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

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.

Sodium Hydroxide

Handling/Processing

Identification of Petitioned Substance

Chemical Names:
Sodium hydroxide

Other Names:
Caustic soda
Sodium hydrate
Soda lye
Ascarite

Trade Names:
Commonly sold as a generic commodity and not a branded product

CAS Numbers:
1310-73-2

Other Codes:
EC No. 215-185-5
ICSC No. 0360
NSC No. 135799
RTECS No. WB4900000
UNII No. 55X04QC321

Summary of Petitioned Use

The United States Department of Agriculture (USDA) has approved synthetic sources of sodium hydroxide as a nonagricultural (nonorganic) substance that can be used in or on products labeled as "organic" or "made with organic," except for lye peeling of fruits and vegetables, in Title 7 of the Code of Federal Regulations (CFR) Section 205.605(b). Sodium hydroxide is also approved for use as plant or soil amendment in the extraction of plant material processes at 7 CFR 205.601(j).

Sodium hydroxide is used in many handling and processing applications across various industries, including food, paper pulping, chemical production and extraction, etching, and detergents and cleaning agents (NRC 1984, ATSDR 2002, Flomenbaum et al. 2006). This technical report will focus on the uses of sodium hydroxide in the processing and handling of organic food products and will update existing technical information available for the substance (USDA 1995).

Characterization of Petitioned Substance

Composition of the Substance:
Sodium hydroxide is an inorganic compound and strong base (Atkins et al. 2008). When the substance dissolves in water, it dissociates into sodium cations (Na^+) and hydroxide anions (OH^-) (ATSDR 2002, Atkins et al. 2008).

Sodium hydroxide is commercially available as a colorless to white solid with ≥96% purity (SC 2016, LC 2018).

Source or Origin of the Substance:
Sodium hydroxide is a synthetic substance that is primarily produced through the electrolysis of aqueous sodium chloride (NaCl, brine) (USDA 1995, Simon et al. 2014, Du et al. 2018). See Evaluation Question #1 below for more information.

Properties of the Substance:
Sodium hydroxide is a strong base (dissolving completely into Na^+ and OH^- ions) with high solubility in water and short-chain alcohols (methanol [CH_3OH], ethanol [CH_3CH_2OH], etc.) (Silberberg 2003, PC 2005, Atkins et al. 2008, SC 2016, LC 2018). The substance is hygroscopic (absorbs water) and highly reactive with atmospheric carbon dioxide (CO_2), forming sodium bicarbonate ($NaHCO_3$) with water and acids in an exothermic reaction. The exothermic nature may result in the potential for violent reactions, including the rapid release of heat and in some cases, gases (Silberberg 2003, PC 2005, SC 2016, LC 2018). Specific chemical properties of NaOH are listed below in Table 1.

Table 1: Properties of Sodium Hydroxide (NaOH)

Property	Sodium Hydroxide
Chemical Formula	NaOH
Molecular Weight	39.997 g/mol
CAS No.	1310-73-2
Appearance	Colorless to white solid
Melting Point	323 ^{o}C
Boiling Point	1388 ^{o}C
Water Solubility	Soluble
Density	2130 kg/m^3
pH	14 (5%)
Reactivity	Undergoes exothermic reaction in with water and acids. Absorbs atmospheric carbon dioxide (CO_2) to form sodium bicarbonate ($NaHCO_3$). Absorbs water from the atmosphere (hygroscopic).

Sources: (PC 2005, ATSDR 2002, Atkins et al. 2008, SC 2016, LC 2018)

Specific Uses of the Substance:
Sodium hydroxide is used in many industries: soap-making, including "made with organic…soap-based algicide/demossers, herbicides, animal repellents, and insecticidal soaps," as described in 7 CFR 205.601; textile and paper production; glass and mineral production and extractions; in food processing as a disinfectant, cleaning agent, and degreaser; and as a food additive and processing aid (NRC 1984, ATSDR 2002, Flomenbaum et al. 2006). Sodium hydroxide is also used in the handling and processing of organic food products, such as poultry, olive processing, and as a production aid for pretzel manufacturing (Humphrey et al. 1981, Brenes-Balbuena et al. 1992, Seetharaman et al. 2002, McKee et al 2008, Rombouts et al. 2012, Johnson and Mitchell 2019).

Sodium hydroxide has been used in conventional fruit processing, primarily in lye peeling processes (Garcia and Barrett 2006, Rock et al. 2012). Despite the frequent use of sodium hydroxide for lye peeling in conventional agricultural processing, lye peeling is not allowed under NOP guidelines due to the high biological oxygen demand (BOD) in the resulting wastewater (Shi and LeMaguer 2000, Garcia and Barrett 2006, Rock et al. 2012, USDA 2016).

Sodium hydroxide is sometimes listed as an alternative alkali to lime (calcium oxide, CaO) and hydrated or slaked lime (calcium hydroxide, $Ca(OH)_2$) in corn products such as hominy and tortilla dough due to its improved solubility over the calcium salts (Wagner 1940, Diez de Sollano and Berriozabal 1955, del Carmen de Arriola et al. 1988). However, lime or slaked lime are the traditional sources of alkali for the production of hominy and tortilla dough and remain the primary alkalis in commercial uses as well (Wagner 1940, Diez de Sollano and Berriozabal 1955, del Carmen de Arriola et al. 1988, Campus-Baypoli et al. 1999).

Cleaning agent/degreaser
Sodium hydroxide is the active ingredient in several commercial formulations of cleaning agents and degreasers. Sodium hydroxide is commonly found in oven cleaners and products to unblock plumbing (Silberberg 2003). Sodium hydroxide acts to break bonds that are commonly found in organic matter, increasing water solubility of the organic matter, which facilitates its removal (Timberlake 2016).

pH adjuster
Sodium hydroxide is a strong base that reacts with substances in acidic conditions (Silberberg 2003). Due to the reactive nature of the base, it is commonly used to adjust the pH of water systems and can be applied to other food and beverage systems for regulation of acidity (ODHS 1998, NHMRC 2011). The addition of sodium hydroxide results in an increased pH or alkalinity of the system.

Cocoa processing
Sodium hydroxide is used to refine the color and flavor profiles of chocolate and cocoa powders (Eggen 1980, Ellis 1990, Rodriguez at al. 2009, Moser 2015). Sodium hydroxide is specifically used in Dutched chocolate products (Dutch processing is the treatment of cocoa with sodium hydroxide or other alkalis) and is associated with enhanced flavors and darker colors (Ellis 1990, Miller et al. 2008, Li et al. 2014, Moser 2015). Sodium hydroxide reacts with compounds associated with bitter or sour tastes in the raw or partially processed cocoa, and promotes darker color development by promoting oxidation processes and Maillard reactions at elevated pHs (7-9) (Miller et al. 2008, Rodriguez et al. 2009, Moser 2015). The alkali treatment of cocoa products also improves their ability to be dispersed in water and milk, an important feature when used in the production of beverages, icings, and creams (Eggen 1980, Miller et al. 2008, Moser 2015).

