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# The incidence and impact of microbial spoilage in the production of fruit and vegetable juices as reported by juice manufacturers

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ABSTRACT

Microbial spoilage of fruit and vegetable juices represents an important threat to food quality and an area of concern in reducing food waste. Despite this, relatively little research is dedicated to microbial spoilage compared to other aspects of food microbiology. Establishing the incidence and impact of microbial spoilage in juice production would provide justification for future research. In this study, we present the findings from a survey of juice processor members of the U.S. based Juice Products Association and the European based International Fruit and Vegetable Juice Association (31.1% response rate). Respondents were asked a series of forced choice, Likert-type, and open response questions regarding microbial juice quality challenges and control measures regarding their facility. The vast majority of respondents (97.4%) indicated that spoilage mattered a lot or a great deal in brand protection. An additional 89.5% indicated that better control over microbial food spoilage would reduce waste and increase profits, with 57.9% indicating a lot or a great deal of impact, perhaps as a result of the frequency with which respondents indicated they discarded ingredients or product to protect quality. The most frequent disposition reportedly occurred on a weekly basis, with over half of respondents indicating discarding ingredients or product at least annually. Manufacturers reported a range of challenges, notably spoilage from *Alicyclobacillus* and heat resistant mold. This was accompanied by an identified need for associated sanitation and production control strategies. This work provides a basis for subsequent research exploring improved control strategies and detection methods used to reduce microbial spoilage of fruit and vegetable juices.



## 1. Introduction

### 1.1. Food waste and loss

Food quality issues resulting from microbial food spoilage are a significant problem within the food industry that result in waste, customer dissatisfaction, and that threaten brand protection. Global estimates on food waste and loss suggest that 40% of the food supply is not consumed due to pre-harvest loss or post-harvest food waste (FAO, 2012). Specifically, 25% of the post-harvest food supply may be wasted due to microbial food spoilage (Gram et al., 2002). Fresh produce and processed fruit and vegetable products are particularly susceptible to spoilage. The Food and Agriculture Organization (FAO) of the United Nations estimates that approximately 45% of grown produce is wasted (FAO, 2012).

Historically, relatively little research has been conducted in the area of food quality/spoilage (Fig. 1). Food laws and regulations are focused on food safety and public health, as opposed to quality and microbial spoilage. Federal research dollars have, likewise, been directed towards reducing the incidence of foodborne illness, while the majority of food security research has targeted pre-harvest loss specific to crop and food animal disease resistance and prevention (USDA, 2016). However, food waste occurs throughout the supply chain and in the developed world, waste is shifted towards the consumer end of the farm-to-fork spectrum.

### 1.2. Microbial food spoilage in fruits and vegetable products

Produce is often grown and handled in unprotected, natural environments which contribute to the level and diversity of microbial contamination (Leff & Fierer, 2013). Although plants possess

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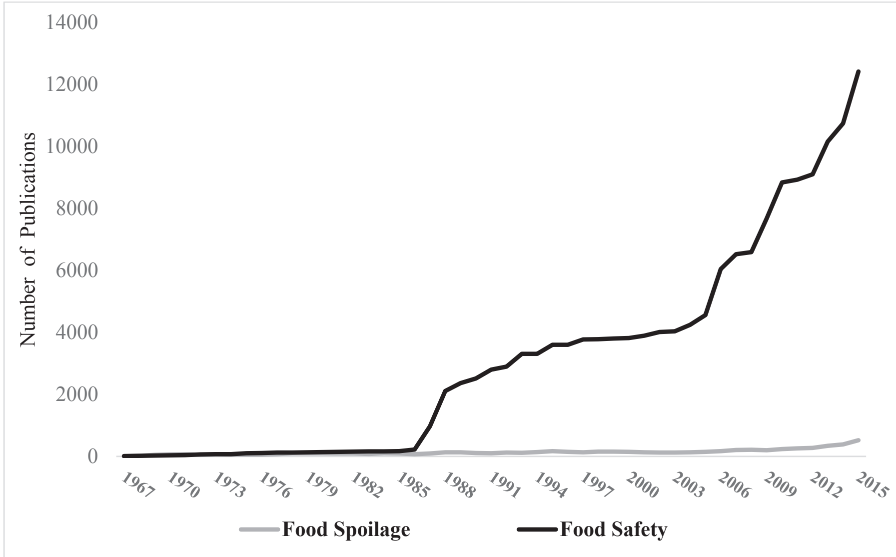



**Fig. 1.** *Publications by topic in the Web of Science food science resource database (FSTA).* The number of annual abstracts containing the words "food safety" have increased dramatically since 1985 in comparison to the number of annual abstracts containing the words "food spoilage."

defense systems against microbial spoilage, following harvest and senescence, these defenses are diminished and the fruit or vegetable becomes particularly susceptible to colonization by secondary plant pathogens (Barth, Hankinson, Zhuang, & Breidt, 2009).

