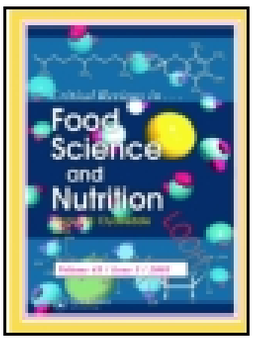

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

# Tailoring functional beverages from fruits and vegetables for specific disease conditions-are we there yet?

Gargi Dey & Srijita Sireswar

**To cite this article:** Gargi Dey & Srijita Sireswar (2020): Tailoring functional beverages from fruits and vegetables for specific disease conditions-are we there yet?, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2020.1769021

**To link to this article:** https://doi.org/10.1080/10408398.2020.1769021

Published online: 25 May 2020.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2020.1769021

Taylor & Francis
Taylor & Francis Group

REVIEW



# Tailoring functional beverages from fruits and vegetables for specific disease conditions-are we there yet?

Gargi Dey and Srijita Sireswar

School of Biotechnology, Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar, India

**ABSTRACT**

On-the-go beverages that may deliver health, increase stamina, reduce stress and provide longevity have captivated consumers and catapulted the food industry into the era of functional food and beverages. The industry initially responded with rapid growth. However, with time product diversification has become somewhat compromised, since most products contain the same bioactive components. Advancement in product technology has to be backed with research. Mere fortification of tea, juices and water, without any scientific evaluation of their functionality, has to be discouraged. Fruits and vegetable juices are excellent matrices for delivery of physiologically active component. Science backed designing will get us closer to tailoring fruits and vegetable juices into 'smart' beverages. As a case study two fruit-based products, probiotic and fruit wines (non-grape) have been considered here. This review explores the possibility of what more may be done to take the fruit and vegetable beverages to next step.

**KEYWORDS**

Anti-inflammatory; fruit; functional foods; infection; probiotics; wine

## Introduction

Attitude to food is now inching toward "smart eating and smart nutrition". Health consciousness is reflected in increased sales of "functional food and beverage" products. Qualities of the product, the nutritional values, calorie content, and health benefits are some of the keys that have captured the consumer attention. The prevailing consumer awareness and acceptance of functional foods and beverages, at least in some parts of the world, has given rise to an expanding and competitive functional beverage market. For instance, in North America, Western Europe, Asia, Japan, Australia and New Zealand, companies are currently investing enormous resources in creating and launching of new functional beverages and building company brand to ensure steady clientele. Almost all the currently available functional beverages have targeted senior nutrition with immune boosters, millennial generation, parents and young children with stress busters or anxiety calmers, athletes with sports nutrition products and performance enhancers, energy drinks, gut health products for general health and wellbeing, and women with calcium-enriched products. However, a closer look will confirm that most of these are tea, water, protein drinks or fruit and vegetable juice based-products that are fortified with, by now, a familiar list of ingredients claiming to have a particular beneficial effect. The question is, is this the best that this industry can do? The answer is, definitely not. Much more can be achieved, but for that, in the coming years an innovation boom is probably required in the functional beverage sector.

First, let us understand what innovation means. Saguy (2011) defined innovations as the process of transforming a discovery (i.e idea, invention) into good (s) or services (s) that consumers/customers are willing to purchase. In order to translate the fruits and vegetable based matrices into innovative products one must first dissect and assess the fruit matrix components and its value. Mounting evidences have pointed to specific flavonoids from grape, berries, and apples and their roles in neuro-protective functions especially in case of neuro-inflammation. They are also known to improve cerebrovascular blood flow and activate synaptic signaling, Present evidences implicate flavonoids in improvement of cognitive performances though the exact mechanism is still patchy and needs to be completely resolved by dietary interventions in human studies using MRI. Nevertheless the potential of long term interventions of the flavonoids on improvements of cognitive functions cannot be ignored (Spencer 2010). Tortora et al. (2018) reported the chemo preservative functions of pomegranate phenolics in case of colorectal cancer when tested on APC mutated Pire rats. Similarly, bioactive compounds of Andean berries were reported to have shown anti-proliferative effects (Agudelo et al. 2018). In past, the anti-cancerous effect of tomato phenolics, lycopene was established. Navarro-Gonzalez, García-Alonso, and Periago (2018) reconfirmed the inhibitory potential of cell cycle progression in phase S by lycopene. It was also shown to decrease ROS generation on HEPG2 cells. Epidemiological researches have provided compelling evidences for specific therapeutic action of many fruit and vegetable compounds. In the light of potential and

CONTACT Gargi Dey drgargi.dey@gmail.com; gargi.dey@kiitbiotech.ac.in School of Biotechnology, Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar, Odisha 751024, India.

real impacts of flavonoids on human body, researchers have comprehensively reviewed the bio accessibility transport and activity of dietary flavonoids (Ballard and Junior 2019).

Emerging evidences are pointing to a very important fact, that the modulatory effects of fruit and vegetable phenolics are probably best tapped by designing them into smart formulations either in the form of food or pharma (Tresserra-Rimbau, Lamuela-Raventos, and Moreno 2018; van Breda and de Kok 2018).

Given their bioactivities, there seems to be tremendous possibilities to convert the fruit and vegetable matrices into functional and personalized beverage products. Or in other words to transform these discoveries into useful good is a possibly the best way to head toward sustainable innovation.

As a point in the case, two products in the beverage sector, the fruit probiotic and fruit wines have been considered in this review. Both these products came into being because of "mindful choices" made my consumers wanting health, wellness and diversity. In the following section, the recent market trends and on-going research in both product brands have been summarized in order to assess whether these two may be reshaped into personalized and functional beverages.

## Fruit and vegetable-based probiotic beverages

Among the food categories, fruits and vegetables seem to be consumer's favorite be it among functional food products or organic food commodities (Ferreira et al. 2015). Recent probiotic formulators are drawn toward harnessing of the bioactive potential of anthocyanin, flavanols, epicatechins, flavanones, procyanidins, lignans, carotenoids, soluble and insoluble fiber, isothiocyanates, phenolic acids, sulfides, Vitamins C, E, A from fruit and vegetable to elicit maximum health benefits. However, innovations and novel product development comes with its own set of challenges. Each fruit or vegetable matrix is unique requiring standardization of the process so as to get a shelf stable product with acceptable organoleptic properties and more importantly, demonstrable health benefits.

Fortification with strains and probioitication of fruit and vegetable juices both necessitates a careful consideration of critical parameters like macro and micro-structure, oxygen levels, pH, ionic strength, presence of competing microbes, components of the juice, presence of activators and inhibitors. These factors are known to significantly influence the survival of probiotic strain and efficacy of the products for instance, the presence of organic acids and low pH of some of the juices can severely affect the survival of even normally acid tolerant strain like *Lactobacillus acidophilus.* Such a problem can usually be overcome by adequate supplementation and pH adjustment of juice (Sireswar et al. 2017). Alternatively, microencapsulation techniques have also been successfully used to protect the strains from the severe juice environment. Another bottleneck with probiotic juice products is the storage conditions. Room temperature storage have known to drastically affect the probiotic survival and product stability (Matilla-Sandholm et al. 2002). Hence mandatory refrigerated storage with vigilance and due diligence in the supply chain is required to control and avoid product deterioration. In spite of the roadblocks, several innovations have been made possible especially by appropriate manipulation of synergies between probiotic strain and juice phytochemicals. Successfully translated commercial products are available globally at super markets and retail shops (Figure 1). Major share of the fruit based probiotic products has come from American food companies. Some of the well-known brands are GoodBelly (Colorado), Obi probiotics, Pressery's organic probiotic soup, Tropicana essential probiotics, Mariana premium, KeVita, Active probiotic, Naked Harvest soul etc. There are several European and Canadian companies which have appreciable market visibility like Danone, Proviva (Sweden and Finland), Biola (Norway), Value bioprofit (Finland), Rela (Sweden), Welo (Canada), Vita Biosa 10+ (Canada). From a market survey, it appears that in recent years several fruit based probiotic beverages have emerged adding diversity to the otherwise dairy-dominated section.

Meanwhile research groups worldwide continue to explore a plethora of fruit and vegetable juice matrices for new probiotic product development. Literature is replete with excerpts of conventional, non-conventional and blended fruit-vegetable probiotic beverages.

Along with survival studies, investigations have focused on whether the fruit/vegetable matrix encourages the probiotic strain to produce beneficial metabolites. For instance, it was reported that fermentation of apple juice with *Lactobacillus plantarum* and *Lactobacillus rhamnosus* GG supported folate biosynthesis and the resulting probioticated product had significant SOD activity. The fermentation of orange and grape juices with the above organism, however, did not result in folate synthesis (Espirito-Santo, Carlin, and Renard 2015). Several workers have addressed the issue of limited probiotic survival in some juice matrix. Their strategy has been blending of fruits and vegetable juice. A blend of blueberry-carrot juice was reported to be an adequate carrier of active culture of *Lactobacillus reuteri* (Mauro, Guergoletto, and Garcia 2016). Using the same rational several other blended carrier matrices were developed for *Lactobacillus casei* using apple, pineapple and mango juices (Mashayekh, Hashemiravan, and Mokhtari 2016).

In search for innovative products, several research groups have also explored uncommon and sometimes exotic fruit juices. Nematollahi et al. (2016) evaluated the Iranian cornelian cherry juice for development of a probiotic product. It was necessary to raise the pH of the juice from 2.6 to 3.5 so that it could successfully support the growth of *Lactobacillus casei* T4 strain. Similarly liquid coconut water has been standardized into a shelf stable beverage containing *Lactobacillus plantarum.* After supplementation with oatmeal, the coconut water based beverage had an enhanced shelf life to 7 weeks which is higher than the usual probiotic products (Dharmasena et al. 2015; Prado et al. 2015).

