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SULFITES ON GRAPES: ISSUES AND ALTERNATIVES

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Sulfites on Grapes: Issues and Alternatives

Introduction

Fumigation with sulfur dioxide (SO_2) gas has been used to control the spread of decay from *Botrytis cinerea* (gray mold) on grapes marketed for fresh use since the 1920s. However, in mid-1986 the Food and Drug Administration (FDA) removed sulfiting agents from the "generally recognized as safe" (GRAS) list for food additive use on fruits or vegetables sold raw to consumers. In response, the Environmental Protection Agency (EPA) initiated a review of the use of SO_2 as a pesticide, and has set up interim standards for its postharvest application to table grapes while developing a longer term policy.

Some key questions considered are whether or not postharvest use of SO_2 on grapes poses any threats to public health and safety, what the EPA's ultimate ruling may be on this usage, what options exist for producers and consumers, and what are the likely economic consequences of the adoption of new regulations. Particularly relevant in this case is the weighing of the direct and indirect costs of regulation against any resultant public health benefits.

Reason for Use and Current Practice

The use of SO_2 to control postharvest diseases was developed early in this century. Winkler and Jacob (1925) in their work at the California Agricultural Experiment Station showed the effectiveness of SO_2 in retarding the growth of decay-causing organisms in fresh grapes; the treatment was applied commercially at about the same time. Research by Harvey (1955) and Nelson (1958) showed that the initial fumigation with SO_2 is insufficient when the infection is established within the berries and that prevention of the spread of decay from infected to uninfected berries requires properly timed refumigation.

The most common current treatment method in California is to refumigate with SO_2 gas in the grape storage chambers or fumigation rooms every seven days following the initial 30 minute, 5,000 to 10,000 parts per million (ppm) treatment. The SO_2 concentration of the subsequent treatments is adjusted according to the relative humidity and air movement within the storage room, the estimated degree of contamination of the fruit, the type of shipping container, and the length of time the grapes have been stored. However, the industry norm is 2,500 ppm or 0.25 percent (Mitchell, 1985; Harvey and Uota, 1978; and Marois et al., 1986).

Early season grapes which are shipped immediately are typically cooled and loaded into the truck trailer, railroad car or other transport vehicle. Then, according to industry sources, they are given their only fumigation with SO_2. Less commonly, grapes which have been stored will be given a final fumigation treatment after loading for shipment, at concentrations equivalent to those used for refumigation in storage (2,500 ppm). However, there are some difficulties in achieving an even distribution of the fumigant under these conditions (Nelson, 1985).

Recent research (Marois et al., 1986) has led to the development of an SO_2 refumigation procedure at much lower concentrations which may increase disease control and at the same time decreases the adverse effects of SO_2 on grape berries. Information from one commercial concern which has been using this procedure for the past two years indicates SO_2 residues on the grapes of less than 10 ppm. Commercial adoption of this method is in its infancy, and its application under a variety of grape and storage conditions is under study. As the industry standard application procedure also results in SO_2 residue levels less than 10 ppm in most cases, it is not known whether the low dose procedure yields residue levels which are either lower or less variable than the current standard.

In the case of exports, it is not possible to re-treat with SO_2 gas in ship holds because other fresh fruits generally shipped in the same hold may be damaged by SO_2 (Winkler et al., 1974). Fortunately, sodium bisulfite was found to be practical for this use. As the bisulfite reacts with moisture in *enclosed* grape shipping containers, sulfur dioxide is released, but the enclosure prevents damage to other nearby fruit. Regulating the amount of SO_2 released was at first problematic, but in recent years, SO_2 generating pads have proven very effective for export marketing where grapes will be in transit for extended periods (Mitchell, 1985).

Peiser and Yang (1985) studied the way in which SO_2 acts biochemically within the grape. They discovered that sulfite is rapidly oxidized to sulfate, with the vast majority of "free form" sulfite (85 percent) converted or dissipated in the first 24 hours following fumigation; about 2 percent is left after three days. The conversion within the berry of the remaining SO_2 into sulfonic acid, a "bound form" of sulfite, may provide five to seven days of protection against *Botrytis* through a slow release back to "free" SO_2, the form effective against the spores. Both forms can be measured as SO_2 in residue testing, though it is not known whether the bound form can cause allergic reactions (Taylor and Bush, 1986).

Importance of Table Grapes to California Agriculture

Production of vinifera table grapes in the United States is essentially limited to California and Arizona in areas with long, relatively dry summers (Nelson, 1980). About 14 percent (or 8.2 million boxes) of California table grapes were sold within the state in 1986, with 69 percent shipped elsewhere in the nation and 16 percent exported. Over the years, technological developments both in cooling and transportation of grapes and the use of SO_2 for decay control have made possible a tremendous market expansion in the United States and an extensive export trade. Table grapes from California are available many months of the year and continue to play an important role in California's agricultural economy.

Grape production was the third ranked agricultural commodity in terms of value for California agriculture in 1986, and the top horticultural commodity. There are three general types of grapes, classified by their most prevalent, but not exclusive use: table grapes, raisin grapes, and wine grapes. In 1986, 60 percent of the table grape production, 15 percent of raisin grapes, and 2 percent of wine grapes were sold on the fresh market; fresh market sales represented 15 percent of the volume of all California grape production, and 31.2 percent of the value (California Crop and Livestock Reporting Service). Fifty-nine million boxes of fresh table grapes were shipped (1357 million pounds) valued at $308.7 million at the farm level and a retail value exceeding $1 billion (California Table Grape Commission). In addition, one of the most important grapes on the fresh market is the Thompson seedless—a raisin grape.

