotations for both substances specify that they are "for use only as a leavening agent."

We use the term "ammonium carbonates" (plural) when referring generically to both ammonium bicarbonate and ammonium carbonate (actually a mixture of ammonium bicarbonate and ammonium carbamate).

Characterization of Petitioned Substance

Composition of the Substance
Ammonium bicarbonate and carbonate are salts composed of ammonium and carbonate ions. The ammonium ion is a common polyatomic cation, consisting of an ammonia molecule covalently bonded to a hydrogen ion, with a single positive charge (Ucko, 1982b). The carbonate anion is also a polyatomic anion, and consists of covalently bonded carbon and oxygen atoms (Ucko, 1982a). Carbonate (CO_3^{2-}) is the conjugate base of the bicarbonate (HCO_3^-) anion, which is itself the conjugate base of carbonic

acid (H_2CO^3) (Ucko, 1982a). The term "conjugate base" refers to a compound remaining after an acid loses a proton (H^+). Both ammonium and carbonate are ubiquitous in the environment.

Complex interactions between ammonia, water, and carbon dioxide lead to the formation of various solid phases referred to as "ammonium carbonates" and include (Brondi et al., 2023; Fortes et al., 2014; Howard, 2019):

- ammonium carbonate monohydrate [$(NH_4)_2CO_3 \cdot H_2O$]
- ammonium sesquicarbonate monohydrate {$(NH_4)_4[H_2(CO_3)_3] \cdot H_2O$}
- ammonium bicarbonate (NH_4HCO_3)
- ammonium carbamate ($NH_4CO_2NH_2$)

Ammonium bicarbonate

Ammonium bicarbonate is the monoammonium salt of carbonic acid with the formula NH_4HCO_3 and a molecular weight of 79.06 g/mol (see *Figure 1*) (National Center for Biotechnology Information, 2024a).

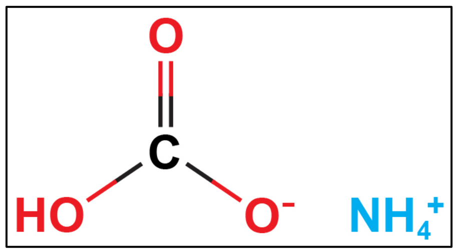

Figure 1: Molecular structure of ammonium bicarbonate

Ammonium carbonate

Ammonium carbonate is the diammonium salt of carbonic acid with the generalized formula $(NH_4)_2CO_3$ and a molecular weight of 96.09 g/mol (see *Figure 2*) (National Center for Biotechnology Information, 2024b). Ammonium carbonate only forms in carefully controlled conditions that are difficult to achieve in production facilities (Zapp et al., 1985). Commercially available ammonium carbonate is not pure and may even be composed of entirely different compounds, typically with a large proportion of ammonium carbamate (Fortes et al., 2014; Howard, 2019).

The FDA describes the standard of identity of ammonium carbonate used in food, as a leavening agent or pH control agent, to be a mixture of ammonium bicarbonate and ammonium carbamate at 21 CFR 184.1137 (see *Approved Legal Uses of the Substance*). The FDA recognizes this mixture as the GRAS form of ammonium carbonate (CAS 8000-73-5) rather than pure ammonium carbonate (CAS 506-87-6). Commercial ammonium carbonate products for food use are usually equal mixtures of ammonium bicarbonate and ammonium carbamate [$(NH_4)NH_2CO_2$] (Royal Society of Chemistry, 2024; Zapp et al., 1985), and these mixtures will be a focal point of this report.

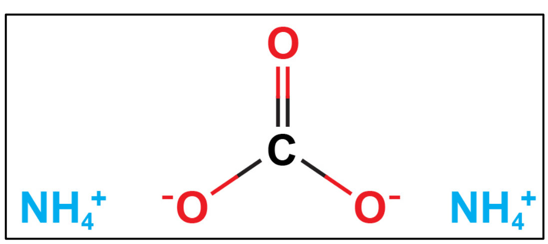

Figure 2: Molecular structure of ammonium carbonate

<u>Source or Origin of the Substance</u>

Ammonium bicarbonate occurs naturally on earth in the mineral teschemacherite, observed in guano deposits in South America and South Africa, and in geothermal waters in New Zealand (Howard, 2019). Other ammonium carbonates are not known to occur naturally (Fortes et al., 2014). Fortes et al. (2014) hypothesize that ammonium carbonate monohydrate may occur in seabird fecal deposits in areas adjacent to glaciers, but this has not been directly observed due to the instability of ammonium carbonate above freezing temperatures.

Ammonium carbonates are manufactured by the reaction of ammonia sourced from the synthetic Haber-Bosch process with carbon dioxide sourced from industrial processes like power generation, cement manufacturing, or fossil fuel processing (Brondi et al., 2023). See *Evaluation Question #1B* for more information on manufacturing processes. The FDA GRAS standard of identity also describes ammonium carbonate prepared by sublimation of a mixture of ammonium sulfate and calcium carbonate.

Properties of the Substance

Ammonium bicarbonate

Ammonium bicarbonate is a colorless to white solid occurring as crystalline masses or powder, with a faint odor of ammonia (see *Table 1*). Ammonium bicarbonate is the only compound in the ternary NH_3-CO_2-H_2O system that is stable above freezing (32 °F/0 °C) (Howard, 2019).

Ammonium bicarbonate thermally decomposes into ammonia gas, carbon dioxide, and water (Penfield & Campbell, 1990). Ammonium bicarbonate has advantages over baking soda (sodium bicarbonate) or baking powder (usually sodium bicarbonate and acid salt) because it produces a greater volume of gas from the same mass of leavening agent (Howard, 2019). The absence of a residual salt in this heating reaction is desirable in baked goods if the ammonia gas is allowed to escape completely (Penfield & Campbell, 1990). Since remaining ammonia imparts an unpleasant taste, the use of ammonium bicarbonate as a leavening agent is limited to products with a large surface area, flat shape, and low moisture content (Howard, 2019; Penfield & Campbell, 1990). The low moisture content of finished baked goods is important since ammonia is soluble in water, and it may be retained in bulky baked goods rendering them unpalatable (Howard, 2019).

Other common chemical leavening agents like baking soda (typically sodium bicarbonate) and baking powder (typically sodium bicarbonate + an acid) rely on the reaction of an alkaline salt with a weak acid to produce carbon dioxide gas (Canali et al., 2020). Baking soda requires the addition of an acid to initiate the reaction, while baking powder already contains a dry, weak acid combined with sodium bicarbonate. By contrast, ammonium bicarbonate dissociates into carbon dioxide and ammonia gas upon heating without the addition of an acid (Canali et al., 2020).

Table 1: Chemical and physical properties of ammonium bicarbonate (ECHA, 2023b; National Center for Biotechnology Information, 2024a).

Property	Value
Physical State and Appearance	Crystalline solid
Odor	Faintly ammoniacal
Taste	Slightly alkaline
Color	Colorless or white
Molecular Weight (g/mol)	79.06
Density (g/cm^3)	1.59
pH	Approx. 8 (5% solution)
Solubility (g/100mL)	17.4
Boiling Point (°C)	n/a
Melting Point (°C)	107 (decomposes)
Vapor Pressure (kPa at 25.4°C)	7.85
Stability	Stable at room temperature, decomposes upon heating
Reactivity	Nonflammable, decomposes in heat

Ammonium carbonate

Ammonium carbonate is a white, crystalline solid or powder consisting of flat, columnar, or prismatic crystals that is very soluble in water (see *Table 2*). Ammonium carbonate is only stable at freezing temperatures and transforms to ammonium bicarbonate (by loss of one ammonia group) at approximately 0 °C (32 °F) (Fortes et al., 2014; Howard, 2019).

Table 2: Chemical and physical properties of ammonium carbonate (ECHA, 2023a; National Center for Biotechnology Information, 2024b).

Property	Value
Physical State and Appearance	Crystals or powder
Odor	Strongly ammoniacal
Taste	Strongly ammoniacal
Color	Colorless or white
Molecular Weight (g/mol)	96.09
Density (g/cm^3 at 20°C)	1.5
pH	Approx. 8.6 (5% solution)
Solubility (g/100mL)	100 (water)
pKa	pKa1: 9.25; pKa2: 6.35
Boiling Point (°C)	n/a
Melting Point (°C)	58 (decomposes)
Stability	Decomposes to NH_3 and CO_2 when heated
Reactivity	Nonflammable, air-sensitive, decomposes in heat

Ammonium carbamate

We include a limited description of the properties of ammonium carbamate (not to be confused with carbonate) due to its explicit inclusion in the FDA standard of identity of ammonium carbonate, as well as its known occurrence in products sold as ammonium carbonate.

Ammonium carbamate forms white crystals and has an ammoniacal odor (National Center for Biotechnology Information, 2024c). It is soluble in water and gradually loses ammonia and carbon dioxide to the air within minutes, transforming to ammonium carbonate (Howard, 2019; National Center for Biotechnology Information, 2024c). It is relatively stable in a closed container in a cool, dry environment (Howard, 2019).