Initial microbial load can vary based on horticultural practices, employee health and hygiene, and aspects related to the field and surrounding areas. Older fields and orchards, or locations where dead and decaying plant material is not frequently removed, can create harborages of spoilage microorganisms. Cultural practices which involve increased manipulation, crop rotation, the use of plant-based amendments, and the lack of conventional pesticides impact the initial microbial population at the point of harvest (van Elsas, Garbeva, & Salles, 2002). Additionally, the source of the agricultural water, use of particular growth substrates and insulation materials, and whether production environments are covered, enclosed, or open, all contribute to the potential for contamination.

At the point of harvest, the rigidity of the culling procedures can impact downstream spoilage potential. The utilization of drops (produce that has fallen to the ground) can introduce additional microorganisms. Similarly, the use of bruised or wounded fruits or vegetables can increase the potential for spoilage as wounds and lesions are niches where spoilage organisms may survive and proliferate more readily than on intact surfaces (Snyder, Perry, & Yousef, 2016; Snyder, Perry, & Yousef, 2016). Sanitation in the production environment mediates the buildup of organic material and vegetative waste on production lines that serve as reservoirs of spoilage organisms (Barth et al., 2009). Bottling or filling areas often require protection and treatment as critical quality points to prevent the introduction of environmental contaminants. For example, air quality monitoring can be essential as the spores of filamentous fungi often become airborne during the normal reproductive cycle which facilitates dissemination and propagation (Codina, Fox, Lockey, Demarco, & Bagg, 2008).

The relevant specific spoilage organism associated with a particular juice is dependent on the type of fruit or vegetable used as ingredients, and the type of processing the juice receives (Gram et al., 2002). Low acid vegetable juices are subject to spoilage from a variety of microorganisms which include Gram-negative bacteria associated with vegetable soft rot, like *Pseudomonas* and various Enterobacteriaceae such as *Pectobacterium*, as well as Gram-positive bacterial sporeformers (Barth et al., 2009). Although non-thermal techniques have gained popularity among juice processors over the past decade, the majority of juice produced in the U.S. has undergone a thermal pasteurization (Mintel, 2009). Heat treatment, particularly at temperatures used in producing shelf-stable products, selects for heat resistant ascospores from fungi like *Paecilomyces* (*Byssochlamys*) and *Aspergillus*, as well as bacterial spore-formers (Splittstoesser, 1996). The additional selective pressure from acidic fruit juices renders the bacterial spore former *Alicyclobacillus* particularly problematic. *Alicyclobacillus* spoilage is not associated with visual defect, the production of detectable off-flavors occurs well below the visual detection limit (Walker & Phillips, 2008). In contrast, heat resistant molds, or HRM, are associated primarily with visual defects. HRMs have posed a chronic challenge for juice producers as the heat resistant ascospores can be found as contaminants in the raw ingredients and the processing environment (Dijksterhuis, 2007; Tournas, 1994). Particularly with the growing popularity of plastic containers which lack a true hermetic seal, there has been an increased potential for spoilage incidents resulting from *Alicyclobacillus* and HRMs (Sperber, 2009). Based on the history of challenges plaguing juice manufacturers, these two spoilage microorganisms were specifically addressed in this survey.

### *1.3. Available data on the impact of microbial spoilage in the food industry*

Despite the contribution of microbial spoilage to waste and loss in the food supply, there remains a need for data quantifying the contribution of microbial spoilage from the point of production through shelf-life. There is limited work establishing the incidence and impact of microbial food spoilage on ingredient loss and finished product spoilage. Based on the number of published abstracts relating to food science and technology, research focused on food safety has drastically increased since the mid-1980's (Fig. 1). This bibliometric assessment is based on literature containing specific search terms. The term "food safety" may have gained popularity around 1985 as a consequence of the Listeriosis outbreak in California associated with soft, Mexican-style cheese (Linnan et al., 1988). Therefore, the 2100 abstracts addressing food safety that were published in 1988 represent the initial baseline publication number based on the use of the term (Thomas Reuters, 2016). Well over 12,000 abstracts were published on food safety in 2015. In contrast, the number of abstract containing the term “food spoilage” has remained relatively stagnant, well below 500 abstracts per year from 1967 to 2012, with only a modest increase in publication number in the past few years.

Eiroa, Junqueira, and Schmidt (1999) determined that 14.7% of commercial orange juices (n75) from 11 different suppliers were contaminated with *Alicyclobacillus.* A survey of 56 UHT juices revealed no detectable contamination, while five of 18 fresh juices contained detectable levels of *Alicyclobacillus.* Of the U.S. apple juice samples tested, four of four juices and one of four concentrates had detectable levels of *Alicyclobacillus* with counts ranging from <5 to more than $10^3$ CFU/ml (Pettipher, Osmundson, & Murphy, 1997). In a study evaluating the prevalence of *Alicyclobacillus* in tropical and subtropical juice concentrates ($n = 180$) produced or imported into the U.S., 6.1% were positive (Danyluck et al., 2011). A previous study (Walls & Chuyate, 1998) surveyed members of the National Food Processors Association and determined that 35% of juice processors had experienced *Alicyclobacillus* spoilage of their product. While useful, these data may not reflect some of the changes and current trends in juice production that have influenced industry practices. As mentioned earlier, the use of plastic juice bottles for shelf-stable juices, instead of hot-filling into glass containers with a plastisol-lined metal lid, leads to a change in the headspace composition (Evancho, Tortorelli, & Scott, 2009; Graumlich, Marcy, & Adams, 1986). And the use of thin-walled plastic containers popular for some products requires manufacturers to reduce the thermal process as these containers cannot withstand high temperatures. This is in addition to the demand among consumers for minimal processing, generally, contributing to the increased popularity in the cold-pressed juice market, and minimal or none use of food additives.