Sugar processing
Sodium hydroxide is used at several stages of sugar manufacturing (Chaji et al. 2010, Prati and Moretti 2010, Doherty 2011, Xu and Cheng 2011, Yoo et al. 2011, Laksameethanasan et al. 2012). Sodium hydroxide applications include as an alkali pretreatment of plant matter to digest lignin and hemicellulose to increase the efficiency of enzymes that break down complex sugar polymers (Chaji et al. 2010, Xu and Cheng 2011, Yoo et al. 2011). Sodium hydroxide is also used to regulate pH and clarify the sugar juices that are produced following the extrusion of plant materials (Prati and Moretti 2010, Doherty 2011, Laksameethanasan et al. 2012).

Poultry processing
Sodium hydroxide is used as an additive to scald water in poultry processing (Humphrey et al. 1981, Brotsky and Bender 1990, Bender and Elfstrum 1995, McKee et al. 2008). In the scalding process, the poultry is immersed in hot water, which is meant to loosen feathers and facilitate the defeathering and evisceration processes (Barbut 2001, Zhuang et al. 2013). The addition of sodium hydroxide increases the pH of the scald water and reduces bacterial populations that might be present in a water-only scald (Humphrey et al. 1981, Brotsky and Bender 1990, Bender and Elfstrum 1995, McKee et al. 2008).

Olive processing
Sodium hydroxide is used in olive processing to remove the bitter taste from ripe olives (Cruess and Alsberg 1934, Johnson and Mitchell 2019). This process typically includes soaking the olives in a sodium hydroxide solution for 12 hours, with soaks being carried out on three successive days. Between soaking periods, the olives are suspended in water or a diluted brine solution (Brenes-Balbuena et al. 1992). In addition to removing bitter tastes from ripe olives, sodium hydroxide treatment also prevents undesired discoloration (Angel and Ben-Shalom 1979, Brenes-Balbuena et al. 1992).

The use of sodium hydroxide in organic olive production is difficult to gauge. Several producers of organic olives have stated that their olives are not produced with sodium hydroxide (Acropolis, Odysea). However, several articles discussing conventional and organic olives mention the use of lye (sodium hydroxide) curing, without discrimination between conventional and organic processing (Superfoodly 2017, George Meteljan Foundation).

Pretzel production
Sodium hydroxide is used in pretzel production as an alkaline dip applied to the shaped dough prior to baking (Kurzius 1975, Walsh 1992). The alkaline dip chemically changes the surface starch and proteins, resulting in a smooth surface (Kurzius 1975, Walsh 1992, Seetharaman et al. 2002, Rombouts et al. 2012). The products of the chemical transformations brought about by sodium hydroxide treatment result in improved browning by promoting the Maillard reaction (Seetharaman et al. 2002, Rombouts et al. 2012).

Approved Legal Uses of the Substance:
The USDA has approved synthetic sources of sodium hydroxide as a "nonagricultural (nonorganic) substance allowed as an ingredient in or on processed products labeled as "'organic' or 'made with organic (specified ingredients or food group(s)'" with the stipulation that the substance is "prohibited for use in lye peeling of fruits and vegetables," at 7 CFR 205.605(b). Sodium hydroxide is also approved by the USDA for use as plant or soil amendments in the extraction of plant material at 7 CFR 205.601(j).

The United States Food and Drug Administration (FDA) has granted sodium hydroxide GRAS (generally recognized as safe) status "when used in accordance with good manufacturing or feeding practice," at 21 CFR 582.1763 and as a "direct human food ingredient," at 21 CFR 184.1763. In addition, the FDA has approved the use of sodium hydroxide for the production of a range of GRAS substances such as benzoyl peroxide, magnesium hydroxide, rapeseed oil, propylene glycol, sodium benzoate, sodium citrate , sodium lactate, sodium propionate, zein, sodium chlorite, sodium formate, sodium oleate, sodium palmitate, and sodium sulfate.

The FDA has approved the substance for use in the production of "modified hop extract," which is a "flavoring agent," at 21 CFR 172.560. Sodium hydroxide has been approved by the FDA to produce "hydroxylated lecithin," which is used as a "multipurpose additive," at §172.814. The FDA has also approved using sodium hydroxide to modify food starch with the stipulation that the amount of sodium hydroxide used for the modification is "not to exceed 1 percent," at §172.892. Additionally, the FDA has approved sodium hydroxide in the production of "canned green beans and canned wax beans," at §155.120, "tomato concentrates," at §155.191, and "catsup," at §155.194. Sodium hydroxide has also been approved by the FDA for use in caramel coloring additives at §73.85.

The FDA has approved sodium hydroxide as an "indirect food additive" to make "sanitizing solutions" for food processing equipment, utensils, or contact articles at 21 CFR 178.1010. In this instance, it is approved when it is combined (as a part of sodium salt reaction products) with the following substances: elemental iodine, hydriodic acid, dodecylbenzene sulfonic acid, phosphoric acid, isopropyl alcohol, and calcium chloride. However, there are specific ratios that are required by the regulation for the sanitizing solutions.

The FDA has approved sodium hydroxide as an "antistatic and/or antifogging agent in food-packaging materials," at §178.3130. The FDA has also approved sodium hydroxide as an additive for boiler water used in the preparation of steam that will contact food, at §173.310. The FDA has approved the substance as a "component of paper and paperboard in contact with aqueous and fatty foods," with the stipulation that the mixture containing sodium hydroxide is "for use only as a retention aid employed prior to the sheet-forming operation in the manufacture of paper and paperboard," at §176.170. Sodium hydroxide and resulting soaps are approved by the FDA for use as a "defoaming agent used in the manufacture of paper and paperboard," at §176.210.

The FDA has approved sodium hydroxides for use in the production of "polymer substances and polymer adjuvants for food treatment," specifically for "acrylate-acrylamide resins," at 21 CFR 173.5, and "sodium polyacrylate," at §173.73. The FDA has also approved sodium hydroxide for use in the production "polymers for use as indirect food additives," specifically "polyethylene resins, carboxyl modified," at §177.1600.

The United States Environmental Protection Agency (EPA) has identified sodium hydroxide as a "hazardous substance," at 40 CFR 116.4. The EPA has also designated sodium hydroxide as a "neutralizer," with an "exemption from the requirement of a tolerance," as an "inert ingredient used pre- and post-harvest," at 40 CFR 180.910, and as an "inert ingredient applied to animals," at §180.930. The EPA has granted a "tolerance exemption for active and inert ingredients for use in antimicrobial formulations (food-contact surface sanitizing solutions)," for sodium hydroxide applied to "dairy processing equipment, and food-processing equipment and utensils," at §180.940.

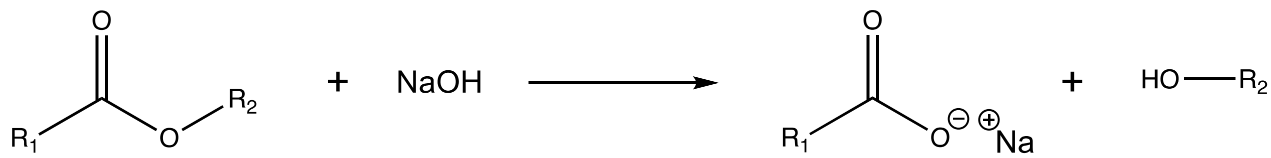
The EPA regulates the use of sodium hydroxide in industrial paper production, including in a "kraft pulp mill," or "soda pulp mill," which use sodium hydroxide solutions to "produce pulp from wood by cooking (digesting) chips ," as defined at 40 CFR 63.861. Within the paper pulping industry, the cellulose ether process and the viscose process use sodium hydroxide in a "reaction of cellulose (e.g., wood pulp or cotton linters) … to produce alkali cellulose," as stated at §63.5610. The viscose process also reacts "sodium cellulose xanthate with additional sodium hydroxide to produce viscose solution," as defined at §63.5610.