Specific Uses of the Substance

The primary use for ammonium carbonates are as leavening agents for low-moisture baked goods, such as dry cookies and crackers (Miller, 2016). Specifically, ammonium carbonates are chemical leavening agents that work to expand and aerate the structure of the finished baked good by releasing gases into the batter (De Leyn, 2014; Sumnu & Sahin, 2008). Moisture in low-moisture baked goods is limited to five percent because the ammonia gas, produced as ammonium carbonates decompose during baking, dissolves in water and is retained in moist products, creating a sharp, pungent odor and an unpleasant taste (Kukurová & Ciesarová, 2024; Miller, 2016). Drier products do not retain the ammonia gas, and the strong odor dissipates by the end of the baking process (Sadd et al., 2008).

While leavening is the primary use of ammonium bicarbonate, it is also used as a nitrogen source for yeast cultures and as smelling salts (Zapp et al., 1985). Ammonium carbonate may also be used as a food acidity regulator, specifically as an optional neutralizing additive in cacao products (21 CFR part 163), and Asian yellow alkaline noodle doughs (Huang & Miskelly, 2016; National Center for Biotechnology Information, 2024b).

Approved Legal Uses of the Substance

Food manufacturers use ammonium bicarbonate and carbonate as processing aids. Therefore, the relevant approved legal uses of these substances are regulated by the FDA (US FDA, 2023).

- Ammonium bicarbonate is Generally Recognized as Safe (GRAS) without limitations other than current good manufacturing practice. The FDA notes its use as a dough softener, leavening agent, pH control agent, and texturizer (see *Ammonium bicarbonate FDA standard of identity*, below).
- Ammonium carbonate is also GRAS without limitations other than current good manufacturing practice. The FDA notes its use as a leavening agent and pH control agent (see *Ammonium carbonate FDA standard of identity*, below).

The FDA lists both substances as ingredients in the production of other products, such as caramel (21 CFR 73.85), cacao nibs (§ 163.110), breakfast cocoa (§ 163.112), and chocolate liquor (§ 163.111).

Ammonium bicarbonate FDA standard of identity

The FDA describes the standard of identity for ammonium bicarbonate as follows (21 CFR 184.1135):

(a) Ammonium bicarbonate (NH_4HCO_3, CAS Reg. No. 1066-33-7) is prepared by reacting gaseous carbon dioxide with aqueous ammonia. Crystals of ammonium bicarbonate are precipitated from solution and subsequently washed and dried.

(b) The ingredient meets the specifications of the Food Chemicals Codex, 3d Ed. (1981), p. 19, which is incorporated by reference…

(c) In accordance with § 184.1(b)(1), the ingredient is used in food with no limitation other than current good manufacturing practice. The affirmation of this ingredient as GRAS as a direct human food ingredient is based upon the following current good manufacturing practice conditions of use:

  (1) The ingredient is used as a dough strengthener as defined in § 170.3(o)(6) of this chapter; a leavening agent as defined in § 170.3(o)(17) of this chapter; a pH control agent as defined in § 170.3(o)(23) of this chapter; and a texturizer as defined in § 170.3(o)(32) of this chapter.

  (2) The ingredient is used in food at levels not to exceed current good manufacturing practice.

(d) Prior sanctions for this ingredient different from the uses established in this section do not exist or have been waived.

The FDA also states that ammonium bicarbonate is GRAS as a general-purpose food additive at § 582.1135 when used in accordance with good manufacturing or feeding practice.

The third edition of the Food Chemicals Codex (National Research Council, 1981) specifies the following for ammonium bicarbonate:

> **Description:** White crystals or a crystalline powder having a slight odor of ammonia. At a temperature of 60° or above, it volatilizes rapidly, dissociating into ammonia, carbon dioxide, and water, but at room temperature it is quite stable. One g dissolves in about 6 ml of water. It is insoluble in alcohol.
>
> **Identification:** It gives positive tests for *Ammonium*, page 515, and for *Bicarbonate*, page 516.
>
> **Assay:** not less than 99.0% of NH_4HCO_3.
> **Arsenic (as As):** Not more than 3 ppm.
> **Chloride:** Not more than 0.003%.
> **Heavy Metals (as Pb):** Not more than 10 ppm.
> **Nonvolatile Residue:** Not more than 0.05% (0.55% for products containing a suitable anticaking agent).
> **Sulfur Compounds:** Not more than 0.007%.
>
> (Various test descriptions then follow in the monograph, which we have omitted here.)

Ammonium carbonate FDA standard of identity

The FDA describes the standard of identity for ammonium carbonate as follows (21 CFR 184.1137):

(a) Ammonium carbonate [$(NH_4)2CO_3$, CAS Reg. No. 8000-73-5] is a mixture of ammonium bicarbonate (NH_4HCO_3) and ammonium carbamate (NH_2COONH_4). It is prepared by the sublimation of a mixture of ammonium sulfate and calcium carbonate and occurs as a white powder or a hard, white or translucent mass.

(b) The ingredient meets the specifications of the Food Chemicals Codex, 3d Ed. (1981), p. 19, which is incorporated by reference…

(c) In accordance with § 184.1(b)(1), the ingredient is used in food with no limitation other than current good manufacturing practice. The affirmation of this ingredient as GRAS as a direct human food ingredient is based upon the following current good manufacturing practice conditions of use:
   (1) The ingredient is used as a leavening agent as defined in § 170.3(o)(17) of this chapter and a pH control agent as defined in § 170.3(o)(23) of this chapter.
   (2) The ingredient is used in food at levels not to exceed current good manufacturing practice.
(d) Prior sanctions for this ingredient different from the uses established in this section do not exist or have been waived.

The FDA also states that ammonium carbonate is GRAS as a general-purpose food additive at § 582.1137 when used in accordance with good manufacturing or feeding practice.

The third edition of the Food Chemicals Codex (National Research Council, 1981) specifies the following for ammonium carbonate:

> **Description:** Ammonium carbonate consists of ammonium bicarbonate (NH_4HCO_3) and ammonium carbamate ($NH_2.COONH_4$) in varying proportions. It occurs as a white powder or as hard, white or translucent masses. Its solutions are alkaline to litmus. On exposure to air it becomes opaque and is finally converted into porous lumps or a white powder of ammonium bicarbonate due to the loss of ammonia and carbon dioxide. One g dissolves slowly in about 4 ml of water.
>
> **Identification:** When heated, it volatilizes without charring and the vapor is alkaline to moistened litmus paper. A 1 in 20 solution effervesces upon the addition of an acid.
>
> **Assay:** Not less than 30.0% and not more than 34.0% of NH3•
> **Arsenic (as As):** Not more than 3 ppm.
> **Chloride:** Not more than 0.003%.
> **Heavy Metals (as Pb):** Not more than 10 ppm.
> **Nonvolatile Residue:** Not more than 0.05%.
> **Sulfur Compounds:** Not more than 0.005%.
>
> (Various test descriptions then follow in the monograph, which we have omitted here.)

<u>Action of the Substance</u>

Ammonium carbonates thermally decompose during baking, thereby functioning as leavening agents in baked goods (Kweon et al., 2014; Miller, 2016). The decomposition products are ammonia gas, carbon dioxide gas, and water (including steam), as shown in *Equation 1*. These products cause the expansion and texturization of baked goods, creating a "lightness" in the crumb structure (De Leyn, 2014; Miller, 2016; Sadd et al., 2008). Carbon dioxide and ammonia off-gas with time. Present in all baked goods, steam is formed from the heating of water; however, it is also created in the decomposition of the ammonium carbonates (Sumnu & Sahin, 2008). Steam contributes to the pressure increase inside the batter, resulting in a greater volume in the finished product.

$$NH_4HCO_3 \xrightarrow{heat} NH_3 + CO_2 + H_2O$$

(ammonium bicarbonate) → (ammonia) + (carbon dioxide) + (water)

Equation 1

According to Sharma et. al. (2017), the general leavening process can be broken down into three stages:

1. Flour is mixed with water and leavening agents, incorporating all the materials into the dough's structure and creating air pockets.
2. The dough is proofed when necessary.[1]
3. The product is baked, releasing gases and creating a leavening action throughout the dough.

Released gases interact with the air that is introduced as the dough is mixed, and the water present in the mixture (Miller, 2016). Air pockets allow for released gas bubbles to expand, using the available air as nuclei for growth (Miller, 2016; van der Sman, 2021). Carbon dioxide is the first and primary gas released into these pockets (De Leyn, 2014; van der Sman, 2021). The carbon dioxide bubbles expand until they rupture, at which point the secondary gas, ammonia, begins to escape from the dough using the same releasing mechanism as carbon dioxide (van der Sman, 2021). The bicarbonate ion is the only gas contributor until the carbon dioxide bubble rupture event. The third and final gas present is water in the form of steam (Miller, 2016).

The release of carbon dioxide and ammonia does not affect the pH or color development of the baked product (Gélinas, 2022; Kweon et al., 2014). However, as mentioned in *Specific Uses of the Substance*, moisture levels above five percent, especially in bulky products, traps ammonia in the dough, preventing off-gassing and causing an unpleasant ammoniacal flavor (Howard, 2019; Kukurová & Ciesarová, 2024; Miller, 2016). In baked goods with less than 5% moisture content, the ammonia gas escapes completely by the end of the baking process (van der Sman, 2021). Therefore, ammonium carbonates are not suitable for products such as cakes and sponges where the moisture content would result in the presence of residual ammonia.

