Center for Chemical Regulation and Food Safety

Exponent®

Science Base to Support the Antimicrobial Action of Raisins

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Contents

List of Tables

Acronyms and Abbreviations

AIB	American Institute of Baking
a_w	Water activity
DOV	Dried-on-the-vine
FSNS	Food Safety Net Services
NFL	National Food Laboratory
MRP	Maillard non-enzymatic browning Reaction Products
pH	Measurement of acidity. Technically, the negative logarithm of the hydrogen ion concentration in an aqueous solution
USDA	United States Department of Agriculture

Executive Summary

Exponent, Inc. (Exponent) was retained by Sun-Maid Growers (Sun-Maid) to prepare a report summarizing all known scientific studies that demonstrate the bacterial inhibition potential of raisins, as well as the current understanding of the mechanisms responsible for this action. Exponent reviewed publically available reports of the antimicrobial activity of raisins and unpublished studies.

The challenge testing sponsored by Sun-Maid Growers, other studies on raisins, and knowledge about specific chemical inhibitors present in raisins, all point to an inhospitable microbiological environment for their growth or survival. Pathogenic microorganisms not only are incapable of growth, they die over a relatively short storage period of days to weeks. A summary of Exponent's conclusions include:

- Raisins have an unsurpassed food safety record, with no reported foodborne illness attributed to their consumption;
- Raisins and raisin components exhibit marked antimicrobial activity against spoilage organisms and human pathogens;
- Raisin products and extracts can impart antimicrobial properties into some food products at levels that do not significantly affect sensory characteristics;
- Differences in field drying and growing practices did not significantly affect the antimicrobial properties of the raisins;
- Microbial growth is prevented by the combination of acidity, low water activity, and inhibitory compounds. This unfavorable environment promotes the relatively rapid decrease in microbial numbers during storage;
- The rate of pathogen inactivation would eliminate likely levels of contamination prior to the product reaching consumers;
- Preliminary studies suggest that antimicrobial chemicals within raisins are responsible for a significant amount of the inactivation observed, however, the interaction between phenolic compounds and pH on inactivation is unknown;

- Phenolic compounds identified in raisins exhibit antimicrobial properties at or below levels that are present in raisins; and
- More research is needed to determine the antimicrobial mechanisms of action, specifically,
    - Compounds and their location within the raisin responsible for the majority of the antimicrobial activity, and
    - The relative contribution, including potential synergistic activity, of the intrinsic antimicrobial factors in raisins.

1 Objectives

Exponent, Inc. (Exponent) was retained by Sun-Maid Growers (Sun-Maid) to prepare a report to serve as the scientific basis to promote to industrial customers and the consuming public the inherent antimicrobial activity of raisins and raisin products. Exponent has summarized all known scientific studies that demonstrate the bacterial inhibition potential of raisins, as well as the current understanding of the mechanisms responsible for this action.

2 Resources

Exponent reviewed published reports, using PubMed and AGRICOLA databases (Table 1), of the antimicrobial activity of: raisins, compounds associated with raisins, other dried fruit, and fresh fruit or berries. Exponent also updated a previous literature search of foodborne illnesses attributed to raisins using AGRICOLA and PubMed databases.

Table 1. Search terms used for literature searches on AGRICOLA and PubMed databases

Commodity	Additional Search Term
Fruit	Antibacterial
Berry	Antifungal
Almond	Antimicrobial
Apple	Bacteria
Apricot	Dried
Cherry (cherr*)	Escherichia coli
Cranberry (cranberr*)	Fungal
Currant	Inhibition
Dates	Intestinal pathogen
Fig	Pathogen
Mango	Preservative
Papaya	Salmonella
Peach	Spoilage
Pear	
Pineapple	
Plum	
Prune	
Raisin	

3 Introduction

Dried fruit consumption has benefited human kind for thousands of years, providing a safe and healthy source of nutrients. This food class is produced in most geographic regions of the world and consumption occurs by all cultures and demographic segments. Certainly, the long and widespread enjoyment of dried fruit contributes to its reputation as a safe and wholesome food. This was supported by a 2006 literature review performed by Exponent, which determined that there were **no** reports of infectious foodborne illness linked to dried fruit. Exponent updated that literature search for this assignment and confirmed our previous findings.