The table grape industry is also an important employer, with several thousand farmers and an estimated 50,000 farmworkers engaged in the production of these grapes on approximately 100,000 acres of vineyards. Indirectly the production of fresh grapes also supports output and employment in other industries as well, given the "multiplier" or ripple effects of this industry. It was estimated that for 1976, the California multipliers for fruit production were 3.2 for output and 1.7 for employment. Using these figures, the total output in California supported by the fresh grape industry may be more than three times the direct value of output, or nearly $1 billion in 1986, and indirect employment an additional 70 percent of direct employment in fresh grape production. Table grape production is concentrated in the Coachella and parts of the San Joaquin valleys. In these regions, the industry is naturally of far greater economic significance than it is to the state as a whole.

International Competition Aspects

In 1986, 229 million pounds (lbs) of California fresh grapes were exported, valued at $98.1 million. These represented 95.8 percent of all U.S. fresh grape exports and 16.3 percent of California production. It is estimated that in 1986 it took 16,938 acres to produce these grapes.

The largest customer for U.S. fresh grape exports is Canada, which imported 125.7 million lbs valued at $45.2 million in 1986, followed by several Asian countries including: Hong Kong (30.9 million lbs), Taiwan (28.2 millions lbs), Japan (10.6 million lbs) and Singapore (8.4 million lbs).

Sulfur dioxide use expands the potential market through the increased storability and transportability of the product. It is in widespread use on grapes throughout the world, and there are no known trade barriers associated with its use in actual or potential export markets.

The United States also imports table grapes, primarily from Chile, whose growing season is offset from ours. In 1985, the United States imported 431.6 million lbs of fresh grapes worth $169.3 million. The 1986 imports were 454.9 million lbs valued at $162.7 million; 84.3 percent of them were from Chile.

The United States is a net importer of fresh grapes, importing nearly twice as many as it exports on a volume basis. The pattern of grape imports and exports from 1977 to 1986 is shown in Figure 1. Note that in recent years fresh grape exports have shown no particular trend, while imports have been steadily increasing. In fact, 43 percent of the increase in U.S. per capita grape consumption over that period was accounted for by imported grapes.

The SO_2 testing regulations apply to imported grapes as well as to domestic grapes, with the same set of standards in force. Despite the application of the same regulations, domestic suppliers feel that the economic burden of testing is greater for them than for importers. Grapes are grown over a large geographic area in this state and are supplied from many sources, whereas oceanic shipping for imported grapes is necessarily centralized, resulting in greater testing efficiencies. Associated with centralization is a big difference in lot size, so the same sampling rate translates into many more tests per ton for domestic than for import shipments.

Gains to Producers and Consumers from SO_2 Treatment of Fresh Grapes

Gain to Producers

The availability of SO_2 as a fresh grape preservative confers many benefits on producers. Its effectiveness as a decay inhibitor extends the market geographically and the time period over which the grapes may be sold, in that treated grapes can be stored for longer periods of time and transported over longer distances. Thus more grapes can be grown and marketed than would be the case without SO_2, or an effective substitute. The storage also makes possible an "orderly flow" of grapes onto the market, meaning that they can be released from storage in such a manner that grower returns and retail prices are relatively stable across a marketing season. Industry sources claim that "as much as 80 percent" of the present table grape revenues would be sacrificed if grapes were left untreated (*California Farmer*, 1987). While this figure has not been substantiated, it can be safely said that the industry would be profoundly affected by a sudden withdrawal of SO_2.

Gain to Consumers

No one, to our knowledge, has measured the benefits to consumers gained through the current system of treating grapes for decay. Benefits are likely to accrue through increased choice, better quality and possibly lower prices. These must be evaluated against potential risks discussed below.

The use of SO_2 increases the postharvest life of fresh grapes. This enlarges the array of grape varieties (cultivars) available by extending the selling season for individual cultivars beyond their harvest season. Consequently, consumers have a greater range of choices in buying fruit throughout the year.

The quality of grapes is directly diminished by the presence of rot and mold. This deterioration proceeds rapidly once started and severely reduces the postharvest life and quality of grapes. Proper treatment increases the likelihood that consumers will receive high quality grapes.

The net effect on prices is not clear. Retail prices may be higher on average due to SO_2 treatment of stored grapes because the sale of grapes can be spread over a longer period than the harvest season and need not all be sold at distress prices at the season's peak. In the longer term, however, growers would reduce production until harvest season prices increased to a profitable level. On the other hand, by reducing losses in distribution (shrinkage), SO_2 fumigation lowers marketing costs and the savings can be passed on to consumers.[1]

Why is SO_2 Treatment an Issue?

Sulfites were removed from the FDA's "generally recognized as safe" or GRAS list in 1986. Widespread use of sulfites as a preservative for restaurant salads —particularly salad bars— led to a recognition that sulfites can cause severe allergic reactions in some people. These reactions include asthma, hives and anaphylactic shock, and can be life threatening. In addition to these are more mild, and rarely reported, allergic reactions such as diahrrea (Taylor and Bush, 1986). Estimates of the number of people who are potentially in physical danger from sulfite exposure in the United States range from 180,000 to 720,000 with an additional 500,000 to 1 million having a lower grade sensitivity (Simon, Green, and Stevenson,1982; Stevenson and Simon, 1984; Taylor and Bush, 1986; Bush et al., 1986).

