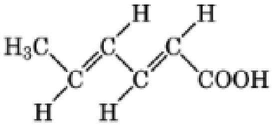
Kirk-Othmer Encyclopedia of Chemical Technology.

SORBIC ACID

Sorbic acid[110-44-1] is a white crystalline solid first isolated in 1859 by hydrolysis of the oil distilled from unripened mountain-ash berries (1). The name is derived from the scientific term for the rowan tree, *Sorbus aucuparia Linne*, which is the parent plant of the mountain ash. Sorbic acid was first synthesized in 1900 (2). Interest in this compound was minimal until independent researchers, E. Mueller of Germany and C. M. Gooding of the United States, discovered its antimicrobial effect in 1939 and 1940, respectively. Early interest in manufacturing sorbic acid centered around its use as a tung oil replacement when tung oil supplies were curtailed in the United States during World War II. High manufacturing costs prohibited expanded use until its approval as a food preservative in 1953. Sorbic acid is widely used in foods having a pH of 6.5 or below, where control of bacteria, molds, and yeasts is essential for obtaining safe and economical storage life.

1. Physical Properties

The sorbic acid crystal has a well-ordered morphology as a result of its hydrogen bonding and trans,trans structure **(1)**.



(1)

Physical properties are given in Table 1, along with those of the commercially most used salt, *E*,*E*-potassium sorbate [24634-61-5]. Table 2 shows the solubility in various solvents. More extensive data on solubility are given in References 3 and 5. Sorbic acid dust, as well as any organic dust, can accumulate a static charge and become an explosion hazard, particularly when mixed with highly flammable solvents or oxidizing agents. Minimum explosive limits are 0.02 g/L of air for sorbic acid (6).

2. Chemical Properties

The chemical reactivity of sorbic acid is determined by the conjugated double bonds and the carboxyl group.

2.1. Conjugated Double Bonds

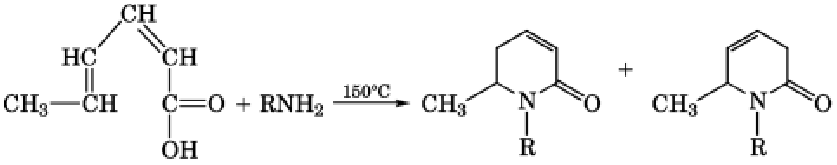
Sorbic acid is brominated faster than other olefinic acids (7). Reaction with hydrogen chloride gives predominately 5-chloro-3-hexenoic acid (8).

Table 1. Physical Properties of Sorbic Acid

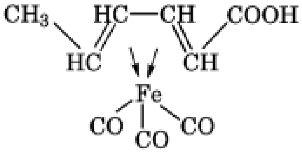
Properties	Sorbic acid
mol wt	112.13
melting point, °C^{a}	134.5
boiling point at 101.3 kPa (=1 atm), °C	228
density, g/cm^3, at 19°C^{b}	1.204
flash point, °C	126–130
dissociation constant at 25°C, mol/L	1.73×10^{-5}
$pK_a{}^{25}$	
H_2O	4.76
50 wt % ethanol	4.62
pK_a, 0.1 M NaCl	4.51
dissociation constant of dimer, K^{24} (CCl_4), mol/L	1.96×10^{-4}
specific heat, J/(g.K)^{c}	1.84
latent heat of fusion, kJ/mol^{c}	13.6
heat of combustion, kJ/mol^{c}	3107
heat of neutralization, kJ/mol^{c}	6.07
vapor pressure, kPa^{d}	
130°C	1.3
150°C	3.7
170°C	9.3

[a] Potassium sorbate, mol wt 150.22, decomposes at 270°C.
[b] Density for potassium sorbate at 20°C = 1.363 g/cm^3.
[c] To convert J to cal, divide by 4.184.
[d] To convert kPa to mm Hg, multiply by 7.5.

Reactions with amines at high temperatures under pressure lead to mixtures of dehydro-2-piperidinones (9):



A yellow crystalline complex (**2**) melting at 198°C is formed from sorbic acid and iron tricarbonyl (10):



(2)

Similar coordination occurs also in the presence of other di- and trivalent metals. Reduction of the double bonds can produce various hexenoic acid mixtures.

Sorbic acid is oxidized rapidly in the presence of molecular oxygen or peroxide compounds. The decomposition products indicate that the double bond farthest from the carboxyl group is oxidized (11). More complete oxidation leads to acetaldehyde, acetic acid, fumaraldehyde, fumaric acid, and polymeric products. Sorbic acid

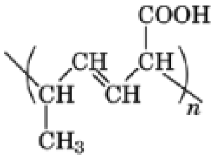
Table 2. Solubility of Sorbic Acid and Potassium Sorbate

Solvent	Temperature, °C	Solubility, g/100 g solvent Sorbic acid	Solubility, g/100 g solvent Potassium sorbate	Reference
water	0	0.14		3,4
	20	0.15	58.2	
	40	0.34		
	60	0.72		
	80	1.6		
	100	3.9		
pH[a]				
4.25	20	0.33		5
6.25	20	3.1		
7.25	20	12.0		
acetic acid (glacial)	23	11.5		4
acetone	20	9.2	0.1	4
butyl alcohol	25	11.3		3
carbon tetrachloride	20	1.3	<0.01	
cyclohexane	20	0.28		
ethyl alcohol				
anhydride	20	12.9	2.0	3,4
60 wt %	20	6.4		4
ethyl ether	20	5.0	0.1	
glycerol	20	0.31	0.2	
isopropyl alcohol	20	12.9		3
methyl alcohol				
anhydride	20	12.9	16	4
50 wt %	20	1.6		4,5
corn oil	20	0.7	0.01	5
soybean oil	20	0.52		5
propylene glycol	20	5.5	20	4
sodium chloride, 15 wt %	20	0.038	15	3,4,5

[a] Controlled pH.

undergoes Diels-Alder reactions with many dienophiles and undergoes self-dimerization, which leads to eight possible isomeric Diels-Alder structures (12).

Polymerization catalyzed by free radicals occurs with sorbic acid. The polymers (**3**) formed have high molecular weights with linear structures; the trans form of the residual double bond is preserved (13).



(**3**)

Copolymers with acrylonitrile, butadiene, isoprene, acrylates, piperylene, styrene, and polyethylene have been studied. The high cost of sorbic acid as a monomer has prevented large-scale uses. The ability of sorbic acid to polymerize, particularly on metallic surfaces, has been used to explain its corrosion inhibition for steel, iron, and nickel (14).

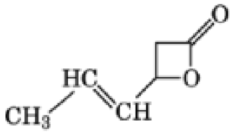
2.2. Carboxylic Acid Group

Sorbic acid undergoes the normal acid reactions forming salts, esters, amides, and acid chlorides. Industrially, the most important compound is the potassium salt because of stability and high water solubility. Sodium sorbate [7757-81-5] (*E*,*E* form [42788-83-0]) is less stable and not commercially available. The calcium salt [7492-55-9], which has limited solubility, has use in packaging (qv) materials.

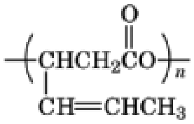
Sorbic acid anhydride [13390-06-2] can be prepared by heating the polyester of 3-hydroxy-4-hexenoic acid with sorboyl chloride [2614-88-2] or by reaction of sorbic acid with oxalyl chloride (15, 16). Preparation of the esters of sorbic acid must be controlled to prevent oxidation and polymerization. The lower sorbic acid esters have a pleasant odor.