Raisins have never been implicated with foodborne illness, suggesting that the following extrinsic or intrinsic factor(s) may impart antimicrobial protection. First, hot desert temperatures may directly kill microorganisms that are in the general environment. Second, the cessation of irrigation prior to harvest promotes drying of the grapes, which starts water activity (a_w) reduction. Drying continues once clusters are cut and placed on Kraft paper, which has ground temperatures of up to 60°C or 140°F. Third, natural acidity may also contribute to the inactivation of microorganisms. Finally, drying concentrates and changes the chemical composition of raisins, forming compounds inhibitory to the growth and survival of pathogenic microorganisms, especially bacteria.

In the following sections of this report, Exponent summarizes scientific observations of the microbial inhibitory activity of raisins and raisin products and current understanding of the potential antimicrobial mechanisms.

4 Scientific Observations of the Antimicrobial Action of Raisins

Exponent reviewed research studies that investigated the antimicrobial potential of raisins and raisin products, which are contained in the following sections:

4.1 Publically Available Studies

Only three peer-reviewed, published studies were found which evaluated the antimicrobial activity of raisins, raisin extracts, raisin paste, or raisin juice concentrate. Exponent also identified one Ph.D. thesis, which demonstrated the potential use of raisins as a food preservative (Wei, 2006). Finally, American Institute of Baking (AIB) released a technical bulletin on this topic (Ziemke, 1980). Table 2 summarizes those findings.

Table 2. Antimicrobial activity of raisin components

	Observation		
Raisin Constituent	**Action**	**Microorganism(s)**	**Citation**
Raisin extracts and raisin puree	15% added to beef jerky inactivated pathogens without adverse sensory effects.	*Staphylococcus aureus*, *Listeria monocytogenes* and *E. coli* O157:H7	Bower *et al*., 2003
Soluble partition of a raisin methanol extract	Extracts inhibited bacterial growth.	*Streptococcus mutans and Porphyromonas gingivalis*	Fausto Rivero-Cruz *et al*., 2008
Water and 60% ethanol extracts of raisins, raisin paste, raisin fiber, and raisin juice concentrate	Extracts inactivated mold and bacteria species in liquid and conventional bread systems, increasing shelf life without adverse sensory effects.	*Bacillus* spp, and *Aspergillus* and *Penecillium* spp.	Wei *et al*., 2009
Ethanol and water extracts of raisin	Extracts inhibited bacteria and fungi in liquid bread systems.	*Bacillus* spp, *Aspergillus* spp.	Wei, 2006
Crushed raisins and raisin juice concentrate	12-17% crushed raisins and 13% concentrate slowed mold growth on bread and extended shelf life without adverse sensory effects.	Unidentified mold species	Ziemke, 1980

Two generalizations can be made from the findings of the publically available literature. First, taken together, the information strongly suggests that raisin components exhibit antimicrobial action against spoilage organisms and human pathogens (Table 2). Second, raisin products and extracts exhibited antimicrobial properties in food at levels that did not significantly affect sensory characteristics (Bower *et al*., 2003, Wei *et al*.; 2009, Ziemke, 1980). Other studies showed that addition of raisin paste to fresh beef, pork, and chicken prevented rancidity and did not alter sensory characteristics (Vasavada and Cornforth, 2006).

4.2 Human Pathogen Challenge Studies

Sun-Maid Growers of California has commissioned three challenge studies to evaluate the antimicrobial potential of raisins products. The three studies were:

- 1997: a study designed and performed by the National Food Laboratory (NFL);
- 2004: a study designed and performed by ANRESCO Laboratories; and
- 2007-2009: designed by Exponent and performed by Food Safety Net Services (FSNS)

Table 3 contains a summary of these findings.