This type of risk should be distinguished from that posed by known carcinogens or reproductive toxins. For these substances, which are subject to regulation under California's Proposition 65, *everyone* must be presumed to be at risk from repeated consumption over a period of time. In contrast, sulfites are generally considered to be safe for consumption at normal levels by most people and are not known to cause cancer, birth defects or sterility. Evidence of other toxic effects in humans is inconclusive (Gunnison, 1981). The "acceptable

[1]Even with current treatment methods, quantitative losses during distribution are estimated to be 9 percent (USDA, ERS, 1987). A study of table grape shipments identified several important causes of shrinkage in addition to losses attributable to gray mold rot (Cappellini, Ceponis and Lightner, 1986).

daily intake," or ADI, set by the Joint FAO/WHO Expert Committee on Food Additives in 1974 is several times greater than the average daily consumption levels estimated for U.S. individuals (Taylor and Bush, 1986).

The problem of allergic reactions among sensitive people is similar to that for foods such as eggs, milk, shellfish or nuts, which a number of people must avoid. However, sulfites are looked upon differently because they are added to rather than being an inherent part of the food.

Table 1 demonstrates that fresh grapes typically have very low residual levels of SO_2, and as such should be expected to be among the least dangerous of the sulfite-containing foods, many of which are commonly eaten. It has been estimated that the average daily consumption of sulfites (SO_2 equivalent basis) for a U.S. resident is 6 milligrams (mg)/day (FASEB, 1985). The most sensitive individuals within the at-risk group have reactions when given capsules containing about 3 mg SO_2 (equivalent). Three mg is the amount of SO_2 contained in 1.3 to 6.6 lbs of table grapes, 5.3 ounces of frozen potatoes, 0.1 to 0.3 ounces of salad bar lettuce (if treated) or 0.05 ounces of dried apricots (if treated with sulfur before drying) (Table 1). For less sensitive at-risk individuals, a threshold level of SO_2 tolerance was reported equivalent to the SO_2 found in 44 pounds of fresh table grapes at 10 ppm (Bush et al., 1986; Stevenson and Simon, 1981).

Sulfite is rapidly metabolized to sulfate, a harmless substance, through an enzymatic process. Consequently, a relatively large volume of grapes would have to be eaten rapidly to have any theoretic potential for harm. Bush, Taylor and Busse (1986) point out that the reactions of sulfite-sensitive persons are dependent on the particular food or medium in which the sulfites are administered, and state that "it is not known if all sulfited foods cause reactions."

There are other problems associated with the postharvest use of SO_2 on grapes. Workers do risk acute respiratory effects up to and including death if they remain in the fumigation chamber without protective gear during the fumigation period and before the scrubbing or exhausting of the residual gas (Winkler et al., 1974). Normal worker safety precautions in accordance with state and federal regulations will avoid this problem, and medical experts in farmworker safety issues perceive no adverse effects from long-term exposure.

A final consideration is potential harm to the environment from the disposal of the non-absorbed gas or the used bisulfite pads. SO_2 is a known air pollutant and where it is vented into the atmosphere it should be considered a source of air pollution. Where scrubbers are in use, the residual can end up in the water, although it is possible to neutralize the sulfurous acid formed during the scrubbing process and reuse the scrubbing water. Retailers have recently been instructed on appropriate handling, but no information is available regarding the actual or ultimate disposal of the used SO_2-generating pads. In any case, the worker safety and pollution/disposal aspects of SO_2 fumigation have

Figure 1. US Exports of Fresh Grapes (including California), California Exports, and US Imports, 1977-1986

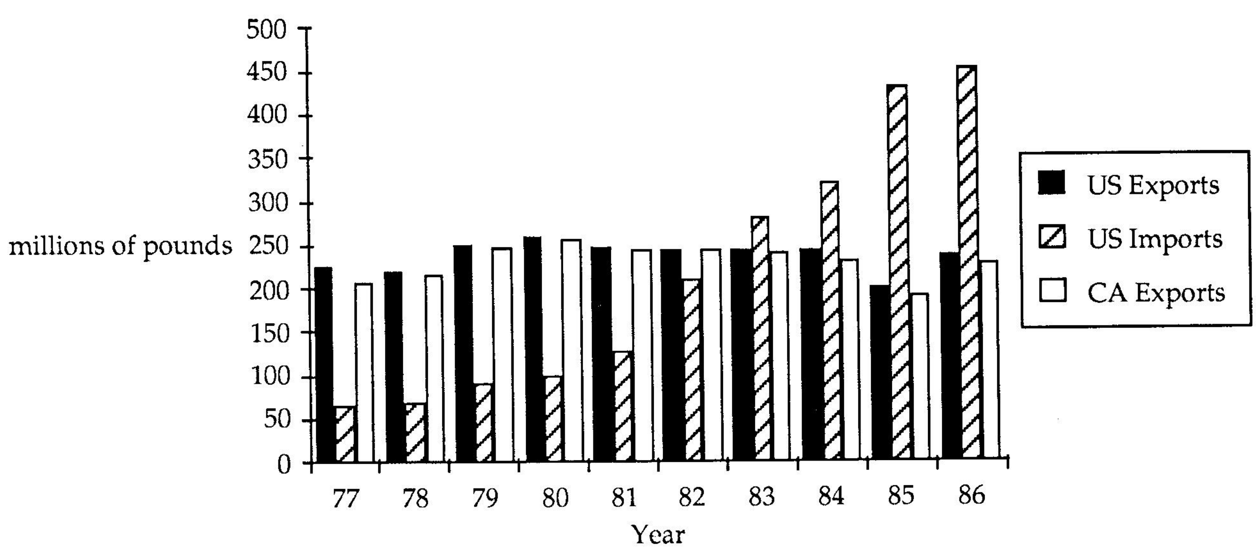

Table 1. Estimated Total SO_2 Level as Consumed for Some Sulfited Foods.