3. Synthesis and Manufacture

The first synthesis of sorbic acid was from crotonaldehyde [4170-30-3] and malonic acid [141-82-2] in pyridine in 32% yield (2, 17, 18). The yield can be improved with the use of malonic acid salts (19). One of the first commercial methods involved the reaction of ketene and crotonaldehyde in the presence of boron trifluoride in ether at 0°C (20, 21). A β-lactone **(4)** forms and then reacts with acid, giving a 70% yield.



(4)



$$-\!\!\left(\underset{\substack{|\\ \mathrm{CH{=}CHCH_3}}}{\mathrm{CH}}\mathrm{CH_2}\overset{\substack{\mathrm{O}\\ \|}}{\mathrm{C}}\mathrm{O}\right)_{n}\!\!-$$

(5)

Most commercial sorbic acid is produced by a modification of this route. Catalysts composed of metals (zinc, cadmium, nickel, copper, manganese, and cobalt), metal oxides, or carboxylate salts of bivalent transition metals (zinc isovalerate) produce a condensation adduct with ketene and crotonaldehyde (22–24), which has been identified as (**5**).

An excess of crotonaldehyde or aliphatic, alicylic, and aromatic hydrocarbons and their derivatives is used as a solvent to produce compounds of molecular weights of 1000–5000 (25–28). After removal of unreacted components and solvent, the adduct referred to as polyester is decomposed in acidic media or by pyrolysis (29–36). Proper operation of acidic decomposition can give high yields of pure *trans*,*trans*-2,4-hexadienoic acid, whereas the pyrolysis gives a mixture of isomers that must be converted to the pure trans,trans form. The thermal decomposition is carried out in the presence of alkali or amine catalysts. A simultaneous codistillation of the sorbic acid as it forms and the component used as the solvent can simplify the process scheme. The catalyst remains in the reaction batch. Suitable solvents and entraining agents include most inert liquids that boil at 200–300°C, eg, aliphatic hydrocarbons. When the polyester is split thermally at 170–180°C and the sorbic acid is distilled directly with the solvent, production and purification can be combined in a single step. The solvent can be reused after removal of the sorbic acid (34). The isomeric mixture can be converted to the

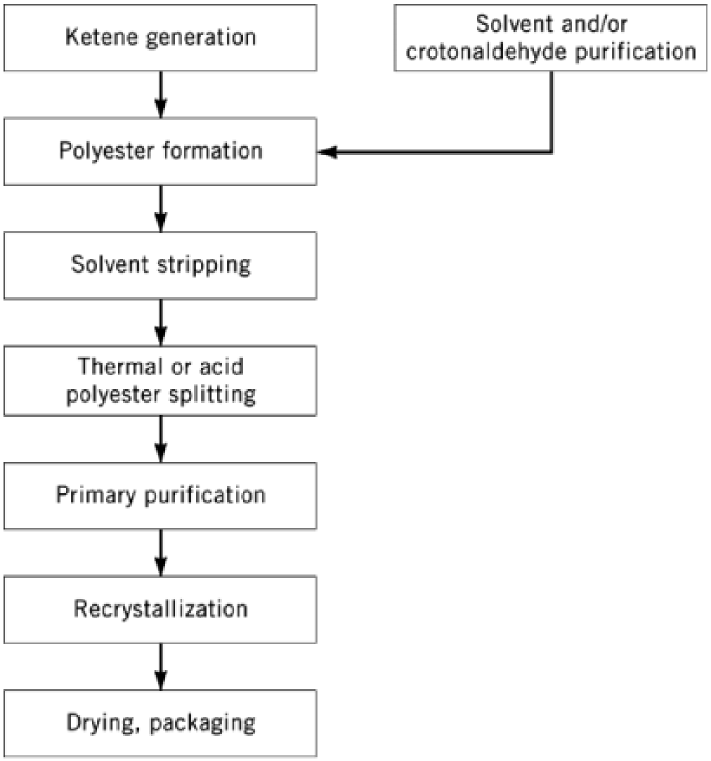


Fig. 1. Sorbic acid production scheme.

thermodynamically more stable trans,trans form in the presence of iodine, alkali, or sulfuric or hydrochloric acid (37, 38).

Food-grade specifications require further purification in the form of carbon treatments and recrystallization from aqueous or other solvent systems. The illustrated flow scheme for sorbic acid production in Figure 1 has been greatly simplified.

The ketene–crotonaldehyde route through polyester with various modifications and improvements is reportedly practiced by Hoechst Celanese, Cheminova, Daicel, Ueno, Chisso, Nippon Gohsei, and Eastman Chemical Company. Differences in their processes consist mostly in the methods of polyester splitting and first-stage purification. Production of the potassium salt can be from finished sorbic acid or from a stream in the sorbic acid production route before the final drying step. Several patents on the process for producing sorbic acid and potassium sorbate from this route are given in the literature.

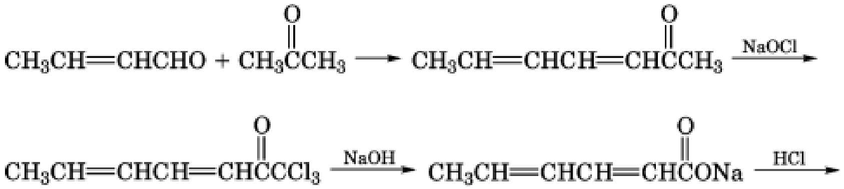
Union Carbide abandoned the ketene–crotonaldehyde route in 1953 in favor of the oxidation of 2,4-hexadienal made by acetaldehyde condensation. A silver compound used as the catalyst prevented peroxidation of the ethylenic bonds (39, 40). Their plant operated until 1970.

Preparing sorbic acid by reaction of crotonaldehyde and acetone followed by oxidation of the crotonylidenacetone is of interest in the former Soviet Union (41, 42):

Table 3. Specifications for Sorbic Acid and Potassium Sorbate[a]

Specification[b]	Sorbic acid	Potassium sorbate
assay (dry basis), wt %	99–101	98–101
arsenic, ppm	3	3
heavy metals (as lead), ppm	10	10
melting range, °C	132–135	
residue on ignition, wt %	0.2	3
water, wt %	0.5	
acidity, as sorbic acid		passes
alkalinity, as K_2CO_3		passes
loss on drying, wt %		1
lead, mg/kg		5

[a] Ref. 51.
[b] Values are maximum unless noted otherwise.



$$CH_3CH{=}CHCHO + CH_3\overset{O}{\overset{\|}{C}}CH_3 \longrightarrow CH_3CH{=}CHCH{=}CH\overset{O}{\overset{\|}{C}}CH_3 \xrightarrow{NaOCl}$$

$$CH_3CH{=}CHCH{=}CH\overset{O}{\overset{\|}{C}}CCl_3 \xrightarrow{NaOH} CH_3CH{=}CHCH{=}CH\overset{O}{\overset{\|}{C}}ONa \xrightarrow{HCl}$$

(1)

Other methods include ring opening of parasorbic acid [108-54-3] (†-lactone of 5-hydroxy-2-hexenoic acid) in hydrochloric acid or in alkaline solutions (43, 44), the ring opening of γ-vinyl- γ-butyrolactone in various catalysts (45, 46), or isomerization of 2,5-hexadienoic acid esters (47, 48). Other methods are described in the literature (6, 49, 50).