Table 3. Summary of pathogen challenge study results

Challenge Study	Raisin Products Tested	Challenge Pathogens	Physical Parameters	Reduction Rate
NFL	Traditionally grown and dried Thompson seedless raisins	Acid adapted *E. coli* O157:H7	25 and 7ºC incubation, 18 and 10% moisture	10^6 (one million-fold) reduction in 160 days
ANRESCO	Traditionally grown and dried Thompson seedless raisins	*E. coli* O157:H7, *Salmonella* spp., *L. monocytogenes*	20 ºC incubation	10^6 reduction of all pathogens in 9 days
FSNS 2008	Traditionally grown and dried Thompson seedless raisins	Acid adapted *E. coli* O157:H7, *Salmonella* spp., *L. monocytogenes*	20 ºC incubation	10^6 reduction of all pathogens in 24 days
	Raisin paste and modified raisin paste (preliminary study)	Acid adapted *E. coli* O157:H7, *L. monocytogenes*	20 ºC incubation pH- 4.09 and 5.54, a_w- 0.65 and 0.96	1 to 2 Log CFU/g reduction (10- to 100-fold) in seven days
FSNS 2009	Zante currants, organically grown raisins, dried-on-the-vine raisins, raisin paste, and raisin juice concentrate	Acid adapted *E. coli* O157:H7, *Salmonella* spp., *L. monocytogenes*	20 ºC incubation	10^6 reduction of all pathogens within 6 days for concentrate and raisin paste 10^6 reduction of all pathogens within 18 days for all intact raisins

Although the three studies were run at different times, and with a slight variation of methodology, several common antimicrobial outcomes were observed. They are:

4.2.1 Antimicrobial Activity of Raisins

There was a consistent and significant dying of pathogenic bacteria after inoculation onto finished raisins or raisin products. Acid-adapted, pathogenic bacteria from a mixture of several outbreak strains were used, demonstrating antimicrobial activity against the hardiest cells of each species tested.

Two studies resulted in a population decrease of greater than a one million-fold (99.9999 % or 6 log) after 18 days of storage, or less, when *Salmonella*, *E. coli* O157:H7 and *Listeria monocytogenes* were inoculated onto finished raisins. One study showed equivalent pathogen reduction on raisins, however, at a slower inactivation rate.

4.2.2 Intact Raisins vs. Raisin Products

Raisin juice concentrate and raisin paste exhibited a greater rate of microbial inactivation, compared to intact raisins. For raisin products, levels of all pathogens decreased over one million-fold, within eight days after inoculation, compared to 18 days for intact raisins. Direct contact of the bacteria with antimicrobial compounds and acids located on the interior of the raisins might account for the increased inactivation activity, whereas microorganisms on the raisin surface can become dried, serving as a potentially preservative effect.

4.2.3 Antimicrobial Action Occurs as a Function of Exposure Time

The microbial inactivation rate on intact raisins was approximately uniform throughout the storage period for all pathogens, with a 90% decrease (1 log) occurring every 4 days. This means that longer storage time yields greater microbial inactivation.

4.2.4 Effect of Neutralizing pH and a_w on Pathogen Reduction

A preliminary study was conducted prior to a larger challenge experiment, where raisin paste was modified by increasing the pH value (reducing the acidity) and the a_w before inoculation with pathogens. This small study showed that there were no bacterial inactivation rate differences between modified and unmodified raisin paste (Table 3). However, both the unmodified and modified raisin paste exhibited greater antimicrobial properties than intact raisins. This initial study suggested that the pH and a_w of the raisin may not be the primary factors contributing to the antimicrobial activity observed. Antimicrobial compounds from the skin and within the raisin meat may work alone or synergistically to inactivate pathogenic bacteria. Low a_w from sugars serve as a protectant for microorganisms and increase their survival; thus, the lower pH and lower a_w may have opposing effects for microbial survival. However, a lower a_w also may concentrate antimicrobial compounds, increasing their effectiveness. It is difficult to estimate the net effect of all of these factors on raisin survival without further research.

4.2.5 Effect of Processing and Storage Temperature

A significant decrease in population levels of acid adapted *E. coli* O157:H7 and *Salmonella* spp. were observed during ambient and refrigerated storage. A greater antimicrobial effect was observed when the finished raisins had higher moisture contents and stored at higher temperatures. The increase in moisture and temperature likely lead to increased efficiency of acidic pH to attack bacterial cells, and/or allowed greater exposure of pathogens to antimicrobial compounds on the surface of the raisins. In general, microbial survival studies in food also showed that higher temperatures during storage increase the rates of inactivation.