Action of the Substance:

The action of the substance varies based on the application in food processing. Given this variation in mode of action, each application will be addressed separately.

Cleaning agent/degreaser

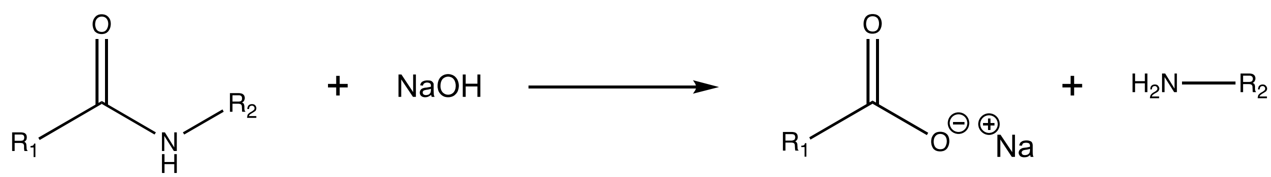
The effectiveness of sodium hydroxide as a cleaning agent and/or degreaser is due to its ability to promote hydrolysis of amide and ester linkages, functionalities that are commonly found in organic matter (Timberlake 2016). The result of the basic hydrolysis of esters is the formation of a carboxylate salt and an alcohol, as shown in Equation 1.



Ester Sodium Hydroxide Carboxolate salt Alcohol

Equation 1.

Likewise, sodium hydroxide facilitates the hydrolysis of amide linkages, producing a carboxylate salt and an amine, as shown in Equation 2.



Amide Sodium Hydroxide Carboxolate salt Amine

Equation 2.

In the hydrolysis reactions shown in Equations 1 and 2, an amide or ester is broken down into two smaller molecules. In both cases a carboxylate salt is produced, whose charged nature increases the water solubility of the molecule, facilitating its removal (Silberberg 2003, Timberlake 2016). Additionally, the alcohol and amine produced by the hydrolysis reactions will also likely exhibit improved water solubility compared to the parent compound due to its reduced size, and ability to participate in hydrogen bonding interactions with water (Timberlake 2016).

pH adjuster

When used as a pH adjuster, sodium hydroxide neutralizes acidic compounds. This is typically demonstrated by the acceptance of a proton (H^+) by the hydroxide ion (OH^-) to form water (H_2O). A generic reaction is shown below with hydroxide (OH^-) neutralizing hydronium (H_3O^+, the active acid species in water), as shown below in Equation 3 (Silberberg 2003, Timberlake 2016).

$$H_3O^+_{(aq)} + OH^-_{(aq)} \rightarrow 2\ H_2O_{(l)}$$

Equation 3.

Additionally, sodium hydroxide can neutralize weak acids (acids that do not completely ionize in water), which generates a sodium salt and water. An example of sodium hydroxide neutralizing a weak phenolic acid is shown in Equation 4.

Cocoa processing

Sodium hydroxide is used in cocoa and chocolate manufacture, specifically in the Dutching process. Sodium hydroxide reacts with acidic components of raw or partially processed cocoa products that are associated with sour and bitter tastes through hydrolysis and neutralization reactions (shown above in Equations 1 and 2, and below in Equation 4) (Rodriguez et al. 2009, Moser 2015). These neutralization and hydrolysis reactions raise the pH of the cocoa from an acidic 5-6 to a basic 7-9 (Rodriguez et al. 2009, Moser 2015).

The hydrolysis of large molecular structures upon alkalization, or Dutching, results in the formation of charged molecules. These smaller, more polar molecules have increased interactions within aqueous solutions, resulting in improved solubility and uniform dispersion (Eggen 1980, Moser 2015).

The Dutching process produces darker brown and red colors upon treatment with sodium hydroxide. The more intense colors following alkali treatment are associated with the formation of polyphenolic polymers and Maillard reactions, both of which are promoted at high pH (Ellis 1990, Rodriguez et al. 2009, Li et al. 2014, Miller et al. 2014, Moser 2015). The polymerization process that gives chocolate its characteristic color is catalyzed by the polyphenol oxidase (PPO) enzyme, which operates most effectively under a pH of ~8 (Rodriguez et al. 2009). Moreover, the neutralized phenolate molecules (see Equation 4 below) are better suited to these polymerization reactions than their neutral and acidic phenolic counterparts, and deeper colors have been associated with increased polymerization of these phenolic compounds (Miller et al. 2008, Rodriguez et al. 2009, Li et al. 2014, Moser 2015).

Sugar processing

Sodium hydroxide is used as a pretreatment to promote the digestion of plant material. Sodium hydroxide facilitates the basic hydrolysis of ester linkages present in hemicellulose (shown in Equation 1), removing natural plant structure and allowing for increased access to the sugar polymers of interest (Chaji et al. 2010, Xu and Cheng 2011, Yoo et al. 2011). The reactive nature of the base results in the neutralization of phenolic functionalities present in both lignin and hemicellulose (shown in Equation 4), making the structures and digested portions of hemicellulose more water soluble and easier to remove from the sugar polymers (Chaji et al. 2010, Xu and Cheng 2011, Yoo et al. 2011).

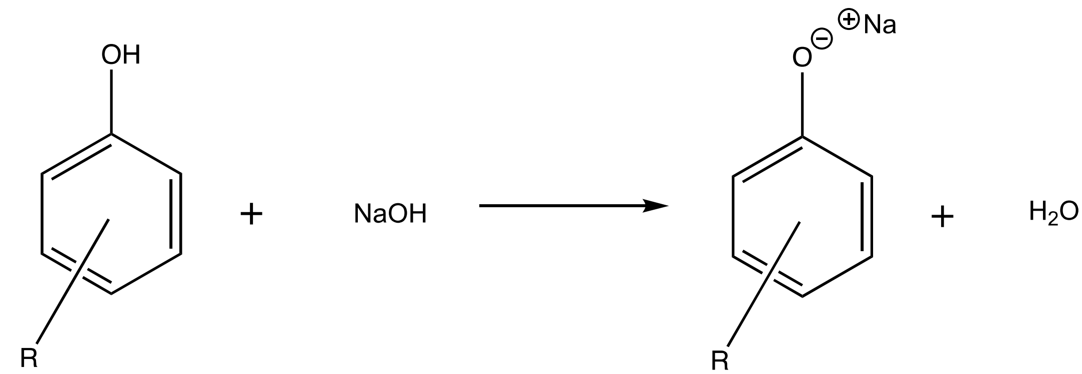
Sodium hydroxide is also used following the extrusion of plant material. The sugar juices produced in the extrusion process are a complex mixture of compounds including chlorophyll, polyphenolic compounds, organic acids, salts, amino acids, proteins and sugar polymers (Prati and Moretti 2010, Doherty 2011, Laksameethanasan et al. 2012). Acids are typically used to remove chlorophyll and similar compounds to prevent discoloration, which leads to a low, acidic pH (Prati and Moretti 2010). Sodium hydroxide is added to raise the pH to 8-11, which prevents the undesired isomerization of sugar molecules (Prati and Moretti 2010, Doherty 2011, Timberlake 2016). Sodium hydroxide is applied as a clarifying agent by breaking the amide linkages (shown in Equation 2) that hold together amino acids and proteins (Laksameethanasan et al. 2012, Timberlake 2016).