Foods	Total SO_2 (ppm)
≥ 100 ppm	
Dried fruit (excluding dark raisins and prunes)	1,200
Lemon juice (non-frozen)	800
Salad bar lettuce	400-950
Lime juice (non-frozen)	160
Molasses	125
Sauerkraut juice	100
50-99.9 ppm	
Dried potatoes	35-90
Grape juice or wine	85
Wine vinegar	75
Gravies, sauces	75
Fruit topping	60
Maraschino cherries	50
10.1-49.9 ppm	
Pectin	≤ 10-50
Shrimp (fresh)	≤ 10-40
Corn syrup	30
Sauerkraut	30
Pickled peppers	30
Pickled cocktail onions	30
Pickles/relishes	30
Corn starch	30
Hominy	20
Frozen potatoes	20
Maple syrup	20
Imported jams and jellies	14
Fresh mushrooms	13
≤ 10 ppm	
Malt vinegar	10
Dried cod	10
Canned potatoes	10
Beer	10
Dry soup mix	≤ 10
Soft drinks	≤ 10
Instant tea	≤ 10
Pizza dough (frozen)	≤ 0
Pie dough	≤ 10
Sugar (esp. beet sugar)	7
Gelatin	6.6
Coconut	5
Fresh fruit salad	5
Domestic jams and jellies	5
Crackers	5
Cookies	5
Grapes	1-5
High fructose corn syrup	3

Source: Reproduced from Taylor and Bush (1986). Original Source: "The Re-examination of the GRAS Status of Sulfiting Agents," Life Science Research Office, Federation of American Societies for Experimental Biology, January 1985.

not been the focus of controversy. The EPA thus far has been strictly concerned with consumer risk issues.

While in the process of setting standards for SO_2 on table grapes, the EPA imposed sets of interim standards for the 1987 and 1988 harvest seasons in lieu of outright banning. The regulations were intended to ensure that grapes be either free of measurable SO_2 residues (below 10 ppm, the lowest level for which testing is reliable using the Monier-Williams method) or that they be labeled to warn consumers of sulfite treatment (40 percent of the bunches had to be marked or a placard placed at the retail point of sale under this option in 1987). A set of interim standards was announced for 1988 requiring certification by the industry (via a testing protocol) that all grapes shipped contain less than 10 ppm of SO_2 (*California Grape Grower*, 1988).

Grape industry representatives object to the regulations on economic grounds and because they feel that SO_2 use on grapes has been judged potentially harmful without any reliable supporting evidence. Sulfur dioxide does belong to the sulfite family, but is applied prior to and during cold storage and dissipates rapidly. It is uncertain whether any SO_2 remains on the grapes by the time a consumer purchases them, or that it would survive home washing if any residues did remain. However, the sulfonic acid formed within grape berries following SO_2 fumigation is a "storage form" of sulfite which releases "free" SO_2 over time, so washing before release would only affect external residues.

Some members of the health/medical community disagree with industry claims regarding the safety of SO_2 use on fresh grapes. Their view is that there is potential for harm whenever the chemical is used on food. The occasional reports in the media about improper use of chemicals in agriculture contribute to their lack of confidence that users can be relied upon to adhere to proper procedures—i.e., those expected to yield acceptably low residue levels.

Costs of Sulfur Dioxide Fumigation

Current direct costs for SO_2 application are about 70 cents/lb of SO_2, with approximately 45 lbs needed to fumigate a 100,000 cubic foot storage room. Sulfur dioxide is sold as part of a fumigation package which includes installation and maintenance of the equipment within the storage facility. These costs are factored into the charge for the fumigant. Additional costs are incurred by the packing/storage house in either venting and re-cooling the chamber or shed or scrubbing the air following fumigation. The total (cumulative) cost of fumigation per pound of grapes depends on their condition prior to storage/shipment, the length of storage and number of treatments required, and various conditions within the storage facility. A rough estimate of the direct fumigation cost is 0.05¢/lb for each week the grapes are in storage. The cost of obtaining federal regulatory approval and of monitoring residue levels will undoubtedly result in an increase in the price of treatment.

Options and Alternatives

The EPA is in the process of receiving and reviewing data from the registrants and has yet to establish a tolerance or set label requirements for the use of SO_2 on grapes marketed for fresh use. Thus the relevant set of options and alternatives available within the market is not known. Therefore, options must be viewed in the context of plausible regulatory outcomes. The major options are summarized in Table 2.

Case 1: The first possibility to consider is that SO_2 residues on grapes pose no health threat to anyone, including the most sensitive asthmatic. Should this be convincingly demonstrated to the EPA, table grapes could receive an exemption from a residue tolerance requirement, and the situation would return to the pre-1986 situation. In fact, the sulfur dusting treatment in the vineyard to control mildew does not leave "significant residues," so this treatment was granted an exemption.

Case 2: At the opposite end of the spectrum is the possibility that sulfites could be banned completely for postharvest use on fresh grapes. In this case the table grape industry would have to choose from among a set of options which is currently quite limited. These options include:

Controlled Atmosphere Storage

Reduced Oxygen with Carbon Monoxide

Recent research has shown that grapes stored in a controlled atmosphere of 2 percent oxygen (O_2), 10 percent carbon monoxide (CO) and 88 percent nitrogen (N_2) at 0°C could be maintained in good condition for as long as four months.[2] In comparison with control grapes preserved with SO_2,

[2]Recently, the $CO\text{-}O_2N_2$ alternative was tested in a commercial establishment. The method was found to be "moderately successful" in terms of grape quality, but expensive, raising questions of cost effectiveness (personal correspondence with Richard MacLeod).