Combinations of the Substance

The industrial process used to produce ammonium carbonate and bicarbonate generates several ammonium salts (Ivanchenko et al., 2020). The final ammonium carbonates mixture may contain ammonium carbonates and carbamates in different proportions (Efimov et al., 1982; Ivanchenko et al., 2020; Sutter & Mazzotti, 2017) as described in *Composition of the Substance*.

All of these ammonia salts are unstable and gradually decompose, releasing ammonia, carbon dioxide, and water (Ivanchenko et al., 2020; Weston et al., 2000; Zapp et al., 1985). Both carbamate and carbonate decompose to yield bicarbonate (Zapp et al., 1985). Ammonium bicarbonate is the most stable salt and the commercial product's main component (Ivanchenko et al., 2020). Zapp et al. (1985) mentioned that equimolar mixtures of ammonium carbonate and ammonium bicarbonate are sold as ammonium carbonate. This is in agreement with the reported composition of the food-grade ammonium carbonates present in technical data sheets, which often indicate that the product is a mixture of ammonium bicarbonate and ammonium carbamate (BASF, 2024; Keystone Universal, 2017; Spectrum Chemical, 2014).

Ammonium carbonates tend to cake, and their flowability is maintained by anticaking additives such as (Zapp et al., 1985):

- cornstarch
- magnesium oxide
- magnesium carbonate

The most popular anticaking agent added to ammonium carbonates is magnesium carbonate (at 3500 to 10,000 parts per million) (BASF, 2024). From the above list, corn starch is the only additive currently permitted as an anticaking agent under 7 CFR 205.606.

Research on microencapsulation of ammonium carbonates using palm stearin and carnauba wax exists (Ding et al., 2018), but encapsulated ammonium carbonates are not yet popular in the marketplace. AMPAK Company launched a line of encapsulated baking ingredients in 2020, including encapsulated

[1] Proofing: resting and allowing the dough to rise before baking.

ammonium carbonate (Ingredients Network, 2020); however, we could not find these products when searching online, and we could not identify the nature of the encapsulating agent used in this product line.

Status

Historic Use

Records of ammonium bicarbonate use date back to the 14th century, where English manuscripts mention "salt of hartshorn" as an expanding agent for certain baked goods (Zapp et al., 1985). Ammonium salt of hartshorn is produced from the dry distillation (heating) of antlers, hooves, and leather, and consists of (Gélinas, 2022; Zapp et al., 1985):

- ammonium bicarbonate (NH_4HCO_3)
- ammonium carbamate ($NH_4CO_2NH_2$)
- ammonium carbonate ($(NH_4)_2CO_2 \bullet H_2O$)

The quantity of use was and still is limited to small amounts, about 0.1% in modern recipes, to avoid the reported unpleasant taste if used in excess (Huber & Schoenlechner, 2017; van der Sman, 2021). According to Page (2013), a report from 1838 instructed bakers to use one quarter ounce of salt of hartshorn for every pound of flour.

By the beginning of the 19th century, salt of hartshorn was manufactured on a semi-industrial scale (Zapp et al., 1985). The first baking powder patent was issued in 1836 and included salt of hartshorn (Gélinas, 2022).[2] This patent was not specifically for ammonium carbonates, as the ingredient was well-known prior to the patent. The first manufacturing patent specific to ammonium carbonate was issued in 1888 in Great Britain, quickly followed by the first ammonium bicarbonate manufacturing patent, issued in 1893 (Gélinas, 2022). By 1919, large-scale production associated with the industrial synthesis of ammonia replaced previous production methods (Zapp et al., 1985). As a result of large-scale production, salt of hartshorn became a mixture of pure ammonium bicarbonate and ammonium carbamate, with a 32.5% ammonia (NH_3) content.

In modern times, ammonium carbonates are commonly combined with other leavening agents, such as sodium bicarbonate, which have a longer shelf-life (Gélinas, 2022). Ammonium carbonates are limited to certain flat, low-moisture baked goods, some of which feature the material as a signature ingredient (Kollemparembil et al., 2023; Kukurová & Ciesarová, 2024). Notable examples of this are black-and-white cookies and ammonia cookies. Other products that may use ammonium bicarbonate alone or in combination with other leavening agents are (Bejosano & Waniska, 2004; Kukurová & Ciesarová, 2024; Kweon et al., 2014):

- biscuits
- cookies
- crackers
- wafers
- bread
- ready-to-eat cereals
- confectioneries
- crisp breads
- breakfast cereals
- cakes
- pastries
- gingerbread
- wheat tortillas

[2] The 1836 patented baking powder was also composed of: baker's salt (ammonium carbonates mixed with magnesium, calcium, aluminum, and iron bicarbonates), carbonate of magnesia, magnesium bicarbonate, potassium carbonate, sodium bicarbonate, and sodium carbonate.

Organic Foods Production Act (OFPA), USDA Final Rule

OFPA (1990) does not include any reference to ammonium bicarbonate or carbonate.

For handling purposes, USDA organic regulations include ammonium bicarbonate and ammonium carbonate on the National List at 7 CFR 205.605(b)(4) and (5), respectively. The annotation specifies that both substances are only for use as a leavening agent. Both ammonium bicarbonate and ammonium carbonate were originally included in the first publication of the NOP Final Rule (65 FR 80548, December 21, 2000).

International

Ammonium bicarbonate and ammonium carbonate are allowed by all of the international standards that we reviewed (see *Table 3*, below). Under these standards, organic producers may use ammonium bicarbonate and ammonium carbonate as leavening agents. Some standards, such as the Codex Alimentarius, also allow ammonium bicarbonate and ammonium carbonate to be used as pH adjusters. All of the standards reviewed limited ammonium bicarbonate and ammonium carbonate, only allowing them for use in products of plant origin (either explicitly or implicitly, such as by limiting their use as a leavening agent only).

Table 3: Allowance of ammonium bicarbonate and ammonium carbonate in processing and handling applications under a selection of international organic standards.

Standard	Applicable regulations	Allowed?	Source and use restrictions (if applicable)
Canada Organic Standards (CAN/CGSB-32.310 – Organic Production systems - General principles and management standards; CAN/CGSB 32.311 – Organic Production Systems Permitted Substances List.)	CAN/CGSB 32.311 PSL Table 6.3—Ingredients classified as food additives	Y	Ammonium bicarbonate: As a leavening agent. Ammonium carbonate: As a leavening agent.
European Economic Community (EEC) Council Regulation (EC No. 834/2007 and EU 2021/1165)	Annex V Part A Section A1 – Food additives, including carriers	Y	E 503, Ammonium carbonates. Organic Foodstuffs to which it may be added: products of plant origin.
Japanese Agricultural Standard (JAS) for Organic Processed Foods	Appended Table 1-1, Additives (Organic processed foods other than organic alcohol beverages) Appended Table 1-2 Additives (Organic alcohol beverages)	Y	INS Number 503i, Ammonium carbonate. Limited to the use in processed products of plant origin. Also allowed as an additive in organic alcohol beverages with no annotation. INS Number 503ii, Ammonium bicarbonate. Limited to the use in processed products of plant origin.
Codex Alimentarius Commission—Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)	Table 3, Ingredients of non-agricultural origin referred to in section 3 of these guidelines. 3.1, Additives permitted for use under specified conditions in certain organic food categories or individual food items.	Y	INS No. 503i, Ammonium carbonate. Functional use allowed in organic production: Acidity regulator, raising agent. Permitted for use in food of plant origin. Permitted, although exclusions of the GSFA still apply. *Not permitted in food of animal origin.* INS No. 503ii, Ammonium hydrogen carbonate. Functional use allowed in organic production: Acidity regulator, raising agent. Permitted for use in food of plant origin. Permitted, although exclusions of the GSFA still apply. *Not permitted in food of animal origin.*
IFOAM-Organics International	Appendix 4—Table 1: List of approved additives and processing/post-harvest handling aids.	Y	INS 503, Ammonium carbonates *(Allowed as an additive)*. Only for cereal products, confectionery, cakes and biscuits.

Evaluation Questions for Substances to be used in Organic Handling

Classification of the Substance

Evaluation Question #1(A): Describe if the substance is extracted from naturally occurring plant, animal, or mineral sources.
Commercial ammonium carbonates are not extracted from naturally occurring plant, animal, or mineral sources.

Evaluation Question #1(B): Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Include any chemical changes that may occur during manufacture or formulation of the substance.
The most prevalent manufacturing process for obtaining commercial food-grade ammonium carbonates and carbamates utilizes ammonia and carbon dioxide as precursors (Ivanchenko et al., 2020; Zapp et al., 1985). Ammonium carbonate is not a stable compound and is only formed under precisely defined conditions that are difficult to achieve in any production plant (Zapp et al., 1985). Due to that manufacturing limitation, an equivalent mixture of two substances, ammonium carbamate and ammonium bicarbonate, is sold as food-grade ammonium carbonate (Zapp et al., 1985). We describe the manufacturing process for ammonium bicarbonate, ammonium carbamate, and their precursors below.