Poultry processing

Sodium hydroxide is used in poultry processing as an antimicrobial, specifically as an anti-salmonella agent (Humphrey et al. 1981, Brotsky and Bender 1990, Bender and Elfstrum 1995, McKee et al. 2008). It is used as an additive in the scalding process and has been reported to reduce bacterial populations compared to a water only scald (Humphrey et al. 1981, Brotsky and Bender 1990, Bender and Elfstrum 1995, McKee et al. 2008). The addition of sodium hydroxide improves the efficacy of the scalding process as the strong base denatures the proteins of the undesired substances, allowing for their more efficient feather removal, while also denaturing bacterial proteins and reducing colony populations (Humphrey et al. 1981, McKee et al. 2008). The alkaline environment is reported to specifically target microbial enzymes, resulting in the inability of bacteria to transport essential nutrients (Jay 2000).

Olive processing

Sodium hydroxide is used in olive processing to remove bitter tastes and prevent undesirable discoloration (Cruess and Alsberg 1934, Angel and Ben-Shalom 1979, Brenes-Balbuena et al. 1992). Sodium hydroxide is alkaline and neutralizes the weakly acidic phenolic compounds in the olives. The phenolic compounds, which are composed of acidic aromatic alcohols, are responsible for the bitterness and discoloration found in untreated olives (Brenes-Balbuena et al. 1992, Andrews et al. 2003, Johnson and Mitchell 2019). Equation 4 shows phenolic compounds neutralized by the alkaline sodium hydroxide.



Phenol compound Sodium hydroxide Sodium phenolate

Equation 4.

The neutralized phenolates no longer contribute to bitter taste. Moreover, the phenolates are no longer able to undergo the polymerization reactions that are responsible for undesirable brown spots (Brenes-Balbuena et al. 1992, Johnson and Mitchell 2019).

Pretzel production

Sodium hydroxide is used as an alkaline dip of formed pretzel dough prior to the baking process (Kurzius 1975, Walsh 1992). The sodium hydroxide dip denatures surface proteins to provide a smooth and uniform surface. The change in pH results in loss of the tertiary and quaternary protein structure (unfolding), specifically by disruption of the hydrogen and disulfide bonding networks that provide this structure in the native protein state (Rombouts et al. 2012). Additionally, sodium hydroxide acts to gelatinize the pretzel surface by hydrolysis of α-1,4-glycosidic bonds found within starch (Seetharaman et al. 2002, Rombouts et al 2012).

The combination of protein denaturation and gelatinization of starch molecules provides a smooth surface that gives pretzels their characteristic texture (Seetharaman et al. 2002, Rombouts et al 2012). Moreover, the cleavage of glyosidic bonds within the surface starch molecules increases the number of sugar molecules present on the pretzel surface for participation in the Maillard reaction responsible for browning (Rombouts et al. 2012).

Combinations of the Substance:

Sodium hydroxide is commercially available in high purity (≥96%) as an ionic compound consisting of sodium (Na^+) and hydroxide (OH^-) ions (Aktins et al. 2008). The hygroscopic nature (propensity to absorb water) of sodium hydroxide results in its ability to form stable hydrates through incorporation of water molecules into the ionic crystal lattice (Pickering 1893, Atkins et al. 2008). Common sodium hydroxide hydrates are the mono, di, tri, tetra, penta, and hepta-hydrated compounds, correlating to the incorporation of 1, 2, 3, 4, 5, and 7 molecules of water, respectively (Pickering 1893, Mraw and Giauque 1962, Murch and Giauque 1962, Siemens and Giauque 1969, Giauque 1974).

Status

Historic Use:
Sodium hydroxide has been historically used in many industries, including soap-making, textile and paper production, glass and mineral production and extractions, as a disinfectant, cleaning agent and degreaser, and as a food additive and processing aid (NRC 1984, ATSDR 2002, Flomenbaum et al. 2006). Using sodium hydroxide or lye in soap production was especially important for historical production of hard soaps, which were preferred because they were easy to store and transport (Thorpe 1913, Stapleton et al. 1927). In early applications, sodium hydroxide was sourced as lye, or caustic soda, a relatively impure and alkaline mixture isolated from the ashes of burned plant material (Thorpe 1913, Stapleton et al. 1927).

In specific relation to this report, the substance has historically been used in the processing of cocoa, pretzels, and olives (Cruess and Alsberg 1934, Brenes-Balbuena et al. 1992, Rodriguez et al. 2009, Moser 2015, Johnson and Mitchell 2019). The use of alkali treatment in cocoa and chocolate manufacture dates back to 1828 when Van Houten used a mixture of alkali salts to treat cocoa beans (Rodriguez et al. 2009, Moser 2015). The "Dutch" process has become popular with chocolate manufacturers since then to improve the flavors and colors of treated cocoa products (Moser 2015). The production of pretzels is documented back to the 13th century. Dipping pretzels in an alkaline dip before baking was introduced in the 20th century and has become a standard across the industry, with sodium hydroxide being the most prominent substance (Seetharaman et al. 2002). In the 20th century, sodium hydroxide was used to treat olives to reduce bitterness and avoid undesirable discoloration (Cruess and Alsberg 1934, Brenes-Balbuena et al. 1992, Johnson and Mitchell 2019).

Organic Foods Production Act, USDA Final Rule:
Sodium hydroxide is not listed in the Organic Foods Production Act of 1990 (OFPA).

The USDA National Organic Program has approved synthetic sources of sodium hydroxide as a "nonagricultural (nonorganic) substance allowed as an ingredient in or on processed products labeled as "'organic' or 'made with organic (specified ingredients or food group(s),'" with the stipulation that the substance is "prohibited for use in lye peeling of fruits and vegetables," at 7 CFR 205.605(b). Sodium hydroxide is also approved by the USDA in the extraction of aquatic plant material for use as plant or soil amendments at 7 CFR 205.601(j). Sodium hydroxide is also allowed as an alkali for the extraction of humic acids (USDA 2012).

International:

Canadian General Standards Board Permitted Substances List –
Sodium hydroxide is listed in the Canadian General Standards Board Permitted Substances List (CAN/CGSB-32.311-2015) in Table 4.2 as allowed for "soil amendments and crop nutrition," for the "extraction of aquatic plants and aquatic plant products" and "plant extracts, oils, and preparations with synthetic solvents," with the condition that "the manufacturer shall prove the need to use sodium hydroxide."

Sodium hydroxide is listed in Table 5.3 as a "health care product and production aid for use in dehorning paste."

Sodium hydroxide is listed in Table 6.3 "ingredient classified as a food additive" and in Table 6.5 as a "processing aid," with the condition that the substance is "prohibited for use in lye peeling of fruits and vegetables."

Table 7.3 lists sodium hydroxide as a "food-grade cleaner, disinfectant, and sanitizer permitted without a mandatory removal event."

CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999) –
Sodium hydroxide is listed in the CODEX (GL 32-1999) in Table 3.1 as a "food additive, including carriers for cereal products." The substance is also listed in Table 4 as a "processing aid which may be used for the preparation of products of agricultural origin," with the specific condition that sodium hydroxide is to be used for "pH adjustment in sugar production."

European Economic Community (EEC) Council Regulation, EC No. 834/2007 and 889/2008 –
Sodium hydroxide is not listed in EC No. 834-151 2007.

Sodium hydroxide is listed in section A of EC No. 889/2008 as a "food additive, including carriers" and is approved for "preparation of foodstuffs of plant origin," specifically "surface treatment of 'Laugengeback [lye or pretzel breads].'"

Japan Agricultural Standard (JAS) for Organic Production –
Sodium hydroxide is listed in the JAS for Organic Production Notification No. 1608 as an "agent for cleaning or disinfecting of housing for livestock."

Sodium hydroxide is listed in the JAS for Organic Production Notification No. 1606 as a "food additive limited to be used for processing sugar as pH adjustment agent or used for grain processed foods."

International Federation of Organic Agriculture Movements (IFOAM) –
Sodium hydroxide is listed in IFOAM as an "approved additive and processing/post-harvest handling aid," with the limitation on use "for sugar processing and the surface treatment of traditional bakery products." Sodium hydroxide is listed in IFOAM as an "equipment cleanser and equipment disinfectant," with the stipulation that "an intervening event or action must occur to eliminate risks of contamination." Sodium hydroxide is listed as a "substance for pest and disease control and disinfection in livestock housing and equipment."

Evaluation Questions for Substances to Be Used in Organic Handling

Evaluation Question #1: Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Further, describe any chemical change that may occur during manufacture or formulation of the petitioned substance when this substance is extracted from naturally occurring plant, animal, or mineral sources (7 U.S.C. § 6502 (21)).

Since the USDA has approved synthetic sources of sodium hydroxide as a nonagricultural (nonorganic) substance that can be used in or on products labeled as "organic" or "made with organic," the most prevalent synthetic method of sodium hydroxide production the is electrolysis of sodium chloride (Lindstrom 1974, Atkins et al. 2008). In this reaction, there are two separate half-reactions that take place to give the overall electrolysis reaction shown in Equation 5.

$$2\ NaCl_{(aq)} + 2\ H_2O_{(l)} \rightarrow 2\ NaOH_{(aq)} + H_{2\,(g)} + Cl_{2\,(g)}$$

Equation 5.

At the cathode, electrons are added to water molecules, resulting in their reduction to form a molecule of dihydrogen and two hydroxide ions, shown in Equation 6 (Atkins et al. 2008, Simon et al. 2014). The hydrogen gas produced evaporates from the cathode and is often burned or discarded as waste (Lindstrom 1974).

$$2\ H_2O_{(l)} + 2\ e^- \rightarrow 2\ OH^-_{(aq)} + H_{2\,(g)}$$

Equation 6.

The current flow in the electrolytic cell is completed by the oxidation of chloride ions at the anode to form chlorine gas (Cl_2), shown in Equation 5 (Lindstrom 1974, Atkins et al. 2008, Simon et al. 2014). Unlike the production of hydrogen at the cathode, the chlorine produced at the anode is isolated as a commercially important by-product (Lindstrom 1974, Atkins et al. 2008). The isolated chlorine is used in a range of industrial applications, predominantly in the production of polyvinyl chloride (PVC) (Atkins et al. 2008).

$$2\ Cl^-_{\ (aq)} \rightarrow Cl_{2\ (g)} + 2\ e^-$$

Equation 7.

After the electrochemical transformations described in Equations 6 and 7, the process yields an aqueous solution that is easily separated from the gas products (Equation 5). Solid sodium hydroxide is isolated from the manufacturing process by the evaporation of water, leaving a white to colorless solid (Lindstrom 1974, Atkins et al. 2008).

Sodium hydroxide was historically produced industrially as the metathesis reaction (a reaction in which the cations and anions salts are exchanged) of aqueous calcium hydroxide ($Ca(OH)_2$) with sodium carbonate (Na_2CO_3), shown in Equation 8, or by the electrolysis of an aqueous solution of sodium chloride (NaCl, salt) shown in Equation 5, Lindstrom 1974, Atkins et al. 2008).

$$Ca(OH)_{2\ (s)} + Na_2CO_{3\ (aq)} \rightleftarrows CaCO_{3\ (s)} + 2\ NaOH_{\ (aq)}$$

Equation 8.

In the metathesis reaction shown in Equation 8, the reaction occurs through the exchange of the calcium (Ca^{2+}) and sodium (Na^+) cations with carbonate (CO_3^{2-}) and hydroxide (OH^-) anions, respectively. The reaction is driven to completion due to the greater solubility of the calcium hydroxide compound compared to the calcium carbonate product (Atkins et al. 2008). The resulting sodium hydroxide-rich solution is evaporated to yield sodium hydroxide solids.

Evaluation Question #2: Discuss whether the petitioned substance is formulated or manufactured by a chemical process or created by naturally occurring biological processes (7 U.S.C. § 6502 (21)). Discuss whether the petitioned substance is derived from an agricultural source.

Sodium hydroxide is not a naturally occurring substance. Modern commercial production of sodium hydroxide occurs through the electrolysis of sodium chloride to produce sodium hydroxide and hydrogen and chlorine gases (Equation 5) (Lindstrom 1974, Atkins et al. 2008, Simon et al. 2014).

Sodium hydroxide was historically produced as lye, or caustic soda, as a relatively impure and alkaline mixture isolated from the ashes of burned plant material (Thorpe 1913, Stapleton et al. 1927).

Evaluation Question #3: If the substance is a synthetic substance, provide a list of non-synthetic or natural source(s) of the petitioned substance (7 CFR § 205.600 (b) (1)).

Sodium hydroxide does not occur naturally and has only been isolated through chemical transformations.

Evaluation Question #4: 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.

Sodium hydroxide has GRAS status as a "general purpose food additive," at 21 CFR 582.1763 and as a "direct food substance," at §184.1763. In addition, the FDA has approved using sodium hydroxide for the production of a range of GRAS substances: benzoyl peroxide at §184.1157, magnesium hydroxide at §184.1428, rapeseed oil at §184.1555, propylene glycol at §184.1666, sodium benzoate at §184.1733, sodium citrate at §184.1751, sodium lactate at §184.1768, sodium propionate at §184.1784, zein at §184.1984, sodium chlorite at §186.1750, sodium formate at §186.1756, sodium oleate at §186.1770, sodium palmitate at §186.17771, and sodium sulfate at §186.1797.

Evaluation Question #5: Describe whether the primary technical function or purpose of the petitioned substance is a preservative. If so, provide a detailed description of its mechanism as a preservative (7 CFR § 205.600 (b)(4)).

When sodium hydroxide is used as a scald additive in poultry processing, it may be viewed as a preservative because the scald additive process reduces salmonella populations on processed poultry (Humphrey et al. 1981, Brotsky and Bender 1990, Bender and Elfstrum 1995, Jay 2000, McKee et al. 2008). Reduced bacterial populations means that processed poultry has a longer shelf life (Brotsky and Bender 1990, Bender and Elfsrtum 1995). The bacterial populations are reduced because the pH in the sodium hydroxide scalds is high, which disrupts bacterial enzymes and prevents bacteria from getting essential nutrients (Jay 2000).