4.2.6 Effect of Variety and Agricultural Practices

The antimicrobial activity of finished raisins observed in the challenge studies were not greatly affected by the field drying method (dried-on-the-vine (DOV) versus traditional) or growing method (organic vs. traditional). Similarly, different varieties tested (Zante currants versus Thompson seedless raisins) did not exhibit differences in antimicrobial properties. This suggests the antimicrobial actions are a general property of raisins and are relatively unaffected by specific varieties and agricultural practices.

4.2.7 Rate of Inactivation

The microbial inhibition studies summarized in Table 3 suggests that pathogenic bacteria are inactivated rapidly. The extent of inactivation (up to one million-fold) occurring in these intentionally contaminated studies is far greater than the amount of pathogenic bacteria that would likely occur on raisins (<1 to 10 colony forming units (CFU)/g). In the rare occurrence of a natural contamination event, any likely pathogen population on raisins would be eliminated within the first few days after contamination. The inactivation rate of 90% in 4 days suggests that most naturally contaminated servings (40 g serving) would be free of viable pathogens in 12 days.

Finished raisins typically do not reach retail or industrial customers before 30 to 60 days of storage (Freeto, 2009). Therefore, by the time the product is available to consumers, any potential contamination would be eliminated. The native ability of raisins to rapidly inactivate large populations of pathogens has likely contributed to their impressive food safety record.

5 Potential Antimicrobial Mechanisms

Several intrinsic factors may contribute to the antimicrobial activity of raisins. pH, a_w, and natural compounds - within grapes or formed during drying - may act to create an environment that is inhibitory to microorganisms. In this section Exponent explores these potential inhibition mechanisms.

5.1 Acidity and Water Activity

The pH range of raisins is 3.5 to 4.0 (Freeto, 2007), which is sufficiently acidic to inhibit growth of all pathogenic foodborne bacteria as shown in Table 3 (IFT, 2001).

The a*w* of raisins typically ranges from 0.50 to 0.65 at moisture levels of 13-18%. Other specialty raisin products at higher moisture levels can have a*w* up to 0.80 (Freeto, 2009). Again, these values are sufficiently low (dry) to inhibit the growth of all bacterial pathogens of concern, as shown in Table 3.

Table 4. Minimum pH and water activity growth values for selected bacterial pathogens

Bacterium	Minimum for Growth	
	pH	a_w
Clostridium perfringens	5.5 – 5.8	0.94
Vibrio spp.	4.8 -5.0	0.94 – 0.96
Bacillus cereus	4.9	0.93
Campylobacter spp.	4.9	0.98
Shigella spp.	4.9	0.97
Clostridium botulinum	4.8	0.97 – 0.93
Staphylococcus aureus	4.5	0.88
E. coli O157:H7	4.4	0.94
Listeria monocytogenes	4.4	0.92
Salmonella spp.	4.2	0.94
Yersinia enterocolitica	4.2	0.97

*Adapted from (IFT, 2001)

As discussed previously, although the low pH and a_w of raisins can prevent growth, the interaction of various factors on the survival of microorganisms is more difficult to predict. Enteric pathogens such as *E. coli* O157:H7 and *Salmonella*, for example, survive for short periods at pH levels in the stomach well below that of the raisins. However, inactivation occurs over a longer time period; the United States Department of Agriculture's (USDA) Pathogen Modeling Program estimates that *E. coli* O157:H7 in a pH 4.0 and 20°C (68°F) broth will decline 3 logs (one thousand-fold) in 5.9 days (USDA, 2009).

Dry environments, as on the surface of a raisin, may actually enhance the survival of bacteria, which have been observed to survive on the surface of plants for months in arid environments (Aruscavage, 2006; Fenlon, 2000; Gagliardi, 2002). In raisin juice concentrate and paste, on the other hand, the microorganisms are in contact with the complete combination of inhibitors discussed below, which cause the relatively rapid decrease in live microorganisms. This suggests that pH and a_w alone or in combination are insufficient to fully account for the antimicrobial action of raisins and raisin products and the other inhibitors are additional important factors.

5.2 Intrinsic Compounds

5.2.1 Phenolics

Raisins have high concentrations of naturally occurring phenolic compounds, which are potent antioxidants and antimicrobial agents (Pupponen-Pimiä et al., 2005; Vinson *et al*., 2005). Phenolic compounds are secondary metabolites ubiquitous in higher plants and are concentrated in the skin of fruits and berries, where they protect against oxidative environmental stress and plant pathogens (Nohynek *et al*., 2006). During the natural sun-drying process, the concentration of polyphenol compounds change. Several polyphenolic compounds have been identified in sun dried raisins, and shown in Table 5, to have antimicrobial action against foodborne pathogens at levels commonly found in raisins (Karadeniz *et al*., 2000, Zhao and Hall, 2008).