Numerous other probiotic fortified or fermented beverages have been recently reported. For instance, Panghal et al. (2017) reported the development of probiotic beetroot drink by fermenting it with probiotic strains, *L. plantarum,*

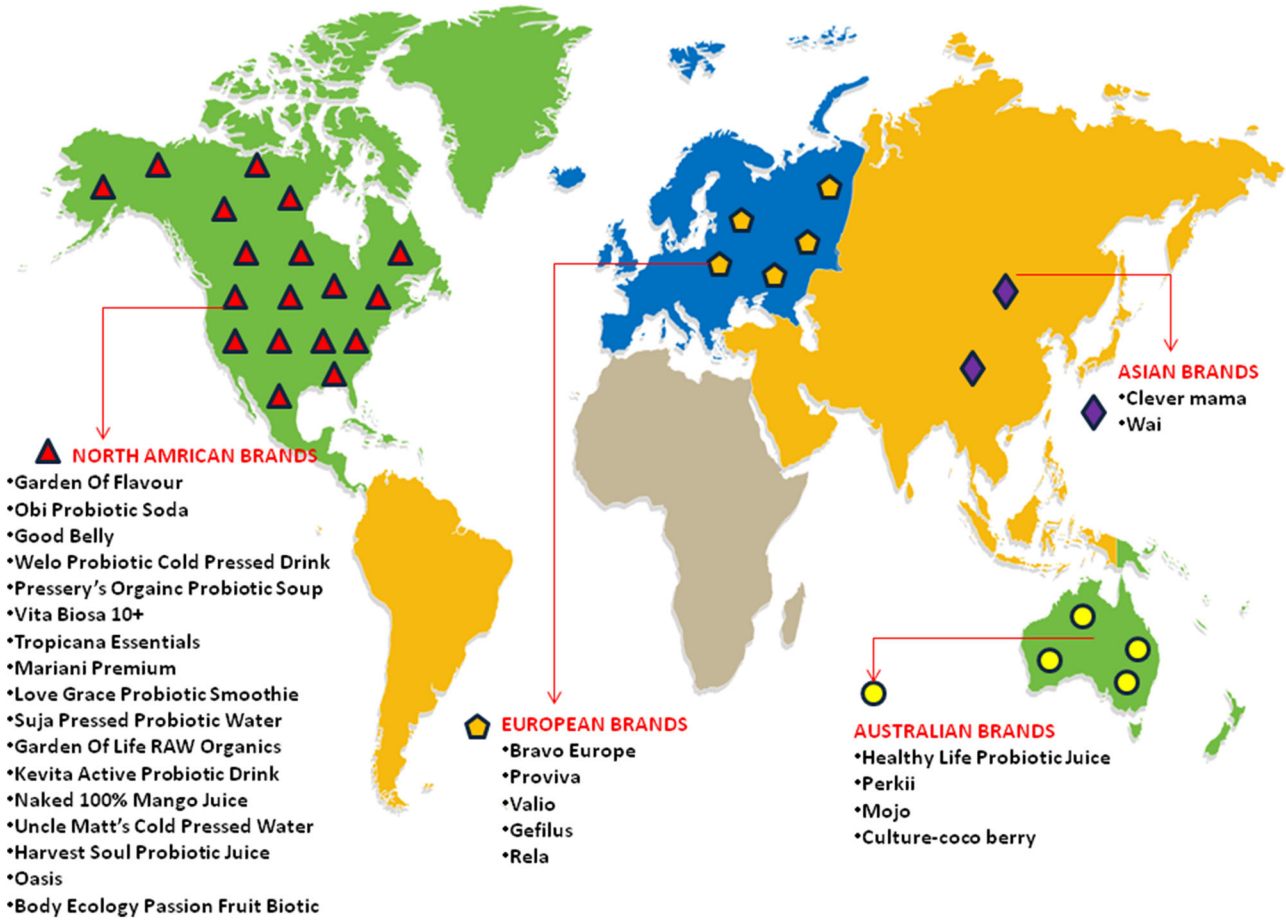


**Figure 1.** Worldwide distribution of commercial fruit based probiotic products.

*L. rhamnosus* and *L. delbrukeii*. Other novel products include jerusalem artichoke fermented with *Lactobacillus plantarum* PCS26 (Dimitrovski et al. 2016), *Lactobacillus plantarum* DW12 fermented mature coconut water (Kantachote et al. 2017), *Lactobacillus rhamnosus* GG fortified in juçara and ubá mango juice mixture (Moreira et al. 2017), *Lactobacillus fermentum* (ATCC 9338) fermented prickly pear juice (Panda et al. 2017) and fermentation of apricot juice with *Lactobacillus* and *Bifidobacterium* species (Bujna et al. 2018).

However, to confer health benefits, it is not only important that probiotic strains remain viable within the food matrices, but also retain and demonstrate functionality throughout the storage period (Flach et al. 2018; Gomand et al. 2019). Detailed investigations on the importance of probiotic-food matrix interactions are relatively lesser. More specifically, the commercial nondairy products have been evaluated merely as LAB carriers. They have been labeled as "good for health" or "overall well-being". These probiotic food formulations have not been designed or evaluated for specific disease conditions (Gomand et al. 2019).

Thus, it is clear that the future products need to be designed based on evidence-based research and not by mere fortifications. Several interesting options and alternatives have emerged in recent years to take this product to the next level. These options have been discussed in the penultimate section of this review.

## Fruit wines

As has been mentioned earlier, global demand for foods with added health benefits has given rise to the emergence of functional beverages based on sources like fruits and vegetables due to their prominent health claims (Sun-Waterhouse 2011). The high phenolic content in certain fruits, especially berries, has paved the way for development of wines from fruit sources. Several wineries of the world have taken up to production of fruit wines, majority of which is in USA (Figure 2). Additionally, fermentation of fruit wines have divulged a novel and promising approach for harnessing the bioactive potential of fruits, thereby enhancing their functionality. Due to these reasons, the production of wines from fruit sources has risen during the recent years. The prevalent hypothesis is that fruit wines will also demonstrate significant physiological effects since they still contain the phytochemicals inherent of the fruit that they are made form. Since the aspect of non-grape wines is not as well described as red wines a more detailed discussion on the topic of fruit wines with respect to their phenolic content and their in vitro and in vivo functionalities is presented here.

Phenolic compounds are large and complex group of chemical constituents from plant sources known for their beneficial health effects (Kala et al. 2016; Shahidi and Ambigapalan 2015). Owing to this, the food industry has associated polyphenolic compounds to essential attributes of

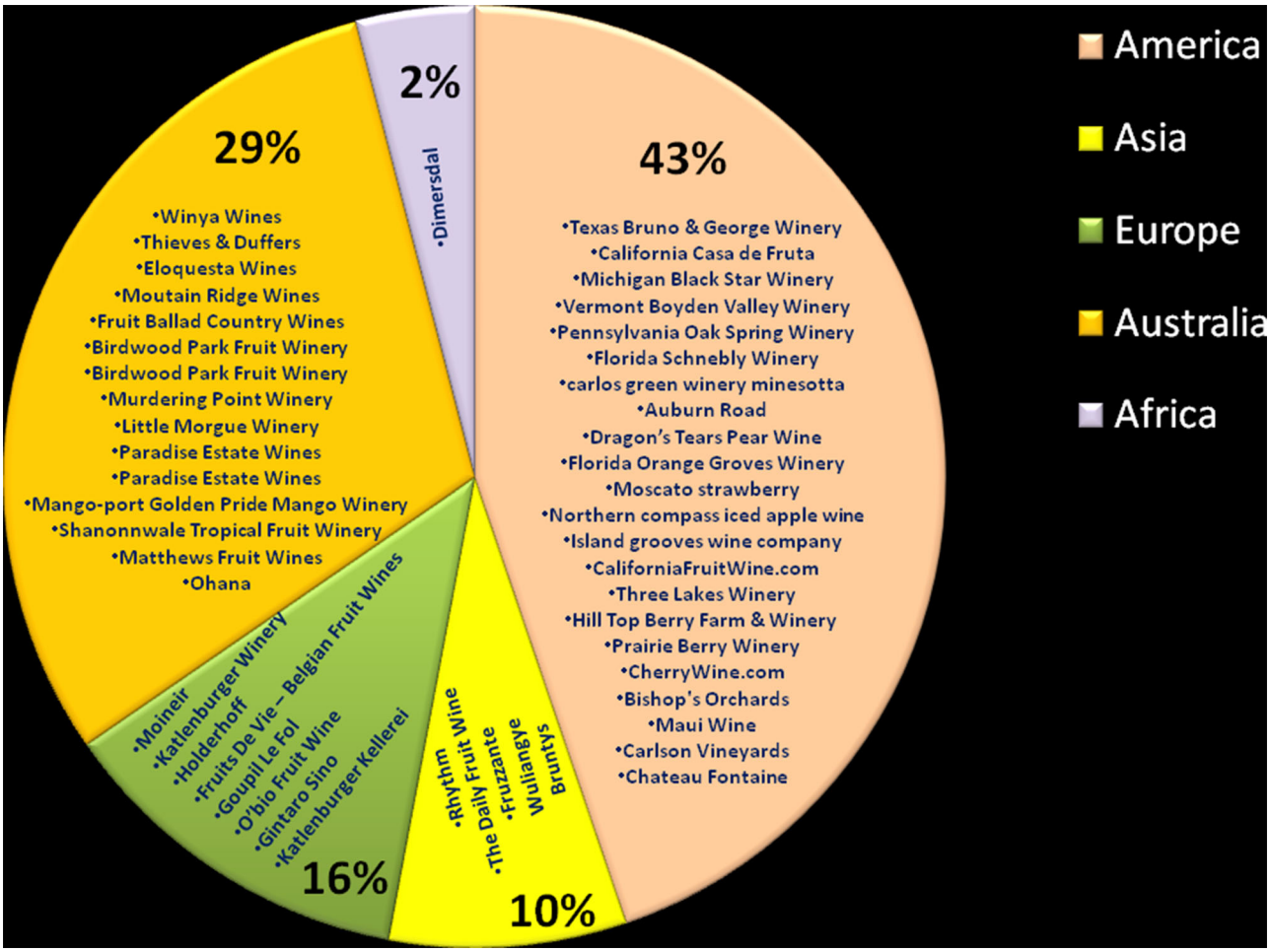


**Figure 2.** Global distribution of fruit wineries.

foods like taste, palatability and nutritional value (Etxeberria et al. 2013; Lima et al. 2014; Zujko and Witkowska 2014).

Several compelling evidences reveal the potential of fruit wines as a polyphenols rich source along with exhibiting noticeable antioxidant activity in vitro (Ljevar et al. 2016; Wang et al. 2015; Xiao et al. 2015). Similar to the red wine from grapes, the pro-health properties of fruit wine are ascribed, among other things, to the presence of polyphenol compounds (Dey, Negi, and Gandhi 2009).

Among the fruits, berries are considered to be one of the most important antioxidant rich foods. However, the potential effects of berry wines have not been elucidated yet.

Out of the very few works reported so far, Mudnic et al. 2012 studied the potential benefits of 4 blackberry wines (*Rubus glaucus* Benth) as vasodialating agents. The total phenolic content (TPC) as determined by Folin–Ciocalteau method were reported to be in the range of 1697 ± 20 to 2789 ± 27 mg GAE/L. White wines were taken as control reporting the least TPC corresponding to only 379 ± 3 to 482 ± 3 mg GAE/L. The flavanol content analysis revealed the abundance of epigallocatechin gallate and procyanidin in the blackberry wines while in contrast, catechin was the predominant phenolic in grape wine. The authors also stated that the procyanidins content of blackberry wines were significantly higher compared to red wine. While stillbenes were detected in all wine varieties, the concentration of gallic acid was reported to be approximately 3 folds higher compared to grape wines. Analysis of the antioxidant activity by FRAP assay revealed a higher antioxidant potential of blackberry wines (15.8 ± 0.6 mmol TE/L) in spite of a lower total phenolic profile compared to that of grape wine. However, the anthocyanin content in blackberry wine was detected to be relatively low (13 to 164 mg/L malvidin-3-glucoside) in comparison to red wine was (212 ± 9- 287 ± 3 mg/L malvidin-3-glucoside). An important fact emerged from this study that higher content of total phenolics may not always result in higher antioxidant potential.