Obtaining information on industrial spoilage incidents is difficult as there are no reportable food quality incidents, unless they have food safety implications as well or if a product withdrawal is initiated. Among U.S. based class III recalls from 2005, the average cost of a spoilage incident due to “mold contamination” or “fermentation” was $2.3 million (Lawlor, Schuman, Simpson, & Taormina, 2009). Individual companies have little impetus to share food quality challenges despite the need for aggregated data to justify a deserving research area. The lack of data establishing the total impact of microbial spoilage and establishing the organisms with the greatest spoilage potential leaves the food industry susceptible to ongoing quality issues. Despite this, companies may perceive food quality surveys as a potential threat to their brand if they are asked to reveal information regarding quality defects or spoilage incidents, and they may feel that revealing their control strategies and sanitation practices is an infringement on proprietary information. Therefore, anonymous surveys which seek to capture the frequency and incidence of microbial food spoilage issues faced by manufacturers in an anonymous, brief, and non-judgmental format are likely to facilitate participation (Jespersen, Griffiths, Maclaurin, Chapman, & Wallace, 2016). The objective of this study is to present a quantitative assessment of the impact and incidence of microbial spoilage in fruit and vegetable juices as reported by manufacturers by using a survey tool that was iteratively developed through stakeholders in international professional associations of juice manufacturers.

## 2. Materials and methods

### 2.1. Survey group

Data were collected from two professional juice manufacturer associations between July 22nd and August 5th, 2016. The survey was administered to the Juice Products Association (JPA) based in the United States (120 companies) and the International Fruit and Vegetable Juice Association (IFU) based in Europe (approximately 44 companies). In total, about 164 fruit and vegetable juice manufacturers (juice producers and/or bottlers) received the request for participation in this survey.

### 2.2. Survey tool development

Questions were initially developed based on relevant spoilage considerations as documented in the scientific literature. The prototype of the survey tool was sent to the Technical Affairs committee of the JPA (which included the coordinating IFU member) for review. Suggestions were integrated into the survey, which received a second and final approval from the committee. A description of the study, the benefits provided with participation (none), and anticipated risks (low risk, equivalent to every day internet use) were included on the first page of the survey. The tool was developed using the online platform, Qualtrics (Qualtrics, Provo, UT). Questions were presented as either forced choice (Yes, No, or Not Applicable, as needed), selection from a Likert-type scale, or open fields for discursive responses. Five-point ordinal Likert scales were used to measure respondents' attitudes regarding microbial spoilage. Interval data were collected on the reported frequency of spoilage events. Respondents were permitted to skip and return to all questions as desired. The survey tool was submitted along with an application for Institutional Review Board exemption to Cornell University's IRB office and exemption status was received on July 18th, 2016.

### 2.3. Questionnaire administration

They survey was delivered to participants through a link embedded in an email and distributed to the listservs for the JPA and IFU. Reminder emails were sent one week after the initial email and one day before the survey window closed. No compensation was offered and participation was voluntary and anonymous. Survey responses were received from 51 participants (31.1% response rate). Responses were not linked with any identifiable information to protect anonymity.

### 2.4. Data analysis

The responses were collated through the Qualtrics user interface and exported to Excel (Microsoft Corporation, Redmond, WA). Examination of the data was performed using descriptive principles and tests (e.g. percent total of responses) to explore the impact of various microbial spoilage challenges on juice production (Jespersen et al., 2016). Due to the ordinal nature of the data, and the distribution of the results, data were reported as the frequencies of the responses or in contingency tables for visualization. Cronbach's alpha was calculated among respondents who completed all questions using the psych package in RStudio (version 3.3.1, Rstudio, Boston, MA) for the Likert-type data as well as the binary data as a measure of internal consistency among the survey questions.

## 3. Results

### 3.1. Impact and significance of microbial food spoilage to juice manufacturers

The relative value of microbial spoilage in terms of its economic impact on fruit and vegetable juice manufacturers needed to be established. Participants were asked to assess the importance of maintaining product quality as it related to brand protection and dedication/conservation of resources through the selection of levels from a Likert-type scale (Fig. 2). Participants overwhelming (71.5%) responded that spoilage mattered a great deal in brand protection, while an additional 26.3% responded that it mattered a lot. The remainder indicated spoilage mattered a moderate amount in brand protection and no respondent indicated that spoilage mattered little or not at all. In terms of the value of dedicating resources towards preventing spoilage, 92.1% of participants indicated that spoilage merited either a great deal or a lot of consideration, and no participants indicated spoilage merited little or no consideration. When asked the extent to which prevention of microbial spoilage would decrease waste and increase profits, 23.7% of respondents indicated it would have a great deal of impact, 34.2% indicated it would have a lot of impact, 31.6% indicated it would moderately impact the reduction of waste and increase of profit, while the remainder, 10.5% indicated it would have a little impact. Collectively, then, 89.5% of manufacturers indicated better control over microbial spoilage would have moderately to greatly increase profits and reduce waste. No participants indicated that better control over microbial food spoilage would not matter in terms of waste reduction and profit increases. Subsequently, the majority of fruit and vegetable juice manufacturers indicated that there was a significant need to control microbial spoilage as part of brand protection and that improved control over microbial spoilage both merits the dedication of resources and, in turn, would improve business efficiency by reducing waste and improving profits.