Sodium hydroxide does not act as a preservative when used in cocoa processing, olive processing, pretzel production, pH adjustment, or sugar processing.

Evaluation Question #6: 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) and how the substance recreates or improves any of these food/feed characteristics (7 CFR § 205.600 (b)(4)).

Sodium hydroxide is not used to improve flavors that are lost during processing. However, sodium hydroxide has many applications within the food industry, including as a processing aid to improve flavor, color, and texture (Cruess and Alsberg 1934, Angel and Ben-Shalom 1979, Brenes-Balbuena et al. 1992, Seetharaman et al. 2002, Rodriguez et al. 2009, Rombouts et al. 2012, Moser 2015). Using the substance in organic food processing, specifically in cocoa processing, olive processing and pretzel production, to improve flavors, colors, and textures. The results of each application are discussed in more detail below.

Cocoa processing

Sodium hydroxide is primarily used to improves flavors and colors of Dutch processed cocoa and chocolate products (Moser 2015). This is achieved by the hydrolysis and neutralization of compounds associated with bitter tastes (Rodriguez et al. 2009, Moser 2015). Additionally, the neutralization of phenolic compounds, and optimization of the PPO enzyme under basic conditions improves the colors of the treated cocoa products (Ellis 1990, Miller 2008, Rodriguez et al. 2009, Moser 2015).

Sugar processing

One application of sodium hydroxide in sugar processing is to clarify sugar juices following plant extrusion. Juice clarification occurs by promoting the hydrolysis of proteins, amino acids, and enzymes found within the sugar mixture (Prati and Moretti 2010, Doherty 2011, Laksameethanasan et al. 2012). The enzymes found in the sugar mixture promote oxidative processes, which result in the darkening of the mixture. Cleavage of ester and amide linkages (shown in Equations 1 and 2) work to shut down and digest oxidative enzymes, preventing discoloration of the sugar mixture (Laksameethanasan et al. 2012).

Olive processing

The strongly basic nature of sodium hydroxide produces a high pH solution that neutralizes the acidic compounds that create the bitter taste found in ripe olives (Cruess and Alsberg 1934, Angel and Ben-Shalom 1979, Brenes-Balbuena et al. 1992). Additionally, the alkaline conditions produced by sodium hydroxide result in the neutralization of a range of phenolic compounds, and the neutralized phenolates are no longer able to undergo the polymerization processes that result in undesirable brown spots formed in olive processing (Brenes-Balbuena et al. 1992).

Pretzel production

Sodium hydroxide is used in pretzel production to create the specific color and texture that is associated with pretzels, which result from an alkaline dip in sodium hydroxide solution prior to baking (Kurzius 1975, Walsh 1992). As a high pH/basic solution sodium hydroxide, produces chemical changes on the surface of the pretzel dough, denaturing the surface protein by disrupting the hydrogen and disulfide bonding networks responsible for tertiary and quaternary protein structure (Rombouts et al. 2012). Additionally, because the solution is basic, hydrolysis occurs in the α-1,4-glycosidic bonds present in starch (Rombouts et al. 2012). Starch hydrolysis is responsible for the smooth surface of the characteristic pretzel texture, and an increased number of sugar molecules promotes browning via the Maillard reaction (Seetharaman et al. 2002, Rombouts et al. 2012).

Sodium hydroxide is not used to improve or recreate color, flavor, texture, or nutritional value lost during processing in poultry processing or as a pH adjuster.

Evaluation Question #7*:* 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)).

When used as approved for organic processing applications, sodium hydroxide is used in low concentrations (~1-2%) and is not expected to affect the nutritional quality of the processed food/feed in terms of sodium content. Sodium hydroxide is used as a pH regulator in many food applications, which may result in loss of some proteins and organic acids, including vitamins, due to degradation and neutralization at high pH.

Cocoa processing

The neutralization of phenolic compounds (see Equation 4) improves their water solubility. This actively works to remove compounds associated with bitter and sour tastes; however, these reactions also occur with beneficial molecules, facilitating their removal as well. Chief among these compounds are flavonols, a subcategory of flavonoids, which have been associated with beneficial antioxidant character (Katsube et al. 2006, Miller et al. 2008, Li et al. 2014, Nakabayashi et al. 2014). The polymerization of these compounds is also improved under the alkaline conditions, which contributes to the darkened color profile (Rodriguez et al. 2009, Li et al. 2014). The oxidation and polymerization processes that occur in the Dutch process greatly reduce their antioxidant character and nutritional value (Miller et al. 2008, Li et al. 2014).

Pretzel processing

The alkaline dip in pretzel manufacture appears to have no effects on the nutritional quality of the finished pretzel. The dips result in changes to the protein structure on the surface of the dough, and hydrolysis of amide bonds aids in the gelatinization process (Seetharaman et al. 2002, Yao et al. 2006, Rombouts et al. 2012, Timberlake 2016). However, these changes are primarily to the three-dimensional structure of the protein, which maintains its composition of amino acids. When hydrolysis reactions occur within the protein, they appear to be limited to the formation of relatively large peptides that remain on the dough surface, which is reported to have no statistically significant changes to the protein content of the dough (Yao et al. 2006).

Starch and sugar molecules on the surface of the dough appear to diminish in content following the alkaline dip. However, the mechanism of this change, and the resulting change to overall nutritional content, is not well established (Yao et al. 2006). Reports show that starches and small sugar molecules (e.g., amylose) are likely to undergo hydrolysis, and that the resulting smaller sugar molecules may have improved solubility in the alkaline solution (Lai et al. 2004, Yao et al 2006). This would result in the loss of starches and sugars on the dough surface, which may negatively affect nutritional quality. However, other literature reports state that these hydrolyzed starches and sugars likely undergo polymerization, which is favorable at high pH (Baunsgaard et al. 2001, Coca et al. 2004, Yao et al. 2006, Rombouts et al. 2012). These polymerization and gelatinization products remain on the surface of the dough to give the smooth surface and golden color associated with pretzels and would not result in significant nutritional changes. Given the uncertainty of the outcome for hydrolysis products, and that the hydrolysis of starches and sugars “does not penetrate the dough piece significantly,” make it difficult to analyze the extent of nutritional changes in pretzels, if present at all (Yao et al. 2006).

Evaluation Question #8: 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)).

There are no known reports of heavy metal contaminants present in sodium hydroxide. Due to the electrolytic manufacturing process, the most likely contaminants would be the remaining starting material, sodium chloride. Most salt (NaCl) is isolated from natural sources and is primarily mined or isolated via the evaporation of sea, or other high-salinity water sources (EUSALT 2020). The natural sources of salt give the possibility for contamination by heavy metals found within the environment where the salt was isolated from (mine or aquatic system). Studies have shown that trace amounts of heavy metals may be present in food or technical grade salt, although they are present well below the maximum standards set forth by the Codex for food grade salt, as shown in Table 2 below (FAO 2001, Heshmati et al. 2014, SPEX 2020). Many heavy metals are insoluble as hydroxide salts, making handling the substance the most likely source of contamination (Atkins et al. 2008).