4. Economic Aspects

Sorbic acid is produced and marketed in the United States in the dust-free powder form. The 1995 truckload (TL) list price was U.S. $8.60–$8.80/kg for food grade and $12.41/kg for National Formulary (NF) grade. Water-soluble potassium sorbate is marketed as a powder or as granules. The 1995 TL list price was U.S. $7.90–$8.15/kg for food grade and $11.75/kg for NF grade. In addition to Eastman, the only U.S. producer, there are four Japanese producers and two producers in the European Union. Worldwide consumption in 1994 was approximately 2700–3000 metric tons and the nameplate productive capacity was approximately 2900–3100 metric tons.

5. Purification Specifications

Sorbic acid and its salts are highly refined to obtain the necessary purity for use in foods. The quality requirements are defined by the *Food Chemicals Codex* (Table 3). Codistillation or recrystallization from water, alcoholic solutions, or acetone is used to obtain sorbic acid and potassium sorbate of a purity that passes not only the *Codex* requirements but is sufficient for long-term storage. Measurement of the peroxide content and heat stability can further determine the presence of low amounts of impurities. The presence of isomers, other than the trans,trans form, causes instability and affects the melting point.

5.1. Analytical Techniques

Sorbic acid and potassium sorbate are assayed titrimetrically (51). The quantitative analysis of sorbic acid in food or beverages, which may require solvent extraction or steam distillation (52, 53), employs various techniques. The two classical methods are both spectrophotometric (54–56). In the ultraviolet method, the prepared sample is acidified and the sorbic acid is measured at $\sim 250-260\ \mathrm{nm}$. In the colorimetric method, the sorbic acid in the prepared sample is oxidized and then reacts with thiobarbituric acid; the complex is measured at $\sim 530\ \mathrm{nm}$. Chromatographic techniques are also used for the analysis of sorbic acid. High pressure liquid chromatography with ultraviolet detection is used to separate and quantify sorbic acid from other ultraviolet-absorbing species (57–59). Sorbic acid in food extracts is determined by gas chromatography with flame ionization detection (60–62).

6. Uses

Sorbic acid and its potassium salt, collectively called sorbates, are used primarily in a wide range of food and feed products (63) and to a lesser extent in certain cosmetics (64), pharmaceuticals, and tobacco products. There are limited applications of the calcium and sodium salts, but the acid and its potassium salt are used almost exclusively.

Since the first demonstration of antimicrobial activity in the 1940s, sorbates have been shown to inhibit a wide spectrum of yeasts, molds, and bacteria (Table 4) (65), including most foodborne pathogens (66–70). As bacterial inhibitors, sorbates are least effective against lactic acid bacteria. Although this can be a problem for foods that suffer from lactic spoilage, it has proven to be a positive point in cases of yeast and mold suppression during lactic fermentations (71–74). The effectiveness of sorbates can be influenced by a number of factors, including pH, microbial load, water activity, temperature, and atmosphere (75). The antimicrobial activity of sorbates has been reviewed (75, 76).

The inhibitory activity of sorbates is attributed to the undissociated acid molecule. The activity, therefore, depends on the pH of the substrate. The upper limit for activity is approximately pH 6.5 in moist applications; the degree of activity increases as the pH decreases. The upper pH limit can be increased in low water activity systems. The following indicates the effect of pH on the dissociation of sorbic acid, ie, percentage of undissociated sorbic acid at various pH levels (76, 77).

pH	Wt %
3.0	98
3.5	95
4.0	86
4.5	65
4.76 (pK_a)	50
5.0	37
5.5	15
6.0	6
6.5	2
7.0	<1

The activity of the sorbates at a higher pH is one distinct advantage over the two other most commonly used food preservatives, benzoic and propionic acids, because the upper pH limits for activity of these compounds are approximately pH 4.5 and 5.5, respectively. Although the effect of sorbates can be microbiocidal under certain conditions, activity is most often manifested as a microbial growth retardant.

Table 4. Genus Names of Molds, Yeasts, and Bacteria Inhibited by Sorbates[a]

Molds

Alternaria citri
A. tenuis
A. spp.
A. cucumis
A. sp.
Aspergillus clavatus
A. elegans
A. flavus
A. fumigatus
A. glaucus
A. niger
A. ocraceus
A. parasiticus
A. sydowi
A. terreus
A. unguis
A. versicolor
Botrytis cinerea
Cephalosporium sp.
Cercospora sp.
Chaetomium globosum
Cladosporium cladosporiodes
Colletotrichum lagenarium
Cunninghamella echinulata
Curvularia trifolii
Fusarium episphaeria
F. moniliforme
F. oxysporum
F. roseum
F. rubrum
F. solani
F. tricinctum
Geotrichum candidum
G. sp.[b]
Gliocladium roseum
Helminthosporium sp.[b]
Heterosporium terrestre
Humicola fusco-atra.
Mucor silvaticus
M. spp.[c]
Myrothecium roridum
M. verrucaria
M. sp.
Papularia arundinis
Penicillium atromentosum
P. chermesinum
P. chrysogenum
P. citrinum
P. digitatum
P. duclauxi
P. expansum
P. frequentans
P. funiculosum
P. gladioli
P. herquei
P. implicatum
P. italicum
P. janthinellum
P. notatum
P. oxalicum
P. patulum
P. piscarium
P. purpurogenum
P. restrictum
P. roquefortii
P. rugulosum
P. sublateritium
P. thomii
P. urticae
P. variabile
P. spp.b
Pestolotiopsis macrotricha sp.
Phoma sp.
Pullularia pullulans
Rhizoctonia solani
Rhizopus arrhizus
R. nigricans
Rosellinia sp.
Sporotrichum pruinosum
Stagonospora sp.
Stysanus sp.
Thielavia basicola
Trichoderma viride
Truncatella sp.

Yeasts

Brettanomyces clausenii
B. versatilis
Candida albicans
C. krusei
C. tropicalis
C. mycoderma
Cryptococcus terreus
C. neoformans
C. sp.
Rhodotorula flava
R. glutinis
R. rubra
R. spp.
Saccharomyces cerevisiae
S. cerevisiae var. ellipsoideus
S. carlsbergensis
S. fragilis
S. rouxii

Table 4. *Continued*

Debaryomyces membranaefaciens
D. membranaefaciens var. hollandicus
D. spp.
Endomycopsis ohmeri
Hansenula anomala
H. saturnus
H. subpelliculosa
Oospora sp.
Pichia alcoholophila
P. membranaefaciens
P. polymorpha
P. silvestris
P. sp.

Acetobacter aceti
A. xylinum
Achromobacter sp.
Alcaligenes faecalis
Azotobacter agilis
Bacillus coagulans
B. cereus
B. polymyxa
B. stearothermophilus
B. subtilis
Clostridium perfringens
C. sporogenes
Enterobacter aerogenes
Escherichia coli
E. freundii
Lactobacillus brevis

S. delbrueckii
S. lactis
Schizosaccharomyces octosporus
Sporobolomyces sp.
Torulaspora rosei
Torulopsis candida
T. caroliniana
T. minor
T. polcherrima
T. versitalis lipofera
Zygosaccharomyces globiformis
Z. halomembranis

Bacteria
- *Micrococcus sp.*
- *Propionibacterium zeae*
- *P. freundenreichii*
- *Proteus vulgaris*
- *Pseudomonas fragi*
- *P. fluorescens*
- *P. sp.*
- *Salmonella heidelberg*
- *S. montevideo*
- *S. typhimurium*
- *S. enteritidis*
- *Sarcina lutea*
- *Serratia marcescens*
- *Staphylococcus aureus*
- *Vibrio parahaemolyticus*

[a] Ref. 65.
[b] Two strains tested.
[c] Five strains tested.