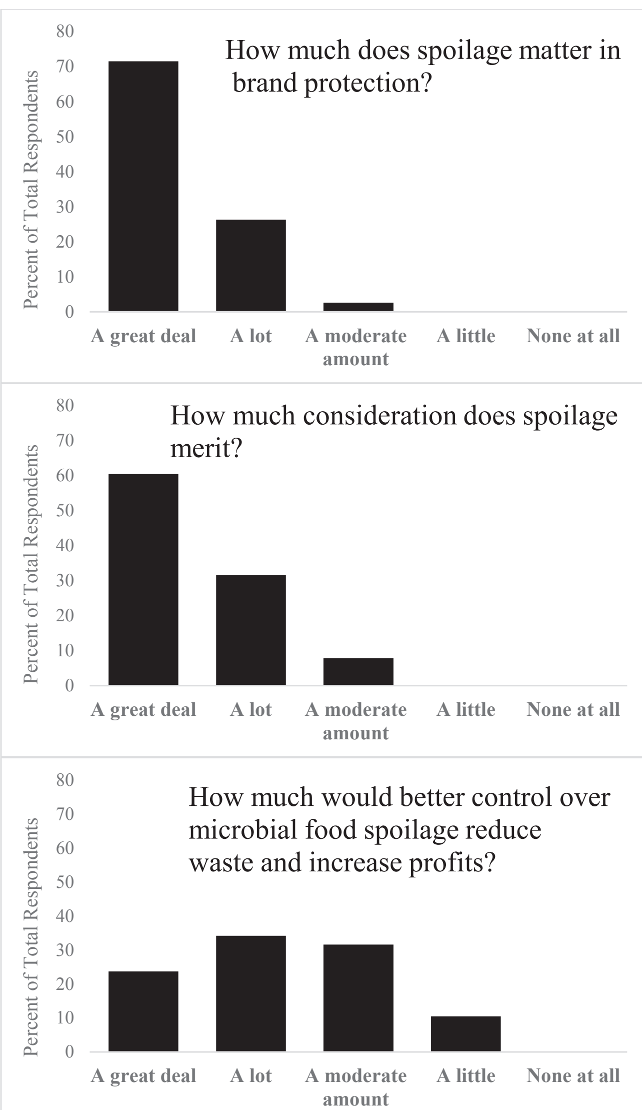



**Fig. 2.** *Self-reported impact of microbial food spoilage in fruit and vegetable juices.* Results are reported as the percent of total respondents based on a Likert-type scale.

### *3.2. Problem areas and analytical techniques utilized by juice manufacturers*

The perspective of industry stakeholders on the microbial spoilage issues in juice production should guide research and development efforts to improve quality control strategies to address the areas of need established in section 3.1. Participants were asked a series of Yes or No questions regarding their experiences with particular types of spoilage (Table 1). In regard to fungal food spoilage, 89% of respondents had experienced mold or yeast spoilage in their ingredients and 92% of respondents had experienced mold or yeast spoilage in their finished product. More specifically, 64% of participants indicated that had experienced HRM in their finished product, indicating that HRM, as a category, are highly problematic for juice processors. As a consequence, 75% of participants responded that they utilized ingredient or finished product testing for HRM. Patulin, a mycotoxin produced by molds including *Penicillium expansium* and *Paecilomyces* (*Byssochlamys*) spp. is considered a chemical hazard in the production of apple juice (Brause, Trucksess, Thomas, & Page, 1995). Apples with core rot or blue/green mold spoilage may be culled to help control this hazard. Of the respondents who manufacture apple juice, 67% reported discarding ingredients or finished product as a patulin control. Finally, 78% of juice processors reported being concerned about *Alicyclobacillus* contamination. Overall, the findings generated from these survey questions regarding the problematic nature of particular spoilage organisms reveal that issues like fungal spoilage, particularly HRM, and *Alicyclobacillus* are not challenges faced by a few manufacturers. Even if spoilage issues arise sporadically, across the industry the majority of manufacturers face these challenged and are actively trying to manage threats to their products' quality.

### *3.3. Food waste due to the quality deterioration of ingredients or finished product*

The frequency with which manufacturers discard ingredients or product as a consequence of microbial quality deterioration is an indicator of the impacts that spoilage control strategies may have on reducing food waste and increasing food security. Juice manufacturers were asked to rate on a Likert-like scale the frequency with which they had to discard ingredients or products due to quality concerns. A total of 16.2% of respondents reported discarding ingredients or finished products on no less than a monthly basis due to quality concerns. An additional 40.5% of respondents reported discarding ingredients or product on an annual basis, and 16.2% of respondents answered they discarded ingredients or products every few years. A total of 27% of respondents indicated they rarely or never discarded ingredients or finished product due to quality deterioration.