Carbon dioxide precursor
As noted in the *Carbon Dioxide* technical report (NOP, 2023), carbon dioxide is mainly a waste or by-product of the following processes:
- combustion of hydrocarbon fuel and chemical decomposition
- hydrogen and ammonia production
- fermentation

This technical report also mentions that after collection, carbon dioxide is typically compressed, purified further using activated carbon beds, and then cooled by water and refrigerants.

Ammonia precursor
Commercial ammonia is produced synthetically from atmospheric nitrogen through the Haber-Bosch process (Amhamed et al., 2022; MacFarlane et al., 2020; Pattabathula & Richardson, 2016). To produce ammonia, gaseous nitrogen and hydrogen are reacted under high pressure in the presence of a metal catalyzer.

The hydrogen feedstock from which the ammonia is derived through the Haber-Bosch Process is almost entirely produced by heating methane through a process called steam methane reforming (MacFarlane et al., 2020; Pattabathula & Richardson, 2016). This process produces hydrogen and carbon dioxide as by-products.

Ammonium bicarbonate
The process of producing ammonium carbonates can follow a batch or a continuous production scheme; the following steps generalized both cases (Ivanchenko et al., 2020; Zapp et al., 1985):
1) Water is saturated with ammonia and carbon dioxide; this reaction generates heat.
2) Cooling systems remove the heat (see *Figure 3*), prompting the formation of ammonium carbonates crystals.
3) The manufacturers then use centrifuges to separate the crystals from the suspension and dry them; the process ends here for batch production.
4) In continuous production systems, manufacturers recirculate the liquid recovered after centrifugation to further saturate it with ammonia and carbon dioxide, which produces more crystals (see *Figure 3*), which are collected again via centrifugation, and the cycle repeats.

5) As described in *Composition of the Substance*, the collected crystals consist of ammonium bicarbonate, ammonium carbonate, and carbamate.

Throughout these processes, many chemical changes occur (see *saturator detail* diagram in *Figure 3*)(Sutter & Mazzotti, 2017), but *Equation 2* summarizes the main reaction:

$$\mathbf{NH_{3}}_{(g)} + \mathbf{CO_{2}}_{(g)} + \mathbf{H_2}\mathrm{O}_{(aq)} \rightarrow\ + (\mathbf{NH_4})\mathrm{H}\mathbf{CO_3}_{(s)} +\ \Delta$$

(ammonium) + (carbon dioxide + water) → (ammonium bicarbonate) + (heat)

Equation 2

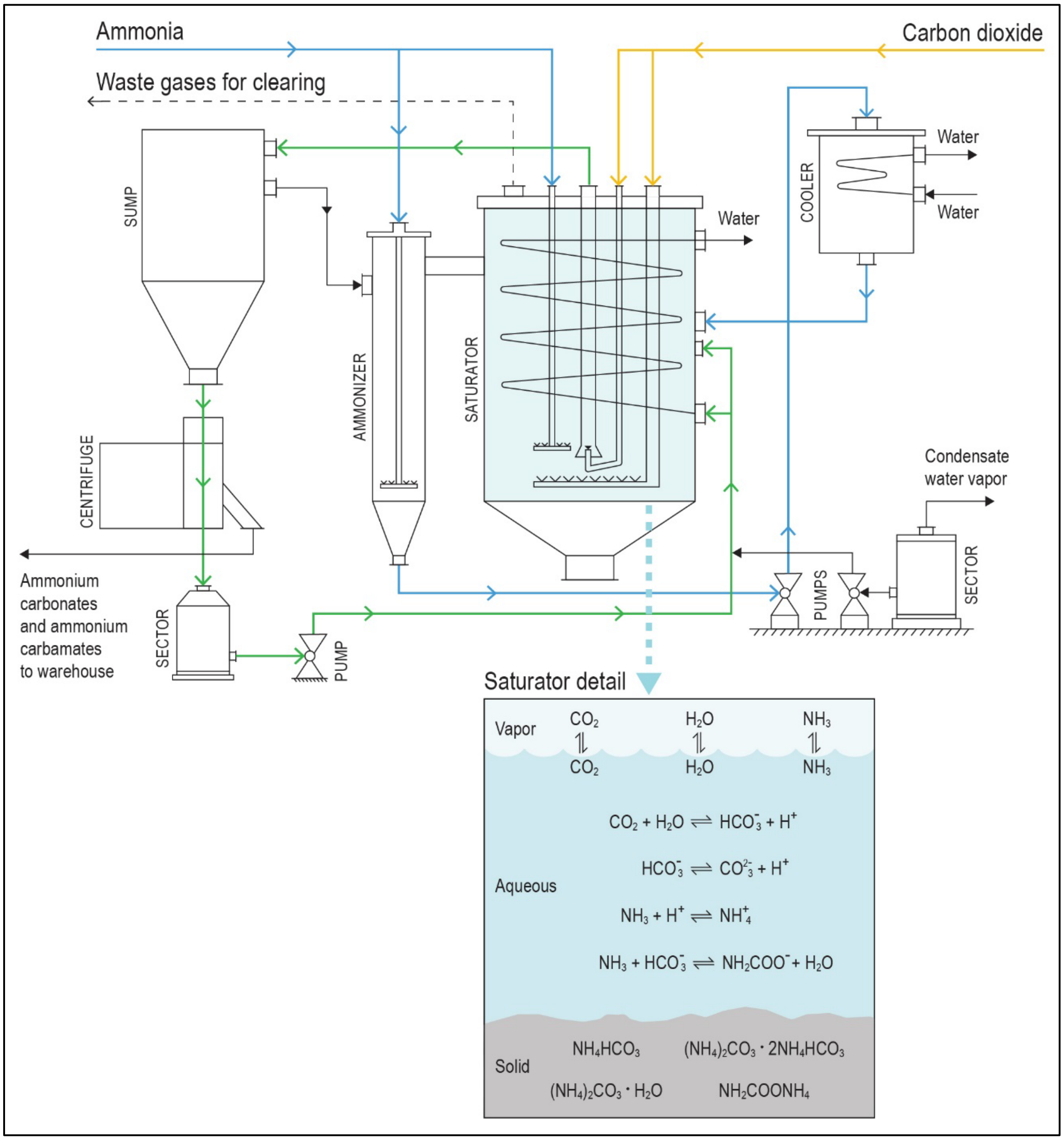

Figure 3: Ammonium carbonates manufacturing process, adapted from Ivanchenko et al. 2020 and Sutter and Mazzoti 2017. Ammonia is supplied while the solution circulates from the ammonizer via a pump, through the external cooler to a saturator, and from the saturator through the sump to the ammonizer unit. As the concentration of the solution increases, saturation occurs, and crystals precipitate (ammonium carbonate, bicarbonate, sesquicarbonates, and carbamate), as shown in the *saturator detail* segment of the figure. The crystals are separated from the suspension through the centrifuge and sent to a warehouse for packaging, and the mother liquor from the collector returns to the saturator via a pump.

Ammonium carbonate

As stated previously, food-grade ammonium carbonate is actually a mixture of ammonium bicarbonate and ammonium carbamate. See section, *Ammonium carbamate*, below.

Ammonium carbamate

Ammonium carbamate is produced industrially by two methods (Dressel et al., 1986; Zapp et al., 1985):

- Through the crystallization of a cooled supersaturated aqueous solution:
    1) Ammonia and carbon dioxide are fed into a concentrated ammonium carbonate solution.
    2) Hydrated carbamate crystals are separated by centrifugation.
    3) The collected crystals are dried carefully under a protective carbon dioxide atmosphere.

Throughout this process, many chemical changes occur in the saturated solution (See the *saturated detail* diagram in *Figure 3*), but the cooled temperatures favor the crystallization of hydrated ammonium carbamate (Dressel et al., 1986) and, in minor quantities, ammonium bicarbonate, and ammonium carbonate.

- Through the interaction of two gasses in a cooled system:
    1) Gaseous ammonia and carbon dioxide are fed into a heat exchanger.
    2) They react in the cooled system as described by *Equation 3*:

$$\mathbf{2NH_3 + CO_2 \rightarrow NH_2COONH_4 + \Delta}$$

(ammonium) + (carbon dioxide) → (ammonium carbamate) + (heat)

Equation 3

3) Carbamate condenses within the pipes and is removed later by partial melting.
4) This carbamate is sold as carbamate rocks or further processed to obtain a powder.

Alternate manufacturing methods for ammonium bicarbonate production

Ammonium bicarbonate can be produced through ammonia-based carbon dioxide capture systems, which are a promising technique for reducing carbon dioxide emissions from several industries (Al-Hamed &Dincer, 2021; Siddiqui et al., 2020; Zhuang et al., 2011, 2012). These ammonia-based carbon capture systems have been investigated at the laboratory-scale (Zhuang et al., 201)and re-engineered utilizing the ammonium carbonates production process as the blueprint (Zhuang et al., 2012). However, more development is needed to adopt this technology on an industrial scale (Al-Hamed & Dincer, 2021; Zhuang et al., 2012). Ammonium bicarbonate produced through these systems is not currently available in the market.