Table 2. Contaminants in Sodium Chloride (NaCl)

Contaminant	Amount detected (ppm)	Codex maximum limit (ppm)
Arsenic (As)	not detected	0.5
Copper (Cu)	1.23, 0.03	2
Lead (Pb)	0.852, 0.44	2
Cadmium (Cd)	0.229, not detected	0.5
Mercury (Hg)	0.054, not detected	0.1

Sources: FAO 2001, Heshmati et al. 2014, SPEX 2020

Evaluation Question #9: 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)).

Sodium hydroxide is a strongly basic and reactive substance. In addition to food processing applications, sodium hydroxide has been used as an herbicide to control tree root growth, adding some risk to the environment in the event of a spill or improper use (EPA 1992). Using sodium hydroxide in water treatment applications has limited the use of resulting effluent "which may not be discharged into lakes, streams, ponds, estuaries, oceans, or public waters" (EPA 1992).

Manufacturing sodium hydroxide produces chlorine gas (Equations 5 and 7) (Lindstrom 1974, Atkins et al. 2008, Simon et al. 2014). Chlorine is a highly reactive substance that can combine with many different chemicals to form chlorinated products. Due to the high reactivity of chlorine, it is not long-lived in the environment and is unlikely to cause environmental damage in its natural gas form (ATSDR 2010). However, the various chlorinated products formed from the release of chlorine gas to the environment could result in the potential for damage to the environment and biodiversity.

Lye peeling is a historically important method of processing fruits and vegetables and is still in use for some peeling processes in non-organic agriculture (Rock et al. 2012, USDA 2016). However, the use of sodium hydroxide in peeling processes for fruits and vegetables results in basic wastewater, which also includes organic matter liberated from the treated fruits and vegetables (Garcia and Barrett 2006, Rock et al. 2012). Unless properly treated, this wastewater increases the pH of soils, and contributes to water pollution (Garcia and Barrett 2006, Rock et al. 2012). The presence of organic matter and remaining base results in a high biological oxygen demand (BOD), which is a measure of the amount of oxygen required for the breakdown of the organic matter via aerobic microorganisms (Sawyer et al. 2003, Garcia and Barrett 2006, Rock et al. 2012). For these reasons, the NOP has prohibited the use of sodium hydroxide for peeling fruits and vegetables at 7 CFR 205.605(b). However, these peeling processes use a much higher concentration of sodium hydroxide (8-25%) than the approved uses (1-2%) (Shi and LeMaguer 2000, Rock et al. 2012). At the time of this report, the author did not find any reports of adverse environmental effects from the relatively low concentrations of sodium hydroxide used in approved organic processes, including increases BOD of aquatic systems.

Evaluation Question #10: 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)).

Sodium hydroxide is a strong base and is a highly reactive and corrosive compound that has been placed into Toxicity Category I by the EPA (EPA 1992). Upon dissociation from the sodium cation (Na^+), the reactive hydroxide (OH^-) begins to disrupt biological tissue. These disruptions occur in many forms including in protein denaturation and dissolution, collagen disruption, saponification (hydrolysis) of fat molecules, emulsification of cellular membranes, and cell death (EPA 1992, Flomenbaum et al. 2006, SC 2016, LC 2018).

Sodium hydroxide is especially hazardous when consumed, although all reported cases of poisoning from sodium hydroxide in adults are from intentional ingestion, most of which are reported in developing countries (Chang et al. 2011). Cases of accidental sodium hydroxide in children are often fatal (NRC 1984, Chang et al. 2011). The reactive and strongly basic nature of sodium hydroxide makes the substance particularly disruptive to the gastrointestinal tract (NRC 1984, ATSDR 2002, Flomenbaum et al 2006, Chang et al. 2011). When sodium hydroxide is ingested, abdominal pain is frequent due to the necrosis and stricture of the esophagus, stomach, and gastrointestinal tract (ATSDR 2002, Chang et al. 2011).

Sodium hydroxide is severely damaging to lung tissue and can result in degradation and dissolution of the lungs (NRC 1984, ATSDR 2002). Most reported deaths from sodium hydroxide are due to a combination of effects from ingestion, shock, infection of corroded tissues, and lung damage (ATSDR 2002).

In addition to the dangers from ingestion, the substance is also highly corrosive to surface tissue. Severe ocular degeneration has been reported to occur upon contact with the substance, resulting in possible severe pain, irritation, and blindness (EPA 1992, ATSDR 2002, Flomenbaum et al. 2006, SC 2016, LC 2018). Sodium hydroxide can penetrate skin, resulting in the potential for deep and slow-healing chemical burns (EPA 1992, ATSDR 2002, Flomenbaum et al. 2006, SC 2016, LC 2018).

Evaluation Question #11: Describe any alternative practices that would make the use of the petitioned substance unnecessary (7 U.S.C. § 6518 (m) (6)).

Cleaning agent/degreaser

As discussed in the action of the substance section, the strongly basic nature of sodium hydroxide allows for the dissolution and removal of organic matter. While strong bases, and sodium hydroxide specifically, are most used in commercial cleaning agents and degreasers, amide and ester functionalities can be hydrolyzed under acidic conditions as well (Timberlake 2016). Under acidic conditions, amides and esters are hydrolyzed to carboxylic acids rather than carboxylate salts, and ammonium salts are produced in place of amines for amides (Timberlake 2016). Despite the slight change in products, acidic hydrolysis reactions yield smaller molecules with enhanced water solubility to facilitate the dissolution and removal of organic matter.

Poultry processing

The scalding process is ubiquitous in poultry processing. However, sodium hydroxide is not a necessary additive for the scalding process. While the alkaline nature of sodium hydroxide scalds reduces salmonella, populations compared to normal scalding conditions, a common alternative is to use higher temperatures (McKee et al. 2008). However, while the higher temperature scald helps to facilitate bacterial removal, it also removes cuticle from the poultry, resulting in a pale appearance and reducing the quality of the poultry products (McKee et al. 2008).

Olive processing

Sodium hydroxide treatments are the predominant industry practice for removing the bitter taste from ripe olives (Brenes-Balbuena et al. 1992, Johnson and Mitchell 2019). However, there are several curing alternatives, that include soaking in water, brine (saturated salt solution), or with the application of dry salt. (ANR 2007). However, water-curing olive processes yield a more bitter product due to the relatively low water solubility of the bitter phenolic compounds. Likewise, dry salt processing results in increased bitterness compared to sodium hydroxide treatments (ANR 2007). Brine processing of olives offers an alternative that is based on natural fermentation processes, although it requires a longer cure time of up to six months (ANR 2007).

Recent reports have offered alternatives to the basic neutralization provided by applying sodium hydroxide. The use of enzyme (protein) catalysts has been reported to effectively remove the phenolic compounds associated with olive bitterness (Johnson and Mitchell 2018). According to Johnson and Mitchell (2018), the bitter phenol compounds are hydrolyzed by the applied enzyme, resulting in products that have either no bitterness or at least a reduced bitterness. (Mitchell and Johnson 2018).

Additionally, using polymeric chromatography, specifically Amberlite resin columns, has been reported to remove phenols responsible for bitter tastes. In this alternative method, the brined olives are processed through an Amberlite resin, to which the phenols adsorb and are then removed from the brine solution (Johnson and Mitchell 2019). The Amberlite resin material can be washed with ethanol for regeneration and reuse (Johnson and Mitchell 2019). While new alternatives to sodium hydroxide neutralization of phenols are promising, they have yet to be applied on a large scale (Johnson and Mitchell 2019).