Table 2. Sulfur Dioxide Fumigation and Alternatives

	Sulfur Dioxide Fumigation				In Combination with Sulfur Dioxide Fumigation:	
Characteristic	Industry Standard ~2500ppm Every 7-10 days	Low Dose: ~200ppm Every 2-3 days	Continuous: 7-20ppm	In-Package Fumigation	Bunch Tagging	Retail Posting
Storage Life	About 3 months	up to 3 months	up to 3 months	up to 3 months	N/A	N/A
Transportability	up to a week without refumigation	not known	not known	controls decay during transit	N/A	N/A
Postharvest losses	SO_2 can damage grapes; total losses about 9%	varies with packing house and fruit conditions	comparison with standard not known	similar to standard fumigation treatment	N/A	N/A
Fruit Taste & Quality	some sulfur taste; can damage fruit	less SO_2 damage to fruit	less SO_2 damage to fruit	good quality--may leave sulfur taste	N/A	N/A
Cost (Packer)	~.05¢/lb/week stored	~.01¢/lb/week stored (if losses not increased)	unknown	more expensive than standard	0.4-0.7¢/lb (40%)	-0-
Price (Consumer)	current standard	may differ depending on postharvest losses	may differ depending on postharvest losses	effect not known	increase by <.01¢/lb	direct cost negligible; indirect effect not known
Safety: Worker	relatively safe (acute effects only--avoidable)	relatively save (acute effects only--avoidable)	OSHA limits exposure at 10 ppm to 15 minutes	safe	N/A (safe)	N/A (safe)
Consumer	safe for most; may or may not affect sensitive individuals at <10 ppm	(see industry standard) preliminary studies show residues <10 ppm	(see industry standard) depends on consumer and residue level	(see industry standard)	at-risk consumers must read tags	shoppers for at-risk consumers must read signs

Table 2 continued.

Characteristic	Sulfur Dioxide Fumigation: Industry Standard ~2500ppm Every 7-10 days	Low Dose: ~200ppm Every 2-3 days	Continuous: 7-20ppm	In-Package Fumigation	In Combination with Sulfur Dioxide Fumigation: Bunch Tagging	Retail Posting
Safety: Environment	without scrubbing, minor source of air pollution; with complete scrubbing, no effect	should reduce air pollution since total SO_2 declines by 75% and venting is not necessary	some leakage into atmosphere likely: minor source of air pollution	must be disposed of properly at destination	no effect	no effect
Other Considerations	there is considerable variability in the level of measured SO_2 residues on grapes	the success of this method has been mixed, in commercial trials to date; success in wet years not yet known, nor is the range of SO_2 residues	may corrode metal equipment in packing house due to constant exposure to sulfurous acid	not currently used for domestic shipments; used on imported and exported grapes which are in transit for extended periods	Pro: informs at-risk consumers; could provide opportunity for brand identification Con: increases packer cost and possibly retail price, which could lower retail sales	Pro: can inform at-risk consumers Con: shifts liability burden to retailers; damage suits could raise price or reduce retail availability

Table 2 continued.

	Alternatives to Sulfur Dioxide Fumigation					
Characteristic	Biological Control Organisms	Controlled Atmosphere ($2\% O_2$ + 10% CO)	Modified Atmosphere (Air + $15\% CO_2$)	Breed for Resistance	Irradiation	No treatment
Storage Life	unknown	up to 4 months	up to 1 month	unknown	mixed results	reduced depending on initial infection
Transportability	unknown	must be continued during extended transit	suitable for 1-2 week transit	unknown	unknown	domestic transport okay under refrigeration
Postharvest losses	unknown	compares favorably with SO_2	unknown	unknown	may increase	expect much higher postharvest losses
Fruit Taste & Quality	unknown	good quality fruit no SO_2 taste	damaged fruit in long-term storage	unknown	mixed results	some quality reduction
Cost (Packer)	unknown	more expensive	unknown	reduce cost to packer	not known	would change industry
Price (Consumer)	unknown	probably more expensive depending on postharvest losses	unknown	unknown	unknown	more variable
Safety: Worker	unknown	extremely hazardous	hazardous (2% CO_2 causes loss of consciousness followed by death)	N/A (safe)	requires precautions	safe
Consumer	unknown	leaves no residues no known health risks	leaves no residues no known health risks	presumed safe	no known health risk	N/A (safe)
Environment	presumed safe if approved	no effect	no effect	no effect	no effect	no effect
Other Considerations	will require govern-ment approval. 1-2 years from potential market availability	probably no commercial potential for worker safety reasons; would require capital investment	in-pallet treatment for grapes during shipment may be feasible with less effect	long-term possibililty only	not approved at required levels; possible consumer acceptance problems; more economical for larger firms than for smaller firms; would require investment capital	would eliminate imports (except air shipped); would shorten season with less effect on early season growers than late season growers

overall decay was prevented at least as well, while the grapes kept under low O_2 and CO atmospheres were subject to less browning and bleaching (Yahia, Nelson, and Kader, 1983).

While the process produces a better product than does the standard SO_2 fumigation during storage, it also has a major drawback for commercial application: Carbon monoxide is extremely toxic to humans, and workers would be at risk without strictly enforced safety precautions. The danger is increased by the continuous nature of the application of the gas and its odorlessness.

It is also expected that the process would be more expensive to use than SO_2 fumigation, and it would require extensive retrofitting of storage facilities to make them more gas-tight. The use of carbon monoxide has not been approved for grape storage, and would be subject to regulatory approval procedures before it could be considered an option for the table grape industry. Worker safety considerations may overwhelm the technical feasibility of this method, which would serve to shift the hazard from one group (at-risk consumers) to another (storage facility employees). The greatest potential for commercial application of the CO-O_2-N_2 method is in treatment for exporting, since it is possible to hold grapes in sealed, gas-tight marine containers during ocean shipping.

