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Use and Removal of Sulfite by Conversion to Sulfate in the Preservation of Salt-Free Cucumbers†

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ABSTRACT

Cucumbers (*Cucumis sativus*) were microbiologically stable in cover liquid containing 300 ppm of added sodium metabisulfite (calculated as SO_2), 20 mM calcium chloride, and HCl to give an equilibrated pH of 3.5. The sulfur(IV) oxoanions could be easily removed to nondetectable levels (<3 ppm) by addition of an equimolar amount of hydrogen peroxide, which rapidly converted S(IV) primarily to sulfate ions. When sulfur(IV) oxoanions were removed from stored fresh cucumbers, 85% of the added metabisulfite could be accounted for by formation of sulfate ions. If cucumbers were heated before addition and removal of sulfur(IV) oxoanions, 96% of that added was converted to sulfate by hydrogen peroxide. Preservation of cucumbers in this way does not require fermentation, so addition of salt is not needed to select for lactic acid bacteria.

Over one-third of the pickling cucumber (*Cucumis sativus* L. var. *sativus*) crop of the United States is fermented in bulk tanks and stored prior to final processing into pickle products. Cucumbers are typically fermented in open fiberglass tanks in 5 to 6% NaCl brine. After the active fermentation, additional NaCl may be added to raise the concentration to as much as 12% to protect against dilution of the brine by rainwater and subsequent growth of spoilage organisms, or, in colder climates, to protect against freezing *(9)*. As restrictions on discharge of chloride in wastewater streams have increased, processors have gradually reduced the salt levels used in fermentation and bulk storage and increased the amount of fermentation brine that is recycled. However, with current fermentation procedures the potential exists for spoilage of fermented cucumbers by clostridia if the salt level is too low and the pH is above 3.6 *(8)*. Despite the efforts to reduce salt waste, there remains a large amount of dilute brine generated from desalting operations for which no practical reuse method is available.

Salt-free storage of olives *(23)* is in general commercial use. The procedure uses anaerobic storage conditions, a mixture of lactic and acetic acids, and sodium benzoate to prevent microbial growth. The only published work on salt-free storage of cucumbers was that of Shoup et al. *(20)* in which an approach was used similar to that used for olive storage to preserve the cucumbers. Sulfites have been used to preserve a variety of acid fruit products. However, the primary objective for use of sulfites has often been to preserve color rather than microbiological stability *(25)*. But at low pH sulfites are very effective at inhibiting microbial growth, although the pH and S(IV) concentrations required for microbiological stability have been defined for only a few products. *(In this paper, free sulfite species [$SO_2 \cdot H_2O$, HSO_3^- and SO_3^{2-}] as a group will be called "sulfur(IV) oxoanions" or "S(IV)," following the suggestion of Wedzicha (27). Reversibly bound forms of sulfite will be referred to as "bound S(IV)." When concentrations of S(IV) are given in parts per million, the amounts are calculated in terms of sulfur dioxide [molecular mass, 64 Da]).* At pH 3.5, 600 ppm of added S(IV) prevented microbial growth in palm wine for at least 30 days *(7)*. Splittstoesser and Mattick *(21)* considered 200 ppm of S(IV) to be optimal for preventing growth of yeasts in refrigerated grape juice during an 8-month storage period. Mango, guava, and pawpaw pulps (pH 3.4 to 4.3) were stored 18 months at 30°C with 2,000 ppm of added S(IV) *(5)*.

This work was undertaken to explore the use of sulfites to prevent growth of microorganisms in cucumbers so they could be stored in bulk without the need to add salt. Since the cucumber is a low-acid fruit, the idea was to lower the pH by direct acidification and then to add sufficient S(IV) to ensure microbiological stability of stored cucumbers. Then, before the stored cucumbers were processed into final products, S(IV) was removed (i.e., converted to sulfate) by addition of an equimolar amount of hydrogen peroxide (H_2O_2). S(IV) causes an off flavor in foods *(3, 16)* and asthmatic reactions in some people *(2, 17)*. S(IV) has been shown to be nearly quantitatively oxidized to sulfate by a 1:1 reaction with H_2O_2 (Fig. 1) *(11)*. At pH 4 or below this reaction is complete in less than a millisecond *(12)*. H_2O_2 is currently used in several food applications *(15)*.