The exact mechanism of inhibition by sorbic acid has not been thoroughly elucidated, even though it has been the subject of extensive research and numerous hypotheses. A number of enzyme systems in fungi and bacteria have been designated as sites of sorbate inhibition (78–84). Sorbic acid has been shown to inhibit the transport of carbohydrates into yeast cells, inhibit oxidative and fermentative assimilation, and uncouple oxidative phosphorylation in a variety of bacteria in studies conducted for various systems, including whole cells, cell-free extracts, and isolated enzyme systems (83, 85–87). Although all events may occur under specific conditions, no single proposed mechanism seems to account wholly for the inhibitory activity of sorbates. More likely, microbial inhibition by sorbates is the result of a combination of events that may differ from one organism to another and from one set of conditions to another.

As of this writing (1996), there has been no evidence to indicate that microorganisms can develop resistance to sorbates, as occurs with antibiotics and certain other antimicrobial chemicals. However, there is variation in the sorbate sensitivity of microorganisms from one genus to another, between different species in the same genus, and even between different strains of the same species. *Saccharomyces bailii* is resistant to sorbates, benzoates, and other short-chain monocarboxylic acids because of an inducible enzyme system that transports these compounds out of the cell (88). Some molds, when present in extremely high numbers, can metabolize sorbates. This has been attributed to typical β-oxidation as occurs with other fatty acids (78). Species of *Penicillium*, particularly *P. roquefortii*, can decarboxylate sorbates to 1,3-pentadiene, resulting in a hydrocarbon odor (89, 90). *Desulfoarculus baarsii* was found to oxidize sorbic acid completely to carbon dioxide, whereas at higher concentrations the bacteria produced pentanone-2 and isopentanone-2 (91).

Food applications of sorbates expanded rapidly after issuance of the original patents in 1945 (92). The first uses were based on their excellent fungistatic properties and thus involved foods with low pH and/or low water activity in which yeasts and molds are the primary spoilage agents. More recent application research has been directed toward utilizing the bacteriostatic properties of sorbates.

Sorbates are classified as generally recognized as safe (GRAS) in the United States, with no upper limit set for foods that are not covered by Standards of Identity. They are also allowed in more than 70 food products having Standards of Identity. Examples of products that often contain sorbates are natural and processed cheeses, other cheese products, salad dressings, bakery products, prepared salads, fermented vegetable products, dried fruits, fruit juices, margarine, wine, fish products, jams, and jellies (65). Use levels in food products are 0.01–0.5 wt % (Table 5). Compared with other antimicrobial preservatives, sorbates can be used in higher concentrations without affecting the flavor of foods. The level of sorbates necessary for preservation of a specific product depends on numerous factors, including product composition (pH, moisture, presence of other inhibitors, fat content), initial contamination level, packaging, and storage temperature. Maximum shelf life extension with sorbates is achieved when products have low initial levels of microbial contamination and are properly handled and stored. Therefore, the preservative cannot be used to mask poor quality product or poor handling practices.

Table 5. Sorbate Concentration in Food Products[a], Wt %

Product	Typical concentration, %
cheese and cheese products[b]	0.2–0.3
fruit drinks	0.025–0.075
beverage syrups	0.1
cider	0.05–0.1
wine	0.02–0.04
cakes and icings	0.05–0.1
pie fillings	0.05–0.1
margarine (unsalted)[b]	0.1
prepared vegetable salads	0.05–0.1
dried fruits	0.02–0.05
semimoist pet food	0.1–0.3
salad dressings (pour-type)[b]	0.05–0.1

[a] Ref. 65.

[b] Maximum use level allowed by Standard of Identity.

Sorbates can be applied to food by any of several methods, including direct addition, dipping in or spraying with an aqueous sorbate solution, dusting with sorbate powder, or addition to food packaging materials. The potassium salt is used in applications where high water solubility is desired.

6.1. Margarine

Improvements in the technology of making margarine have greatly reduced the associated spoilage problems. Sorbates and benzoates are both used in margarine; sorbates is the more effective because of the high product pH and the comparative oil:water distribution coefficients for the two compounds, ie, sorbic acid 3:1, benzoic acid 6:1 (93, 94). A greater proportion of the sorbate thus remains in the water phase, where microbial spoilage occurs. Sorbates are generally used at 0.1 wt % and are most often used in product forms with higher spoilage potential, eg, unsalted or reduced-, low-, or no-fat margarine, or product packaged in plastic tubs leaving headspace.

6.2. Wine

Sorbic acid is used in table wines to prevent secondary fermentation of residual sugar. It is used at 0.01–0.025 wt % in addition to sulfur dioxide. Adding sorbic acid affords protection against recontamination by yeasts for wines that have been heated or filter-sterilized, but at those low levels it does not provide adequate protection against undesirable malolactic or acetic acid bacteria (95, 96). It has been found that bacteria in red wine containing residual sugar can metabolize potassium sorbate, resulting in off-odors and -flavors even in trace amounts (97). The most offensive by-product was 2-ethoxy-3,5-hexadiene, which produces a geranium-like odor. Other odors identified were 1-ethoxyhexa-2,4-diene (mint/garlic) and ethyl sorbate (honey/apple).

6.3. Dairy Products

The dairy industry is the largest commercial user of sorbates, with the largest portion used in processed cheeses. Data on the antimicrobial efficacy of sorbates in cheese have been published (98, 99). The most common application methods include dipping or spraying with potassium sorbate solutions for natural cheeses and direct addition of sorbic acid to processed cheeses and cold-pack cheeses. Sorbate-impregnated wrapping material can be used for packaged cheese slices and pieces. For cottage cheese, sorbic acid is added to the cream dressing prior to pasteurization to a level of 0.075 wt % in the finished product (100, 101). Common cheese processing and storage conditions, particularly heat treatment, do not affect the stability or efficacy of sorbic acid (102). Most cheese products are covered by Standards of Identity and, except for cottage cheese, a maximum use level is set (see Table 5).

6.4. Seafood

Sorbates are used to extend the shelf life of many seafood products, both fresh and processed (103, 104). For smoked or dried fish, an instantaneous dip in 5 wt % potassium sorbate or a 10-minute dip in 1.0 wt % potassium sorbate prior to drying or smoking inhibits the development of yeast and mold (105, 106). For fresh fish, sorbates can be incorporated at approximately 0.5 wt % into the ice, refrigerated seawater, or ice-water slush in which fish are packed, or applied as a 2.5–5.0 wt % potassium sorbate dip for fillets (107, 108). Sorbates inhibit the growth of psychrotrophic spoilage bacteria, but the treatment must be applied while the product is fresh (109, 110). Sorbates can extend shelf life and delay *Clostridium botulinum* type-E toxigenesis in fish that has been packaged in modified atmospheres (111).

6.5. Fruit and Vegetable Products

Sorbates are applied at 0.05–0.1 wt % as a fungistat for prunes, pickles, relishes, maraschino cherries, olives, and figs (64, 112). The same levels extend shelf life of prepared salads such as potato salad, cole slaw, and tuna salad (99). In fermented vegetables, sorbates protect the finished product by retarding yeasts during fermentation or in the cover brine (r65,r72–r74,r94).