Table 5. Potential antimicrobial compounds identified in raisins

Antimicrobial Compound/Class	Concentration in Raisins	Lowest Inhibitory Concentration Observed	Microorganisms Inhibited	Reference
Oleanic acid, oleanic aldehyde/ Triterpenoids	Levels not reported*	4 µg/g	*Streptococcus mutans and porphyromonas gingivalis*	Fausto Rivero-Cruz *et al*.; 2008
Catechin/ Flavonoids	406 µg/g	50 µg/g	*E. coli*	Vaquero *et al*.; 2008
Gallic acid/ Phenolic acid	76.6 µg/g	50 µg/g	*E. coli* spp.	Vaquero *et al*.; 2008
Quercetin/ Flavonoids	7.3 – 34.7 µg/g	500 µg/g	*Bacillus*, *Shigella*, *Salmonella*, *Vibrio*, and *E. coli* species.	Naz et al.; 2007
Ferulic acid/ Phenolic acid	9.8 µg/g	500 µl/g	*E. coli* and *Salmonella* spp.	Pimia *et al*.; 2001
Protocatechuic acid/ Phenolic acid	150 µg/g	50 µg/g	*E. coli* spp.	Vaquero *et al*.; 2008

*Compounds were isolated from raisins in sufficient strength to inhibit test bacteria

Catechin, an antioxidant flavonoid, is found in raisins at levels markedly higher than the minimum inhibitory concentrations for pathogenic bacteria that were reported in the literature (Table 5). Therefore, intact raisins and raisin paste should contain sufficient levels of this compound to account for some or all of the antimicrobial effects observed in the challenge studies.

Concentrations of gallic acid and protocatechuic acid, both phenolic acids, found in raisins, are also at sufficient levels to inactivate bacteria. Ferulic acid and quercetin levels are most likely too low to significantly contribute to the antimicrobial activity.

Several triterpenoid compounds isolated from a methanol extract of Thompson seedless raisins were found to inhibit bacteria associated with dental caries and periodontal disease (Fausto Rivero-Cruz et al., 2008). These compounds are found on the skin of the grape and the raisin surface.

5.2.2 Maillard Non-enzymatic Browning Products

A second broad class of antimicrobial compounds found in raisins includes the Maillard non-enzymatic browning reaction products (MRP), which increase as drying occurs and is directly responsible for the color of naturally dried and processed raisins (Karadeniz *et al*., 2000). Some of these compounds were also identified as having antimicrobial activity (Einarsson et al., 1983, Stecchini et al., 1993).

5.2.3 Location of Antimicrobial Compounds within the Raisin

The research techniques used to extract phenolic and MRP compounds require grinding the raisins. Therefore, the chemical compound profile and their concentrations available on the skin and in the meat of the raisins are unknown. Several compounds are known to be located within the raisin skin and, therefore, may be active against bacteria with intact raisins. However, the increased antimicrobial effect observed in raisin paste suggests that either greater concentrations of or more effective antimicrobial compounds exist in the meat portion of the raisin. More research is needed to determine the location of antimicrobial compounds within the raisin and their modes of action.

6 Intrinsic Properties and Interactions

Pathogen challenge studies funded by Sun-Maid Growers of California have suggested that antimicrobial compounds within the raisins may account for a significant portion of the antimicrobial activity observed. In addition, other published studies demonstrated the interaction of pH and the activity of antimicrobial compounds in raisins. For examples, phenolic acids have increased antimicrobial properties at the pH range of raisin and raisin products (*Wen* et al., 2003). These acids are more effective against bacteria in the undissociated state - at acidic pHs - and thus more effective at preventing outgrowth or eliminating bacterial populations (Puupponen-Pimiä *et al*., 2005). Therefore, the low pH of the raisin and the antimicrobial compounds may work in synergy to more effectively eliminate any bacteria present. These observations are in agreement with conclusions made in other studies that reported antimicrobial activity from raisin products (Bower *et al*., 2003, Wei *et al*., 2009).