Specific objectives were to define the pH and added S(IV) concentrations that would ensure the microbiological stability of stored cucumbers, to find conditions which would allow removal of S(IV) to nondetectable levels by

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$$HSO_3^- + H_2O_2 \longrightarrow SO_4^{-2} + H^+ + H_2O$$

FIGURE 1. *Reaction of bisulfite ion with hydrogen peroxide at pH 3.5.*

using H_2O_2, and to measure the efficiency of conversion of sulfur(IV) oxoanions to sulfate in stored cucumbers by H_2O_2.

MATERIALS AND METHODS

Size 2B cucumbers (32 to 38 mm diameter) obtained from local processors were used for all experiments. Sodium metabisulfite (Sigma Chemical Co., St. Louis, Mo.) was the source of S(IV) for all experiments. $CaCl_2 \cdot 2\ H_2O$ and HCl were purchased from Aldrich Chemical Company (Milwaukee, Wis.). Hydrogen peroxide (30%) was obtained from J. T. Baker Chemical Company (Phillipsburg, N.J.).

Measurement of pH. The pH was measured with a Fisher Accumet digital pH meter (model 825MP) and a Corning combination electrode (#476570). The pH meter was calibrated with pH 7.0 and pH 4.01 buffers. Samples and standard buffers were at the same temperature.

Determination of pH and S(IV) concentration required for preservation. Fresh cucumbers were cut into 6-mm-thick slices. Slices (180 ± 2 g) were packed into 360-ml (12-oz) jars and covered with 180 ml of cover liquid to give a 50:50 pack-out ratio on a volume basis. Jars were hermetically sealed by heating caps in boiling water and then closing by hand. A single rubber septum was put in each cap to allow removal of liquid samples during incubation. Jars were stored at 25°C. Calcium chloride (20 mM equilibrated) was added to all treatments in all preservation experiments.

Two experiments with different lots of cucumbers were done to define conditions that would ensure microbe-free preservation of cucumbers by addition of sodium metabisulfite and pH adjustment. The first experiment consisted of 24 treatments with duplicate jars of all combinations of 0, 100, 200, and 300 ppm of equilibrated added S(IV) and pH adjusted with HCl to 3.0, 3.25, 3.5, 3.75, 4.0, and 4.25. For the next experiment, triplicate jars of the following treatments were evaluated for microbial growth: 150 ppm of S(IV), pH 3.25; 200 ppm of S(IV), pH 3.25 and 3.5; 250 ppm of S(IV), pH 3.5, 3.75, and 3.85; and 300 ppm of S(IV), pH 3.5, 3.75, and 3.85. In addition, duplicate jars of positive controls without added S(IV) with the pH adjusted to 3.25, 3.5, 3.75, and 3.85 were prepared. The jars were evaluated for turbidity and pressure, and high-pressure liquid chromatography (HPLC) analysis of brine samples removed by syringe from the jars was done 2 months after storage. Jars continued to be observed for the development of turbidity and pressure for 6 months.

The amount of HCl required to adjust the pH was determined by blending ten cucumbers from a lot to make a uniform slurry. Then 100 g of cucumber slurry was mixed with 100 ml of a solution containing 40 mM calcium chloride and 600 ppm of S(IV) added as sodium metabisulfite. This mixture was titrated with aliquots of standardized 3 N HCl until the pH was less than the lowest pH intended for the experiment. From this titration curve the amount of HCl required in a cover solution to give the intended equilibrated pH values in the jars was calculated and added along with calcium chloride and sodium metabisulfite. Since there was some jar-to-jar variation in the equilibrated pH values obtained with this method of acidification, the pH values reported were measured after equilibration of the stored cucumbers.

Removal of S(IV) from stored cucumbers. Whole cucumbers (680 ± 5 g) were packed in 1,360-ml (46-oz) jars. Jars were filled with 680 ml of cover liquid that contained 40 or 80 mM calcium chloride and HCl to lower the equilibrated pH to 3.5 as determined by titration of cucumber slurry (see above). A rubber septum was placed in the jar lids so that after closure a solution of 200 mg of sodium metabisulfite per ml could be injected with a syringe to give 300 ppm of S(IV) (4.68 mM) equilibrated. To assess the effect that heating cucumbers might have on removal of S(IV) by H_2O_2, some cucumbers were blanched for 3 min in boiling water and then cooled in tap water before being packed in jars and covered with the solution. In addition, some jars were pasteurized after being filled with cucumbers and cover liquid by heating in a steam-jacketed kettle to a center temperature of 74°C for 15 min and then cooling with cold tap water to 40°C or less. Sodium metabisulfite was added to these jars after cooling.