Sorbates reduce post-harvest losses of fresh citrus fruit, particularly when the spoilage fungi are resistant to chemical treatments (113, 114). Post-harvest treatment of apples and apple juice with potassium sorbate decreases spoilage and may prevent mycotoxin production (115). A combination of potassium sorbate and sodium benzoate greatly reduces mold caused by mold during drying and gives the additional benefit of reducing the drying time required (116–118).

Sorbate combined with mild heat has a synergistic effect with regard to microbial destruction; thus, in the presence of 0.025–0.06 wt % sorbate, products such as apple juice, peach and banana slices, fruit salads, and strawberries can be treated with less severe heat treatments to extend shelf life (119, 120). Sorbates increase the heat sensitivity of various spoilage fungi under varying conditions of pH and water activity (121–124). A similar synergistic effect has been reported for the combination of sorbate with irradiation (125).

6.6. Bakery Products

Sorbates are used in and/or on yeast-raised and chemically leavened bakery products. The internal use of sorbates in yeast-raised products at one-fourth the amount of calcium–sodium propionate that is normally added provides a shelf life equal to that of propionate without adversely affecting the yeast fermentation. Sorbates added at one-tenth the propionate level reduce the mix time by 30% (126). This internal treatment combined with an external spray of potassium sorbate can provide the same or an increased shelf life of pan breads, hamburger and hot-dog buns, English muffins, brown-and-serve rolls, and tortillas. The total sorbate useful in or on these baked goods ranges from 0.03 wt % for pan breads to 0.5 wt % for tortillas; 0.2–0.3 wt % sorbic acid protects chemically leavened yellow and chocolate cakes (127). Fruit-pie fillings and icings can be protected with 0.03–0.1 wt % sorbates.

6.7. Meat and Poultry

The only sorbate treatment of meat permitted by the United States Department of Agriculture (USDA) is a potassium sorbate dip for dry sausages to prevent mold growth. Numerous research studies support increased sorbate use in meat and poultry, but most of these applications have not been approved for use in the United States. A combination of 0.26 wt % potassium sorbate with 0.004 wt % sodium nitrite in curing bacon has been shown to reduce nitrosamine formation during frying and provide a safe antibotulinal shelf life (128, 129). In cooked cured sausages (beef, pork, and chicken frankfurter emulsions), 0.004 wt % nitrite/0.20 wt % sorbic acid delayed germination and outgrowth of *Clostridium botulinum* (130, 131). In sausage or tryptose broth, potassium sorbate alone or combined with sodium nitrate caused an initial minimal reduction of *L. monocytogenes* (132).

For fresh poultry, a potassium sorbate dip significantly reduces total viable bacteria and doubles the refrigerated shelf life of ice-packed broilers (133). In cooked, uncured, vacuum-packaged turkey and poultry stored at 4°C, 0.2–0.25 wt % potassium sorbate suppresses microbial growth for up to 10 days (134). Sorbic acid at 0.5% in a marinade mixture for chicken drummettes extends refrigerator shelf life (135). Country-cured hams sprayed with a 10 wt % potassium sorbate solution showed no mold growth for up to 30 days (136). A review of sorbate use in meat and fish products has been published (137).

6.8. Pet Foods and Commercial Animal Feeds

For many years, it has been known that stable, long-shelf-life, intermediate-moisture pet foods can be prepared through the use of 0.1–0.3 wt % sorbates. In these products, the antimicrobial effectiveness of sorbates is enhanced by a combination of moderate heat treatment, pH adjustment, and reduced water activity via humectants such as propylene glycol, or by adjusting sugar and salt content. These techniques have been reviewed extensively (138, 139).

As energy costs have escalated in recent years, the use of high moisture food by-products in commercial animal feeds has also escalated, particularly in beef cattle and dairy rations, as a means of reducing production costs. Because of the broad activity spectrum, sorbates are extremely effective in the preservation of wet by-products, eg, brewers' and distillers' grains, beet pulp, citrus pulp, and condensed whey (139).

Treating alfalfa hay with potassium sorbate and potassium carbonate at cutting decreases drying time and improves preservation (140). Potassium sorbate applied to tobacco at a pH below 5.0 inhibits a number of spoilage fungi (141). A longer, safe storage period results in high moisture corn from the treatment of potassium sorbate alone or combined with propylene glycol (142).

Sorbic acid is not only suitable for preservation of feedstuffs but also improves the feed utilization and weight gain of chickens. This has proven to be of economic value under practical conditions when sorbic acid is added to the feed at 0.02–0.04 wt % (143–145). Similar effects have been observed for the use of sorbic acid in swine feeds (146).

7. Regulatory Status

7.1. United States

Sorbic acid and potassium sorbate are generally recognized as safe (GRAS) for use in food under U.S. food ingredient regulations in the *Code of Federal Regulations* (147, 148) when used in accordance with current good manufacturing practice and where permitted by applicable U.S. FDA Food Standards of Identity. U.S. regulations, including the Food Standards of Identity, cover about 70 foods or food product categories. Among them are cheese (limit 0.3%) (149), baked goods (limit 0.23%) (150), and margarine (limit 0.1% individually or 0.2% in combination with other preservatives) (151, 152). Other permitted food categories include salad dressings (153) and condiments, where the limit of addition is generally 0.2%. Thus users must ascertain whether their particular food products are subject to a standard and, if so, what limitations apply.

Potassium sorbate, but not sorbic acid, is generally recognized as safe for use in animal feeds (154) and in paper and paperboard products for food packaging (155).

Potassium sorbate may also be used in meat and poultry food products under USDA regulations (156, 157). The USDA regulations allow its use only to retard mold growth in sausage, including beef jerky, when applied from a 10% water solution to casings before or after stuffing.

Both sorbic acid and potassium sorbate may be used under U.S. Department of Treasury, Bureau of Alcohol, Tobacco, and Firearms regulations as sterilizing and preservative agents for treatment of wine and juice at up to 300 ppm/L (158).

Other U.S. regulatory clearances for sorbic acid allow its use as an antimicotic in the manufacture of food packaging materials (159), as a pesticide adjuvant when applied to growing crops (160), and with methylcellulose and dimethylpolysiloxane as an antifoaming agent (161).

7.2. Canada

Sorbic acid and potassium sorbate are cleared in Canada as Class II and Class III preservatives (Table XI, Parts II and III, Food and Drug Regulations) (162). They are cleared for use in the same food types. As in the United States, their lawful use is predicated upon conformity with published food standards. Otherwise they may be used in bread and unstandardized foods, except meat (Divisions 14 and 21 of the regulations), fish, and poultry, at levels up to 1000 ppm, in cider and wine at 500 ppm, and in cheeses at 3000 ppm in accordance with the food standards for cheese (Section B of the regulations).

7.3. Japan

The Japanese Standards for Food Additives allow sorbic acid and potassium sorbate to be used as antimicrobial agents in a variety of foods; specific limitations depend on the food (163).

7.4. European Union

As of this writing (1996), sorbic acid (E 200) and potassium sorbate (E 202) may be used without restriction in foods under European Union legislation (164). This legislation provides food use limitations similar to those under United States, Canadian, and Japanese food regulations. Specific food use limitations and restrictions are given in the legislation in Annex III, Part A, and allow use of the sorbates in food at levels ranging from 200 to 2000 ppm, depending on the food type.

