Cranberries and their potential application against foodborne pathogens

SC Ricke*, NE Wideman

Abstract

Introduction
There continues to be interest in developing antimicrobial strategies to limit pathogens, including foodborne pathogens that are based on botanical products. Among these, berries have examined in the form of both extracts and juices for potential inhibitory properties against pathogens that are of public concern. Several candidates such as blueberries and cranberries appear to have potential along these lines. Of these, cranberry proanthocyanidins have been associated with specific anti-adhesion properties against uropathogenic Escherichia coli. However, impact on pathogen growth is less clear. Although in vitro studies demonstrate growth inhibition against most of the primary foodborne gastrointestinal pathogens, it remains unclear whether these can be expressed in vivo under gastrointestinal environmental conditions. Despite the complexity of the gastrointestinal ecosystem, recent developments in comprehensive genomic and metabolic methods should help delineate specific factors attributable to cranberry components. The aim of this review was to discuss cranberries and their potential application against foodborne pathogens.

Conclusion
Since at least some pathogenic bacteria appear to be limited by cranberry juices and extracts, there is the potential that they could be used as interventions in nutritional diets and during food production.

Introduction
It is estimated that millions of people are infected with a foodborne illness every year in the United States, leading to several billion in medical expenses and lost productivity. The most common sources of food poisoning include bacteria, with the primary ones being Escherichia coli, Salmonella, Listeria and Campylobacter as well as viral pathogens such as noroviruses, all of which can be isolated from a variety of environments. Numerous alternatives for controlling foodborne pathogens have been suggested over the years, including organic acids, antimicrobial proteins and peptides, bacteriophage, antibodies, prebiotics, probiotics and symbiotics, just to name a few of the wide range of candidates that are either currently employed or have been examined for potential efficacy. With all natural health trends becoming more common in the United States, compounds derived from plant origin such as plant essential oils, berry juice extracts and other sources of phenolic juices have become more of the focus for research. In this review, the general aspects of berry extracts will be examined followed by assessment on the attributes of cranberry juice and extracts as potential sources of antimicrobial activity against foodborne and human pathogens.

Discussion
The authors have referenced some of their own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in these studies. Animal care was in accordance with the institution guidelines.

Berry Extracts—General Aspects
Historically, the drive for more botanical sources of food additives comes from a multitude of sources including consumer nutritional inclination for foods based on organic and natural origins as well as increasing interest in plants as sources of medicinal compounds. Numerous berry species have generally been touted as being rich in health, supporting phytochemicals such as antioxidants, anthocyanins and flavanoids. Berry species that have primarily been examined for such properties include blueberries, raspberries and strawberries. However, issues remain in terms for retaining activity of these berry sources and their corresponding components during processing as well as during their passage through the gastrointestinal tract.

Along with the nutritional benefits, there is also an interest in assessing naturally occurring products such as these berry extracts for potential antimicrobial compounds that could be effectively and economically used in natural and organic systems. There have been several studies on various berry fruit juices and extracts that demonstrate antimicrobial potential. Strawberry phenolic extracts...
have been shown to inhibit the growth of Campylobacter jejuni and Candida albicans as well as Staphylococcus aureus when these organisms were exposed to the extracts for 24 h. 

Strawberry extracts also severely inhibited the growth of S. typhimurium and E. coli when grown overnight in liquid cultures. Chardonnay and black raspberry seed flour extracts exhibited bactericidal activity against E. coli and growth inhibition of Listeria monocytogenes. Both fresh and processed red muscadine juice have been shown to elicit strong antimicrobial properties towards E. coli O157:H7 and L. monocytogenes.

Puupponen-Pimiä et al. examined the antimicrobial activity of pure phenolic compounds and extracts from common Finnish berries and found them to be effective inhibitors of Gram-negative bacteria but not Gram-positive bacteria. In a follow-up study, Puupponen-Pimiä et al. screened Nordic berries and their phenolic extracts and purified phenolic fractions for antimicrobial activity among a range of Gram-positive and Gram-negative human pathogenic bacteria. Among the berry species examined, cloudberry and raspberry appeared to be the most effective antimicrobials, with Staphylococcus and Salmonella being the most susceptible. Of the isolated compounds, the phenolic compounds referred to as ellagitannins appeared to be most inhibitory toward Staphylococcus, while Salmonella was less inhibited by berry phenolics and may have more inhibited by lowered pH due to the presence of organic acids. Conversely, berry sources except cranberry did not influence Listeria strains.

While phenolics have been shown to be inhibitory to E. coli O157:H7 when administered as individual compounds, the potential confounding impact of organic acids is not surprising since organic acids are well-known inhibitors of most human pathogens, with the mechanism(s) being fairly complex as well variable depending on both the genera and species of the bacteria and their respective acid-tolerance capabilities as well as the type of organic acid, pH level and other interventions combined with the application of the acid. Likewise, when Puupponen-Pimiä et al. administered pectinase enzymes on bilberries, increases in antimicrobial activities against Staphylococcus and S. typhimurium were only observed under acidic conditions associated with berry juices.