Sequential removal of S(IV) by addition of H_2O_2 was done by determination of the concentration of sulfur(IV) oxoanions by using HPLC and then addition of an equimolar amount of 30% H_2O_2 through the septum sufficient to react with the S(IV) present in the cover liquid, but not the cucumbers in the jar. After re-equilibration of the S(IV) inside the cucumbers with the cover liquid, H_2O_2 sufficient to remove it from the cover liquid was added again. This was repeated five or six times until the S(IV) in the cover liquid was reduced below the detectable limit. In an experiment to determine if sufficient H_2O_2 to remove S(IV) in both the cucumbers and cover liquid could be added in a single addition, 30% H_2O_2 was added to each jar sufficient to react with 50, 75, 90, 100, and 120% of all the S(IV) determined to be in the jar by HPLC analysis.

Conversion of added S(IV) to sulfate in nonpasteurized and pasteurized cucumbers. Cucumber slices (680 ± 5 g) were packed in 36 1,360-ml (46-oz) jars. An equal weight of cover solution containing 40 mM $CaCl_2$ and sufficient HCl to give an equilibrated pH of 3.5 was added. The jars were closed with lids fitted with a rubber septum for sampling. After closure, six jars were refrigerated without addition of S(IV) or sulfate. Sodium metabisulfite was added to six jars to give an equilibrated S(IV) concentration of 4.68 mM (300 ppm). Sulfate (4.68 mM) was added to six jars which were then refrigerated because sulfate ions are not inhibitory to microorganisms. The sulfate solution added to the cucumber jars was prepared by addition of an equimolar amount of 30% H_2O_2 to a 0.137 M solution of sodium metabisulfite to convert S(IV) ions to sulfate ions. The other 18 jars were pasteurized after closure to an internal temperature of 74°C for 15 min. Six of the pasteurized jars were stored without further additions. S(IV) or sulfate ions (4.68 mM equilibrated) were added to 6 each of the remaining 12 jars. The pasteurized jars to which sulfate was added were refrigerated.

After 2 weeks' storage, S(IV) was removed from jars to which it had been added by sequential addition of 30% hydrogen peroxide as described above. After S(IV) removal was completed, the equilibrated sulfate ion concentration in all treatments was determined by HPLC.

HPLC analysis of sugars, alcohols, organic acids, and sulfite. A method developed to analyze the substrates and products of lactic acid fermentations *(13)* was used. A conductivity detector (Dionex Corp., Sunnyvale, Calif.) and Dionex pulsed amperometric detector (PAD) were connected in series so that organic acids and S(IV) were measured with the conductivity detector and sugars and alcohols with the PAD. Components analyzed in addition to S(IV) were: malic acid, lactic acid, succinic acid, acetic acid, propionic acid, butyric acid, glucose, fructose, glycerol, and ethanol. Some modifications of the earlier procedure were made.

The heptafluorobutyric acid concentration of the eluant solution was increased from 1.6 to 3.0 mM, so the sulfite peak eluted between malic acid and succinic acid. A PL Hi-Plex H column (300 by 7.7 mm, 8 μm particle size, #1170-6830) (Polymer Laboratories, Amherst, Mass.) with guard column (#1170-1830) was used because the uniform particle size allowed an increased flow rate of 1.0 ml/min. A Dionex AMMS-ICE suppressor was used. Samples were injected with a 20-μl loop on a Spectra-Physics AS3000 autosampler (Thermo Separation Products, Fremont, Calif.). Data were collected and analyzed with a Gateway 486-25 personal computer using Chromperfect chromatography software (Justice Innovations, Inc., Mountain View, Calif.).