8. Health and Safety Factors

The health effects of sorbic acid and sorbates have been reviewed (165–167). The extremely low toxicity of sorbic acid enhances its desirability as a food preservative. The oral LD_{50} for sorbic acid in rats is 7–10 g/kg body weight compared to 5 g/kg for sodium chloride (165–169). In subacute and chronic toxicity tests in rats, 5% sorbic acid in the diet results in no abnormal effects after 90 days or lifetime feeding studies. A level of 10% in rat diets results in a slight enlargement of the liver, kidneys, and thyroid gland (170). This same dietary level fed to mice also resulted in an increase in liver and kidney weight (171). These increased organ weights were not associated with any histopathological changes and are attributed to the energy utilization of sorbic acid (165, 166). Studies of the long-term toxicity of sorbic acid in mice and in rats indicate no carcinogenic effects at dietary levels up to 10% (170, 171).

Literature reports indicate that sodium sorbate causes weak genotoxic effects such as chromosomal aberrations and mutations in mammalian cells (172, 173). This effect is thought to be caused by oxidative products of sodium sorbate in stored solutions (173–175). The main oxidation product of sodium sorbate, 4,5-oxohexenoate, is mutagenic in a *Salmonella*/mammalian-microsome test (176). Sorbic acid and potassium sorbate were not genotoxic under the same test procedures (167, 172, 174–177).

Sorbic acid is metabolized to carbon dioxide and water in the same way as other fatty acids, releasing 27.6 kJ/g sorbate (6.6 kcal/g) (165). As a result of the favorable toxicological and physiological aspects, the World Health Organization (WHO) has allowed sorbic acid at the highest acceptable daily intake of all food preservatives, 25 mg/kg body weight (178).

BIBLIOGRAPHY

"Sorbic Acid" in *ECT* 1st ed. Vol. 6, pp. 272–274, by J. A. Field, Union Carbide and Carbon Corp.; Suppl. 1, pp. 840–849, by A. E. Montagna, Union Carbide Chemicals Co.; in *ECT* 2nd ed., Vol. 18, pp. 589–599, by S. W. Moline, C. E. Colwell, and J. E. Simeral, Union Carbide Corp.; in *ECT* 3rd ed., Vol. 21, pp. 402–416, by C. L. Keller, S. M. Balaban, C. S. Hickey, and V. G. DiFate, Monsanto Co.

Cited Publications

1. A. W. Hofmann, *Lieb. Ann. Chem. Pharm.* **110**, 129 (1859).
2. O. Doebner, *Ber. Dtsch. Chem. Gas.* **33**, 2140 (1900).
3. N. G. Polyanskii and co-workers, *Zh. Prikl. Khim. (Leningrad)*, **39**, 2005 (1966).
4. E. Lück, *Sorbinsäure*, Vol. **1**, B. Bher's Verlag GmbH, Hamburg, Germany, 1969.
5. Trolle-Lassen Co., *Arch. Pharm. Org. Chem.* **66**(23), 1235 (1959).
6. *U.S. Bureau of Mines*, Report 7132, May 1968.
7. J. J. Sudborough and J. Thomas, *J. Chem. Soc.* **97**, 2450 (1910).
8. C. K. Ingold, G. J. Pritchard, and H. G. Smith, *J. Chem. Soc.* 79 (1934).
9. R. Fittig, *Lieb. Ann. Chem. Pharm.* **161**, 307 (1872).
10. U.S. Pat. 3,126,401 (Mar. 24, 1964), G. Ecke (to Ethyl Corp.).
11. P. Heinänen, *Ann. Acad. Sci. Fenn. Ser.* **A49**(4), 112 (1938).
12. Technical data, J. J. Bloomfield, Monsanto Co., St. Louis, Mo., 1981.
13. K. Fugjiwana and co-workers, *Nippon Hoshasen Kobunshi Kenkyu Kyokai Nempo*, **4**, 183 (1962).
14. I. N. Putilova, *Tr. Mezhd. Kongr. Korrozii Metallov (Moscow)*, **2**, 32 (1966).
15. Ger. Pat. 1,283,832 (Jan. 27, 1965), H. Fernholz and H. J. Schmidt (to Hoechst).
16. R. Adams and L. Ulich, *J. Am. Chem. Soc.* **42**, 599 (1920).
17. O. Doebner, *Ber. Dtsch. Chem. Gas.* **23**, 2372 (1890).
18. *Ibid.*, **35**, 1136 (1902).

19. Pol. Pat. 47,632 (Oct. 14, 1963), I. Nagrodzka and co-workers.
20. U.S. Pat. 2,484,067 (Oct. 11, 1949), (to Union Carbide Corp.).
21. H. J. Hagemeyer, *Ind. Eng. Chem.* **41**, 765 (1949).
22. Rus. Pat. 39-13,849 (Aug. 5, 1967), H. Nakamura (to Nippon Gohsei).
23. Rus. Pat. 45-9,368 (Apr. 14, 1970), O. Nakamura (to Nippon Gohsei).
24. Ger. Pat. 1,042,573 (Nov. 6, 1958), H. Fernholz (to Hoechst).
25. U.S. Pat. 3,022,342 (Feb. 20, 1962), H. Fernholz, K. Ruths, and K. Heinmann-Trosien (to Hoechst).
26. U.S. Pat. 3,021,365 (Feb. 13, 1962), H. Fernholz and E. Munolos (to Hoechst).
27. Ger. Pat. 1,150,672 (June 27, 1963), O. Probst (to Hoechst).
28. U.S. Pat. 3,499,029 (Mar. 3, 1970), H. Fernholz and H. Neu (to Hoechst).
29. Rus. Pat. 44-26,646 (Nov. 7, 1969), I. Nakajima (to Nippon Gohsei).
30. U.S. Pat. 3,759,988 (Sept. 18, 1973), G. Kunstle (to Wacker).
31. Can. Pat. 8,982,73 (Apr. 18, 1972), R. Smith and E. Jeans, (to Chemcell).
32. Ger. Pat. 2,203,712 (Aug. 16, 1973), H. Fernholz, H. J. Schmidt, and F. Wunder (to Hoechst).
33. Ger. Pat. 1,153,742 (Sept. 5, 1963), K. Ruths and O. Probst (to Hoechst).
34. Ger. Pat. 1,059,899 (June 25, 1959), H. Fernholz (to Hoechst).
35. U.S. Pat. 3,461,158 (Aug. 12, 1969), L. Hörnig and H. Neu (to Hoechst).
36. N. G. Polyanskii and co-workers, *Tr. Tombovsk Inta Khim. Mashinostr.* **2**, 94 (1968).
37. U.S. Pat. 3,642,885 (Feb. 15, 1972), L. Hörnig and co-workers (to Hoechst).
38. Ger. Pat. 1,281,439 (Oct. 31, 1968), L. Hörnig and O. Probst (to Hoechst).
39. U.S. Pat. 2,887,496 (May 19, 1959), E. Lashley (to Union Carbide).
40. G. F. Woods and co-workers, *J. Am. chem. Soc.* **77**, 1800 (1955).
41. V. S. Markevich and S. M. Markevich, *Khim. Promst. (Moscow)*, **12**, 898 (1973).
42. Rus. Pat. 169,520 (Mar. 17, 1965), S. M. and V. S. Markevich.
43. R. Joley and C. Amiaro, *Bull. Soc. Chem. Fr.*, 139 (1947).
44. U. Eisner, J. Elvidoe, and R. Lindstead, *J. Chem. Soc.* 1372 (1953).
45. U.S. Pat. 4,022,822 (May 10, 1977), Y. Tsu Jino (to Nippon Gohsei).
46. U.S. Pat. 4,158,741 (June 19, 1979), M. Goi (to Nippon Gohsei).
47. Ital. Pat. 719,380 (Nov. 2, 1966), G. P. Chiusoli, S. Merzoni, and G. Cometti (to Montecatini).
48. G. P. Chiusoli, *Angew. Chem.* **72**, 74 (1960).
49. B. N. Utkin, *Khimiya Sorbinovoi Kislofy, M. NIITE Khim.* (1970).
50. N. G. Polyanskii, *Khim. Promst. (Moscow)*, **1**, 20 (1963).
51. *Food Chemicals Codex*, 3rd ed. and 1st, 2nd, 3rd, and 4th Supplements to the 3rd ed., National Academy of Science, National Academy Press, Washington, D.C., 1981.
52. *Official Methods of Analysis*, 15th ed., Sections 971.15, 974.10, 975.10, and 983.16, Association of Official Analytical Chemists, Arlington, Va., 1990.
53. *Pearson's Composition and Analysis of Foods*, 9th ed., Longman Scientific and Technical, London, U.K., 1991.
54. A. Caputi and P. A. Stafford, *J. Assoc. Off. Anal. Chem.* **60**, 1044–1047 (1977).
55. G. Wilamowski, *J. Assoc. Off. Anal. Chem.* **57**, 675–677 (1974).
56. G. Wilamowski, *J. Assoc. Off. Anal. Chem.* **54**, 663–665 (1971).
57. M. C. Bennett and D. R. Petrus, *J. Food Sci.* **42**, 1220–1221 (1977).
58. M. S. Ali, *J. Assoc. Off. Anal. Chem.* **68**, 488–492 (1985).
59. H. Terada and Y. Sakabe, *J. Chroma.* **346**, 333–340 (1985).
60. B. K. Larsson, *J. Assoc. Off. Anal. Chem.* **66**, 775–780 (1983).
61. A. Graveland, *J. Assoc. Off. Anal. Chem.* **55**, 1024–1026 (1972).
62. D. E. LaCroix and N. P. Wong, *J. Assoc. Off. Anal. Chem.* **54**, 361–363 (1971).
63. E. Lück, *Food Add. Contam.* **7**(5), 711–715, (1990).
64. R. Woodford and E. Adams, *Am. Perfum. Cosmet.* **85**, 25 (1970).
65. *Sorbic Acid and Potassium Sorbate for Preserving Food Freshness*, Eastman Chemical Co. Publication ZS-1C, Kingsport, Tenn., 1995.
66. E. S. Beneke and F. W. Fabian, *Food Technol.* **9**, 486 (1955).
67. T. A. Bell, J. L. Etchells, and A. F. Borg, *J. Bacteriol.* **77**, 573 (1959).