Another study by Ortiz et al. 2013 also assess the phenolics and antioxidant potential of 70 wines from Ecuador made up of black berry (*Rubus glaucus* Benth.) along with blue berry (*Vaccinium floribundum* Kunth.), and Golden Reinette apples. The TPC of blackberry (1265 ± 91 mg/L) was the highest followed by blueberry wines (1086 ± 194 mg/L). Apple wine revealed the lowest TPC (608 ± 86 mg/L). Similar works from other authors confirming the superiority of blueberry have also been reported earlier (Johnson and Gonzalez de Mejia 2012; Klaric, Klarić, and Mornar 2011; Rupasinghe and Clegg 2007). Blackberry wine revealed the highest monomeric anthocyanin concentration. The major anthocyanins in black berry wines were cyanidin-3-rutinoside and cyanidin-3-glucoside. Similarly the antioxidant capacity blackberry was the highest (11.6 ± 0.7 mM TE) followed

by blueberry (5.4 ± 0.8 mM TE) and apple (2.1 ± 0.3 mM TE). These data reveal that blackberry wines can be considered as the most effective in vitro antioxidants.

Due to the surplus availability of berries, Illinois wineries boast of various high quality fruit wines. Another group of workers from Illinois, Johnson and Gonzalez De Meija (2012) reported the phenolic content of commercially available blackberry and blueberry wines. Estimation of TPC in both the berry wines revealed a high phenolic concentration ranging from 966.7 ± 44.8 mg EAE/L to 3620.8 ± 165.8 mg EAE/L. The total anthocyanin content of the wines ranged from 10.71 mg/mL to 191.95 mg/L where the average anthocyanin content in blackberry wine was the highest (75.56 mg/L) in comparison to blueberry wine (20.82 mg/L). The total antioxidant activity measured by the ORAC assay revealed a radical scavenging potential of blackberry wines than blueberry. The results are indicative of the fact the higher content of phenolic compounds and anthocyanins are responsible for the higher anti-oxidant potential of the blackberry wines.

In Mitic et al. (2013) evaluated the total phenolic content of four different wines prepared from sour cherry, blackberry and raspberry. A high TPC was recorded from the evaluation that ranged from 1051.9 ± 58 to 2752.03 ± 33.93 mg GAE/ml. The authors reported a 1.76 fold difference in the TPC between the highest and lowest ranked blackberry wine samples followed by 1.73 fold and 1.42 fold difference in the cherry and raspberry wine samples respectively.

Celep et al. (2015) recently evaluated the phenolic content in different turkish berry wines. The authors reported that the wines made from black mulberry, blue berry and cherry depicted a fairly high TPC ranging from 19.64 ± 1.07 to 64.1 ± 1.93 GAE/g dry extract. Black mulberry wines revealed the highest phenolic content followed by the blue berry and cherry wines. DPPH and CUPRAC assay to assess the anti-oxidant potential of the wine samples revealed a high anti-oxidant activity in all the fruit wines ranging from 211.01 ± 6.47 BHTE-353.49 ± 4.61 BHTE and 54.54 ± 2.49 AAE- 152.48 ± 2.37 AAE, respectively. Mulberry wine possessed the highest anti-oxidant activity. Additionally the authors depicted a significantly high radical scavenging potential of all three wine varieties when compared to Papazkarası, a Turkish red wine made up of native grape varieties.

Arozarena et al. (2012) reported the phenolic content of wines prepared form the Andean blackberries which is a native fruit of the Central and South America. 28 blackberry wines prepared under different processing conditions was evaluated for the phenolic composition. TPC in this study ranged from 601 − 1624 mg GAE/L which is showed comparatively lower concentration than other reports on the blackberry wines. However, the major phenolic compounds detected were cyanidin glucoside, cyanidin rutinoside, vitisins, ellagic acid and elagitanins. Among the anthocyanins, cyanidin-3-rutinoside and cyanidin 3-glucoside were reported as the major compounds.

Sea buckthorn berries belonging to the *Eleganaceae* family has been known for its medicinal and therapeutic properties (Eccleston et al. 2002). Rich in phenolics, several extracts from sea buckthorn has been used as antioxidants, immunomodulatory, anti-atherogenic, anti-stress, hepatoprotective, radioprotective agents and in tissue repair (Saggu et al. 2007; Upadhyay et al. 2009). In this light, our lab had earlier developed a seabuckthorn wine and examined its properties (Negi and Dey 2009). The TPC of sea buckthorn juice to be 689 mg GAE/L was comparable to grape wine (647 mg GAE/L). In 2013 we evaluated the potential of sea buckthorn wines and their potential effect on oxidative stress and hypercholesterolemia. A very high TPC 2182 ± 1.01 mg GAE/L was recorded in sea buckthorn wine compared to other commercial wines, Cabernet Shiraz (1747 ± 1.78 mg GAE/L) and Beaujolais (1545 ± 2.50 mg GAE/L) (Negi, Kaur, and Dey 2013). The phenolic composition of sea buckthorn wine showed a predominance of rutin (68.39 ± 5.40 mg/L), followed by myricetin (40.30 ± 0.90 mg/L), quercetin (1.04 ± 0.04 mg/L) and trace amounts of kaempferol (<0.18 ± 0.01 mg/L) The free radical scavenging potential by DPPH assay was recorded at 2.63 ± 0.01TE mmol/L, with ABTS assay it was 7.03 ± 0.04 TE mmol/L and with FRAP assay it was recorded at 3.10 ± 0.02 TE mmol/L (Negi, Kaur, and Dey 2013).

In another elaborate study by Čakar et al. (2016), the phenolic and antioxidant profiles of wines developed from different berries with several therapuetic potential were evaluated. The TPC of blue berry and black chokeberry was highest (2234.46 ± 1.51 mg GAE/L and 2234.46 ± 1.51 mg GAE/L), followed by blackberry (2230.46 ± 1.55 mg GAE/L), sour cherry (2084.28 ± 1.76 mg GAE/L), wild blueberry fruit (1899.90 ± 1.88 mg GAE/L) and raspberry (1418.17 ± 2.90 mg GAE/L). The TPC assay depicted the least concentration of phenolics in apples (584.28 ± 4.98 mg GAE/L). Chlorogenic acid was the predominant phenolic in apple, blueberry, black chokeberry and sour cherry wines ranging from 70.71 ± 0.78- 474.34 ± 32 µg/ml. Gallic acid and epicatechin were the major phenolics present in black berry and raspberry wines respectively. The highest anti-oxidant potential according to the FRAP and DPPH assay was found to be in blackberry (103.90 ± 4.02%) and apples (83.33 ± 2.80%) respectively.

The traditional use of the rosa species in different foods due to their therapeutic claims are long known (Zhang et al. 2008). Apart from the therapeutic and curative potential of rose flower against gastrointestinal inflammation and related diseases and upper respiratory infections, *Rosaceae* fruits rich in phenolics, $\beta$-carotene, lycopene, ascorbic acid, tocopherol, bioflavonoid, tanins and pectins are also considered to be of high medicinal value (Demir and Ozcan 2001; Ercisli 2007; Uggla, Gao, and Werlemark 2003, Uggla et al. 2005). Owing to the beneficial effect Czyzowska et al. (2015) evaluated the polyphenol content of wines prepared from *Rosa canina* L. and *Rosa rugosa* Thunb. The fermented products contained total phenolic (TPC) in the range of 3389 ± 245 mg/L GAE and 3990 ± 256 mg/L GAE for *Rosa rugosa* and *Rosa canina*, respectively. However, the authors

reported a considerable decrease in the total phenolics of the wines after ageing with a TPC of 2786 ± 156 mg/L GAE and 3456 ± 134 mg/L GAE in *Rosa rugosa* and *Rosa canina*, respectively. The total flavonoid content was also reported to be as high as 2666 mg/L for *Rosa rugosa* Thunb. and 3008 mg/L for *Rosa canina* L. The wines successfully retained about 70% of ascorbic acid content and their final concentration was 1200 and 600 mg/L for *Rosa rugosa* Thunb. and *Rosa canina* L., respectively. From the polyphenolic profile of these wines it was found that gallic acid was the most abundant phenolic acid. Other significant polyphenols detected were chlorogenic acid, ferulic acid, syringic acid, p-Coumaric acid and derivatives of quercetin. The antioxidant capacities of wines were found to be within a range of 8-13 mmol TEAC. Results were slightly contradicting when Ros*a canina* L. derived wine depicted a higher ABTS value (13.5) than *Rosa rugosa* Thunb, while, by the DPPH assay; the authors found that the activity of Rosa *rugosa* Thunb wine was higher than *R. canina*. They inferred that in conjunction, the phenolic content and the anti-oxidant potential of the wine may be significant.

An aspect of functional food development that has drawn a lot of research attention is food fortification. In compliance with such recent developments, Lee et al. (2013) reported the efficacy of fortifying apple wines with medicinal herbs so as to enhance its functionality. The authors used the herbal formulations made up of pine, hwanggi and mistletoe for fortification which significantly enhanced the total phenolic content of the apple wine. ABTS assay depicted high free radical quenching capacity in comparison to the normal apple wine.

Srikanta et al. 2016 performed the phenolic profiling of two fruit wines based on jamun and mulberry. While transpicied (274.4 ± 14.10 mg/L) was predominant in jamun wines the phenolic profiling of mulberry wines revealed *cis*-picied as the major phenolic compound.

Berenguer et al. 2016 reported the anthocyanin content of pomegranate wines fermented with 3 different *S. cerevi-ciae* yeast strains. The anthocyanin compounds belonging to the cyanidin and delphindin derivates were found to be the most predominant constitutents of the fruit wines. Additionally, the authors also reported the abundance of cyanidin 3,5-di (Cy3,5dG) and Cyanidin 3-*O*-*β*-glucopyranoside (Cy3G) in the end product, thereby indicating their stability during the wine processing conditions. Another study on pomegranate wines was performed by Lan et al. (2017). The phenolic compounds identified at different winemaking time were as follows: punicaligin, gallic acid, ellagic acid, vanillic acid, ferulic acid, procatechuic acid and *p*-coumaric acid respectively. Punicaligin was found to be the predominant phenolic in the fermented product with a concentration of about 30 mg/100 ml. DPPH for free radical scavenging potential of the wine samples depicted a high anti-oxidant activity above 95% in the samples.

Coelho et al. 2015 reported a systematic approach of developing fruit wines from commercially available fruit concentrates. The anti-oxidant capacity of the wines made up of orange, mango, cherry and banana was evaluated. Results from the FRAP assay revealed the antioxidant capacity of cherry wines was the highest (28.0 ± 1.84 mmol/L), followed by orange (22.6 ± 0.46 mmol/L), banana (9.54 ± 0.89 mmol/L) and mango wines (7.14 ± 0.77 mmol/L). The high antioxidant activity of cherry wines may be attributed to its high concentration of phenolic and anthocyanin compounds.

