Wines from fruits other than grapes: Current status and future prospectus

Umesh B. Jagtap, Vishwas A. Bapat

Department of Biotechnology, Shivaji University, Vidyanagar, Kolhapur 416 004, (MS), India

Abstract

Several tropical, subtropical and temperate fruits although they differ in shape, colour, taste and nutritive values, provide numerous health benefits. Some of the edible fruits ripen within a very short period, usually leading to an overabundance of the fruits when harvested. Many of the fruits are consumed fresh, but large quantities of harvested fruits are wasted during peak harvest periods, due to the high temperature and humidity, poor handling, poor storage facilities and microbial infections. Therefore, winemaking from such ripe fruits or their juices is considered as an alternative of utilizing surplus and over-ripe fruits for generating additional revenues for the fruit growers. This review summarizes current knowledge about the usage of fruits other than grapes for winemaking and elaborates their properties; mainly quality, consumption, nutrition, sensory evaluation and health benefits. Hence, production and commercialization of non-grape fruit wines is the basis for the standardization of technologies for reducing post-harvest losses and contributes to the economy of the existing wine industry.

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Contents

1. Introduction ................................................................................ 81
2. Case studies ............................................................................. 83
   2.1. Temperate fruit crops ............................................................... 83
       2.1.1. Apple (Malus domestica Borkh.) ......................................... 83
       2.1.2. Blueberry (Vaccinium spp.) ............................................... 85
       2.1.3. Cherry (Prunus cerasus L.) .................................................. 85
       2.1.4. Elderberry (Sambucus nigra L.) .......................................... 85
       2.1.5. Peach (Prunus persica (L.) Batsch). ..................................... 86
       2.1.6. Raspberry (Rubus spp.) ...................................................... 86
   2.2. Tropical and subtropical fruits .................................................. 86
       2.2.1. Banana (Musa spp.) ......................................................... 86
       2.2.2. Cacao (Theobroma cacao L) ............................................... 87
       2.2.3. Cagaita (Eugenia dysenterica DC) ...................................... 87

*Corresponding author. Tel.: +91 231 2609365/+91 231 2609155; fax: +91 231 2691533.
E-mail address: vabapat@gmail.com (V.A. Bapat).

http://dx.doi.org/10.1016/j.fbio.2014.12.002
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1. Introduction

Winemaking is one of the most ancient of man’s technologies, and is now one of the most commercially prosperous biotechnological processes (Moreno-Arribas & Polo, 2005). The technique of winemaking is known since the dawn of civilization and has followed human and agricultural progress (Chambers & Pretorius, 2010). The earliest biomolecular archaeological evidence for plant additives in fermented beverages dates from the early Neolithic period in China and the Middle East, when the first plants and animals were domesticated and provided the basis for a complex society and permanent settlements (McGovern, Mirzoyan, & Hall, 2009). In ancient China, fermented beverages were routinely produced from rice, millet and fruits (McGovern et al., 2004). However, in earlier years in Egypt, a range of natural products specifically; herbs and tree resins were served with grape wine to prepare herbal medicinal wines (McGovern et al., 2009). Many of the polyphenols and other bioactive compounds in the source materials are bonded to insoluble plant compounds. The winemaking process releases many of these bioactive components into aqueous ethanolic solution, thus making them more biologically available for absorption during consumption (Shahidi, 2009). Wine is a distinctive product that influences major life events, from birth to death, victories, auspicious occasions, harvest and other events, due to its analgesic, disinfectant, and profound mind-altering effects (Bisson, Waterhouse, Eberle, Walker, & Lapsley, 2002; McGovern et al., 2004). Fruits produced by many indigenous trees are edible and can ripen within a very short span of time, generating surplus production. Many of these are consumed fresh, but large quantities are wasted during peak harvest periods, due to high temperature, humidity fluctuations, improper handling, inadequate storage facilities, inconvenient transport and microbial infections. The food industry uses a variety of preservation and processing, methods to extend the shelf life of fruits and vegetables such that they can be consumed year round, and transported safely to consumers all over the world, not only those living near the growing region (Barret & Lloyd, 2012). Therefore, utilization of ripe fruits or their juices for wines production is considered to be an attractive means of utilizing surplus and over-ripened fruits. Moreover, fermentation helps to preserve and enhance the nutritional value of foods and beverages. The research underway currently is to assess the potential of fruit species which have been explored by the food industries to meet the growing needs of the ever increasing consumer market for several fruits by-products including wines. In this context, fermentation steps aim to achieve the following:

- Preservation by means of acidification/alcohol production
- Alteration of chemical nature and sensory properties of fruit
- Improvement in efficacy of some bioactive constituents
- Enhancement of nutritional value of foods and beverages
- Increase in consumption and export of processed fruit products
- Attribution to better transportation and distribution system
- To reduce post-harvest and production losses
- To generate more profits
- Improved cultivation and commercialization
- Promote sustainable use of biomes

A wide variety of analytical techniques have been standardized for characterizing various foodstuffs mainly wine, honey, tea, olive oil and juices (Table 2). Simultaneously, consumer preferences for wine selection depend on several properties such as pleasant colour, taste, aroma, ecological
Wine consists of a diverse commodity class composed of the yeast fermentation products of must (or fruit juice). Wine is a fermented beverage produced from grapes only, otherwise wine is given the prefix of the fruit from which it originates (Voguel, 2003). Today, a big variety of fruits which differ in shape, colour, taste and nutritive value, are available in the market and many are utilized widely for production of fermented beverages (Fig. 1 and Table 1).