Since dilute S(IV) solutions are not stable during extended storage, sodium metabisulfite solution was freshly prepared each day and added to standard solutions of the other compounds *(13)* at concentrations of 0.032, 0.08, 0.20, and 0.50 mM each time samples were run. Cover liquids from stored cucumber samples or cucumber slurry samples were centrifuged at full speed (10,000 × *g*) in a Beckman microcentrifuge for 5 min. After centrifugation, samples were diluted in autosampler vials with 100 μl of internal standard solution (80 mM isobutyric acid and 25 mM meso-erythritol) and the appropriate amount of water to a total volume of 1,000 μl. The identity of low levels of S(IV) in samples was confirmed by preparing two identical vials of a sample with the only difference between the two vials being the addition of 10 μl of a 100 mM solution of iodine dissolved in *n*-propanol solution to one vial. If an S(IV) peak was present in a chromatogram without added iodine, it would be the only peak to disappear after iodine treatment because iodine oxidizes S(IV) ions to sulfate ions. If samples were run without dilution except for the addition of internal standard, the minimum detectable level of S(IV) was 3 ppm (0.047 mM).

HPLC analysis of sulfate ion. Sulfate ion concentrations were determined according to the procedure described by Florin et al. *(10)*, except that a different column and eluant solution were used. A Dionex AS10 ion-exchange column (Dionex #43118) was eluted at room temperature with 70 mM NaOH prepared from carbonate-free 50% NaOH solution (Fisher Chemical Co., Pittsburgh, PA) at a flow rate of 1.0 mL/min. Eluant was run through an AMMS-II suppressor cell (Dionex #043074) to reduce the conductivity of the eluant solution. The suppressor solution (0.05 N sulfuric acid) was run through the column at a flow rate of 6 mL/min. Sulfate ion was detected with a Dionex conductivity detector CDM-II (#40157) set at 30 μS full-scale with a 0 to 1 V output. Sulfate was determined by using external standardization with 20-μl injections of 0.02, 0.1, 0.2, 0.4, and 0.5 mM sodium sulfate solutions. Samples for sulfate analysis were taken aseptically from jars and centrifuged at full speed (10,000 × *g*) in a Beckman microcentrifuge for 5 min. After centrifugation, the samples were diluted in an autosampler vial 10-fold or 15-fold with water. The diluted samples were injected with a 20 μl loop on a Spectra-Physics AS3000 autosampler. Other anions that might be present in the samples including S(IV), chloride, phosphate, malate, nitrate, nitrite, and citrate were shown not to interfere with the sulfate peak.

RESULTS AND DISCUSSION

Fresh cucumbers have a mixed microbial flora primarily on or near the surface of the fruit *(4)*. Aerobic bacterial counts have been found to range from 10^5 to 10^7 CFU/g of cucumber tissue *(4, 19)*. However, populations of lactic acid bacteria and yeasts, which may be capable of growth at low pH, have been found at $<10^4$ CFU/g *(6, 19)*. The initial objective was to determine combinations of pH and S(IV) concentrations required to prevent microbial growth in fresh cucumber slices. HCl was used to acidify the cucumbers rather than an organic acid such as acetic acid because its only inhibitory effect would be due to the increase in hydrogen ion concentration. Reducing the pH with an organic acid would have an additional inhibitory effect due to the addition of protonated acid molecules *(18)*. The highest S(IV) concentration investigated (300 ppm) was somewhat greater than the amount considered optimal for preservation of refrigerated grape juice *(21)*.

Figure 2 shows the pH and S(IV) concentration region where preservation was achieved (clear) and the region where microbial growth was observed (shaded). The jars were visually evaluated for turbidity and gas production (bulging cap) to determine if microbial growth occurred. In addition, each jar was analyzed by HPLC for changes in organic acids, sugars, and alcohols which would be a consequence of microbial growth. Jars without added S(IV) developed gas pressure and turbidity within a few days of filling. HPLC analysis showed declines in glucose, fructose, and malic acid with formation of lactic acid. This pattern was indicative of growth of lactic acid bacteria *(13)*. All jars with added sodium metabisulfite in which microorganisms grew developed gas pressure and turbidity in less than 6