Manufacturers can produce ammonium bicarbonate, purified by anaerobic digestion of wastewater, at a commercial scale using a system patented by Bion Environmental Technologies Inc (Bassani et al., 2024; Orentlicher & Simon, 2018). It is important to note that the ammonium bicarbonate obtained through these systems is marketed only as fertilizer input.

Evaluation Question #1(C): Discuss whether the petitioned substance is agricultural or non-agricultural. If the substance is non-agricultural, is it synthetic or non-synthetic? [7 U.S.C. 6502(21); NOP 5032-1; NOP 5033-2].

Synthetic or Nonsynthetic Classification

Evaluation of ammonium carbonates against Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a) is discussed below.

1. *Is the substance manufactured, produced, or extracted from a natural source?*

No. Ammonium carbonates are manufactured by reacting synthetic ammonia and carbon dioxide under controlled conditions. Thus, when produced from known commercial methods, these materials are synthetic according to the decision tree.

Agricultural or Nonagricultural Classification

Evaluation of ammonium carbonates against Guidance NOP 5033-2 *Decision Tree for Classification of Agricultural and Nonagricultural Materials for Organic Livestock Production or Handling* (NOP, 2016b) is discussed below.

1. *Is the substance a mineral or bacterial culture as included in the definition of nonagricultural substance at section 205.2 of the USDA organic regulations?*

No. Ammonium carbonates are synthetic substances produced industrially from ammonia and carbon dioxide.

2. *Is the substance a microorganism (e.g., yeast, bacteria, fungi) or enzyme?*

No. Ammonium carbonates are synthetic salts.

3. *Is the substance a crop or livestock product or derived from crops or livestock?*

No.

4. *Has the substance been processed to the extent that its chemical structure has been changed?*

Yes. The substance is produced through chemical means and is a mixture of synthetic salts.

5. *Is the chemical change a result of naturally occurring biological processes such as fermentation or use of enzymes; or a result of mechanical/physical/biological processes described under section 205.270(a)?*

No. The chemical change results from the chemical interaction of ammonia and carbon dioxide under controlled cooled conditions.

Therefore, when produced from known commercial methods, ammonium carbonates are nonagricultural substances.

Evaluation Question #1(D): Does the substance in its raw or formulated forms contain nanoparticles?

According to NOP Policy Memo 15-2 *Nanotechnology* (NOP, 2015), nanotechnology is conducted at the nanoscale, which is about 1 to 100 nanometers (nm). NOP uses the term "incidental nanomaterials" to refer to substances that are byproducts of other manufacturing (*e.g.,* homogenization, milling) or that occur naturally (NOP, 2015).

The ammonium carbonates available in the marketplace do not contain intentionally engineered nanomaterials. Ding et al. (2018) conducted microencapsulation experiments with ammonium carbonates, and encapsulated ammonium carbonate is presumed to exist in the marketplace (Ingredients Network, 2020); however, these products would likely have diameters between 1 and 1000 micrometers (µm) and would not fall within the diameters considered nanoparticles as indicated in NOP Policy Memo 15-2 *Nanotechnology* (NOP, 2015) (*i.e.,* 1 to 100 nm).

Nanomaterials that could occur naturally or may be incidental byproducts of human activity are unlikely to be present in ammonium carbonates because the particle sizes fall in the micrometric scale (from 98-500µm) (Anderson et al., 2014; BASF, 2019a, 2019b, 2021; Muehling et al., 1995). Muehling et al. (1995) studied three samples of reagent-grade ammonium carbonate and examined a minimum of 100 particles per sample, finding that the particle size of the original sample was 302 ± 80 µm (mean ± standard deviation). A sample pulverized with a mortar and pestle had a particle size distribution of 98 ± 36 µm, while a third sample, obtained by using ultrasound to fragment the large crystals, had a size distribution of 34 ± 10 µm (Muehling et al., 1995).

Evaluation Question #1(E): Does the substance in its raw or formulated forms contain ancillary substances?
In some cases, ammonium carbonates are mixed with anticaking agents (see *Combinations of the Substance*) (BASF, 2019a, 2019b, 2021; Zapp et al., 1985). The identity and percentage of the anti-caking agent are generally described in the product's technical data sheet. The most common anticaking agent mixed with ammonium carbonates is magnesium carbonate (0- 10,000 parts per million) (BASF, 2019a, 2021); however, as mentioned in *Combinations of the Substance*, cornstarch and magnesium oxide may also be used to improve flowability (Zapp et al., 1985).

Evaluation Question #1(F): Is the substance created using Excluded Methods?

i. *Techniques found to be "excluded methods" by the NOSB were considered, including Targeted genetic modification (TagMo), synthetic gene technologies, genome engineering, gene editing, gene targeting, gene silencing, accelerated plant breeding techniques, synthetic biology, cloned animals and offspring, plastid transformation, cisgenesis, intragenesis, agro-infiltration, transposons developed using invitro nucleic acid techniques, induced mutagenesis developed through in vitro nucleic acid techniques, and cell and protoplast fusion (NOP Policy Memo 13-1).*

No technique considered an "excluded method" is used to manufacture ammonium carbonates.

ii. *If the substance is manufactured from agricultural raw materials, are those materials derived from genetically engineered crops, or crops resulting from excluded methods?*

No agricultural raw materials are used to produce industrial, food-grade ammonium carbonates.

iii. *If the substance is manufactured from other biological raw materials – such as those produced by fermentation or enzymatic action – are those biological materials derived from genetically engineered organisms, or crops organisms resulting from excluded methods?*

No biological raw materials, genetically engineered organisms, or enzymes are used in the manufacturing of industrial, food-grade ammonium carbonate.

Evaluation Question #2: Specify whether the petitioned substance is categorized as generally recognized as safe (GRAS) when used according to FDA's good manufacturing practices [7 CFR 205.600(b)(5)]. If not categorized as GRAS, describe the regulatory status.
When used as a general-purpose food additive, the FDA has categorized ammonium bicarbonate as GRAS, per 21 CFR 184.1135 and § 582.1135. Likewise, ammonium carbonate is categorized as GRAS per § 184.1137 and § 582.1137. See section *Approved Legal Uses of the Substance* above for more details.

Purpose and Necessity of the Substance

Evaluation Question #3: Describe whether the primary technical function or purpose of the petitioned substance is a preservative [7 CFR 205.600(b)(4)].
According to the FDA definition at 21 CFR 101.22(a)(5), ammonium carbonates are not chemical preservatives as they do not prevent the deterioration of food. Instead, they are the source of a decomposition reaction induced by heat that results in ammonia and carbon dioxide gas release. The gas provides a physical rise when added to baked goods and does not affect the pH of the final product (Gélinas, 2022; van der Sman, 2021).

Bejosano and Waniska (2004) found that compared to sodium bicarbonate, ammonium bicarbonate improved shelf life in wheat tortillas; however, the study focused on comparing the two materials as leavening agents rather than as preservatives.

Evaluation Question #4: Describe whether the petitioned substance will be used primarily to recreate or improve flavors, colors, textures, or nutritive values lost in processing (except when required by law). If so, how? [7 CFR 205.600(b)(4)].
Ammonium carbonates are not used to recreate flavors, colors, textures, or nutritive values lost during processing. However, ammonium carbonates are used to assist in improving the texture of specific baked

products. According to Kollemparembil et al. (2023), the use of leavening agents is crucial to creating a softer, more edible baked good. The structural development of baked goods takes place in the leavening and baking steps (Canali et al., 2020), where ammonium carbonates reduce density by opening textural pores in the baked good's structure.

Canali et al. (2020) tested the density of several cookies that contained varying amounts of leavening agent. They compared baking powder mixtures including:

- ammonium bicarbonate
- sodium bicarbonate combined with potassium tartrate and cornstarch
- sodium bicarbonate combined with diphosphates and cornstarch

Next, they measured the adsorption potential, weighing the cookie before and after soaking it in milk.[3] The results showed that the ammonium bicarbonate cookie provided the highest degree of leavening and adsorbed 115% of its initial weight. This was correlated with low hardness, a large diameter and thickness, and low weight. A more homogenous pore size was also attributed to the use of ammonium bicarbonate.

Reports regarding the use of ammonium bicarbonate as a flavoring agent are varied. Huber and Schoenlechner (2017) and Kollemparembil (2023) report a strong characteristic flavor, the latter reporting that black and white cookies' distinctive flavor, for example, is due to the use of ammonium bicarbonate. However, Sadd (2008) and Howard (2019) report that ammonium carbonates do not leave any flavor or odor behind after the baking process is finished. All sources indicate that ammonium carbonates decompose entirely and do not remain in the final baked products.

Ammonium carbonates are not associated with the color development of baked products (Kweon et al., 2014); however, as a result of its instability, baked goods may develop a dark color if the ammonium carbonates are not first dissolved in water and well-distributed throughout the mixture (Gélinas, 2022). Ammonium carbonates' instability results in early decomposition and subsequent oxidation. We discuss ammonium carbonates' instability further in *Evaluation Question #1B* and *Properties of the Substance*.