Another factor in the antimicrobial activity of these compounds is their action against different classes of bacteria. Flavonoids and triterpenoids have been reported to be antimicrobial against both Gram-positive (*Listeria*) and Gram-negative (*E. coli* and *Salmonella*) species, while the phenolic acids identified in raisins were observed to be antimicrobial against only Gram-negative species (Table 4). This is in agreement with published reports that conclude that the mode of action of phenolic acids against Gram-negative bacteria occurs by destabilization of the outer membrane (Pupponen-Pimiä et al., 2005). In the Sun-Maid challenge studies, both Gram-positive and Gram-negative pathogens were inactivated when inoculated on intact raisins and raisin products. This suggests that bacteria are exposed to several antimicrobial compounds on and within raisins.

Although some interactions between pH and antimicrobial compounds have been identified, research is needed to better identify the interactions responsible for the antimicrobial activity in raisins. Better understanding of these interactions and the mechanisms involved will help determine the overall food safety of raisins and the potential use of raisin products as a food ingredient.

7 Summary

The challenge testing sponsored by Sun-Maid Growers, other studies on raisins, and knowledge about specific chemical inhibitors present in raisins, all point to an inhospitable microbiological environment for their growth or survival. Pathogenic microorganisms not only are incapable of growth, they die over a relatively short storage period of days to weeks. The observed antimicrobial activity contributes its exemplary food safety record and further confirms raisins as a safe, nutritious, wholesome food. A summary of Exponent's conclusions include:

- Raisins have an unsurpassed food safety record, with no reported foodborne illness attributed to their consumption;
- Raisins and raisin components exhibit marked antimicrobial activity against spoilage organisms and human pathogens;
- Raisin products and extracts can impart antimicrobial properties into some food products at levels that do not significantly affect sensory characteristics;
- Differences in field drying and growing practices did not significantly affect the antimicrobial properties of the raisins;
- Microbial growth is prevented by the combination of acidity, low water activity, and inhibitory compounds. This unfavorable environment promotes the relatively rapid decrease in microbial numbers during storage;
- The rate of pathogen inactivation would eliminate likely levels of contamination prior to the product reaching consumers;
- Preliminary studies suggest that antimicrobial chemicals within raisins are responsible for a significant amount of the inactivation observed, however, the interaction between phenolic compounds and pH on inactivation is unknown;
- Phenolic compounds identified in raisins exhibit antimicrobial properties at or below levels that are present in raisins; and
- More research is needed to determine the antimicrobial mechanisms of action, specifically,
    - Compounds and their location within the raisin responsible for the majority of the antimicrobial activity, and

- The relative contribution, including potential synergistic activity, of the intrinsic antimicrobial factors in raisins.

Exponent reserves the right to modify these observations if new information is presented.

8 Literature Cited

Aruscavage, D., Lee, K., Miller, S., and J. T. LeJune. 2006. Interactions affecting the proliferation and control of human pathogens on edible plants. J. Food Sci. 71: 89-99.

Bower C. K., Schilke, K. F., and M. A. Daeschel. 2003. Antimicrobial properties of raisins in beef jerky preservation. J. Food Sci. 68: 1484-1489.

Einarsson, H., Snygg, B. G., and C. Eriksson. 1983. Inhibition of bacterial growth by Maillard reaction products. J. Agric. Food. Chem. 31: 1043-1047.

Fausto Rivero-Cruz, J., Zhu, M., Kinghorn, A. D. and C. D. Wu. 2008. Antimicrobial constituents of Thompson seedless raisins (Vitis vinifera) against selected oral pathogens. Phyto. Letters 1: 151-154.

Fenlon, D. R., Ogden, I. D., Vinten, A., and I. Svoboda. 2000. The fate of *Escherichia coli* and *E. coli* O157 in cattle slurry after application to land. Symp. Ser. Soc. Appl. Microbiol 29: 149S-156S.

Freeto, T. 2 October 2009. Personal communication [TFreeto@SunMaid.com].

Freeto, T. 23 January 2007. Personal communication [TFreeto@SunMaid.com].

Gagliardi, J. V., and J. S. Karns. 2002. Persistence of *Escherichia coli* O157:H7 in soil and on plant roots. Environ. Microbiol. 4: 89–96.