McDougall et al. (2016) reported the phenolic content and anthocyanin of Salal (*Gaultheria shallon*) and aronia (*Aronia melanocarpa*) fruits from Orkney. Salal wines depicted higher anthocyanin content (44.1 ± 0.8 µg/ml) in comparison to aronia wine (18.4 ± 0.6 µg/ml) and salal + aronia wine (33.0 ± 1.1 µg/ml). Similar to the above trend, the TPC was also higher in salal wine (1413 ± 14 µg/ml) compared to the other two wine samples (aronia-966 ± 12 µg/ml andaronia + salal-1122 ± 14 µg/ml).

A research group from Stellenbosch worked on the development of wines from kei-apple (*Dovyalis cafra*), a fruit native to Southern Africa (Minnaar et al. 2017) utilizing two different yeast strains, *S. cerevisiae* and *Schizosaccharomyces pombe*. The TPC of the wine was found to be as high as 1187.04 mg/L. The phenolic profiling of kei-apple wines revealed the presence of diverse groups of phenolic compounds, namely, caffeic acid, ferulic acid, chlorogenic acid, procatechuic, sinapic acid and *p*-coumaric acid. Chlorogenic acid was the predominant phenolic compound with a concentration of 1128.34 ± 4.71 mg/L. de de Oliveira Brandao et al. (2017) assessed the functionality of Jambolan or Jamun wine with respect to their phenolic and anthocyanin content. The total phenolic content and the total anthocyanin content of the wine were recorded to be 845.09 ± 0.22 mg/L 326.9 ± 0.13 mg/L respectively.

Li et al. (2017) investigated the effects of different commercial *S. cerevisiae* on the phenolic profiles and antioxidant activity of kiwifruit wines. Wine fermented with strain RC212 showed the highest phenolic content and DPPH radical scavenging activity. The total phenolic content of the kiwifruit wines ranged from 234 ± 10-317 ± 11 mg/L. The DPPH and ABTS radical scavenging potential of the wine samples were recorded to be about 16.05 ± 0.76 and 201 ± 8 mg/L Trolox equivalents respectively. Gallic acid, proanthocyanidin, epicatechin, caffeic, caftaric, ferulic, ellagic, catechin, procatechuate, *p*-coumaric acid and chlorogenic acid were the phenolic compounds detected in the wine samples where the presence of caffeic acid (2.797 ± 0.157 mg/L) dominated the others.

Akalin et al. (2018) evaluated the antioxidant phenolic compounds of pomegranate wines post fermentation and storage. The total monomeric anthocyanin and phenolic content of the wines post fermentation was recorded to be 160.1 ± 0.6 mg/L and 1799.7 ± 72.9 mg/L respectively. The pomegranate wines produced in this study with different maceration techniques depicted the presence of catechin, epicatechin, gallic acid, vanillic acid, caffeic acid, *p*-coumaric acid, ferulic acid and hydroxycinnamic acid. The antioxidant capacities of pomegranate wines were recorded to be about 9.9 ± 0.1 mm/L Trolox equivalent.

In another study by Liu, Liu, et al. (2018), the impact of maceration time on the phenolic content of mulberry wines was evaluated. Long time maceration significantly increased the TPC, particularly anthocyanin content. The total anthocyanin content of the differently processed mulberry wine ranged from 439.91-387.71 mg/L and Cyanidin-3-O-rutinoside was detected as the major anthocyanin compound. The total phenolic content was ranged from 66.16-70.31 mg/L. Chlorogenic acid, followed by procatechuic acid were reported to be the predominant phenolic compunds in the wines post processing. The authors also evaluated the total flavanol and falvan 3-ol content where querctein and gallocatechin predominated respectively among other detected compounds.

Tchabo et al. (2017) also evaluated the effect of different processing conditions on the phenolic profile and anti-oxidant potential of mulberry wine. The TPC, flavonoid and anthocyanin content of the differently processed wines ranged from 631.32 ± 5.32- 658.00 ± 6.03 mg/100 ml, 477.80 ± 4.05- 507.01 ± 5.35 mg/100 ml and 131.25 ± 0.29-140.60 ± 0.33 mg/100 ml respectively. A plethora of phenolic componds in the mulberry wines were reported in the study. Among the hydroxybenzoic acid procatechuic acid was recorded to be the major compound. Caffeic acid, morin and cyanidin-3-O-glucoside dominated the list of hydroxycinnamic acid, flavanol and anthocyanin content respectively.

More recently, Tchabo et al. 2018 evaluated the phytochemical profile of mulberry wine submitted to non-thermal maturation process. The total phenolic, total flavonoid and the total anthocyanin index of the mulberry wines was recorded to be in a range of 391.6 ± 1.1-428.0 ± 1.5 mg/100 ml, 250.6 ± 1.6-285.1 ± 2.5 mg/100 ml and 107.9 ± 0.3-111.4 ± 0.2 mg/100 ml respectively.

Liu, Sun, et al. (2018) studied the fermentation process optimization of longan (*Dimocarpus longan* Lour) wine. The TPC, flavonoid and tannin content of the longan wine was found to be0.781 ± 0.002 mg GAE/mL, 0.157 ± 0.004 mg RE/mL and 0.772 ± 0.002 mg GAE/mL repectively. A high radical scavenging activity was recorded in the wine samples (90%) by DPPH assay.

Thus in support of the earlier hypothesis, the fruit wines definitely seem to contain a large repertoire of beneficial flavonoids, anthocyanins and other phenolics (Table 1). Therefore, it seems worthwhile to examine the reports available on functional value of these fruit wines.

## Evaluation of health benefits of fruit wines

For the discussion on functional properties and health benefits of wines, the authors have included some of the studies performed on red wine. The rationale for this inclusion is that the health benefits demonstrated are majorly because of a diverse combination of phenolic acids, anthocyanins and flavonoids, which are not exclusive to grapes, but are also found, sometimes in higher amounts, in other fruit wines. Therefore, it is expected that fruit wines would also demonstrate the potential health benefits, when tested in similar models with same biomarkers. Abundant literature is available on clinical intervention of red wine to evaluate different markers but here the focus is on comparative studies which have been performed in red wines and different fruit wines.

A vasodialatory effect of blackberry wine was reported by Mudnic et al. (2012) and this bioactivity was related to anthocyanin, protocatechueic, syringic and gallic acid contents. Similarly wine phenolics, catechin, epicatechin and quercitin have been implicated in the inhibition of aggregation.

While evaluation of health benefits of different wine varieties have been under progress, several researchers have expressed doubts about the health benefits of wine consumption. Their main point of argument was that the concentration of phenolic acid, anthocyanins, flavonoids remain in the plasma after wine consumption may not be enough to bring about significant physiological effects on the host. This criticism has been addressed with transcriptomic data. Mauray et al. (2012) confirmed that at a lower concentration of bilberry anthocyanin extract, it could alter the expression of 1261 genes which encoded aortic proteins that were involved in angiogenesis. These were some of the first in vivo elucidation of mechanisms of action of polyphenols both at cellular and genetic levels. The group also demonstrated protective activity of bilberry extract against hypercholesterolemia even with lower concentrations of anthocyanin (Mauray et al. 2010). Other fruit wines have also been tested against the hypercholesterolemia model. In our lab, earlier, the protective effects of sea buckthorn wine against oxidative stress and hypercholesterolemia in male LACA mice was evaluated. Promising results reporting the reduction of oxidized glutathione levels and hepatic lipid peroxidation along with increase in the superoxide dismutase activity was observed. Administration of sea buckthorn wine to high-cholesterol-fed mice also led to a marked increase of the HDL-C/LDL-C ratio (Negi, Kaur, and Dey 2013). Similarly, interesting result was documented from clinical trials performed by Opie and Lecour 2007, where red wine consumption improved hypertension, elevated HDL levels, decreased triglyceride levels.

Fruit wines from berries have been frequent subjects of research focus because of their high anthocyanins, phenolic acid content. Johnson et al. (2013) assessed the anti-inflammatory potential of anthocyanins and proanthocyanins from blueberry–blackberry wine and the inhibition of carbohydrate utlilzing enzyme in vitro. The study showed that both anthocyanidins and proanthocyanidians inhibited starch-degrading enzyme, α-glucosidase and dipeptidyl peptidase-IV activity. While computational docking data revealed promising results where delphinidin-3-arabinoside was able to effectively inactivate dipeptidyl peptidase-IV by binding with the lowest interaction energy, these compounds could reduce the LPS-induced inflammation in mouse macrophages via the nuclear factor kappa B-mediated pathway, thereby decreasing iNOS and COX-2 expression.

The antimutagenic effect of rose wines on *Salmonella typhimurium* TA98 and *Salmonella typhimurium* TA100 was reported by Czyzowska et al. (2015). They evaluated the