Evaluation Question #5: Describe any effect or potential effect on the nutritional quality of the food or feed when the petitioned substance is used [7 CFR 205.600(b)(3)].

Ammonium carbonates do not directly contribute to the nutritional quality of food when used as leavening agents because they do not remain in the final food product. Instead, they have indirect nutritional effects as a result of their decomposition.

Sodium intake reduction

Ammonium carbonates decompose completely with heat (Miller, 2016). A unique aspect of these materials is that their mode of action does not contribute to increased sodium content, which is often the case with other chemical leavening agents such as baking soda and baking powder (Miller, 2016; World Health Organization & Food and Agriculture Organization of the United Nations, 2009). Unlike other common leavening agents, ammonium carbonates do not need an acid activator to complete their gas release, therefore salt residues are not created. When used as leavening agents, ammonium carbonates are functional from the viewpoint of overall sodium intake reduction (van der Sman, 2021).

Evaluation Question #6: List any reported residues of heavy metals or other contaminants in excess of FDA tolerances that are present or have been reported in the petitioned substance [7 CFR 205.600(b)(5)].

The FDA establishes "action levels" for poisonous or deleterious substances that are unavoidable in human food and animal feed (U.S. FDA, 2000). These include aflatoxin, cadmium, lead, polychlorinated biphenyls (PCBs), and many other substances. The FDA uses different action level tolerances for these substances, depending on the commodity. Commodities are largely food items; however, the FDA also includes tolerances for ceramic and metal items, such as eating vessels and utensils. Ammonium

[3] Adsorb: attract to the surface of the material, in this case the cookie, by physical attraction.

bicarbonate, ammonium carbonate, and ammonium carbamate are not included on the list of commodities with action levels (U.S. FDA, 2000).

The Food Chemicals Codex specifies limits on impurities in ammonium bicarbonate to 3 ppm of lead (U.S. Pharmacopeia, 2024). The Food Chemicals Codex does not provide specific limit values for other heavy metals or contaminants in ammonium bicarbonate. Other inorganic impurities that may occur in ammonium bicarbonate are (U.S. Pharmacopeia, 2024):

- chloride, no more than 30 ppm when evaluated by a turbidity test
- sulfate, no more than 70 ppm when evaluated by a turbidity test
- nonvolatile residues, no more than 0.05% or 0.55% for products containing a suitable anticaking agent

Researchers attribute heavy metal contamination in baked goods to fertilizers and pesticides used in wheat cultivation (Mocanu et al., 2023). Acrylamide is the most concerning substance, as ammonium carbonates are noted to be one of the major contributors to acrylamide formation (Pasqualone et al., 2021).

Evaluation Question #7: Discuss and summarize findings on whether the manufacture and use of the petitioned substance may be harmful to the environment or biodiversity [7 U.S.C. 6517(c)(1)(A)(i) and 7 U.S.C. 6517(c)(2)(A)(i)].

As a leavening agent in the food industry

Ammonium carbonates are unlikely to harm the environment or biodiversity at the concentrations used in the baking industries. As described in *Action of the Substance*, when ammonium carbonates are used correctly as a leavening agent in baking, they fully decompose into gaseous carbon dioxide, ammonia, and water and, therefore, are not present in the final product.

Ammonia and carbon dioxide emissions can be harmful to the environment; however, the amounts emitted during the baking process can be considered harmless. For instance, when baking a batch of one kilogram of product containing the maximum allowable percentage of ammonium carbonates (3.2% per FDA regulations) (ATSDR, 2004b), approximately 5.6 grams of ammonia gas would be produced. This amount of ammonia gas would translate into about 40 parts per million (ppm) of ammonia gas inside a standard oven space (five cubic feet). Upon opening the oven, ammonia odor might be detected, but the carbon dioxide and ammonia gases would quickly dissipate (National Research Council, 2008). In a standard kitchen with a space of about 195 square feet and a height of 8 feet, the concentration of ammonia gas would remain at approximately 0.127 ppm in the room if it is closed and not ventilated. This concentration is harmless and undetectable by humans, as the odor of ammonia can only be detected at concentrations higher than 5 ppm (National Research Council, 2008). Additionally, mild irritation from ammonia gas does not occur until the concentration reaches 30 ppm and the exposure lasts for 10 minutes (National Research Council, 2008); assuming that the baking space is well-ventilated, such exposure is unlikely. In this same scenario, the concentration of carbon dioxide dispersed in the standard kitchen coming exclusively from the ammonium carbonates used would be about 0.33 ppm. This concentration is far below the typical carbon dioxide levels found in outdoor spaces (300-900 ppm) (FSIS, 2024).

The Food Safety and Inspection Services (2024) indicate that only values of carbon dioxide as high as 40,000 ppm are considered an immediate danger, this is further discussed in *Evaluation question #8*.

When compared to the emissions of ammonia produced by other industries, such as the fertilizer industry and the animal production sector, the emissions from the baking industry are negligible. For example, in the United States, the annual ammonia emissions from livestock production are about 19 kilograms (kg) for dairy, 7.6 kg for swine, and 0.18 kg for poultry per animal (Arogo et al., 2001). In addition, the concentration of ammonia in such emissions can be as high as 18.2 ppm (swine barns) and 29.2 ppm (poultry houses) (Arogo et al., 2001). Rotz (2023) states that beef cattle production in the United States emits approximately 900 million kg of ammonia per year, which accounts for roughly 30% of the total annual ammonia emissions in the United States. In terms of carbon dioxide equivalents, the emissions from beef cattle in the United States amount to about 243 billion kg per year (Rotz et al., 2019).

Breakdown products in soil, water, and air

Ammonium carbonates are highly volatile compounds; in soil, they disassociate into ammonia and carbon dioxide at temperatures as low as 20°C (Behera et al., 2013; Zapp et al., 1985). In moist environments, ammonium carbonates are unstable and produce ammonium ions which can then volatilize as ammonia (Brondi et al., 2023). Depending on the conditions, ammonium in soils can be taken up by plants (Brondi et al., 2023). Ammonium ions can also transform into a range of other compounds, including nitric oxide, nitrous oxide, and molecular nitrogen, first by microbes through nitrification, and then through denitrification (Brondi et al., 2023; The Royal Society, 2020). Excessive ammonia in soil can impact species composition through (Guthrie et al., 2018; The Royal Society, 2020):

- soil acidification
- toxic damage to leaves
- susceptibility of plants to frost, drought, and pathogens (including insect pests and invasive species)

Some species and habitats that are particularly susceptible to ammonia pollution and excessive nitrogen include (Guthrie et al., 2018):

- bog and peatland habitats
- grasslands
- heathlands
- forests

Ammonia can damage lichens and mosses even at low concentrations (Guthrie et al., 2018).

Sheppard et al. (2011) conducted a comprehensive nine-year field experiment to evaluate the impact of various nitrogen forms on vegetation. They found that ammonia levels ranging from 20 to 56 kg NH_3-N $ha^{-1}yr^{-1}$ correlated with a significant decline in the populations of *Sphagnum capillifolium* moss and *Cladonia portentosa* lichen within three years. Such ammonia deposition levels are commonly observed in rural areas with intensive and extensive livestock production (Tang et al., 2009). In another study, Deshpande et al. (2024) quantified ammonia deposition in forest ecosystems in Scotland (12 to 162 kg NH_3-N $ha^{-1}yr^{-1}$) and Sri Lanka, reporting estimates ranging from in Scotland and in Sri Lanka (16 to 426 kg NH_3-N $ha^{-1}yr^{-1}$). Research by Herk (2003) indicated that nitrogen concentrations as low as 0.3 mg N per liter in precipitation can adversely affect the occurrence of certain lichen species, including *Bryoria capillaris*, *B. fuscescens*, *Imshaugia aleurites*, and *Chaenotheca ferruginea*.

Guthrie (2018) also mentions that nitrogen pollution has a negative correlation with the presence of pollinators such as bees and butterflies.

Excess ammonia from fertilizer application can leach into the soil, air, and water (The Royal Society, 2020). Ammonium in the water leads to eutrophication and to various issues that stem from nitrogen overload, such as (Fields, 2004; Guthrie et al., 2018; Han et al., 2020):[4]

- toxic algal blooms
- oxygen depletion
- fish kills
- poor drinking water quality

Aquatic animals are especially susceptible to the toxic effects of ammonia because they have thin, permeable skin surfaces (Guthrie et al., 2018); even very low concentrations of ammonia (0.6 ppm, over a few days) can cause fish mortality (Buss et al., 2004; Durborow et al., 1997). Ammonium can lead to nitrate formation in drinking water, causing an unpalatable taste and odor (Buss et al., 2004). In the human body, nitrates are converted into nitrite, which can cause methemoglobinemia by interfering with the ability of hemoglobin to take up oxygen (Galloway et al., 2003). Drinking water with elevated

[4] Eutrophication: An increase in the rate of supply of organic matter to an ecosystem (Nixon, 1995).

concentrations of nitrate can also cause respiratory infections, alteration of thyroid metabolism, and cancer (Galloway et al., 2003).