Among the four Likert-scale questions, the Cronbach's alpha value was determined to be 0.57. Alpha increased to 0.65 with the elimination of the question "How frequently have you had to discard ingredients or product due to quality?" Moreover, the binary (yes/no) questions had an alpha level of 0.73. This indicates the responses to the question about disposition frequency had greater variance compared to the rest of the Likert-scale questions,

**Table 1**
*Incidence of bacterial and fungal spoilage and intervention strategies used in the production of fruit and vegetable juices*. Results are reported as the percent of total respondents, excluding answers of "N/A" for product specific questions.

| Survey Question | "Yes" Responses | "No" Responses |
|---|---|---|
| Is *Alicyclobacillus* contamination a concern for your company? | 78% | 22% |
| Have you ever experienced heat resistant mold in your finished product? | 64% | 36% |
| Do you utilize ingredients or finished product testing for heat resistant molds? | 75% | 25% |
| If you manufacture apple juice products, have you had to discard ingredients or finished product to control patulin? | 67% | 33% |
| Have you had to discard ingredients or product due to spoilage in the past year? | 69% | 31% |

which generally had a strong degree of internal consistency suggesting the survey tool consistently measured the same underlying concepts.

### 3.4. Control strategies utilized by juice manufacturers against spoilage microorganisms

In addition to ingredient quality, sanitation programs are another primary method manufacturers use to manage their food spoilage risks. When juice processors were asked if their sanitation program completely controlled contamination from spoilage microorganisms, 53% of respondents indicated that it did not. Additionally, 69% of respondents indicated that additional, targeted sanitation strategies designed to reduce harborages of spoilage molds would be useful to their company. Manufacturers reported a range of sanitation programs in place at their own facilities designed to reduce food spoilage issues. These included institutionalized food quality programs like SSOPs and HACCP-based plans, CIP/COP sanitation regimes and sanitation verification methods including ATP swabs, microbiological testing, and internal audits. Other manufacturers reported adopting mitigation strategies such as strict maintenance of the cold chain or elevated processing temperatures designed to target spoilage microorganisms.

Respondents were asked what additional work they felt should be addressed in the area of food spoilage, and there were several independent discursive responses that dealt with particular aspects of HRM and *Alicyclobacillus* spoilage. These included thermal tolerance values, for both organisms, in different food matrices (e.g. high Brix), improved detection methods, and prevention from initial contamination. These two microbial spoilage issues received the most repeated comments about the need for additional research. Some respondents had very particular needs for the scientific research, including an improved understanding of the off-flavors produced by *Alicyclobacillus* and formulation strategies which may be used to control spoilage. However, other areas were addressed sporadically and included issues like biofilm elimination, resistance parameters of yeast to HPP, spoilage prevention in UHT products, anaerobic spores, and lactic acid bacteria. There were several mentions of non-microbial spoilage issues such as haze development in pear juice, adulteration with water or other beverages, and chemical hazards such as mycotoxins and plasticizers. Additionally, some manufacturers voiced concerns over the potential intersection of food spoilage and food safety issues. There also appeared to be a demand for improved risk management for microbial food spoilage. Respondents requested additional mitigation strategies, such as defined rework practices in the hot-fill industry, validation if CIP/COP methods, systematic prevention of cross-contamination, and sanitary controls for cooling water used in production.

## 4. Discussion and conclusions

Overall, the results of the survey indicated that there is a demand among companies in the fruit and vegetable juice industry for increased control over microbial food spoilage. The preponderance of respondents who indicated that increased control would help in brand protection (Fig. 1) and have positive economic impacts (Figs. 1 and 3) may explain this response.

A spoilage issue resulting in a June, 2016 recall of protein beverages (U.S. FDA, 2016a) affected 3.8 million bottles which had quality defects impacting flavor, aroma, and texture. Similarly, over a dozen SKUs of a second UHT processed protein beverage were also recalled in June, 2016 "out of an abundance of caution" and as a result of quality defects that included bloated containers, and off flavors and aromas (U.S. FDA, 2016b). Spoilage by anaerobic spore formers and spoilage of UHT products were both mentioned in the responses from participants about areas of remaining concern, and the effect of these recent recalls may have influenced responses. However, spoilage of low acid juices and beverages by spore formers are, potentially, becoming increasingly relevant as the popularity of vegetable juices increases and various juice-containing dairy and nut milks increases. In 2012 and 2013, consumers reported mold growth in beverage pouches identified by mycelium development that either clogged the straw or became visible once the package was cut open (Wong, 2014; U.S. FDA, 2016c). As a consequence of these spoilage events, some companies have since opted to use a clear panel on their package so that consumers can see that their product is free from mold.