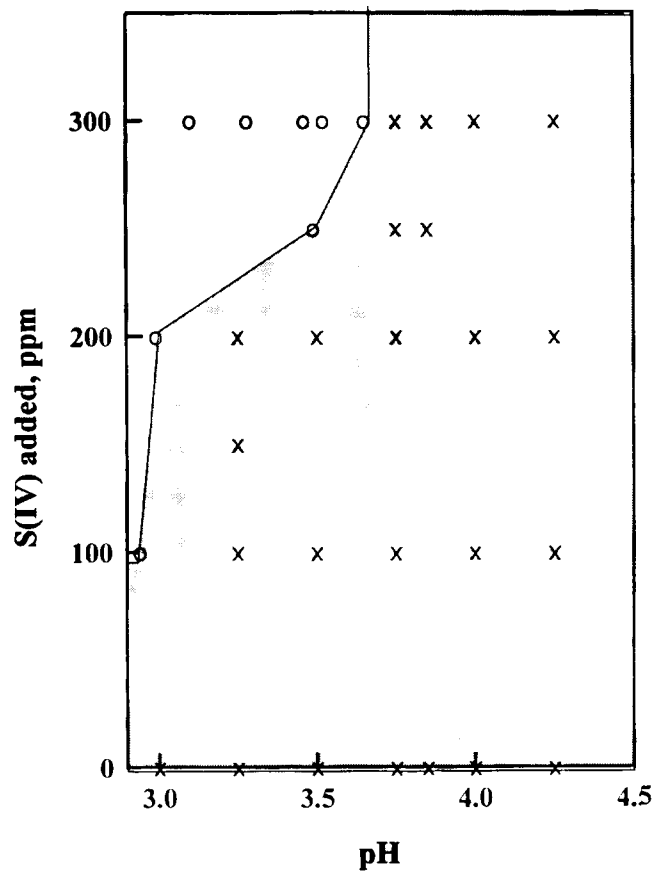

FIGURE 2. *Effect of added sodium metabisulfite concentration and pH on the ability to prevent growth of microorganisms (clear area) in stored cucumbers. Growth of microorganisms (shaded area) was judged to have occurred if there was visible turbidity in the cover liquid, pressure on the jar lids, or fermentation products present as determined by HPLC of the cover liquid.*

weeks. When microbial growth occurred in the presence of added sodium metabisulfute, glucose and fructose declined, but not malic acid. Formation of ethanol and a small amount of glycerol was observed, but no lactic acid or acetic acid. This fermentation pattern was consistent with the growth of yeasts *(13)*.

In all cases, the visual evaluation and HPLC analysis of jars were consistent. That is, changes in fermentation substrates and products from HPLC analysis were only observed in jars in which there was also turbidity and gas production. A treatment was considered to be stable only if all jars in the treatment showed no evidence of microbial growth. For the highest S(IV) concentration added (300 ppm), the highest pH that prevented microbial growth was 3.65.

For subsequent work, 300 ppm of sulfite with a target pH of 3.5 was chosen for salt-free preservation of cucumbers. This concentration is somewhat higher than the 2.9 mM (185 ppm) S(IV) required to prevent the growth of *Zygosaccharomyes bailii* at pH 3.5. This was the most sulfite-resistant yeast among a group of 11 yeasts investigated by Warth *(24)*. Stratford et al. *(22)* found that it took 15.6 mM S(IV) (1,000 ppm) to kill 10^5 CFU/ml of the sulfite-resistant yeast, *Saccharomycodes ludwigii*, at pH 4.0. An equivalent amount of free SO_2 at pH 3.5 would require an S(IV) concentration of 5.0 mM (320 ppm), assuming a pK_a of 1.86 for the dissociation constant of $SO_2 \cdot H_2O$ *(26)*. Previous work on the effect of pH on the firmness of cucumbers has shown that storage at pH 3.5 results in good firmness retention *(9, 14)*. No indication of microbial growth has been observed in more than a dozen lots of cucumbers when this pH and S(IV) combination has been used in subsequent work directed toward optimization of quality factors in stored salt-free cucumbers.

Although added sulfiting agents are effective inhibitors of microbial growth, it would be desirable to remove S(IV) before using cucumbers for consumer products because it has an off flavor *(3, 16)* and because there is the potential for an asthmatic reaction for a small fraction of the population *(2, 17)*. Sulfur(IV) oxoanions have been found to react almost quantitatively with H_2O_2 to form water and sulfate ions *(11, 12)*, which are normally present in plants and animals. Since H_2O_2 has been used as an oxidant in several food applications *(15)*, its ability to oxidize sulfite in acidified cucumbers was investigated.