Other fruits, such as blueberries, bilberries, muscadine grapes and chardonnay grapes, have been tested to a lesser extent as natural antimicrobials. The composition of blueberries has been fairly well characterized, but this has been more with regard to their human health benefits. Less is known about their antimicrobial activities. Biswas et al. tested the antimicrobial properties of blueberry juice against the foodborne pathogens S. typhimurium, C. jejuni, L. monocytogenes and enterohemorrhagic E. coli O157:H7. They measured inhibition in 100% blueberry juice or a 1:1 (v/v) mixture of milk and blueberry juice, with growth in 100% milk used as a control. The growth of all four pathogens was reduced below the detection level by blueberry juice and reduced by 4 to 7 log colony-forming units per ml in a mixture of milk and blueberry juice. However, probiotic bacteria Lactobacillus bulgaricus and Bifidobacterium were able to survive and grow in a mixture of blueberry juice and skim milk as compared with milk alone. These results are particularly interesting as they suggest that blueberry juice may have some selectivity as a potential dietary component where it would support beneficial gastrointestinal bacteria while limiting foodborne pathogens. To delineate the gastrointestinal tract impact between these two populations will require in vitro modelling of mixed microbial populations cultivated under these types of conditions.

Cranberries

Cranberries (Vaccinium macrocarpon) are native berries originating from North America that have historically been identified as well-known sources of antioxidants and phytochemicals including flavonoids, and these have been reviewed extensively elsewhere. Traditionally, cranberry juices, extracts and their corresponding components have received attention as possessing cardiovascular, dental health benefits and anticancer properties as well as interest in their potential for prevention of urinary tract infections.

Much of the interest in the impact of cranberries on reducing urinary tract infections focused on the mechanism(s) potentially associated with phytochemical components. Early work on the anti-adhesion of E. coli to urinary tract cells was suggested to be linked to two inhibitors found in cranberry juice—a fructose-based inhibitor and a high-molecular-weight P-fimbriated inhibitor. Later research suggested based on studies with isolated uropathogenic P-fimbriated E. coli that in vitro attachment to uroepithelial cells was limited by the condensed tannins known as proanthocyanidins that are contained in cranberry juices. In a follow-up study utilizing in vitro attachment approaches as well as urine samples collected from people consuming different berry juices, the prevention of uropathogenic E. coli by cranberry juice proanthocyanidins was demonstrated to be due to their unique A-type linkages versus B-linked proanthocyanidins found in other berry sources.

In general, the interference with specific pathogen attachment to biological surfaces has been suggested by Pappas and Schaich to be the primary mechanism by which cranberry constituents elicit microbial interactions.
anti-pathogen properties. Certainly, this appears to be the case with urinary tract infections, and Pappas and Schaicth, given the wide variety of surfaces but only certain pathogens being inhibited, concluded that this anti-adherence property of cranberries is more likely linked to the specific organism rather than the surface. At least, some growth inhibition by cranberry extracts has also been reported for most of the major gastrointestinal pathogens including Clostridium perfringens, E. coli, L. monocytogenes, S. typhimurium and S. aureus when incubated in the presence of cranberry extracts or juice concentrates. Mechanism(s) for direct influence on bacterial growth by cranberry juice remain to be elucidated, but Johnson et al. observed an acidification of the growth medium from a pH of 7.4 to approximately 5 after 60 generations of E. coli growth in nutrient media, which could only be attributable to the cranberry juice added to the media as this pH drop did not occur in media without cranberry juice added or in the presence of sugars, proanthocyanidins or metal chelators.

How cranberries consumed either as a juice or in other edible forms behave against foodborne pathogens in the gastrointestinal tract is less certain. There are a number of factors that may come into play, which dictate relatively the effectiveness of cranberries and their various phytochemical components when in transit in the gastrointestinal tract. For example, natural flora based on bacterial fatty acid analyses of stool samples appeared to be unaffected in children consuming cranberry juice, suggesting that colonic bacterial balance was not influenced by the presence of cranberry juice constituents. There is indirect evidence for this as Pérez-Vicente et al. demonstrated that in vitro incubation conditions simulating the stomach and small intestine could transform pomegranate-derived anthocyanins due to pH. Given the complexity of the gastrointestinal microflora as well as the environment they reside in, delineating direct impacts of cranberries on their various forms remains an elusive target.

Conclusion
Since at least some pathogenic bacteria appear to be limited by cranberry juices and extracts, there is the potential that they could be used as interventions in nutritional diets and during food production. In particular, the anti-adhesive properties could translate well into preventing pathogen colonization in the gut, and the bactericidal properties suggest that cranberry extracts could be applied as external antimicrobials for certain food products. For example, the high-molecular-weight inhibitors of the berries offer an attractive complement to the competitive exclusion mechanisms of the probiotic cultures, particularly since some of these bacterial species seem to not be harmed by cranberry constituents. One could envision a combination of probiotics and phenolic-rich berries as a dietary means to promote gastrointestinal tract health and select against pathogen establishment. However, this will require more research on the mechanism(s) to identify factors that may confound their effectiveness and in turn optimize their implementation.

Most of the current research is in vitro pure culture environments. To better support these findings, testing in mixed cultures in the presence of natural gastrointestinal micro flora as well as in vivo will be necessary. Such research will have to be done to determine how much of a role environmental gastrointestinal conditions such as bile salts, fermentation products, pH, limiting nutrient concentrations along with many other factors influence the effectiveness of consumed cranberries and the forms that are available as food products. The recent advent of comprehensive biological systems tools such as proteomics, genomics and metabolomics should help to sort out some of these questions and identify practical dietary strategies.

References


47. Kwon YM, Ha SD, Ricke SC. Growth response of a Salmonella typhimurium...