Volatilized ammonia is a strong base and corrosive pollutant, and it affects human health and life expectancy (Van Damme et al., 2018). At concentrations as low as 50-100 ppm, it can cause severe burning of the eyes, skin, and respiratory system (Han et al., 2020). Other air quality issues caused by ammonia include (The Royal Society, 2020):

- increased particulate matter
- greenhouse gas emissions
- stratospheric ozone loss

In summary, excessive ammonium carbonates released into the environment could lead to emissions of ammonia and the production of ammonium, potentially contributing to the acidification and eutrophication of ecosystems, widespread biodiversity loss, and climate change (Guthrie et al., 2018; The Royal Society, 2020; Van Damme et al., 2018). However, ammonium carbonates are used in minute amounts in the food processing industry, therefore, significant environmental impacts are not expected to occur within this context.

Manufacturing process

The production of industrial ammonia (the main precursor of ammonium carbonates) is a highly polluting process. Current global ammonia production is about 176 million tons per year (The Royal Society, 2020), with about 6% used to produce ammonium bicarbonate (Amhamed et al., 2022). Other sources suggest that only about 7,000 tons of food-grade ammonium carbonate are produced worldwide every year (The Chemical Company, 2024); however, we were not able to independently verify this latter quantity.

The ammonia industry is currently responsible for consuming about 2% of the world's total fossil fuel, accounts for 2% of the global greenhouse gas emissions, and is considered one of the largest carbon dioxide-emitting chemical industry processes worldwide (The Royal Society, 2020). According to researchers, environmental experts, and policy authorities, ammonia manufacturers need to find a more sustainable production method to meet the recent climate goal set by the United Nations in its net-zero climate action plan (Mayer et al., 2023; The Royal Society, 2020).

In contrast, we did not find studies indicating that the manufacturing of ammonium carbonates is detrimental to the environment. Ammonia/carbon dioxide-capturing systems follow a similar scheme as ammonium carbonates manufacturing processes and researchers propose that they are a potential solution for reducing greenhouse gas emissions in the industry (Wang et al., 2007; Zhuang et al., 2011, 2012).

Evaluation Question #8: Describe and summarize any reported effects upon human health from use of the petitioned substance [7 U.S.C. 6517(c)(1)(A)(i), 7 U.S.C. 6517(c)(2)(A)(i), and 7 U.S.C. 6518(m)(4)].

We did not find reports of negative effects directly caused by ammonium carbonates when used as leavening agents nor explicit safety considerations that need to be taken when using them as leavening agents. As described in *Action of the Substance*, if used properly at the recommended concentration, ammonium carbonates will fully decompose into ammonia, carbon dioxide, and water during the baking process. The FDA states that the levels of ammonia and ammonium compounds normally found in food do not pose a health risk (ATSDR, 2004a). In cases where ammonium carbonate is misused (*i.e.,* overused or used on baked products that contain more than 5% moisture), it might remain in the baked good and its presence would make the product unpalatable due to the ammoniacal flavor or odor (Huang & Miskelly, 2016; Vetter, 2003). When consumed in small quantities, the ammonia ion of ammonium carbonates would be metabolized by the body and disposed of primarily by the hepatic formation of urea (Mohiuddin & Khattar, 2024).

Breakdown products

Ammonium carbonates can degrade at temperatures above 60°C, producing carbon dioxide and ammonia fumes. The amount of carbon dioxide in these fumes is not harmful since their concentration would be far below the values considered dangerous (above 40,000 ppm) (FSIS, 2024). The symptoms associated with various levels of carbon dioxide exposure are as follows (FSIS, 2024):

- 5,000 ppm (for 8 hours of exposure): headache, dizziness, and nausea.
- 10,000 ppm (short-term exposure): possible drowsiness.
- 15,000 ppm (short-term exposure): mild respiratory stimulation in some individuals.
- 30,000 ppm (short-term exposure): moderate respiratory stimulation, increased heart rate, and elevated blood pressure.
- 40,000 ppm (short-term exposure): immediate danger to life or health.
- 50,000 ppm (short-term exposure): strong respiratory stimulation, dizziness, confusion, headache, and shortness of breath.
- 80,000 ppm (short-term exposure): dimmed vision, sweating, tremors, unconsciousness, and potential death due to asphyxiation.

Ammonia has a very strong, irritating odor that is detectable through smell at levels higher than 5 ppm (ATSDR, 2004a). Therefore, the smell would be detected before being exposed to harmful concentrations. Short exposure to ammonia fumes may cause (ATSDR, 2004a):

- eye, nose, throat and lung irritation
- cough
- difficulty breathing

Volunteers exposed to different concentrations of ammonia for a set period presented the following effects (National Research Council, 2008):

- Slight irritation at 30 ppm for 10 minutes
- Moderate irritation to the eyes, nose, throat, and chest at 50 ppm for 10 minutes to 2 hours
- Moderate to highly intense irritation at 80 ppm for 30 minutes to 2 hours
- Highly intense irritation at 110 ppm for 30 minutes to 2 hours
- Unbearable irritation at 140 ppm for 30 minutes to 2 hours
- Immediate tearing and irritation at 500 ppm
- Reflex glottis closure (a protective response to inhaling irritant vapors) occurred around 570 ppm for 21- to 30-year-old subjects, 1,000 ppm for 60-year-old subjects, and 1,790 ppm for 86- to 90-year-old subjects

The accidental exposure of a man to 10,000 ppm of ammonia vapor for 3 hours (National Research Council, 2008) caused him a fatal cardiac arrest 6 hours after the exposure. The autopsy revealed severe damage to the whole respiratory system.

Ammonium carbonates are used in smelling salts because the ammonia gas irritates the membranes of the nose and lungs, thereby triggering an inhalation reflex (McCrory, 2006). This reflex alters the pattern of breathing, resulting in improved respiratory flow rates and increased alertness (McCrory, 2006).

In summary, ammoniacal agents can be toxic when ingested in large doses or inhaled in high concentrations for prolonged periods (McCrory, 2006), but this is unlikely when ammonium carbonates are used for baking.

Acrylamide formation in baked goods

Ammonium carbonates promote the creation of acrylamide (a probable human carcinogen) in baked goods (Komprda et al., 2017; Pasqualone et al., 2021). Acrylamide produced in the presence of ammonium carbonate is more than six times the amount produced in the presence of other leavening agents, and is generally associated as a part of the Maillard reaction that occurs in the baking process

(Kukurová & Ciesarová, 2024; Pasqualone et al., 2021).[5] Specifically, acrylamide forms by the reaction of the amino acid asparagine with a reducing sugar (*e.g.,* glucose and fructose) at temperatures above 120°C and at low moisture levels (World Health Organization & Food and Agriculture Organization of the United Nations, 2009). Ammonium carbonates serve as the source of the base intermediate required for this reaction (Komprda et al., 2017).

Though the FDA has not established a maximum recommended level or action level, the current guidance is to reduce acrylamide levels as much as possible (Center for Food Safety and Applied Nutrition, 2024).

<u>Alternatives</u>

Evaluation Question #9: Are there alternative natural (nonsynthetic) source(s) of the substance? [7 CFR 205.600(b)(1)].

We were not able to find nonsynthetic alternatives for ammonium carbonates. Teschemacherite, the only known natural ammonium bicarbonate (Fortes et al., 2014; Hazen et al., 2016), is a scarce mineral (Mindat, 2024), and therefore not a viable source to satisfy the commercial demand.

Novel technologies to produce industrial amounts of ammonium carbonates through anaerobic digestion exist (Bassani et al., 2024; Orentlicher & Simon, 2018); however, these techniques utilize cow manure wastewater as a feedstock. Therefore, it is unlikely that the final ammonium carbonates are food-grade. In addition, ammonium carbonates resulting from these novel processes are currently only marketed as fertilizers, and it is unclear whether they would be considered nonsynthetic or synthetic using Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016a).

Evaluation Question #10: Describe all nonagricultural non-synthetic substances or products which may be used in place of the petitioned substance [7 U.S.C. 6517(c)(1)(A)(ii)]. Additionally, identify which of those are currently allowed under the NOP regulations.

Various authors discuss many alternatives to ammonium carbonates, each with their own advantages and drawbacks. *Table 4* shows each alternative with a comparison to ammonium carbonates. Although these alternatives may replace ammonium carbonates under certain contexts, leavening agents are chosen for their specific qualities, aiming to produce a specific baked good taste, rheology, texture, color, and aromatic profile (Canali et al., 2020). When launching a product into the market, leavening agents are evaluated for their influence on the quality and sensory characteristics of the product (Rodriguez Sandoval et al., 2020). Some recipes do not allow for a direct leavening agent replacement (Canali et al., 2020).

Table 4: Leavening agent comparison (Canali et al., 2020; De Leyn, 2014; Miller, 2016)

Material	Leavening acid needed	Taste contribution	Residue	National List allowance
Ammonium carbonates	No	No	No	205.605(b)(4) and (5)
Sodium bicarbonate	Yes	No*	Yes	205.605(a)(26) and (27)
Potassium bicarbonate	Yes	Yes	Yes	No handling allowance
Yeast	No	Yes	Yes	205.605(a)(30)

Sodium bicarbonate does not contribute to taste in low amounts. Higher amounts may cause a bitter taste.