**Table 1.** Major phenolic acids of fruit wines (Source: Dey and Sireswar, 2019).

| S. no | Wine samples | Phenolic profiles | References |
|---|---|---|---|
| 1 | Mulberry | Cyanidin-3-O-glucoside, Cyanidin-3-O-rutinoside, Pelargonidin-3-O-rutinoside, Delphinidin-3-O-rutinoside, Dephinidin-3-O-glucoside, Malvidin-3-O-glucoside, Pelargonidin-3-O-glucoside, Chlorogenic acid, Protocatechuic acid,4-Hydroxybenzoic acid,4-Hydroxycinnamic acid, Caffeic acid, Sinapic acid, Ferulic acid, Gallic acid, Quercetin-glucoside, Dihydrokeampferol, Kaempferol-glucoside, Isorhamnetin, Quercetin, Keampferol, Isorhamnetin-glucoside, Myricetin-galactoside, Myricetin-glucoside, Quercetin-glucuronide, Isorhamnetin-glucoside, Syringetin-galactoside, Procyanin, Gallocatechin, Catechin, Epicatechin | Liu, Liu, et al. (2018) |
| 2 | Mulberry | Gallic acid, gentisic acid, chlorogenic acid, vanilic acid, caffeic acid, syringic acid, hydroxybenzoic acid, procatechuic acid, ferulic acid, p-coumaric acid, kaempferol, myricetin, rutin, morin, quercetin, cyanidins | Tchabo et al. (2017) |
| 3 | Mulberry | Gallic acid, Gentisic acid, Protocatechuic acid, p-Hydroxybenzoic acid, Vanillic acid, Syringic acid, Chlorogenic acid, Caffeic acid, p-Coumaric acid, Ferulic acid, Rutin, Quercitrin, Myricetin, Morin, Kaempferol, Cyanidin-3-O-glucoside, Cyanidin-3-O-rutinoside, Quercetin | Tchabo et al. (2018) |
| 4 | Pomegranate | Epicatechin, Catechin, Gallic acid, Vanillic acid, Caffeic acid, p-coumaric acid, Ferulic acid, Hydroxycinnamic acid | Akalin et al. (2018) |
| 5 | Kiwifruit | Gallic acid, Proanthocyanidins, L-Epicatechin, Caffeic acid, Caftaric acid, Ferulic acid, Ellagic acid, Catechin, Protocatechuate, p-Coumaric acid, Chlorogenic acid | Li et al. (2017) |
| 6 | Kei-apple | Caffeic acid, Ferulic acid, Chlorogenic acid, Protocatechuic acid, Sinapic acid, p-Coumaric acid (HCA) | Minnaar et al. (2017) |
| 7 | Salal | Chlorogenic acid, Delphinidin pentose-hexose, Delphinidin hexose, Cyanidin pentose-hexose, Delphinidin dipentose, Cyanidin hexose, Delphinidin pentose, Cyanidin dipentose, Cyanidin pentose, PAC trimer, PAC tetramer, Myricetin hexose, Myricetin glucuronide, Myricetin pentose, Myricetin rhamnoside, Quercetin hexose, Quercetin glucuronide, Quercetin pentose, Quercetin rhamnoside | McDougall et al. (2016) |
| | Aronia | Neochlorogenic acid, Chlorogenic acid, Cyanidin hexose, Cyanidin pentose, PAC trimer, Quercetin dihexose, Quercetin pentose hexose (vicianoside), Quercetin rutinoside, Eriodictoyl glucuronide, Quercetin hexose | |
| 8 | Blueberry | Gallic acid, caffeic acid, vanilin, *p*-coumaric acid, rutin, quercetin | Celep et al. (2015) |
| | Black mulberry wine | Gallic acid, chlorogenic acid, caffeic acid, vanilin, *p*-coumaric acid, rutin, quercetin | |
| | Cherry | Gallic acid, caffeic acid, vanilin, p-coumaric acid, rutin, quercetin | |
| 9 | Jamun | Gallic acid, gallocatechin, catechin, caffeic acid, *p*-coumaric acid, t0resveratrol, *t*-piceid and *c*-resveratrol | Srikanta et al. (2016) |
| 10 | Apple | Epicatechin, *p*-hydroxybenzoic acid, catechin, chlorogenic acid, vanillic acid, caffeic acid, naringinin, quercetin | Cakar et al. (2016) |
| | Blueberry | Epicatechin, *p*-hydroxybenzoic acid, catechin, chlorogenic acid, vanillic acid, caffeic acid, naringenin, quercetin, sinapinic acid, gallic acid, procatechuic acid, *p*-coumaric acid, ellagic acid | |
| | Black chokeberry | Epicatechin, *p*-hydroxybenzoic acid, rutin, chlorogenic acid, vanillic acid, caffeic acid, naringenin, quercetin, sinapinic acid, gallic acid, procatechuic acid, *p*-coumaric acid, ellagic acid and quercetin | |
| | Blackberry | Epicatechin, *p*-hydroxybenzoic acid, vanillic acid, caffeic acid, naringenin, quercetin, sinapinic acid, gallic acid, procatechuic acid, ellagic acid and quercetin | |
| | Sour cherry | Epicatechin, *p*-hydroxybenzoic acid, catechin, chlorogenic acid, vanillic acid, caffeic acid, naringenin, sinapinic acid, procatechuic acid, quercetin, kaempferol | |
| | Raspberry | Epicatechin, *p*-hydroxybenzoic acid, catechin, vanillic acid, caffeic acid, naringenin, sinapinic acid, quercetin, gallic acid,*p*-coumaric acid, ellagic acid and quercetin | |
| 11 | Rose fruit wine *Rosa canina* L. | Chlorogenic acid, ferulic acid, Syringic acid, p-coumaric acid | Czyzowska et al. (2015) |
| | *Rosa rugosa* | Gallic acid, chlorogenic acid, ferulic acid, syringic acid, p-coumaric acid, Quercetin- rutinoside, Quercetin-glucoside | |
| 12 | Blackberry | Cyanidin-3-rutinoside and cyanidin-3-glucoside | Ortiz et al. (2013) |
| 13 | Sea buckthorn | Rutin, Myrectein, Quercetin, Kaempferol | Negi, Kaur, and Dey (2013) |
| 14 | Andean blackberry | Cyanidin glucoside, cyanidin rutinoside, vitisins, ellagic acid, elagitanins. | Arozarena et al. (2012) |
| 15 | Blackberry 1 | Gallic acid, catechin, epicatechin, epigallocatechin gallate, Procyanidin B2, Quercetin-4-glucoside, cis,trans-resveratrol, piceid, astringin | Mudnic et al. (2012) |
| | Blackberry 2 | Gallic acid, catechin, epicatechin, epigallocatechin gallate, Procyanidin B2, Quercetin-4-glucoside, trans-resveratrol, piceid | |
| | Blackberry 3 | Gallic acid, catechin, Procyanidin B2, Quercetin-4-glucoside, cis,trans-resveratrol, piceid, astringin | |
| | Blackberry 4 | Gallic acid, catechin, epicatechin, epigallocatechin gallate, Procyanidin B2, cis,trans-resveratrol, piceid | |

effect in wines made of two different species of rose fruit. Results revealed that wine prepared from *Rosa rugosa* Thunb. could reduce the intensity of mutation by 16–48% in *Salmonella typhimurium* TA98 and by 12–52% in *Salmonella typhimurium* TA100. In comparison, wines from *Rosa canina* L. showed a higher potential to reduce mutations.

Srikanta et al. (2016) studied the anti-diabetic properties of mulberry and jamun wines. The authors reported a significant decrease in renal lipid peroxidation, reduced proteinuria and NEFA content, improved antioxidant enzyme activities along with GSH content in animals fed with mulberry and jamun wines.

An elaborate experiment was performed by Boban and Modun (2010), to confirm that a polyphenol concentration of approximately 100 $\mu$M could be found available in colon tissue and have potential of detoxifying local carcinogens. They further established that the residual unabsorbed polyphenols could scavenge free radicals and prevent lipid peroxidation. Similarly, Celep et al. (2015) confirmed the bioavailability and the antioxidant efficiency of Turkish blueberry, black mulberry and cherry wines on a simulated in vitro gastro intestinal model. Comparatively, the black mulberry wine performed the best followed by blueberry and cherry wines. Recently, El-Beltagi et al. (2019) demonstrated the anticancer potential of plum wine on liver cells (HepG2), colorectal adenocarcinoma (Caco-2) and breast cell lines (MCF-7).

Fernandes et al. (2017) have critically reviewed the health benefits and disease prevention potential of wine flavonoids. Tracing the sequence of events that take place in human body after consumption of wine starting from mouth to colon they have reviewed the data available on bioavailability and established physiological activities on wine consumption against a large number of conditions like oral hygiene, obesity, CVD, neurodegenerative diseases, allergies and some cancer. The final inference drawn is that while there is tremendous potential for wine related compounds to positively influence and provide prophylactic action against various metabolic conditions, there are still a lot of knowledge gap filling needed for confirmation of bioavailability and establishment of health benefits which may be done by conducting more randomized clinical trials.

Probably taking cue from these studies, wineries worldwide are experimenting on production and marketing of fruit wines (Figure 2).

A fortunate thing for these nontraditional wineries is that there is an ever increasing demand of personalization amongst consumers of millennial generation. The largest section of this generation is from USA and has now reached the legal drinking age. An interesting statistics has been reported in wine market council that millennial drinkers make up for 36% of wine purchasers and 17% among them have paid extra per bottle (Kellershohn 2018). Thus consumer psychology among millennials clearly indicates they seek product exploration and with their growing and buying power, they don't mind paying extra for premium products.

Coming back to the original discussion as to whether fruit-based wines can be tailored or customized functional beverages; there definitely seem to be a strong possibility. Some of the current possibilities have been discussed in the next section.

## What is the next step?

There is tremendous scope for designing novel probiotic with well-defined functions. In this context, the authors have worked extensively on value addition of *Lactobacillus rhamnosus* GG-fortified sea buckthorn beverages developed in the lab. Functional assessment of the probiotic-fortified sea buckthorn beverage showed a significant pathogen elimination potential especially when co-incubated with enteropathogenic *E. coli* (ATCC 43887), *Salmonella enteritidis* (ATCC 13076), *Shigella flexneri* (ATCC 12022) and *Shigella dysenteriae* (ATCC 29026) (Sireswar et al. 2017; Sireswar, Montet, and Dey 2018). Furthermore, an apple-based beverage was also developed in our lab. Comparative evaluation of in vivo efficacies of both sea buckthorn and apple showed interesting results. The protective action against chemically induced colitis varied in case of both the beverages when tested on TNBS induced zebra fishes (Sireswar and Dey 2019). Based on these results, the efficacy of the sea buckthorn beverage was further evaluated against LPS challenged-zebrafishes (Sireswar, Biswas, and Dey 2020). The results showed that sea buckthorn beverage could reverse histological damage, reduce the expression of pro-inflammatory markers, TNF-$\alpha$ and IL-1$\beta$ and increase the expression of anti-inflammatory cytokine IL-10. This strongly indicates that cooperative action of seabuckthorn phenolics and *Lb rhamnosus* can be extracted for enhanced physiological functionality. Hence, evidence-based probiotic-phenolic combinations need to be created which may be evaluated against specific biomarkers and may be developed into disease-specific products as opposed to one product for "overall health benefit".

Alternatively, probiotic strains are now being screened as live biotherapeutic for application in prevention, treatment, or cure of human diseases. The tools of CRISPER CAS-9 techniques have been applied to design tailor made probiotics for efficient drug delivery or synthesis of physiologically active metabolites to target specific disease conditions like CVD, IBD and Cancer. For instance, Del Carmen et al. (2014) genetically modified probiotic strain *S. thermophilus* CRL 807 by transforming it with plasmid harboring genes encoding catalase (CAT) and superoxide dismutase (SOD) to specifically enhance the production of anti-oxidant enzymes to reduce the severity of inflammation in colitis induced mice models. Yang et al. (2015) evaluated the efficacy of genetically engineered *Lb plantarum* NC8 (RLP) to produce recombinant ACEIP (Angiotensin-converting enzymes inhibitory peptides) and their impact in regulation of hypertension. Oral administration of RLP could regulate blood pressure and reduce angiotensin II and endothelin levels in the plasma, heart and kidney in spontaneous hypertensive rats. Similarly, Tabashsum et al. (2019) reported the

efficacy of a recombinant *Lactobacillus casei* strain to combat *Camplyobacter jejuni* infection by overproducing conjugated linoleic acid (CLA). These designer strains are also simultaneous being tested for long term safety.

Therefore, time has come for second generation probiotic formulations which may include genetically engineered strains to be used for specific disease conditions and not just for general well-being. Likewise the lab developed probiotic prototypes based on fruits and vegetables need to be wetted more thoroughly by the investigators with respect to their in vivo functionalities. In-depth analysis and knowledge of juice components and matrix specific interactions should be the tools for designing novel probiotic beverages.