68. R. H. Vaughn and L. O. Emard, *Bacteriol. Proc.* **5**, 38 (1951).
69. L. O. Emard and R. H. Vaughn, *J. Bacteriol.* **63**, 487 (1952).
70. G. K. York, Ph.D. dissertation, *Studies on the Inhibition of Microbes by Sorbic Acid*, University of California, Davis, 1960.
71. G. F. Phillips and J. O. Mundt, *Food Technol.* **4**, 291 (1950).
72. R. N. Costilow, W. E. Ferguson, and S. Ray, *Appl. Microbiol.* **3**, 341 (1955).
73. R. N. Costilow and co-workers, *Food Res.* **21**, 27 (1956).
74. R. N. Costilow and co-workers, *Appl. Microbiol.* **5**, 373 (1957).
75. M. B. Liewen and E. H. Marth, *J. Food Prot.* **4**(48), 364–375 (1985).
76. J. N. Sofos and F. F. Busta, *J. Food Prot.* **4**, 614 (1981).
77. F. Sauer, *Food Technol.* **31**, 66 (1977).
78. D. Melnick, F. H. Luckmann, and C. M. Gooding, *Food Res.* **19**, 44 (1954).
79. J. J. Azukas, R. N. Costilow, and H. L. Sadoff, *J. Bacteriol.* **81**, 189 (1961).
80. G. K. York and R. H. Vaughn, *Bacteriol. Proc.* **55**, 20 (1955).
81. W. Martoadiprawito and J. R. Whitaker, *Biochem. Biophys. Acta*, **77**, 526 (1963).
82. J. R. Whitaker, *Food Res.* **24**, 37 (1959).
83. G. K. York and R. H. Vaughn, *J. Bacteriol.* **88**, 411 (1964).
84. J. A. Troller, *Can. J. Microbiol.* **11**, 611 (1965).
85. T. Deak and E. K. Novak, *Yeasts: The Proceedings of the Second Symposium on Yeasts*, Slovac Academy of Sciences, Bratislava, Czech Republic, 1966, 533–536.
86. A. G. Man, in A. G. Man, *Bacteria: A Treatise on Structure and Function*, Vol. **1**, Academic Press, New York, 1960.
87. G. K. York and R. H. Vaughn, *Bacteriol. Proc.* **60**, 47 (1960).
88. A. D. Warth, *J. Appl. Bacteriol.* **43**, 215 (1970).
89. E. H. Marth and co-workers, *J. Dairy Sci.* **49**, 1197 (1966).
90. J. L. Kinderlerer and P. V. Hatton, *Food Add. Contam.* **7**(5), 657–669 (1990).
91. S. Schnell and co-workers, *Biodeg.* **2**, 33–41 (1991).
92. U.S. Pat. 2,379,294 (June 26, 1945), C. M. Gooding (to Best Foods, Inc.).
93. C. J. Doherty, *Technical Service Report*, Union Carbide Corp., South Charleston, W. Va., 1965.
94. E. Beker and I. Roeder, *Fette Seifen Austrichm*, **49**, 321 (1957).
95. G. Wurdig, *Brew. Distill. Int.* **6**, 42 (1976).
96. R. C. Auerbach, *Wines Vines*, **40**, 26 (1959).
97. M. G. Chisholm and J. M. Samuels, *J. Agric. Food Chem.* **40**(4), 630–633 (1992).
98. M. D. Bonner and L. G. Harmon, *J. Dairy Sci.* **40**, 1599 (1957).
99. E. Lüeck and K. H. Remmert, *Indus. Lech.* **60**, 10–14, 6 (1980).
100. *Sorbic Acid and Potassium Sorbate for Use in Cottage Cheese*, Publication No. IC/FI-20, Monsanto, Co., St. Louis, Mo., 1977.
101. E. B. Collins and H. H. Moustafa, *J. Dairy Sci.* **52**, 439 (1969).
102. J. A. Torres, J. O. Bouzas, and M. Karel, *J. Food Process. Preserv.* **13**(6), 409–415 (1989).
103. B. R. Thakur and T. R. Patel, *Food Rev. Inter.* **10**(1), 93–107 (1994).
104. A. Pedrosa-Menabrito and J. M. Regenstein, *J. Food Qual.* **13**, 129–146 (1990).
105. J. J. Geminder, *Food Technol.* **13**, 459 (1959).
106. J. W. Boyd and H. L. A. Tarr, *Food Technol.* **9**, 411 (1953).
107. J. P. H. Wessels and co-workers, *J. Food Technol.* **7**, 303 (1972).
108. N. Tomlinson and co-workers, *Technical Report No. 783*, Canadian Fisheries and Marine Service, Vancouver, B.C., Canada, 1978.
109. J. M. Debevere and J. P. Voets, *J. Appl. Bacteriol.* **35**, 351 (1972).
110. M. S. Fey, Ph.D. dissertation, *Extending the Shelf Life of Fresh Fish by Potassium Sorbate and Modified Atmospheres at 0–1° Celsius*, Cornell University, Ithaca, N.Y., 1980.
111. R. C. Lindsay, *Appl. Environ. Micro.* **44**(5), 1212–1221 (1982).
112. *CRC Handbook of Food Additives*, 2nd ed., CRC Press, Boca Raton, Fla., 1972.
113. J. J. Smoot and A. A. McCormack, *Proc. Fla. State Hortic. Soc.* **91**, 119 (1978).
114. *Use of Potassium Sorbate in Protecting Citrus Fruit*, Publication No. IC/NC-602, Monsanto Co., St. Louis, Mo., 1981.