Figure 3 shows the decline in S(IV) in a jar with equal amounts of cucumbers and cover liquid with five successive additions of S(IV). For each addition, a sufficient amount of H_2O_2 was added to react with only the sulfite in the cover liquid, which was half the total S(IV) in the jar. The S(IV) remaining in the cucumbers was allowed to equilibrate and was then measured by HPLC; then another addition of H_2O_2 was made to again remove the S(IV) in the cover liquid. This process continued for five additions until S(IV) was below the limit of detection. Comparison of the expected S(IV) concentration to the analyzed S(IV) level after each H_2O_2 addition shows that the amount remaining was always slightly less than predicted on the basis of a 1:1 reaction of H_2O_2 with S(IV). This result showed that H_2O_2 removed

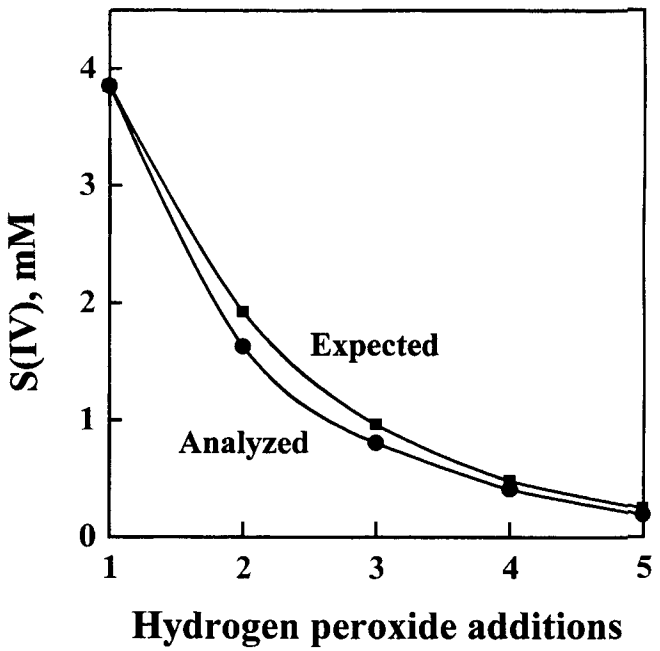

FIGURE 3. *Analyzed and expected removal of S(IV) from stored cucumbers with sequential addition of H_2O_2 equal to the molar concentration of S(IV) in the cover liquid.*

S(IV) from the cucumbers, but the loss was slightly in excess of a 1:1 ratio. This suggested there may be a small amount of S(IV) degradation by some other reaction.

S(IV) removal would be faster and more convenient if all of the H_2O_2 necessary to remove it from both the cover liquid and cucumbers in a jar could be added in a single addition. However, since H_2O_2 is a reactive compound, it had to be determined whether H_2O_2 would react with other components of the cover liquid or cucumbers so that less than the expected amount of S(IV) would be removed. Table 1 shows results of adding H_2O_2 sufficient to remove 50% (cover liquid S(IV) only), and 75%, 90%, 100%, and 120% (excess) of the S(IV) present in jars of cucumbers. The amount of S(IV) removed was always somewhat greater than expected on the basis of the expectation that there would be a 1:1 reaction of an H_2O_2 molecule with S(IV) oxoanions. When sufficient H_2O_2 was added to react with all of the S(IV), S(IV) removal was complete within the limits of detection. Results were the same whether fresh cucumbers were stored, cucumbers were blanched before storage, or the jars of cucumbers were pasteurized before addition of sodium metabisulfite. This indicated that added H_2O_2 would remove at least an equimolar amount of S(IV), though it was not determined whether all of the H_2O_2 reacted directly with sulfur(IV) oxoanions.

In addition to reacting with added H_2O_2 to form sulfate, sulfur(IV) oxoanions may also be removed by irreversible reactions with food components *(29)*. To determine the amount of S(IV) converted to sulfate, sulfate was measured after S(IV) removal. Table 2 shows that fresh cucumbers stored in cover solution without added sodium metabisulfite contained 1.16 mM sulfate. Chromatography after addition of sulfate equivalent to that expected if all added S(IV) were converted to sulfate showed that added sulfate could be measured with good accuracy. When fresh cucumbers were

TABLE 1. *S(IV) removal from stored cucumbers by a single addition of hydrogen peroxide*