Similarly, current research is opening up newer avenues for up gradation of fruit wines. As the recent in vivo evidences on health benefits of red wines and fruit wines are slowly trickling, wine is gaining popularity as a functional beverage. Very recently in April, 2020, an interesting theory paper was published (Champ and Kundu-Champ 2019) where wine is differentiated from other alcoholic beverages based on the chemical composition (phenolic acid, flavonoids, anthocyanins) that can influence cellular functions and can promote health. This theory draws support from past and recent evidences that have been mentioned earlier. Champ and Kundu-Champ (2019) propose that wines resulting from fermentation of grapes grown at 15-25 °C under moderate sun exposure with lower vine-water status, limited application of fertilizers, extended maceration and aging in oak barrel will result in wines with adequate phenolic acid content to be able to significantly impact cancer. Extrapolating from this theory, since many of the phenolic acids and flavonoids are commonly found in grapes and other fruits, it may be proposed that one of the methods of tapping the health benefits from fruit wines would be to standardize agronomic and wine making conditions of fruit wine to obtain sufficiently high content of phenolic acids. The resulting wine would have enhanced bioactivities and may be labeled as functional beverage, after preclinical and clinical testing. From the reviews and research findings so far it is now well established that a rational and moderate daily intake of red wine does supply adequate amount of bioactive phytochemicals that can provide protection against physiological stresses like oxidation and inflammation. An elaborate chapter authored by Giovinazzo and Grieco (2019) have explained unambiguously the major and minor components of the red wine and the intricate health benefits that have been demonstrated by these compounds.

The effect of wine polyphenolics is being researched from different angles. A group from Australia (Nash et al. 2018) reviewed the clinical trial data available and established the fact that gut microbiota definitely modulates the wine polyphenols, thereby increasing the number and diversity of the metabolites. The consensus is that consumption of wine derived polyphenols contribute to beneficial gut microbial ecology. Nevertheless, few more clinical trials on different wines interventions are required to establish and reinforce these research finding.

Ever since it was confirmed that tapping of health benefits from wines is poised on one important factor which is the chemical composition of wine, this aspect and related factors have been the research focus for many scientists. Modern techniques of proteomic, trancriptomic and metabolomic analysis have not only been applied for wine traceability aspects (Dey and Montet 2018) but also to evaluate physiological responses to wine interventions (González-Dominguez et al. 2019).

Therefore, application of metabolomic tools can give a large set of useful information like precise metabolic alterations, associated with wine consumption and discovery of biomarker of wine intake. These informations can in turn be used to elucidate potential health benefits that may be tapped by regular and moderate intake of different wines. Fruit wines, with their diverse polyphenols have the highest likelihood of getting tailored into functional beverages targeted toward specific disease conditions.

## Concluding remarks

The need for tailoring functional beverages to configure special health benefits like lowering blood pressure, reducing risk of diabetes, decreasing insulin resistance, decreasing obesity markers, increasing Vit A bioavailability, improving cognitive functions etc have never been greater. In order to fulfill the need what is required is to pursue the concept of functional beverages with a more research and technology driven approach. Designing functional beverages through fortification is deceptively easy. It is worthwhile to dip in and recover useful information that has been generated by several databases on health benefit of phytochemicals. The already growing popularity of both probiotic fruit beverages and fruit wines can and should be used to tailor them into tomorrow's second generation beverages. Along with these their non-probiotic and nonalcoholic counterparts can also be designed into "smart" drinks.

It needs to be mentioned here that apart from the obvious benefits of eliciting enhanced functionality, there is another advantage in the rationale of designing of second generation functional beverages. Constantly evolving consumer needs, fierce competition at entry level for startups, market visibility of international brands due to globalization, all these factors impact the launch of a new product. It is probably imperative to have a strong R & D support to gain an edge over competitors. Fruits and vegetable beverages with distinct and focused functionality will definitely add to brand distinction for the company and pave way to assured IPR.

The functional beverage industry needs to shift toward more evidence-based beverage formulations in the next few years to increase their consumer base and have significant return of investment. Some of the mega brands and medium sized brands have identified high growth potential in this sector. In order to realize the maximum benefits of functional beverages throughout the segments of population various stunt marketing, promotional gimmick and publicity events have to be organized. For translation of functional

beverages into commercial success a plethora of marketing strategies including smart apps, social media, virtual reality technology, immersive experiences, visitor centers, loyalty programs & sensory marketing are available today.

Fortunately functional beverages based on different blends of fruits and vegetables play well into consumer expectation of healthy yet unusual products. Fruit wineries can take cue from trendy gyms which provide alcoholic juice bars to promote their products.

For the functional beverage industry it is indeed an exciting time ahead. What is now required is to capitalize on the insights obtained through strong R&D to create functional beverages with focused bioactivities.

## Conflict of interest

The authors declare no conflict of interest.

## References


Agudelo, C. D., N. Ceballos, A. Gómez-García, and M. E. Maldonado-Celis. 2018. Andean Berry (*Vaccinium meridionale Swartz*) Juice improves plasma antioxidant capacity and IL-6 levels in healthy people with dietary risk factors for colorectal cancer. *Journal of Berry Research* 8 (4):251–61. doi: 10.3233/JBR-180312.

Akalın, A. C., M. Bayram, and R. E. Anlı. 2018. Antioxidant phenolic compounds of pomegranate wines produced by different maceration methods. *Journal of the Institute of Brewing* 124 (1):38–44. doi: 10.1002/jib.468.

Arozarena, Í., J. Ortiz, I. Hermosín-Gutiérrez, I. Urretavizcaya, S. Salvatierra, I. Córdova, M. R. Marín-Arroyo, M. J. Noriega, and M. Navarro. 2012. Color, ellagitannins, anthocyanins, and antioxidant activity of Andean blackberry (*Rubus glaucus* Benth.) wines. *Journal of Agricultural and Food Chemistry* 60 (30):7463–73. doi: 10.1021/jf300924z.

Ballard, C. R., and M. R. M. Junior. 2019. Health benefits of flavonoids. In *Bioactive Compounds*, ed. M. Rubi and S. Campos, 185–201. Duxford, UK: Woodhead Publishing. doi: 10.1016/B978-0-12-814774-0.00010-4.

Berenguer, M., S. Vegara, E. Barrajón, D. Saura, M. Valero, and N. Martí. 2016. Physicochemical characterization of pomegranate wines fermented with three different *Saccharomyces cerevisiae* yeast strains. *Food Chemistry* 190:848–55. doi: 10.1016/j.foodchem.2015.06.027.

Boban, M., and D. Modun. 2010. Uric acid and antioxidant effects of wine. *Croatian Medical Journal* 51 (1):16–22. doi: 10.3325/cmj.2010.51.16.

Bujna, E., N. A. Farkas, A. M. Tran, M. Sao Dam, and Q. D. Nguyen. 2018. Lactic acid fermentation of apricot juice by mono- and mixed cultures of probiotic Lactobacillus and Bifidobacterium strains . *Food Science and Biotechnology* 27 (2):547–54. doi: 10.1007/s10068-017-0269-x.

Cakar, U., A. Petrovic, M. Zivkovic, V. Vajs, M. Milovanovic, J. Zeravik, and B. Djordjevic. 2016. Phenolic profile of some fruit wines and their antioxidant properties. *Hemijska Industrija* 70 (6):661–72. doi: 10.2298/HEMIND150722002C.

Celep, E., M. Charehsaz, S. Akyüz, E. T. Acar, and E. Yesilada. 2015. Effect of *in vitro* gastrointestinal digestion on the bioavailability of phenolic components and the antioxidant potentials of some Turkish fruit wines. *Food Research International (Ottawa, Ont.)* 78:209–15. doi: 10.1016/j.foodres.2015.10.009.

Champ, C. E., and A. Kundu-Champ. 2019. Maximizing polyphenol content to uncork the relationship between wine and cancer. *Frontiers in Nutrition* 6:44. doi: 10.3389/fnut.2019.00044.

Coelho, E., M. Vilanova, Z. Genisheva, J. M. Oliveira, J. A. Teixeira, and L. Domingues. 2015. Systematic approach for the development of fruit wines from industrially processed fruit concentrates, including optimization of fermentation parameters, chemical characterization and sensory evaluation. *Lwt - Food Science and Technology* 62 (2):1043–52. doi: 10.1016/j.lwt.2015.02.020.

Czyzowska, A., E. Klewicka, E. Pogorzelski, and A. Nowak. 2015. Polyphenols, vitamin C and antioxidant activity in wines from *Rosa canina* L. and *Rosa rugosa* Thunb. *Journal of Food Composition and Analysis* 39:62–8. doi: 10.1016/j.jfca.2014.11.009.

de Oliveira Brandão, T. S., L. S. Pinho, A. F. da Silva Hughes, J. L. de Souza, C. A. Rosa, E. Teshima, H. N. Brandão, and J. M. David. 2017. Characterization of the Jambolan (*Syzygium cumini* L.) fruit wine processing. *BioResources* 12 (4):7069–83.

Del Carmen, S., A. D. M. de LeBlanc, R. Martin, F. Chain, P. Langella, L. G. Bermúdez-Humarán, and J. G. LeBlanc. 2014. Genetically engineered immunomodulatory *Streptococcus thermophilus* strains producing antioxidant enzymes exhibit enhanced anti-inflammatory activities. *Appl. Environ. Microbiol* 80 (3):869–77. doi: 10.1128/AEM.03296-13.

Demir, F., and M. Özcan. 2001. Chemical and technological properties of rose (*Rosa canina* L.) fruits grown wild in Turkey. *Journal of Food Engineering* 47 (4):333–6. doi: 10.1016/S0260-8774(00)00129-1.

Dey, G., and D. Montet. 2018. Chemical and biological 'Barcodes' or markers in food traceability: A case study on Wines. In *Food Traceability and Authenticity: Emerging Analytical Techniques*, ed. D. Montet and R. C. Ray, 90–115. Boca Raton, FL: CRC Press, Taylor & Francis Publications.

Dey, G., B. Negi, and A. Gandhi. 2009. Can fruit wines be considered as functional food?—An overview. *Natural Product Radiance* 8 (4):314–32.

Dey G., and S. Sireswar. 2019. Emerging Functional Beverages: Fruit wines and transgenic wines. In *Alcoholic beverages, The science of Beverages*, ed. A. M. Grumezescu and A. M. Holban, vol 7, 471–514. UK: Woodhead Publishing, Elsevier.

Dharmasena, M., F. Barron, A. Fraser, and X. Jiang. 2015. Refrigerated shelf life of a coconut water-oatmeal mix and the viability of *Lactobacillus plantarum* Lp 115-400B. *Foods (Basel, Switzerland)* 4 (3):328–37. doi: 10.3390/foods4030328.

Dimitrovski, D., E. Velickova, M. Dimitrovska, T. Langerholc, and E. Winkelhausen. 2016. Synbiotic functional drink from Jerusalem artichoke juice fermented by probiotic *Lactobacillus plantarum* PCS26. *Journal of Food Science and Technology* 53 (1):766–74. doi: 10.1007/s13197-015-2064-0.