Greig, J. D., Todd, E. C. D., Bartleson, C. A., and B. S. Michaels. 2007. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 1. Description of the problem, methods, and agents involved. J. Food Protect. 70: 1752-1761.

Institute of Food Technologist (IFT). 2003. Evaluation and definition of potentially hazardous foods. Comp. Rev. Food Sci. Food Safety 2: 1-109.

Karadeniz, F., Durst, R. W., and R. E. Wrolstad. 2000. Polyphenolic composition of raisins. J. Agric. Food Chem. 48: 5343-5350.

Naz, S., Siddiqi, R., Ahmad, S., Rasool, S. A., and S. A. Sayeed. 2007. Antibacterial activity directed isolation of compounds from *Punica granatum*. J. Food Sci. 72: M341-M344.

Nohynek, L. J., Alakomi, H. L., Kähkönen, M. P., Heinonen, M., Helander, I. M., Oksman-Caldentey, K. M., and R. Puupponen-Pimiä. 2006. Berry phenolics: Antimicrobial properties and mechanisms of action against severe human pathogens. Nutrit. and Cancer 54: 18-32.

Puupponen-Pimiä, R., Nohynek, L., Alakomi, H. L., and K. M. Oksman-Caldentey. 2005. Bioactive berry compounds-novel tools against human pathogens. Appl. Microbial Biotechnol 67: 8-18.

Puupponen-Pimiä, R., Nohynek, L. C., Meire, C., Kähkönen, M., Heinonen, M., Hopia, A., and K. M. Oksman-Caldentey. 2001. Antimicrobial properties of phenolic compounds from berries. J. Appl. Microbial. 90: 494-507.

Rodriguez Vaquero, M. J., and M. C. Manca de Nadra. 2008. Growth parameter and viability modifications of *Escherichia coli* by phenolic compounds and argentine wine extracts. Appl. Biochem and Biotechnol. 151: 342-352

Stecchini, M., Giavedoni, P., Sarais, I., and C. Lerici. 1993. Antimicrobial activity of Maillard browning reaction products against *Aeromonas hydrophila*. Itl. J. Food Sci. 5; 147-150.

Vasavada, M. N., and D. P. Cornforth. 2006. Evaluation of antioxidant effects of raisin paste in cooked ground beef, pork, and chicken. J. Food Sci. 71: C242-C245.

Vinson, J. A., Zubik, L., Bose, P. B., Samman, N., and J. Proch. 2005. Dried fruits: Excellent in vitro and in vivo antioxidants. J. Am. Col. Nutrit. 24: 44-50.

United States Department of Agriculture (USDA). 2009. Pathogen Modeling Program Version 7.0. Available at http://pmp.arserrc.gov/PMPOnline.aspx. Accessed on September 23, 2009.

Wei, Q. 2006. Antimicrobial activity of raisins and application as a food preservative. Unpublished PH. D. dissertation North Dakota State University.

Wei, Q., Wolf-Hall, C., and C. A. Hall III. 2009. Application of raisin extracts as preservatives in liquid bread systems. J. Food Sci. 74: M177-M184.

Wen, A., Delaquis, P., Stanich, K., and P. Toiven. 2003. Antilisterial activity of selected phenolic acids. Food Microbial. 20:305-311.

Zhang, Y., Jayaprakasam, B., Seeram, N. P., Olson, L. K., DeWitt, D., and M. G. Nair. 2004. Insulin secretion and cyclooxygenase enzyme inhibition by cabernet sauvignon grape skin compounds. J. Agric. Food Chem. 52; 228-233.

Zhao, B., and C. A. Hall III. 2008. Composition and antioxidant activity of raisin extracts obtained from various solvents. Food Chem. 108: 511-518.

Ziemke, W. H. 1980. Raisins and raisin products: mold retarding properties and raisin conditioning. Am Inst Baking Tech Bull. 2: 1-6.