Cucumber treatment	Mean ± SD initial S(IV) (mM)	H_2O_2 added (mM)	Intended final S(IV) (mM)	Mean ± SD[c] analyzed final S(IV) (mM)	Expected S(IV) removed, %	Measured S(IV) removed, %
Fresh	4.09[a] ± 0.21	2.04	2.04	1.48 ± 0.06	50	63.9
		3.07	1.02	0.64 ± 0.09	75	84.4
		3.68	0.41	0.20 ± 0.06	90	95.1
		4.09	0.00	0.08 ± 0.01	100	98.0
		4.91	0.00	0.01 ± 0.01	120	99.8
Blanched	4.26[a] ± 0.22	2.13	2.13	1.44 ± 0.07	50	66.2
		3.19	1.06	0.56 ± 0.03	75	86.8
		3.83	0.43	0.15 ± 0.02	90	96.6
		4.26	0.00	0.02 ± 0.02	100	99.5
		5.11	0.00	0.02 ± 0.02	120	99.6
Pasteurized	4.58[b] ± 0.34	3.43	1.14	0.58 ± 0.14	75	87.4
		5.49	0.00	0.07 ± 0.02	120	98.4

[a] Replicates: $n = 15$.
[b] Replicates: $n = 6$.
[c] Replicates: $n = 3$.

preserved with addition of 300 ppm (4.68 mM) S(IV), about 15% of the added S(IV) could not be accounted for by the increase in sulfate ions after H_2O_2 treatment. If cucumbers were heated before sodium metabisulfite was added, 96% of the S(IV) removed by H_2O_2 treatment could be accounted for by the increase in sulfate. These results indicated that most of the S(IV) was removed by conversion to sulfate ions, but a small fraction of it disappeared by means of unknown reactions, presumably with components of the cucumbers. Wedzicha and McWeeny *(28, 29)* and Wedzicha *(25)* found that sulfonates are formed by reaction of S(IV) with sugars, ascorbic acid, components containing disulfide bonds, and Malliard browning intermediates when sulfited fruits and vegetables were dried. It is possible that some of these reactions could occur in acidified cucumbers.

These results suggest a different approach to bulk storage of cucumbers and perhaps other fruits and vegetables that are to be used for further processing. Microbiological stability can be assured by direct acidification and addition of sulfiting agents. However, problems associated with the use of sulfites, namely off flavor and asthmatic reactions, can be avoided because sulfur(IV) oxoanions can be removed by addition of H_2O_2. Compared to a traditional fermentation process, this approach to preservation would have significant advantages. The fact that preservation does not require addition of salt would mean that desalting operations and a high chloride waste stream could be eliminated. Also, it would not be necessary to carry out and monitor lactic acid fermentations. It should be noted that this process would not be suitable for commodities that serve as significant sources of thiamin *(1)*, since sulfur(IV) oxoanions are known to react with the vitamin *(30)*.

These storage conditions for cucumbers are quite different from the conditions that occur in a lactic acid fermentation. This difference means that quality factors such as firmness changes and development of a cured appearance need to be compared to the changes that occur in a fermentation process. The effects of S(IV) addition and its removal (i.e., conversion to sulfate) by H_2O_2 on cucumber components, particularly generation of volatile flavor compounds, also need to be investigated. Evaluation of such quality factors will be the subject of future reports. However, hamburger dill chips have been prepared from cucumbers stored at room temperature for 4 months. Sensory analysis showed that, after S(IV) removal, dill chips prepared from cucumbers preserved without fermentation were equal in acceptability to dill chips prepared commercially or in the laboratory from fermented cucumbers (McFeeters, unpublished data).

TABLE 2. *Conversion of S(IV) to sulfate in fresh and pasteurized cucumbers by oxidation with hydrogen peroxide*

Cucumber treatment	Mean[a] ± SD analyzed sulfate (mM)	Sulfate increase above natural conc. (mM)	Recovery of added S(IV) or sulfate calc. as SO_2 (%)
Fresh: no S(IV)	1.16 ± 0.09	NA[b]	NA
Pasteurized: no S(IV)	1.09 ± 0.06	NA	NA
Fresh: plus 4.68 mM sulfate	6.03 ± 0.10	4.87	103.8
Pasteurized: plus 4.68 mM sulfate	5.90 ± 0.10	4.81	102.6
Fresh: plus 4.68 mM (300 ppm) S(IV)	5.15 ± 0.31	3.99	85.1
Pasteurized: plus 4.68 mM (300 ppm) S(IV)	5.59 ± 0.07	4.49	95.9

[a] Mean of six jars for each treatment.
[b] NA, not applicable.

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