Commercial leaveners can be classified as either chemical leaveners or yeasts. Chemical leavening agents are sold in powdered form and work by releasing carbon dioxide as they decompose (De Leyn, 2014). These materials can be further classified as leavening acids or leavening bases (Miller, 2016). Commercially, leavening acids and bases are combined, mixed with a diluent (*e.g.,* cornstarch), and sold

[5] The Maillard reaction is a multi-step reaction between reducing sugars and amino compounds. The process involves a series of condensations, compound isomerization (rearrangement of atoms in a compound), amidation (addition of a $-NH_2$ group), oxidations, and polymerization.

as "baking powder" (Canali et al., 2020; Miller, 2016; Rodriguez Sandoval et al., 2020).[6] Though most acids could be used in this process, manufacturers generally use a small group of cheap, stable acids (*e.g.*, sodium acid pyrophosphate, monocalcium phosphate, glucono delta-lactone) (De Leyn, 2014). Most of these acids are synthetic. Baking powders are available as single-acting or double-acting (Rodriguez Sandoval et al., 2020). Single-acting baking powders contain one acid, either a fast-acting acid that reacts in the mixer, or a slow-acting acid that reacts in the oven. Double-acting baking powders contain both fast-acting and slow-acting acids.

Sodium bicarbonate

Sodium bicarbonate is a leavening base that decomposes when exposed to heat, releasing carbon dioxide gas, water, and sodium carbonate (De Leyn, 2014; Miller, 2016). While in the oven, sodium bicarbonate loses about half of its weight in the form of carbon dioxide (Gélinas, 2022). In the presence of an acid, the remaining sodium carbonate further decomposes to produce additional carbon dioxide (De Leyn, 2014). Because of the potential for unreacted residue, sodium bicarbonate is not commonly used alone, but in combination with at least one leavening acid. Leavening acids are discussed in section *Leavening acids* below.

No more than approximately 25% of sodium carbonate and bicarbonate dissolve into the final baked good. This residue causes an increase in pH, leading to more intensive browning and an increase in alkaline taste, known as "soda bite" (Canali et al., 2020; Huber & Schoenlechner, 2017). Strong tastes, such as ginger, may mask an excess amount of sodium bicarbonate (Gélinas, 2022).

In order to decompose the sodium bicarbonate completely, manufacturers may increase the moisture levels and carefully choose the leavening acid (De Leyn, 2014). These two environmental changes adjust the rate of reaction and, therefore, the residue. In high-moisture products, sodium salt is produced at the end decomposition instead of sodium carbonate (De Leyn, 2014).

Sodium bicarbonate is the most popular gas-releasing material after baker's yeast because of its low cost, ease of handling, low toxicity, high purity, and lack of taste contribution when used in low amounts (Gélinas, 2022). Performance information is generally dependent on the exact recipe used, as interactions between sugar, fat, and moisture may alter the rising effect in leavening agents. In lower-moisture baked goods where ammonium bicarbonate is primarily used, sodium bicarbonate causes dark spots (Gélinas, 2022) This is due to the incomplete dissolution of sodium bicarbonate. Ultrafine sodium bicarbonate (particle size = 1 μm) is more efficiently distributed throughout the low-moisture dough than the traditional, courser sodium bicarbonate (particle size = 70–90 μm) (Gélinas, 2022).

Potassium bicarbonate

Potassium bicarbonate is a leavening base that slowly decomposes when exposed to heat, releasing carbon dioxide (De Leyn, 2014). It requires an acid and a long baking process to completely decompose. If it is not decomposed completely, the final baked good is discolored and has a bitter taste. The use of this leavening agent is associated with a fine crumb structure and it is often used when the amount of sodium in the product must be reduced (De Leyn, 2014).

Yeast

Yeast is commonly used in higher moisture, bread-type baked goods (Miller, 2016; van der Sman, 2021). Ammonium bicarbonate is limited to applications under five percent moisture. Although yeast is the most popular leavening agent, it is typically not a suitable substitute for ammonium bicarbonate because the two materials are generally used in different contexts. Yeast is available as a certified organic product and is also allowed for use in organic handling/processing as it is on the National List at 7 CFR 205.605(a)(30) as a nonagricultural (nonorganic) nonsynthetic substance.

[6] The most common leavening base used is sodium bicarbonate. Multiple sources define "baking powder" as a mixture of sodium bicarbonate, one or more leavening acids, and a diluent. However, this term can be commercially found applied to a variety of mixtures that do not include sodium bicarbonate.

Leavening acids
Leavening acids are used in conjunction with leavening bases. The materials listed below are commercially available, nonsynthetic options.

Cream of tartar, potassium bitartrate
Potassium bitartrate, or cream of tartar, is a leavening acid and an agricultural byproduct of grape production (Canali et al., 2020; De Leyn, 2014). It is allowed for use in organic handling/processing as it is on the National List at § 205.606(p) (as "potassium acid tartrate") as a nonorganic agricultural substance that can be used in organic products when organic versions are not commercially available. Though the product is agricultural, we did not find evidence of a certified organic product available on the market.

Tartaric acid
Tartaric acid reacts immediately with sodium bicarbonate (De Leyn, 2014). Sodium tartrate, associated with laxative action, is formed as a residual salt. While no problems are reported with small amounts of residual salt, this is not a preferred acid. Tartaric acid (specifically, tartaric acid made from grape wine) is allowed for use in organic handling/processing as it is on the National List at § 205.605(a)(28) as a nonagricultural (nonorganic) nonsynthetic substance.

Citric and lactic acid
Citric and lactic acid are two leavening acids used in baking powders. Lactic acid is fast-acting and reacts as early as the mixing stage (De Leyn, 2014). Although lactic acid (along with *Cream of tartar, potassium bitartrate*) is one of the original acidulants, its quick reaction time has been almost completely replaced by newer compounds. Lactic acid was included as a leavening acid by adding soured milk to the mixture.

According to van der Sman (2021), citric acid can also be used as a fast reactor in sodium bicarbonate baking powders; however, this use may be limited to bread doughs that have a higher moisture content rather than those that would be suitable for ammonium bicarbonate use. Both citric acid (produced by microbial fermentation of carbohydrate substances) and lactic acid are allowed for use in organic handling/processing as they are on the National List at § 205.605(a)(1) as nonagricultural (nonorganic) nonsynthetic substances.

Glucono delta-lactone
Glucono delta-lactone is a slow-releasing leavening acid that continuously produces carbon dioxide (De Leyn, 2014). Glucono delta-lactone has a sweet taste initially, a slightly acidic aftertaste, and is derived from gluconic acid. Glucono delta-lactone is allowed for use in organic handling/processing as it is on the National List at § 205.605(a)(14). However, glucono delta-lactone produced by the oxidation of D-glucose with bromine water is prohibited in organic handling/processing.

Evaluation Question #11: Provide a list of organic agricultural products that could be alternatives for the petitioned substance [7 CFR 205.600(b)(1)].
We did not find evidence that organic agricultural products are being used as alternatives to ammonium carbonates. Most leavening agents are nonagricultural, inorganic salts (De Leyn, 2014). Yeast, which is available as a certified organic agricultural product (see section *Yeast*, in *Evaluation Question #10*), may be an alternative in very specific situations. Alternative leavening agents and their properties are described in *Evaluation Question #10*.

Evaluation Question #12: Describe if there are any alternative practices that would make the use of the petitioned substance unnecessary [7 U.S.C. 6518(m)(6)].
The use of yeast could be considered an alternative practice; however, yeast is typically not a suitable substitute for ammonium carbonates because the two leavening agents are used to produce baked goods of different humidities and textures as described in *Evaluation Question #10*. In addition, the use of yeast alters the taste of the baked good and adds a distinct flavor profile (Birch et al., 2013), which is not desired in all products.

The only alternative practice we found that could potentially replace ammonium carbonates successfully in the future (in terms of leaving no residue, not altering the taste, the pH, and improving texture) is the use of carbon dioxide gas hydrates. Gas hydrates are formed when water and low molecular weight gases (like carbon dioxide) are subjected to low temperature and high-pressure conditions; the majority of molecules in a gas hydrate are hydrogen-bonded water molecules that create cages and contain the gas molecules in ice-like structures (Frühling et al., 2023; Srivastava et al., 2022).

Stability and baking tests showed that carbon dioxide hydrates are, in principle, suitable as a leavening agent (Frühling et al., 2023). In addition, their use would not increase the acrylamide content of baked goods to the level that ammonium carbonates do (Kollemparembil et al., 2023). Carbon dioxide gas hydrates have been used to produce bread (Frühling et al., 2023; Srivastava et al., 2022) and black and white cookies (Kollemparembil et al., 2023). These studies concluded that, although promising, the use of carbon dioxide gas hydrate production still needs to be optimized, and recipes for their application require further development (Frühling et al., 2023).

This technology is not commercially available yet, and further research is required for it to improve (Srivastava et al., 2022).

Report Authorship

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