9 Biographies

Arthur J. Miller, Ph.D.,
Principal Scientist, Center for Chemical Regulation and Food Safety
Microbiology, public health, food safety systems, food regulation

Dr. Art Miller is a microbiologist who specializes in food protection, specifically related to the behavior and control of microbiological pathogens in foods. He has extensive experience in produce related food safety, having investigated outbreaks and conducted root-cause analyses for the federal government and the private sector. He has experience in food safety research and regulatory policy development. Prior to joining Exponent Dr. Miller had a distinguished 30-year food safety career in federal service, having led the largest USDA food safety research laboratory and served in executive positions within FDA's Center for Food Safety & Applied Nutrition. There, Dr. Miller was the Associate Director for Joint Institute for Food Safety & Applied Nutrition (JIFSAN) and Lead Scientist for Microbiology. Prior positions included the Lead Scientist for the National Food Safety Initiative. He served as the editor of the FDA Bacteriological Analytical Manual (BAM) and co-editor of the Journal of Food Safety. During his tenure with the FDA, Dr. Miller participated in many projects related to the microbiological safety of foods, ranging from agricultural production, processing, distribution, food service and retail. He was twice certified by peer review to the Senior Biomedical Research Service, the highest scientific distinction awarded to a federal scientist. Dr. Miller received more than 50 awards and honors, authored or co-authored over 200 publications, and gave over 100 invited lectures globally. Dr. Miller is a Fellow of the Institute of Food Technologists. He received his B.S. degree in Biology, from Kansas State University, M.S. in Food Science, from Penn State University, and Ph.D. in Environmental Studies, from Drexel University.

Richard C. Whiting, Ph.D.,
Senior Managing Scientist Center for Chemical Regulation and Food Safety
Microbiology, public health, food safety systems, predictive microbiology

Dr. Richard C. Whiting is a Senior Managing Scientist in Exponent's Health Sciences Center for Chemical Regulation and Food Safety. Dr. Whiting is internationally recognized for his pioneering research and applications in mathematical modeling of foodborne microorganisms, the development of the USDA's Pathogen Modeling Program and use of microbial risk assessments. He is an authority on predictive microbiology and on estimating the growth, survival or inactivation of harmful and spoilage bacteria in foods. Prior to joining Exponent in 2008, Dr.

Whiting was a Senior Scientist with the Food and Drug Administration, Center for Food Safety and Applied Nutrition (FDA, CFSAN). At the FDA, he was a valued technical leader, advising senior managers and shaping the design of microbial risk assessments, including the *Listeria monocytogenes* risk assessment in ready-to-eat foods (2003) and the *L. monocytogenes* risk assessment on smoked seafood. He was a member of the US team to Codex Alimentarius Committee on Food Hygiene and involved with numerous microbial issues before the Center. From 1977 to 1998, Dr. Whiting was a research food technologist at the USDA, Agricultural Research Service, Eastern Regional Research Laboratory. There he conducted research on muscle biochemistry and meat quality and safety, including the functionality and microbiological safety of reduced-salt meat products, and creating models for foodborne microbiological pathogens. Dr. Whiting has published over 130 research papers, book chapters, risk assessments and other scientific works. He has lectured extensively in the U.S. and internationally on predictive microbiology and microbial risk assessments and has participated in numerous workshops/training programs in this area. He has served on the Editorial Boards for J. Food Protection and the International J. Food Microbiology and is an Associate Editor for the J. Food Science. In recognition of his contributions to food science and food microbiology, Dr. Whiting was presented with the Food Safety Award by the National Center for Food Science and Technology and was elected a Fellow of the Institute of Food Technologists in 2006. He received his Ph.D. from Oregon State University, M.Sc. from the University of British Columbia, and B.S. from the University of Wisconsin, all in food science.

Brian Shawn Eblen, M.S.,
Senior Scientist, Center for Chemical Regulation and Food Safety
Microbiology, public health, food safety systems

Shawn Eblen has extensive expertise in technical food safety issues, having conducted outbreak investigations and root-cause analyses for the FDA, USDA, and the private sector. He has conducted field and laboratory research on a variety of bacterial pathogens, including: *Listeria monocytogenes, Clostridium botulinum, Escherchia coli O157:H7, Salmonella spp. Clostridium perfringens* and *Bacillus cereus* in foods. His 15 years of research experience with both the FDA and USDA has given Mr. Eblen in depth knowledge of food safety policy and technical issues covering a broad array of commodities across the entire food chain, from the farm to retail and food service. He holds a B.S. in Microbiology from Auburn University and a M.S. in Food Science from Drexel University.