115. D. Ryu and D. L. Holt, *J. Food Prot.* **56**, 862–867 (1993).
116. J. N. Bizri and I. A. Wahem, *J. Food Sci.* **59**, 130–134 (1994).
117. C. B. Hall, *Proc. Fla. State Hortic. Soc.* **72**, 280 (1959).
118. *Use of MP-11 for Mold Protection of Field-Drying Raisins*, Publication No. IC/NC-603, Monsanto, Co., St. Louis, Mo., 1981.
119. J. R. Robinson and C. H. Hills, *Food Technol.* **16**, 77 (1962).
120. U.S. Pat. 2,992,114 (July 11, 1961), E. A. Weaver (to U.S. Government).
121. L. R. Beuchat, *J. Food Sci.* **46**, 771 (1981).
122. L. R. Beuchat, *J. Food Prot.* **44**, 450 (1981).
123. L. R. Beuchat, *Appl. Environ. Microbiol.* **41**, 472 (1981).
124. L. R. Beuchat, *J. Food Prot.* **44**, 765 (1981).
125. C. F. Niven, Jr. and W. R. Chesbro, *Antibiot. Annu.* 855 (1956–1957).
126. *Potassium Sorbate Surface Treatment for Yeast-Raised Bakery Products*, Publication No. IC/FI-21, Monsanto Co., 1977.
127. D. Melnick, H. W. Vahlteich, and A. Hackett, *Food Res.* **21**, 133 (1956).
128. *Shelf Life Sensory, Cooking, and Physical Characteristics of Bacon Cured with Varying Levels of Sodium Nitrate and Potassium Sorbate*, U.S. Dept. of Agriculture, Washington, D.C., July 1979.
129. F. J. Ivey and co-workers, *J. Food Prot.* **41**, 621 (1978).
130. M. C. Robach, *Appl. Environ. Microbiol.* **38**, 840 (1978).
131. J. N. Sofos, F. F. Busta, and C. E. Allen, *Appl. Environ. Microbiol.* **37**, 1103 (1979).
132. Y. A. Hefnawy, S. I. Moustafa, and E. H. Marth, *Lebensm. Wiss. U. Technol.* **26**, 167–170 (1993).
133. E. C. To and M. C. Robach, *J. Food Technol.* **15**, 543 (1980).
134. M. C. Robach and co-workers, *J. Food Sci.* **45**, 638 (1980).
135. J. T. Chuang and co-workers, *Korean J. Food Sci. Technol.* **23**(6), 717–722 (1991).
136. J. D. Baldock and co-workers, *J. Food Prot.* **42**, 780 (1979).
137. M. C. Robach and J. N. Sofos, *J. Food Prot.* **45**, 374 (1982).
138. R. Davis, G. G. Birch, and J. J. Parker, eds., *Intermediate Moisture Foods*, Applied Science Publishers, Ltd., London, U.K., 1976.
139. N. W. Desrosier, *The Technology of Food Preservation*, AVI Publishing Co., Westport, Conn., 1970, 365–383.
140. E. H. Jaster and K. J. Moore, *Anim. Feed Sci. Technol.* **38**, 175–186 (1992).
141. E. S. Mutasa, N. Magan, and K. J. Seal, *Mycol. Res.* **94**(7), 971–978 (1990).
142. M. Yasin, M. A. Hanna, and L. B. Bullerman, *Am. Soc. Agric. Eng.* **35**(4), 1229–1233 (1992).
143. G. Dust, in E. Lück, eds., *Sorbinsäure*, Vol. **3**, B. Berhr's Verlag GmbH, Hamburg, Germany, 1970.
144. B. C. Dilworth and co-workers, *Poult. Sci.* **6**, 1445 (1979).
145. M. Suwathep and co-workers, *Poult. Sci.* **7**, 1741 (1981).
146. Technical data, T. Veum, University of Missouri, Columbia, Mo., 1981.
147. 21 CFR 182.3089, Apr. 1994.
148. 21 CFR 182.3640, Apr. 1994.
149. 21 CFR Part 133, Apr. 1994.
150. 21 CFR Part 136, Apr. 1994.
151. 21 CFR Part 166, Apr. 1994.
152. 9 CFR 318.7, *Miscellaneous*, 219, Jan. 1995.
153. 21 CFR Part 169, Apr. 1994.
154. 21 CFR 582.3640, Apr. 1994.
155. 21 CFR 182.90, Apr. 1994.
156. 9 CFR 318.7, Jan. 1995.
157. 9 CFR 381.147, Jan. 1995.
158. 27 CFR 24.246, Apr. 1988.
159. 21 CFR 181.23, Apr. 1994.
160. 21 CFR 182.99, Apr. 1994.

161. 21 CFR 177.2260, Apr. 1994.
162. *The Food and Drugs Act and Regulations*, Departmental Consolidation of the Food and Drugs Act and the Food and Drug Regulations, with amendments to Dec. 15, 1994, Minister of Supply and Services, Canada, 1994.
163. *The Japanese Standards for Food Additives*, 6th ed., Japan Food Additives Association, Tokyo, 1994.
164. European Parliament and Council Directive 95/2/EC, Feb. 1995.
165. J. N. Sofos and F. F. Busta, in P. M. Davidson and A. L. Branen, eds., *Antimicrobials in Foods*, 2nd ed., Marcel Dekker, New York, 1993, 49–94.
166. J. N. Sofos, *Sorbate Food Preservatives*, CRC Press, Inc., Boca Raton, Fla., 1989, 205–224.
167. R. Walker, *Food Add. Contam.* **7**, 671–676 (1990).
168. H. J. Deuel and co-workers, *Food Res.* **19**, 1–12 (1954).
169. H. F. Smyth and C. P. Carpenter, *J. Indus. Hygiene Toxic.* **30**, 63–68 (1948).
170. I. F. Gaunt, K. R. Butterworth, and S. D. Gangolii, *Food Cosm. Toxic.* **13**, 31–45 (1975).
171. R. J. Hendy and co-workers, *Food Cosm. Toxic.* **14**, 381–386 (1976).
172. M. M. Hasegawa and co-workers, *Food Chem. Toxic.* **22**, 501–507 (1984).
173. R. Munzner, C. Guigas, and H. W. Renner, *Food Chem. Toxic.* **28**, 397–401 (1990).
174. D. Schiffmann and J. Schlatter, *Food Chem. Toxic.* **30**, 669–672 (1992).
175. J. Schlatter and co-workers, *Food Chem. Toxic.* **30**, 843–851 (1992).
176. R. Jung and co-workers, *Food Chem. Toxic.* **30**, 1–7 (1992).
177. F. E. Wurgler, J. Schlatter, and P. Maier, *Mut. Res.* **283**, 107–111 (1992).
178. Joint FAO/WHO Expert Committee on Food Additives, *WHO Food Add. Ser.* **5**, 121–127 (1974).

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