Visibly defective products are often the only spoilage-specific issues that rise to the level of product withdraws. For example, *Alicyclobacillus* spoilage is not associated with visible defects as the microbial count necessary to generate detectable off-aromas is well below visible detection. Moreover, consumer sensitivity to these off-aromas is highly variable, so that there is not a well-established limit at which consumers reject the product. Therefore, product withdraws due to juice spoilage as a consequence of *Alicyclobacillus* spoilage are unusual, no associated withdraws are known to the authors. Instead, *Alicyclobacillus* is a chronic quality defect that plagues the industry, but the problem is not well quantified in the


**Fig. 3.** *Food waste due to quality deterioration among fruit and vegetable juice manufacturers*. Results are reported as the percent of total respondents based on a Likert-type scale.

literature.

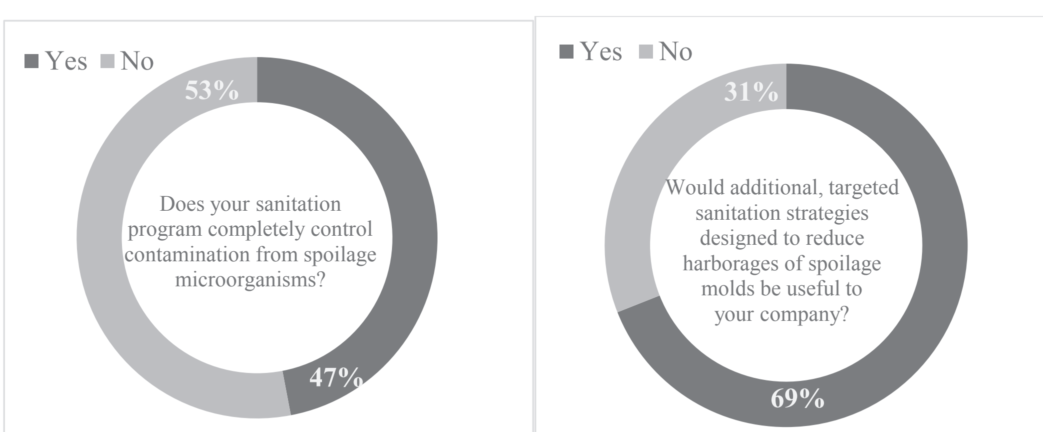
The respondents indicated a discrepancy between the criteria established in processing and sanitation SOPs, as part of industry best practices developed to target microbial pathogens, and more rigorous criteria needed to control for spoilage microbiota. This response suggested that developing protocols designed targeting more resistant spoilage microorganisms may be an effective method for some manufactures to improve product quality and reduce the risk of spoilage. Conditions established for clean-in-place protocols and thermal processing, among other processes, are a function of the target organism, and its relative resistance, used in challenge studies. Previous work has indicated the variability in phenotypic attributes regarding survival and proliferative ability among various isolates, emphasizing the importance of strain selection or cocktail composition in challenge studies. Bacterial and fungal strains which have been adapted to low pH, low water activity, and elevated or depressed temperatures have been shown to provide increased resistance to various treatments in juice (Usaga, Worobo, & Padilla-Zakour, 2014; Yuk & Schneider, 2006; Mazzota, 2001). One respondent indicated a need for "good" thermal process values to control for *Paecelomyces* (*Byssochlamys*), another respondent indicated a desire for thermal destruction parameters (*D*, z, and F-values) for *Alicyclobacillus* spores, a third requested inactivation data for spoilage yeast treated with HPP processing, and a fourth requested CIP treatments validated against more resilient spoilage organisms.

This lack of specific messaging around industry best practices to control microbial spoilage hazards puts the burden on individual manufacturers to develop control strategies. Multiple respondents indicated that they had developed company and product-specific sanitation and processing approaches to control for microbial food spoilage (Table 1 and Fig. 4). These practices included in-house data-based decisions regarding the placement of critical quality points in their food quality plan, the development of elevated processing or hurdle approaches, rigorous sanitation programs, and the use of produce sanitizers and preservatives (Fig. 4). Many sanitation practices have been developed through the lens of controlling contamination from bacterial pathogens, with limited consideration for contamination from sources that are associated with transmission of fungi (Benedict, Chiller, & Mody, 2016).

Although improvement in food quality is often presented as having positive impacts regarding sustainability and reducing food waste, one respondent pointed to the need for increased research on the tradeoffs between more intense sanitation programs and environmental impacts. The commenter specifically mentioned the impact of releasing waste water containing cleaning and sanitizing agents (salts, caustic or acidic solutions, detergents, etc.). Indeed, there are scant recommendations that are harmonized between the U.S. EPA guidance and GMP/GAP guidance for producers (U.S. EPA, 1999). And, as producers seek to increase the efficacy of their sanitization procedures by adding or increasing sanitizer levels, they also increase the potential to incur negative environmental impacts. Another respondent mentioned using a sanitizer in their flume tank to reduce microbial loads and, similarly, the addition and elevated levels of sanitizer at this step may constitute a tradeoff in environmental considerations.