Eccleston, C., Y. Baoru, R. Tahvonen, H. Kallio, G. H. Rimbach, and A. M. Minihane. 2002. Effects of an antioxidant-rich juice (sea buckthorn) on risk factors for coronary heart disease in humans. *The Journal of Nutritional Biochemistry* 13 (6):346–54. doi: 10.1016/S0955-2863(02)00179-1.

El-Beltagi, H. S., A. E. El-Ansary, M. A. Mostafa, T. A. Kamel, and G. Safwat. 2019. Evaluation of the phytochemical, antioxidant, antibacterial and anticancer activity of *Prunus domestica* fruit. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 47 (2):395–404. doi: 10.15835/nbha47111402.

Ercisli, S. 2007. Chemical composition of fruits in some rose (*Rosa spp.*) species. *Food Chemistry* 104 (4):1379–84. doi: 10.1016/j.foodchem.2007.01.053.

Espirito-Santo, A. P., F. Carlin, and C. M. Renard. 2015. Apple, grape or orange juice: Which one offers the best substrate for lactobacilli growth? - A screening study on bacteria viability, superoxide dismutase activity, folates production and hedonic characteristics . *Food Research International (Ottawa, Ont.)* 78:352–60. doi: 10.1016/j.foodres.2015.09.014.

Etxeberria, U., A. Fernández-Quintela, F. I. Milagro, L. Aguirre, J. A. Martínez, and M. P. Portillo. 2013. Impact of polyphenols and polyphenol-rich dietary sources on gut microbiota composition. *Journal of Agricultural and Food Chemistry* 61 (40):9517–33. doi: 10.1021/jf402506c.

Fernandes, I., R. Pérez-Gregorio, S. Soares, N. Mateus, and V. D. Freitas. 2017. Wine flavonoids in health and disease prevention. *Molecules* 22 (2):292. doi: 10.3390/molecules22020292.

Ferreira, M. S., M. C. Santos, T. M. Moro, G. J. Basto, R. M. Andrade, and É. C. Gonçalves. 2015. Formulation and characterization of

functional foods based on fruit and vegetable residue flour. *Journal of Food Science and Technology* 52 (2):822–30. doi: 10.1007/s13197-013-1061-4.

Flach, J., M. B. van der Waal, M. van den Nieuwboer, E. Claassen, and O. F. Larsen. 2018. The underexposed role of food matrices in probiotic products: Reviewing the relationship between carrier matrices and product parameters. *Critical Reviews in Food Science and Nutrition* 58 (15):2570–84. doi: 10.1080/10408398.2017.1334624.

Giovinazzo, G., and F. Grieco. 2019. Tapping into health: wine as functional beverage. In *Alcoholic Beverages*, ed. A. Grumezescu and A. M. Holban, 279–302. Duxford, UK: Woodhead Publishing. doi: 10.1016/B978-0-12-815269-0.00009-X.

Gomand, F., F. Borges, J. Burgain, J. Guerin, A. M. Revol-Junelles, and C. Gaiani. 2019. Food matrix design for effective lactic acid bacteria delivery. *Annual Review of Food Science and Technology* 10:285–310. doi: 10.1146/annurev-food-032818-121140.

González-Domínguez, R., A. Sayago, and Á. Fernández-Recamales. 2019. Metabolomics: an emerging tool for wine characterization and the investigation of health benefits. In *Engineering tools in the beverage industry*, ed. A. M. Grumezescu and A. M. Holban, 315–50. Duxford, UK: Woodhead Publishing. doi: 10.1016/B978-0-12-815258-4.00011-1.

Johnson, M. H., and E. G. de Mejia. 2012. Comparison of chemical composition and antioxidant capacity of commercially available blueberry and blackberry wines in Illinois. *Journal of Food Science* 77 (1):C141–8. doi: 10.1111/j.1750-3841.2011.02505.x.

Johnson, M. H., E. G. de Mejia, J. Fan, M. A. Lila, and G. G. Yousef. 2013. Anthocyanins and proanthocyanidins from blueberry–blackberry fermented beverages inhibit markers of inflammation in macrophages and carbohydrate-utilizing enzymes in vitro. *Molecular Nutrition & Food Research* 57 (7):1182–97. doi: 10.1002/mnfr.201200678.

Kala, H. K., R. Mehta, K. K. Sen, R. Tandey, and V. Mandal. 2016. Critical analysis of research trends and issues in microwave assisted extraction of phenolics: Have we really done enough. *Trac Trends in Analytical Chemistry* 85:140–52. doi: 10.1016/j.trac.2016.09.007.

Kantachote, D., A. Ratanaburee, W. Hayisama-Ae, A. Sukhoom, and T. Nunkaew. 2017. The use of potential probiotic *Lactobacillus plantarum* DW12 for producing a novel functional beverage from mature coconut water. *Journal of Functional Foods* 32:401–8. doi: 10.1016/j.jff.2017.03.018.

Kellershohn, J. 2018. Alcoholic beverages: technology and next-generation marketing. In *Innovations in technologies for fermented food and beverage industries*, ed. S. K. Panda and P. H. Shetty, 105–20. Cham, Switzerland: Springer International Publishing AG. doi: 10.1007/978-3-319-74820-7_6.

Klarić, D. A., I. Klarić, and A. Mornar. 2011. Polyphenol content and antioxidant activity of commercial blackberry wines from Croatia: Application of multivariate analysis for geographic origin differentiation. *Journal of Food & Nutrition Research* 50 (4):199–209.

Lan, Y., J. Wu, X. Wang, X. Sun, R. M. Hackman, Z. Li, and X. Feng. 2017. Evaluation of antioxidant capacity and flavor profile change of pomegranate wine during fermentation and aging process. *Food Chemistry* 232:777–87. doi: 10.1016/j.foodchem.2017.04.030.

Lee, J. H., T. H. Kang, B. H. Um, E. H. Sohn, W. C. Han, S. H. Ji, and K. H. Jang. 2013. Evaluation of physicochemical properties and fermenting qualities of apple wines added with medicinal herbs. *Food Science and Biotechnology* 22 (4):1039–46. doi: 10.1007/s10068-013-0181-y.

Li, X., Y. Xing, L. Cao, Q. Xu, S. Li, R. Wang, Z. Jiang, Z. Che, and H. Lin. 2017. Effects of six commercial *Saccharomyces cerevisiae* strains on phenolic attributes, antioxidant activity, and aroma of Kiwifruit (*Actinidia deliciosa cv.*) wine. *BioMed Research International* 2017: 2934743. doi: 10.1155/2017/2934743.

Lima, G. P. P., F. Vianello, C. R. Corrêa, R. A. D. S. Campos, and M. G. Borguini. 2014. Polyphenols in fruits and vegetables and its effect on human health. *Food and Nutrition Sciences* 05 (11): 1065–82. doi: 10.4236/fns.2014.511117.

Liu, S., E. Liu, B. Zhu, B. Chai, R. Liu, Q. Gao, and B. Zhang. 2018. Impact of maceration time on colour-related phenolics, sensory characteristics and volatile composition of mulberry wine. *Journal of the Institute of Brewing* 124 (1):45–56. doi: 10.1002/jib.476.

Liu, G., J. Sun, X. He, Y. Tang, J. Li, D. Ling, C. Li, L. Li, F. Zheng, J. Sheng, et al. 2018. Fermentation process optimization and chemical constituent analysis on longan (*Dimocarpus longan* Lour.) wine. *Food Chemistry* 256:268–79. doi: 10.1016/j.foodchem.2018.02.064.

Ljevar, A., N. Ćurko, M. Tomašević, K. Radošević, V. G. Srček, and K. K. Ganić. 2016. Phenolic composition, antioxidant capacity and in vitro cytotoxicity assessment of fruit wines. *Food Technology and Biotechnology* 54 (2):145–55. doi: 10.17113/ftb.54.02.16.4208.

Mashayekh, S., M. Hashemiravan, and F. D. Mokhtari. 2016. Study on Chemical and Sensory Changes of probiotic fermented beverage based on mixture of pineapple, apple and mango juices. *Journal of Current Research in Science* 4 (3):1–5.

Mattila-Sandholm, T., P. Myllärinen, R. Crittenden, G. Mogensen, R. Fondén, and M. Saarela. 2002. Technological challenges for future probiotic foods. *International Dairy Journal* 12 (2–3):173–82. doi: 10.1016/S0958-6946(01)00099-1.

Mauray, A., C. Felgines, C. Morand, A. Mazur, A. Scalbert, and D. Milenkovic. 2010. Nutrigenomic analysis of the protective effects of bilberry anthocyanin-rich extract in apo E-deficient mice. *Genes & Nutrition* 5 (4):343–53. doi: 10.1007/s12263-010-0171-0.

Mauray, A., C. Felgines, C. Morand, A. Mazur, A. Scalbert, and D. Milenkovic. 2012. Bilberry anthocyanin-rich extract alters expression of genes related to atherosclerosis development in aorta of apo E-deficient mice. *Nutrition, Metabolism, and Cardiovascular Diseases* 22 (1):72–80. doi: 10.1016/j.numecd.2010.04.011.

Mauro, C. S. I., K. B. Guergoletto, and S. Garcia. 2016. Development of blueberry and carrot juice blend fermented by *Lactobacillus reuteri* LR92. *Beverages* 2 (4):1–11.37. doi: 10.3390/beverages20400:.

McDougall, G. J., C. Austin, E. Van Schayk, and P. Martin. 2016. Salal (*Gaultheria shallon*) and aronia (*Aronia melanocarpa*) fruits from Orkney: Phenolic content, composition and effect of wine-making. *Food Chemistry* 205:239–47. doi: 10.1016/j.foodchem.2016.03.025.

Minnaar, P. P., N. P. Jolly, V. Paulsen, H. W. Du Plessis, and M. Van Der Rijst. 2017. *Schizosaccharomyces pombe* and *Saccharomyces cerevisiae* yeasts in sequential fermentations: Effect on phenolic acids of fermented Kei-apple (*Dovyalis caffra* L.) juice. *International Journal of Food Microbiology* 257:232–7. doi: 10.1016/j.ijfoodmicro.2017.07.004.

Mitic, M. N., M. V. Obradovic, S. S. Mitic, A. N. Pavlovic, J. L. Pavlovic, and B. T. Stojanovic. 2013. Free radical scavenging activity and phenolic profile of selected Serbian red fruit wines. *Revista de Chimie* 64 (1):68–73.

Moreira, R. M., M. L. Martins, B. R. d C. Leite Júnior, E. M. F. Martins, A. M. Ramos, M. Cristianini, A. N. D. R. Campos, P. C. Stringheta, V. R. O. Silva, J. W. Canuto, et al. 2017. Development of a juçara and Ubá mango juice mixture with added *Lactobacillus rhamnosus* GG processed by high pressure. *LWT* 77:259–68. doi: 10.1016/j.lwt.2016.11.049.

Mudnic, I., D. Budimir, D. Modun, G. Gunjaca, I. Generalic, D. Skroza, V. Katalinic, I. Ljubenkov, and M. Boban. 2012. Antioxidant and vasodilatory effects of blackberry and grape wines. *Journal of Medicinal Food* 15 (3):315–21. doi: 10.1089/jmf.2011.0129.