Adding 15 Percent Carbon Dioxide to Air

There is some current experimentation with controlled atmosphere environments containing 15-20 percent added carbon dioxide (CO_2) as a fungistat for short periods of time (up to one month). Earlier research cited by Yahia, Nelson and Kader (1983) indicated that controlled atmosphere storage with elevated CO_2 was "not very promising for commercial grape storage" since the level of CO_2 necessary to control decay caused chemical changes and browning of the grape berries over time. The use of CO_2-enriched atmospheres, if proved successful, could be suitable for decay control during shipment and/or temporary storage. EPA approval would be required prior to commercial application.

Biological Control of Botrytis Cinerea

Recent research at the plant pathology unit at the USDA, Agricultural Research Service, Appalachian Fruit Research Station in a cooperative effort between Charles Wilson and other U.S. and Israeli scientists has led to the development of an antagonistic microorganism for the control of *Botrytis cinerea* in table grapes. Crateloads of grapes are dipped in a solution containing the anti- organism. Further information and possible commercial experimentation awaits a pending patent. Regulatory approval will also be required before the process can be marketed.

Wilson and Pusey (1985) refer to successful biological control of *Botrytis* with the organism *Trichoderma* by researchers in Norway. The procedure which was tested in both preharvest and postharvest applications on strawberries, performed at least as well as chemical treatment.

According to Brian Federici, an entomologist specializing in bio-control at UC Riverside, the main barrier to the commercial use of many of the microbial control agents previously developed has been the high cost of their production relative to existing chemical pesticides. *Bacillus thuringensis* has been one of a very few commercial successes in this area.

It is too early to tell how biological control agents for *Botrytis* will compare with their alternatives on a cost basis for grapes. Part of the answer depends on the EPA ruling on sulfite use.

Breeding for Resistance

A possible future alternative to the use of SO_2 on table grapes is to breed grapes that are resistant to gray mold. However, Marois and others at UC Davis, indicate that current breeding research is directed more towards the development of additional seedless grape types such as early green and late red cultivars, rather than focusing on disease resistance. Banning of SO_2 could be expected to affect research priorities, providing an incentive to develop *Botrytis*-resistant grapes. It should be kept in mind that genetic alteration using traditional plant-breeding methods, and even molecular biology techniques, is a relatively slow process with potential for long run rather than short run solutions to problems such as this.

Use of Gamma Irradiation

The use of gamma irradiation to extend the storage life of fresh produce, including grapes, has been investigated. A recent report on food irradiation (Morrison and Roberts, 1985) reviews the available literature on the subject, pointing out that for control of postharvest fungi like *Botrytis*, the key factor is whether a particular fungus is more susceptible to irradiation damage than is the fruit itself. Tomatoes, strawberries and figs have been shown to meet the relative susceptibility criterion. The available evidence for fresh table grapes is equivocal at best. One study (Maxie, Nelson and Johnson, 1964) found that Emperor and Tokay grapes do not meet the criterion, although they admit their conclusions are at odds with an earlier study on Thompson Seedless grapes. They found that *Botrytis* resumed its proliferation two weeks following irradiation at 2 kilograys (200 kilorads), a dosage high enough to damage the fruit. Injury to the grapes was observed as soon as one week after treatment, thereby limiting the potential for even short-term control. Even if it were technically feasible, irradiation of table grapes might still face resistance from consumers, many of whom are uncomfortable with the thought of irradiated foods. Furthermore, the 1986 FDA approval of irradiation of fresh produce was limited to a maximum of 1 kilogray (100 kilorads).

Discussion

Even if postharvest SO_2 use on table grapes was banned for grapes to be sold in the United States, its use might still be allowed on grapes for export. For example, sodium metabisulfite-impregnated paper is presently used in grape boxes for export, while its use for domestic shipments is regulated (Section 801 of the Federal Food, Drug and Cosmetic Act). This type of differentiation could lead to segmentation of the market into export and domestic components, thereby reducing suppliers' flexibility to respond to market changes as a season progresses.

No alternative to postharvest SO_2 fumigation is currently available for commercial use. None of the options reviewed above is ready for commercial application; many unanswered questions remain for most of them. The immediate effect of an outright ban on SO_2 use would be a drastically reduced storage life, higher postharvest losses, some reduction in grape quality, the absence of imports except for those shipped by air, a shorter season of availability, and more variable prices. Without grape storage, the volume produced would have to be correspondingly lower, causing some growers and packers to go out of business, resulting in local economic disruptions.

Shipments to markets around the country should still be possible, as they were before the SO_2 innovation, even without the implementation of any of the technical options presented here. Packing and shipping of grapes without SO_2 treatment were discontinued long ago, so there are no data to estimate the loss in quality and quantity of marketable grapes at the ultimate destination. However, the inevitable increased losses would add to retail prices, since retailers must pay for spoiled fruit which cannot be sold. And consumers would respond to higher prices by buying fewer grapes.

If adoption of the "best" alternatives adds significantly to the cost of grapes sold, this could be expected to change the storage and shipping patterns and the flow of product to the market. Growers in the Coachella Valley and others specializing in early season cultivars which are not stored would probably be the least affected, while growers of late and peak harvest season grapes might find their optimal shipment patterns changed. Consumer demand is responsive to price changes, so the industry could expect the market to be weaker if alternatively treated grapes are more expensive. According to our analysis, there could be a drop in the quantity demanded of about 1.5 percent for every 1 percent increase in retail price.