By extension, rigorous cull programs to prevent elevated microbial loads through the addition of low quality produce, as discussed in section 1.2, may also increase food waste. Introduction of such practices may necessitate a diverted use for the culled produce; although, produce destined for juice, like other processed products, may already represent fruits and vegetables which have been culled from fresh market sale. The data presented in Fig. 3 illustrated the range in frequency with which respondents reported discarding ingredients or product due to quality, ranging from weekly to never with a normal distribution, but these findings may underlie the responses in Fig. 2 regarding the economic benefit to improving control over microbial spoilage. Even manufacturers who rarely or never discard ingredients or products as a result of quality deterioration may only be able to do so at the cost of a

**(A)**




| **(B) Reported sanitation programs and monitoring practices** | | | | |
|---|---|---|---|---|
| SSOPs | ATP swabbing | Microbiological testing | CIP/COP | Ingredient inspection and grading |
| Antimicrobial treatment | Verification strategies including audits | Strict maintenance of the cold chain | Food safety programs (e.g. HACCP) | Elevated thermal processes |

**Fig. 4.** *Value of sanitation strategies and analytical technique used as controls in microbial food spoilage*. Results are reported as (A) the percent of total respondents and (B) discursive responses provided to the question "What sanitation programs and monitoring practices do you use to reduce the potential for microbial food spoilage?"

quality program or strict supplier guarantees that, likewise, increase cost and waste at other points in the supply chain. Some respondents indicated a desire for processing conditions designed to target more resistant spoilage organisms. While these processes may have non-microbial quality tradeoffs that result from the processing treatment, these approaches may minimize microbial spoilage with less environmental impact.

Based on the responses of juice manufacturers to questions regarding the incidence and their intervention strategies (Table 1), the presence of *Alicyclobacillus* and HRM remains a serious threat to juice quality. Per the discursive responses, manufacturers requested improved detection, sanitation, and inactivation strategies against these organisms. Although these microbiological challenges have been known for over 50 years, manufacturers still report remaining needs addressing these problem areas. The data presented in this paper substantiated the need for continued and increased work in the area of microbial food spoilage.

## References


Barth, M., Hankinson, T., Zhuang, H., & Breidt, F. (2009). Microbiological spoilage of fruits and vegetables. In W. Sperber, & M. Doyle (Eds.), *Compendium in the microbiological spoilage of foods and beverages* (pp. 135–183). Springer Science+Business Media, LLC.

Benedict, K., Chiller, T. M., & Mody, R. K. (2016). Invasive fungal infections acquired from contaminated food or nutritional supplements: A review of the literature. *Foodborne Pathogens and Disease., 13*, 343–349.

Brause, A. R., Trucksess, M. W., Thomas, F. S., & Page, S. W. (1995). Determination of patulin in apple juice by liquid chromatography: Collaborative study. *Journal of AOAC International, 79*(2), 451–455.

Codina, R., Fox, R. W., Lockey, R. F., Demarco, P., & Bagg, A. (2008). Typical levels of airborne fungal spores in houses without obvious moisture problems during a rainy season in Florida, USA. *Journal of Investigational Allergology and Clinical Immunology, 18*(3), 156–162.

Danyluck, M. D., Friedrich, L. M., Jouquand, C., Goodrich-Schneider, R., Parish, M. E., & Rouseff, R. (2011). Prevalence, concentration, spoilage, and mitigation of *Alicyclobacillus* spp. in tropical and subtropical fruit juice concentrates. *Food Microbiol., 28*(3), 472–477.

Dijksterhuis, J. (2007). Heat-resistant ascospores. In J. Dijksterhuis, & R. A. Samson (Eds.), *Food mycology: A multifaceted approach to fungi and food* (pp. 101–117). CRC Press.

Eiroa, M. N. U., Junqueira, V. C. A., & Schmidt, F. L. (1999). *Alicyclobacillus* in orange Juice: Occurrence and heat resistance of spores. *J Food Prot., 62*(8), 883–886.

van Elsas, J. D., Garbeva, P., & Salles, J. (2002). Effects of agronomical measures on the microbial diversity of soils as related to the suppression of soil-borne plant pathogens. *Biodegredation, 13*(1), 29–40.

Evancho, G. M., Tortorelli, S., & Scott, V. N. (2009). Microbiological spoilage of canned foods. In W. H. Sperber, & M. P. Doyle (Eds.), *Compendium of the microbiological spoilage of foods and beverages*. New York: Springer.

Food and Agriculture Organization (FAO) of the United Nations. (2012). *Save Food: Global initiative on food loss and waste reduction*. http://www.fao.org/save-food/en/ Accessed 2015.

Gram, L., Ravin, L., Rasch, M., Bruhn, J. B., Christensen, A. B., & Givskov, M. (2002). Food spoilage – interactions between food spoilage bacteria. *International Journal of Food Microbiology, 78*, 79–97.

Graumlich, T. R., Marcy, J. E., & Adams, J. P. (1986). Aseptically packaged orange juice and concentrate: A review of the influence of processing and packaging conditions on quality. *Journal of Agricultural and Food Chemistry., 34*(3), 402–405.

Jespersen, L., Griffiths, M., Maclaurin, T., Chapman, B., & Wallace, C. A. (2016). Measurement of food safety culture using survey and maturity profiling tools. *Food Control, 66*, 174–182.