There are no suitable alternatives for sodium hydroxide in alkaline dough dips for pretzel production, pH adjustment, or sugar processing.

Evaluation Question #12: Describe all natural (non-synthetic) substances or products which may be used in place of a petitioned substance (7 U.S.C. § 6517 (c) (1) (A) (ii)). Provide a list of allowed substances that may be used in place of the petitioned substance (7 U.S.C. § 6518 (m) (6)).

Potassium hydroxide is the best alternative to sodium hydroxide within all the applications below. However, potassium hydroxide has the same negative aspects as sodium hydroxide. Potassium hydroxide is more reactive than sodium hydroxide, making it a more dangerous chemical to work with and store, and offer increased hazards to aquatic life (USDA 2016). Additionally, potassium hydroxide is a more expensive base than sodium hydroxide, limiting its commercial appeal as an alternative to sodium hydroxide (USDA 2016).

Cleaning agent/degreaser

There are several substances that are alternatives to sodium hydroxide for use as a cleaning agent or degreaser. Calcium hydroxide ($Ca(OH)_2$) is also a strong base, with the potential to promote hydrolysis reactions (Silberberg 2003, Timberlake 2016). However, unlike sodium hydroxide, calcium hydroxide is limited by low water solubility (Silberberg 2003). The low solubility of calcium hydroxide limits its maximum hydroxide (OH^-) concentration, and therefore its capacity as a cleaning agent or degreaser. Sodium carbonate (Na_2CO_3) and sodium bicarbonate (baking soda, $NaHCO_3$) are also alternatives that are used in commercial cleaning agents (Silberberg 2003). However, the reduced basicity to carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) have reduced reactivity. This is especially important in some cleaning applications, where the strongly basic nature of soluble hydroxide sources is required for the removal of organic matter.

The ability of acids to catalyze the hydrolysis of amides and esters, thereby breaking up and removing unwanted organic matter, make various acids alternatives to sodium hydroxide. There are many approved acids, although all are weak acids (do not dissociate completely when dissolved in water) (Silberberg 2003). These acids include citric acid, lactic acid, L-malic acid, tartaric acid, alginic acid, ascorbic acid, hypochlorous acid, and phosphoric acid. Due to the weak strength of these approved acids, they would need to be used in a higher concentration than sodium hydroxide to produce the same hydrolysis results.

pH adjustment
The basic character of sodium hydroxide allows it to be used to regulate pH and increase the alkalinity of applied systems. The National List includes many basic substances that are possible alternatives for pH regulation applications. These include calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), magnesium sulfate ($MgSO_4$), sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), calcium citrate, calcium hydroxide ($Ca(OH)_2$), potassium carbonate (K_2CO_3), potassium citrate, potassium lactate, potassium phosphate (K_3PO_4), sodium citrate, and sodium lactate.

Among the possible alternatives listed above, only calcium hydroxide ($Ca(OH)_2$) is also a strong base. However, calcium hydroxide has low water solubility, which reduces its usefulness as a pH adjuster (Silberberg 2003). Calcium carbonate ($CaCO_3$) also has low solubility, which coupled with the weak strength of the base, makes it a poor substitute for sodium hydroxide. The remaining weak bases have adequate water solubility to allow for their use as pH regulators and may be appropriate alternatives to sodium hydroxide in specific processing applications.

Cocoa processing
Sodium hydroxide (NaOH) and potassium carbonate (K_2CO_3) are the predominant alkali salts used in the Dutch process (Miller et al. 2008, Li et al. 2014). However, the literature includes many alternatives for cocoa alkalization, specifically potassium carbonate (K_2CO_3), sodium carbonate (Na_2CO_3), ammonium carbonate ($(NH_4)_2CO_3$), magnesium carbonate ($MgCO_3$), potassium bicarbonate ($KHCO_3$), sodium bicarbonate ($NaHCO_3$), ammonium bicarbonate (NH_4HCO_3), ammonium hydroxide (NH_4OH), and magnesium oxide (MgO) (Moser 2015). However, all of the above alkali salts are weaker bases than sodium hydroxide and would likely require increased concentrations to achieve a similar pH change and alkaline conditions.

Poultry processing
There are several approved substances that are alternatives for sodium hydroxide in poultry processing, including tartaric acid, citric acid, lactic acid, L-malic acid, potassium iodide (KI), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium chloride (KCl), and calcium carbonate ($CaCO_3$) potassium carbonate (K_2CO_3), and calcium hydroxide ($Ca(OH)_2$). Calcium carbonate, potassium carbonate, and calcium hydroxide offer the same mode of action as sodium hydroxide by increasing the pH of the scald solution. However, both calcium carbonate and calcium hydroxide have poor water solubility, which limits their ability to raise the pH of the scald solution. The carbonate (CO_3^{2-}) anions found in calcium carbonate and potassium carbonate are weakly basic, especially compared to sodium hydroxide. The reduced alkalinity of calcium carbonate and potassium carbonate make them poor substitutes for sodium hydroxide in poultry processing applications.

The acids (tartaric, citric, lactic, and L-malic) offer a similar mode of action to sodium hydroxide, although with reduced solution pH. The reduced pH results in denaturation of proteins, especially at the increased temperatures employed during the scalding process (Barbut 2001, Zhuang et al. 2013, Timberlake 2016).

Potassium iodide (KI), potassium chloride (KCl), magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) additions would increase the salinity of the scald as an alternative mode of action to pH adjustment. The increased scald salinity promotes cellular crenation, a dehydration that results in the diffusion of water from the cell to the solution to establish a concentration equilibrium (Timberlake 2016). However, the increased salt content in of the scald solution may result in altered organoleptic properties and nutritional content of the poultry products.

Olive processing
Given the strongly basicity required to achieve the neutralization of phenolic compounds, there are no natural alternatives to sodium hydroxide for olive processing for either reducing bitterness, or preventing discoloration.

Pretzel production

Given the high pH required for the alkaline dip in pretzel production, alternatives to sodium hydroxide are unlikely to be commercially viable. Calcium carbonate ($CaCO_3$), sodium carbonate (Na_2CO_3), potassium carbonate (K_2CO_3) and sodium bicarbonate ($NaHCO_3$) are approved basic compounds, but the anions in these compounds (CO_3^{2-} and HCO_3^-) are weakly basic which do not make them feasible replacements for the denaturation and hydrolysis of surface proteins and starch molecules in pretzel production (Kurzius 1975, Walsh 1992, Seetharaman et al. 2002, Rombouts et al. 2012). Calcium hydroxide ($Ca(OH)_2$) is a strong base; however, it has limited value for use in pretzel production due to its poor water solubility.

Evaluation Information #13: Provide a list of organic agricultural products that could be alternatives for the petitioned substance (7 CFR § 205.600 (b) (1)).

There are no organic agricultural products that could serve as an alternative for sodium hydroxide.

Report Authorship

The following individuals were involved in research, data collection, writing, editing, and/or final approval of this report:

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All individuals are in compliance with Federal Acquisition Regulations (FAR) Subpart 3.11—Preventing Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.

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