The storage and shipping practices of foreign suppliers of fresh grapes to the United States (notably Chile) would have to comply with the regulations or forego the U.S. market. The decisions of foreign suppliers could have important ramifications for the annual period of availability of table grapes on the U.S. market. A complete withdrawal would return fresh grapes to seasonal fruit status.

Case 3: The EPA may continue to allow the use of SO_2 in the postharvest storage of grapes, but require that the grapes be certified as having SO_2 residues below some specified level of tolerance (such as the 10 ppm standard, the lowest level that can be reliably determined by the currently approved testing method). Whether the allowable level of residues would change as testing methods are refined remains to be seen.

Normally, approval of a pesticide for use on food crops involves the setting of label requirements which specify the conditions of its use. Based on research regarding residues, following the directions printed on the label ensures compliance with safety standards. One of the purposes of the interim standards for SO_2 use on grapes is to allow time to develop the data needed on the relationships between SO_2 concentration, application frequencies, and the resulting residues on grapes. In California, label requirements are backed up by periodic sampling and testing for residues by the California Department of Food and Agriculture (CDFA). The alternative to setting product label standards is some form of testing protocol which may or may not be similar to that in place under the current interim EPA standards, with the burden of administration and enforcement falling to the FDA. Such an ongoing testing program would be significantly more expensive than labeling, with the costs borne either by producers and consumers of grapes (if the industry is made responsible for testing) or by taxpayers (if the USDA, CDFA, or FDA conducts the testing).

Industry options available to meet residue standards will depend on the EPA's ruling. To allow for the full range of fumigation methods and storage conditions, label requirements will have to be somewhat flexible—perhaps specifying a maximum total dosage per unit of time rather than prescribing a particular interval or fumigant concentration. Since SO_2 residues dissipate rapidly after fumigation (Peiser and Yang, 1985), the label may well specify a minimum interval between last fumigation and shipping to control residues at the destination.

Under a testing protocol, packers/shippers would have flexibility as long as the standards were not exceeded. Currently identified options include:

(1) Continue the current industry practice of an initial fumigation at 5,000 to 10,000 ppm SO_2 followed by refumigation at intervals of seven to ten days at a concentration of 2,500 ppm. During the 1987 season, the California Grape and Tree Fruit League reported that over 97 percent of the 1,700 samples tested complied with the interim 10 ppm residue tolerance limit (California Grape Grower, January 1988).

(2) Use a more frequent (three times a week) refumigation with 200 ppm SO_2 following the initial fumigation. This procedure reduces total SO_2 use by 75 percent and has been shown to be capable of good *Botrytis* control while causing less SO_2 damage to the grapes (Marois et al., 1986). Limited commercial application to date indicates compliance with the 10 ppm residue tolerance limit and packer costs which are competitive. Given the lower total amount of SO_2 used, the option should also reduce the amount of SO_2 gas released into the atmosphere. Research has not been conducted comparing the transportability of grapes treated in this manner with grapes given the standard fumigation treatment.

3) Use a continuous treatment with 7 to 20 ppm SO_2 (Ginsburg, 1965; Combrink and Ginsburg, 1972; Ginsburg and Combrink, 1969).[3] Like (2) above, this application procedure can presumably provide good control of decay with less SO_2 injury to the fruit than the standard treatment. Since some SO_2 is absorbed by packing boxes, with the lower concentrations, some grapes may not get the minimum concentration needed to provide a fungistatic effect, 5 ppm. Forced air cooling systems can be used to help distribute the gas evenly, improving the effectiveness of this method. Whether continuous low-level treatment also reduces residues while maintaining transportability of the grapes is not known. This method has not been used commercially in California to date, and relative cost figures are not available.

Discussion

Sulfur dioxide residue on table grapes has only recently been identified as a possible problem. Information is being collected on the relationships between the initial condition of the grapes, storage conditions, concentration and timing of fumigations, the cumulative total SO_2 application, the length of time since the last fumigation, and the level of residues on the grape berries at various points in the marketing chain. The three fumigation methods plus the in-box SO_2-generating pads for export use all appear potentially capable of achieving *Botrytis* control while meeting the interim residue standard. Variations in individual conditions from year to year, vineyard to vineyard, and packer to packer may dictate which methods are the most cost effective.

Case 4: Sulfur dioxide fumigation of table grapes allowed, but retail labels required. This approach would treat fresh table grapes like foods which contain sulfites as food additives and whose packages bear warning labels (e.g., dried fruits, wine). An important difference is that grapes are often not sold in packages. Grapes could be labeled at either the packer or the retail level.

Tagging individual bunches of grapes with labels, stating that the grapes have been treated with SO_2 to preserve freshness, is possible, and was included as an option in the first set of interim standards. It is opposed by grape industry members. The major drawback is that bunch tagging is a relatively labor intensive procedure which adds to the cost of the grapes and, presumably, to retail grape prices if the cost is passed through. Higher prices would be expected to lead to fewer grapes sold. (A 1.5 percent increase

[3]The Occupational Safety and Health Administration limits worker exposure to 10 ppm for 15 minutes per exposure, with protective gear required for higher concentrations.

could lead to a 1 percent reduction in sales.) On the positive side, labels could be combined with a brand name or logo, providing an opportunity for brand identification such as is currently used in the banana and citrus markets, allowing reputations for good quality grapes to be established.

Labeling at the retail level has different implications depending upon the region of the country. In California, most produce (including grapes) is sold in bulk. Here it would be most practical to include a statement on the identification and price sign. The drawback from a public safety point of view is that shoppers may not read "fine print" on the sign or may fail to pass along the information, so those at risk might not be adequately warned. In some other parts of the country, produce is typically sold in sealed consumer packages which are pre-weighed and labeled. The direct cost of including a warning on the label would not be great, and the grapes would reach purchasers' homes with warnings intact.