Nash, V., C. S. Ranadheera, E. N. Georgousopoulou, D. D. Mellor, D. B. Panagiotakos, A. J. McKune, J. Kellett, and N. Naumovski. 2018. The effects of grape and red wine polyphenols on gut microbiota - A systematic review. *Food Research International (Ottawa, Ont.)* 113:277–87. doi: 10.1016/j.foodres.2018.07.019.

Navarro-González, I., J. García-Alonso, and M. J. Periago. 2018. Bioactive compounds of tomato: Cancer chemopreventive effects and influence on the transcriptome in hepatocytes. *Journal of Functional Foods* 42:271–80. doi: 10.1016/j.jff.2018.01.003.

Negi, B., and G. Dey. 2009. Comparative analysis of total phenolic content in sea buckthorn wine and other selected fruit wines. *World Academy of Science Engineering and Technology* 3 (6):300–3.

Negi, B., R. Kaur, and G. Dey. 2013. Protective effects of a novel sea buckthorn wine on oxidative stress and hypercholesterolemia. *Food & Function* 4 (2):240–8. doi: 10.1039/C2FO30125C.

Nematollahi, A., S. Sohrabvandi, A. M. Mortazavian, and S. Jazaeri. 2016. Viability of probiotic bacteria and some chemical and sensory characteristics in cornelian cherry juice during cold storage. *Electronic Journal of Biotechnology* 21:49–53. doi: 10.1016/j.ejbt.2016.03.001.

Opie, L. H., and S. Lecour. 2007. The red wine hypothesis: From concepts to protective signalling molecules. *European Heart Journal* 28 (14):1683–93. doi: 10.1093/eurheartj/ehm149.

Ortiz, J., Marín, M. R. -Arroyo, M. J. Noriega,-Domínguez, M. Navarro, and I. Arozarena. 2013. Color, phenolics, and antioxidant activity of blackberry (*Rubus glaucus* Benth.), blueberry (*Vaccinium floribundum* Kunth.), and apple wines from Ecuador. *Journal of Food Science* 78 (7):C985–93. doi: 10.1111/1750-3841.12148.

Panda, S. K., S. K. Behera, X. W. Qaku, S. Sekar, D. T. Ndinteh, H. M. Nanjundaswamy, R. C. Ray, and E. Kayitesi. 2017. Quality enhancement of prickly pears (*Opuntia sp.*) juice through probiotic fermentation using *Lactobacillus fermentum*-ATCC 9338. *LWT* 75:453–9. doi: 10.1016/j.lwt.2016.09.026.

Panghal, A., K. Virkar, V. Kumar, S. B. Dhull, Y. Gat, and N. Chhikara. 2017. Development of Probiotic Beetroot Drink. *Current Research in Nutrition and Food Science Journal* 5 (3):257–62. doi: 10.12944/CRNFSJ.5.3.10.

Prado, F. C., J. D. D. Lindner, J. Inaba, V. Thomaz-Soccol, S. K. Brar, and C. R. Soccol. 2015. Development and evaluation of a fermented coconut water beverage with potential health benefits. *Journal of Functional Foods* 12:489–97. doi: 10.1016/j.jff.2014.12.020.

Rupasinghe, H. V., and S. Clegg. 2007. Total antioxidant capacity, total phenolic content, mineral elements, and histamine concentrations in wines of different fruit sources. *Journal of Food Composition and Analysis* 20 (2):133–7. doi: 10.1016/j.jfca.2006.06.008.

Saggu, S., H. M. Divekar, V. Gupta, R. C. Sawhney, P. K. Banerjee, and R. Kumar. 2007. Adaptogenic and safety evaluation of seabuckthorn (*Hippophae rhamnoides*) leaf extract: A dose dependent study. *Food and Chemical Toxicology : An International Journal Published for the British Industrial Biological Research Association* 45 (4):609–17. doi: 10.1016/j.fct.2006.10.008.

Saguy, I. S. 2011. Paradigm shifts in academia and the food industry required to meet innovation challenges. *Trends in Food Science & Technology* 22 (9):467–75. doi: 10.1016/j.tifs.2011.04.003.

Shahidi, F., and P. Ambigaipalan. 2015. Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects–A review. *Journal of Functional Foods* 18:820–97. doi: 10.1016/j.jff.2015.06.018.

Sireswar, S., S. Biswas, and G. Dey. 2020. Adhesion and anti-inflammatory potential of *Lactobacillus rhamnosus* GG in a sea buckthorn based beverage matrix. *Food & Function* 11 (3):2555–72. doi: 10.1039/C9FO02249J.

Sireswar, S., and G. Dey. 2019. Matrix-wise evaluation of in vivo and in vitro efficiencies of *L. rhamnosus* GG-fortified beverages. *Food Research International (Ottawa, Ont.)* 119:908–19. doi: 10.1016/j.foodres.2018.10.077.

Sireswar, S., G. Dey, T. K. Sreesoundarya, and D. Sarkar. 2017. Design of probiotic-fortified food matrices influence their antipathogenic potential. *Food Bioscience* 20:28–35. doi: 10.1016/j.fbio.2017.08.002.

Sireswar, S., D. Montet, and G. Dey. 2018. Principal Component Analysis for Clustering Probiotic-Fortified Beverage Matrices Efficient in Elimination of *Shigella sp*. *Fermentation* 4 (2):34. doi: 10.3390/fermentation4020034.

Spencer, J. P. 2010. The impact of fruit flavonoids on memory and cognition. *British Journal of Nutrition* 104 (S3):S40–S47. doi: 10.1017/S0007114510003934.

Srikanta, A. H., A. Kumar, S. V. Sukhdeo, M. S. Peddha, and V. Govindaswamy. 2016. The antioxidant effect of mulberry and jamun fruit wines by ameliorating oxidative stress in streptozotocin-induced diabetic Wistar rats. *Food & Function* 7 (10):4422–31. doi: 10.1039/C6FO00372A.

Sun-Waterhouse. D. 2011. The development of fruit-based functional foods targeting the health and wellness market: A review. *International Journal of Food Science & Technology* 46 (5):899–920. doi: 10.1111/j.1365-2621.2010.02499.x.

Tabashsum, Z., M. Peng, E. Kahan, S. O. Rahaman, and D. Biswas. 2019. Effect of conjugated linoleic acid overproducing *Lactobacillus* with berry pomace phenolic extracts on *Campylobacter jejuni* pathogenesis. *Food & Function* 10 (1):296–303. doi: 10.1039/c8fo01863d.

Tchabo, W., Y. Ma, E. Kwaw, H. Zhang, X. Li, and N. A. Afoakwah. 2017. Effects of ultrasound, high pressure, and manosonication processes on phenolic profile and antioxidant properties of a sulfur dioxide-free mulberry (*Morus nigra*) wine. *Food and Bioprocess Technology* 10 (7):1210–23. doi: 10.1007/s11947-017-1892-5.

Tchabo, W., Y. Ma, E. Kwaw, H. Zhang, L. Xiao, and M. T. Apaliya. 2018. Statistical interpretation of chromatic indicators in correlation to phytochemical profile of a sulfur dioxide-free mulberry (*Morus nigra*) wine submitted to non-thermal maturation processes. *Food Chemistry* 239:470–7. doi: 10.1016/j.foodchem.2017.06.140.

Tortora, K., A. P. Femia, A. Romagnoli, I. Sineo, M. Khatib, N. Mulinacci, L. Giovannelli, and G. Caderni. 2018. Pomegranate By-Products in Colorectal Cancer Chemoprevention: Effects in Apc-Mutated Pirc Rats and Mechanistic Studies *in vitro* and *ex vivo*. *Molecular Nutrition & Food Research* 62 (2):1700401. doi: 10.1002/mnfr.201700401.

Tresserra-Rimbau, A., R. M. Lamuela-Raventos, and J. J. Moreno. 2018. Polyphenols, food and pharma. Current knowledge and directions for future research. *Biochemical Pharmacology* 156:186–95. doi: 10.1016/j.bcp.2018.07.050.

Uggla, M., X. Gao, and G. Werlemark. 2003. Variation among and within dogrose taxa (*Rosa sect.* caninae) in fruit weight, percentages of fruit flesh and dry matter, and vitamin C content. *Acta Agriculturae Scandinavica, Section B- Soil & Plant Science* 53 (3):147–55. doi: 10.1080/09064710310011746.

Uggla, M., K. E. Gustavsson, M. E. Olsson, and H. Nybom. 2005. Changes in colour and sugar content in rose hips (*Rosa dumalis* L. and *R. rubiginosa* L.) during ripening. *The Journal of Horticultural Science and Biotechnology* 80 (2):204–8. doi: 10.1080/14620316.2005.11511918.

Upadhyay, N., R. Kumar, S. K. Mandotra, R. N. Meena, M. S. Siddiqui, R. C. Sawhney, and A. Gupta. 2009. Safety and healing efficacy of Sea buckthorn (*Hippophae rhamnoides* L.) seed oil on burn wounds in rats. *Food and Chemical Toxicology : An International Journal Published for the British Industrial Biological Research Association* 47 (6):1146–53. doi: 10.1016/j.fct.2009.02.002.

van Breda, S. G., and T. M. de Kok. 2018. Smart combinations of bioactive compounds in fruits and vegetables may guide new strategies for personalized prevention of chronic diseases. *Molecular Nutrition & Food Research* 62 (1):1700597. doi: 10.1002/mnfr.201700597.

Wang, X., K. Xie, H. Zhuang, R. Ye, Z. Fang, and T. Feng. 2015. Volatile flavor compounds, total polyphenolic contents and antioxidant activities of a China gingko wine. *Food Chemistry* 182:41–6. doi: 10.1016/j.foodchem.2015.02.120.

Xiao, Z., L. Fang, Y. Niu, and H. Yu. 2015. Effect of cultivar and variety on phenolic compounds and antioxidant activity of cherry wine. *Food Chemistry* 186:69–73. doi: 10.1016/j.foodchem.2015.01.050.

Yang, G., Y. Jiang, W. Yang, F. Du, Y. Yao, C. Shi, and C. Wang. 2015. Effective treatment of hypertension by recombinant *Lactobacillus plantarum* expressing angiotensin converting enzyme inhibitory peptide. *Microbial Cell Factories* 14 (1):202. doi: 10.1186/s12934-015-0394-2.

Zhang, G.-Q., X.-D. Huang, H. Wang, A. K.-N. Leung, C.-L. Chan, D. W. F. Fong, and Z.-L. Yu. 2008. Anti-inflammatory and analgesic effects of the ethanol extract of *Rosa multiflora* Thunb. hips. *Journal of Ethnopharmacology* 118 (2):290–4. doi: 10.1016/j.jep.2008.04.014.

Zujko, M. E., and A. M. Witkowska. 2014. Antioxidant potential and polyphenol content of beverages, chocolates, nuts, and seeds. *International Journal of Food Properties* 17 (1):86–92. doi: 10.1080/10942912.2011.614984.