Lawlor, K. A., Schuman, J. D., Simpson, P. G., & Taormina, P. J. (2009). Microbiological spoilage of beverages. In W. H. Sperber, & M. P. Doyle (Eds.), *Compendium of the microbiological spoilage of foods and beverages*. New York: Springer.

Leff, J. W., & Fierer, N. (2013). Bacterial communities associated with the surface of fresh fruits and vegetables. *PLOS One, 8*, e59310. https://doi.org/10.1371/journal.pone.0059310.

Linnan, M. . j., Mascola, L., Lou, X. D., Goulet, V., May, S., Salminen, C., et al. (1988). Epidemic Listeriosis associated with Mexican-style cheese. *The New England Journal of Medicine., 319*(13), 823–828.

Mazzota, A. S. (2001). Thermal inactivation of stationary-phase and acid-adapted *Escherichia coli* O157:H7, *Salmonella*, and *Listeria monocytogenes* in fruit juices. *Journal of Food Protection, 64*(3), 315–320.

Mintel. (2009). *Fruit juice and juice drinks – US – January 2009*. http://store.mintel.com/fruit-juice-and-juice-drinks-us-january-2009 Accessed 10.23.16.

Pettipher, G. L., Osmundson, M. E., & Murphy, J. M. (1997). Methods for the detection and enumeration of *Alicyclobacillys acidoterrestris* and investigation of growth and production of taint in fruit juice and fruit juice-containing drinks. *Letters in Applied Microbiology, 24*(3), 185–189.

Reuters, T. (2016). *Web of science. Food science & technology abstracts*. http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/fsta.html Accessed 10.23.16.

Snyder, A. B., Churey, J. J., & Worobo, R. W. (2016). Characterization and control of *Mucor circinelloides* spoilage in yogurt. *International Journal of Food Microbiology, 228*, 14–21.

Snyder, A. B., Perry, J. J., & Yousef, A. E. (2016). Developing and optimizing bacteriophage treatment to control enterohemmorrhagic *Escherichia coli* on fresh produce. *International Journal of Food Microbiology, 236*, 90–97.

Sperber, W. H. (2009). Introduction to the microbiological spoilage of foods and beverages. In W. Sperber, & M. Doyle (Eds.), *Compendium in the microbiological spoilage of foods and beverages* (pp. 1–40). Springer Science+Business Media, LLC.

Splittstoesser, D. F. (1996). Microbiology of fruit products. In L. P. Somogyi, & Y. H. Ramaswamy (Eds.), *Processing fruits: Science and technology* (pp. 261–292). Technomic Basel.

Tournas, V. (1994). Heat-resistant fungi of importance to the food and beverage industry. *Critical Reviews in Microbiology, 20*(4), 243–263.

United States Department of Agriculture. (2016). *National institute of food and agriculture. Agriculture and food research initiative – food security challenge area*. https://nifa.usda.gov/funding-opportunity/agriculture-and-food-research-initiative-food-security-challenge-area-rfa Accessed 10.23.16.

United States Environmental Protection Agency. (1999). *Multimedia environmental compliance guide for food processors*. National Service Center for Environmental Publications. EPA 305-B-99–005.

United States Food and Drug Administration. (2016a). *Bolthouse farms voluntarily recalls protein beverages due to possible spoilage*. http://www.fda.gov/Safety/Recalls/ucm508221.htm Accessed 10.23.16.

United States Food and Drug Administration. (2016b). *HP hood, LLC voluntarily recalls protein drinks from its sacramento facility due to premature spoilage*. http://www.fda.gov/Safety/Recalls/ucm507529.htm Accessed 10.23.16.

United States Food and Drug Administration. (2016c). *Gerber is voluntarily recalling two batches of GERBER organic 2nd FOODS pouches due to a packaging defect that may results in product spoilage*. http://www.fda.gov/Safety/Recalls/ucm492260.htm Accessed 10.23.16.

Usaga, J., Worobo, R. W., & Padilla-Zakour, O. I. (2014). Thermal resistance parameters of acid-adapted and unadapted *Escherichia coli* O157:H7 in apple-carrot juice blends: Effect of organic acids and pH. *Journal of Food Protection, 4*, 528–690.

Walker, M., & Phillips, C. A. (2008). *Alicyclobacillus acidoterrestris*: An increasing threat to the fruit juice industry. *International Journal of Food Science and Technology., 43*, 250–260.

Walls, I., & Chuyate, R. (1998). Alicyclobacillus — historical perspective and preliminary characterization study. *Dairy, Food and Environmental Sanitation, 18*, 499–503.

Wong, V. (2014). *CapriSun tackles mold problem with a new pouch and positive*. Bloomberg. http://www.bloomberg.com/news/articles/2014-04-10/capri-sun-tackles-mold-problem-with-a-new-pouch-and-positive-spin Accessed 10.2316.

Yuk, H. G., & Schneider, K. R. (2006). Adaptation of *Salmonella* spp. in juice stored under refrigerated and room temperature enhances acid resistance to simulated gastric fluid. *Food Microbiology, 23*(7), 694–700.