The retail industry is concerned that any form of retail labeling would shift the responsibility (and liability) from those using the chemical to the retailers. Retailers have no way of knowing how much SO_2 was used nor do they know how much residue remains unless they institute a program of testing. This leaves them open to damage suits. Restaurants and other food establishments face the same problem of notification and liability. Fresh grapes could become less widely available if restaurants and retail food stores determined that the potential costs of damage claims exceeded the profit to be derived from grape sales. In such a case, all market participants would lose.

Another option is to provide information to appropriate health professionals treating asthmatics and other sulfite sensitive individuals. Some useful information would be the range of residue levels detected at either the packing houses or retail points of sale and the patterns of residue dissipation over a period of days. Health care providers would then be in a position to give guidance to their patients.

At-risk consumers could be informed that all table grapes on the market have been treated with SO_2 unless labeled otherwise. During the table grape harvest season, which typically begins in May and ends in November, the California industry could provide some table grapes without SO_2 treatment (and label them as such) for the benefit of at-risk consumers.

The likelihood of the labeling options being adopted is small since the FDA has already determined labels to provide "inadequate protection" for sulfite-sensitive people in the context of food additive uses of sulfites on raw fruits and vegetables (*Federal Register*, 1986).[4]

Conclusion

Use of SO_2 as a fungistat is at present an integral part of the postharvest procedures of the table grape industry. While safe for the vast majority of consumers, there is a small minority who may risk serious health problems from exposure to SO_2 residues found on grapes. Current fumigation methods in the industry, in most cases, leave grapes free of residues above 10 ppm which is the lowest limit that can be reliably detected by the currently accepted measurement technique. Occasionally, however, residues exceed those levels.

A search of the available literature and discussions with experts in the field revealed that there are some fumigation alternatives to the standard application of SO_2. These methods appear to control *Botrytis* well, at least under some conditions, may damage the fruit less than the traditional fumigation protocol, and may or may not reduce the level of SO_2 residues. Recently available information suggests that SO_2 has a fairly short half life in fresh grapes, apparently through conversion to sulfate (SO_4), a substance which causes no health problems. However, no conclusive research results have established SO_2 residue levels over a several-day period as a function of initial fumigation concentrations.

No options for the replacement of SO_2 fumigation are currently commercially available, although some are under investigation. A controlled atmosphere system containing carbon monoxide is technically successful but would introduce new hazards into the grape handling facilities, substituting the group of packinghouse/storage facility workers for sulfite-sensitive consum-

[4]Although there are currently no federal statutes covering retail labeling of pesticides (as opposed to food additives), the EPA did allow bunch tagging or retail placarding combined with a table grape industry information dissemination campaign during 1987, an option which was revoked in 1988. As a part of that program, the California Table Grape Commission distributed information to numerous health professional groups whose members may be in contact with allergic asthmatics.

ers as the at-risk group. A method for biological control of *Botrytis* with an antagonistic organism is awaiting a patent, after which it will take several years for EPA approval and commercial availability. Little is known about this method, including its cost—a factor which has impeded the adoption of some other biological pesticide replacements. A modified atmosphere environment (containing 15 to 20 percent CO_2) is being tested for short term transportation and storage applications, but has been shown to induce browning of grapes when maintained for longer than 30 days at 0 to 5°C. Irradiation has been shown to damage grapes at levels too low to effectively reduce the *Botrytis* spore population. A long-term option might include breeding new grape cultivars with *Botrytis* resistance. Other possibilities worthy of further testing include better field control to reduce initial infection of grape berries, and intermittant treatment with 15 to 20 percent CO_2-enriched atmosphere.

One other option is to allow SO_2 fumigation but require warning labels at the point of sale, or to make information available to the medical profession so that at-risk individuals can be notified of the presence (and approximate level) of SO_2 residues on grapes. Further research on the dissipation of residues over time could potentially establish guidelines for grape consumption by sulfite-sensitive individuals—e.g., wait for two days after purchase to consume grapes.

In terms of economics, the withdrawal of SO_2 from the fresh grape industry prior to the development of replacements would be disruptive. Patterns of shipments and the size of the industry would be affected, with growers of mid-to-late season grapes receiving the brunt. Imports would be seriously curtailed, at least until alternative procedures were adopted. Retail grape prices could be expected to be much more variable than they are at present, the season would be shorter, and increased losses would tend to raise average annual prices. Consequently, demand would be reduced.

The implementation of technical alternatives could provide some relief from the above situation, although possibly at a higher cost. This, again, would affect mid-to-late season growers and grape importers more than early season growers. Higher storage and/or transportation costs in the long run would mean higher prices at the retail level which would have a tendency to reduce demand. But in the short run there is no guarantee that growers/packers could pass on increased costs in the form of higher prices.

Labeling of SO_2 treated grapes is one solution to the problem. Tagging each bunch is more expensive than retail posting, but is more likely to reach the at-risk consumer. Warning of restaurant customers would be more difficult. Liability problems could interfere with retail or restaurant labeling. The most narrowly targeted, and probably the most cost effective approach is to provide information directly to at-risk consumers and indirectly through the health care profession.

Which sets of options will be available will ultimately be decided by the EPA, which will have to weigh the costs to society (including grape growers and packers, grape consumers, and taxpayers) of regulating the use of SO_2, against the cost of effectively providing information to at-risk individuals. The public health benefits of SO_2 control or labeling are confined to one relatively small group of sulfite-sensitive people, while any associated costs are incurred more generally.

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