<table>
<thead>
<tr>
<th>Common/ vernacular name</th>
<th>Latin name</th>
<th>Family</th>
<th>Fermentative microorganism used</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>Musa sapientum L.</td>
<td>Musaceae</td>
<td>S. cerevisiae</td>
<td>Akbor et al. (2003)</td>
</tr>
<tr>
<td>Black Raspberry</td>
<td>Rubus occidentalis L.</td>
<td>Rosaceae</td>
<td>–</td>
<td>Jeong et al. (2010)</td>
</tr>
<tr>
<td>Cacao</td>
<td>Theobroma cacao L.</td>
<td>Malvaceae</td>
<td>S. cerevisiae UFSA CA 1162</td>
<td>Duarte et al. (2010a)</td>
</tr>
<tr>
<td>Cagaita</td>
<td>Eugenia dyssenterica DC</td>
<td>Myrtaceae</td>
<td>S. cerevisiae UFSA CA 11</td>
<td>Dias, Schwan and Lima (2003)</td>
</tr>
<tr>
<td>Cajá</td>
<td>Spondias mombin L.</td>
<td>Anacardiaceae</td>
<td>–</td>
<td>Ogunjobi and Ogunwolu (2010)</td>
</tr>
<tr>
<td>Cashew nut apple</td>
<td>Anacardium occidentale L.</td>
<td>Anacardiaceae</td>
<td>S. cerevisiae</td>
<td>Sun et al. (2011)</td>
</tr>
<tr>
<td>Cherry</td>
<td>Prunus cerasus L.</td>
<td>Rosaceae</td>
<td>S. cerevisiae UFSA CA 1162</td>
<td>Duarte et al. (2010a)</td>
</tr>
<tr>
<td>Cupuassu</td>
<td>Theobroma grandiflorum</td>
<td>Malvaceae</td>
<td>S. cerevisiae UFSA CA 1162</td>
<td>Jagtap and Bapat (2014)</td>
</tr>
<tr>
<td>Custard apple</td>
<td>Annona squamosa L.</td>
<td>Annonaceae</td>
<td>S. cerevisiae NCIM 3282</td>
<td>Schmitzer et al. (2010)</td>
</tr>
<tr>
<td>Elderberry</td>
<td>Sambucus nigra L.</td>
<td>Caprifoliaceae</td>
<td>Wine yeast</td>
<td>Duarte et al. (2010a)</td>
</tr>
<tr>
<td>Galiobroha</td>
<td>Campomanesia pubescens</td>
<td>Myrtaceae</td>
<td>S. cerevisiae UFSA CA 1162</td>
<td>Sevda and Rodrigues (2011)</td>
</tr>
<tr>
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<td>Psidium guajava L.</td>
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<td>Chowdhury and Ray (2007)</td>
</tr>
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<td>–</td>
<td>–</td>
<td>–</td>
</tr>
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<td>Myrtaceae</td>
<td>S. cerevisiae</td>
<td>Alves et al. (2011)</td>
</tr>
<tr>
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<td>S. cerevisiae UFSA CA 1162</td>
<td>Duarte et al. (2010a)</td>
</tr>
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<td>Lychee</td>
<td>Litchi chinensis Sonn</td>
<td>Sapindaceae</td>
<td>S. cerevisiae UFSA CA11, UFSA CA1174, and UFSA CA1183</td>
<td>Reddy and Reddy (2005)</td>
</tr>
<tr>
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<td>Nuenchammond and Ingkaninan (2010)</td>
</tr>
<tr>
<td>Mao</td>
<td>Antidesma thuwaitesianum</td>
<td>Euphorbiaceae</td>
<td>–</td>
<td>Sevda et al. (2008)</td>
</tr>
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<td>Citrus sinensis (L.) Osbeck</td>
<td>Rutaceae</td>
<td>–</td>
<td>Lasekan et al. (2007)</td>
</tr>
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<td>Elaeis guinensis Jacq.</td>
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<td>–</td>
<td>Lee et al. (2011a)</td>
</tr>
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<td>Alves et al. (2011)</td>
</tr>
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<td>Peach</td>
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<td>Rosaceae</td>
<td>S. cerevisiae</td>
<td>Reddy and Reddy (2005)</td>
</tr>
<tr>
<td>Purple Sweet</td>
<td>Ipomoea batatas L.</td>
<td>Convolvulaceae</td>
<td>S. cerevisiae</td>
<td>Su and Chien (2010)</td>
</tr>
<tr>
<td>Potato</td>
<td>Vaccinium ashei Reade</td>
<td>Ericaceae</td>
<td>S. cerevisiae</td>
<td>Alves et al. (2011)</td>
</tr>
<tr>
<td>Raspberry</td>
<td>Rubus idaeus L.</td>
<td>Rosaceae</td>
<td>S. cerevisiae and S. bayanus</td>
<td>Duarte et al. (2010b)</td>
</tr>
<tr>
<td>Sourcosp</td>
<td>Annona Muricata L.</td>
<td>Annonaceae</td>
<td>S. cerevisiae</td>
<td>Obiko and Obire (2009)</td>
</tr>
<tr>
<td>Umbu</td>
<td>Spondias tuberosa L.</td>
<td>Anacardiaceae</td>
<td>S. cerevisiae UFSA CA 1162</td>
<td>Duarte et al. (2010a)</td>
</tr>
</tbody>
</table>
evidences suggest that moderate consumption of red wine offers greater protection to health by reducing cardiovascular morbidity and mortality and this is attributed to antioxidant polyphenolics other than alcohol which are found particularly in red grape wine (Gresele et al., 2011; Halpern, 2008). The phenolic acids can scavenge free radicals and quench reactive oxygen species and therefore provide effective means of preventing and treating free radical mediated diseases (Shahidi, 2009). Also, wine polyphenols can lead to the modulation of both oral and gut microbiota (Requena et al., 2010). A partial summary of phytochemicals present in fruit wines (excluding grape wine) along with their bioactivities is presented in Table 3.

The focus of this review is to present a survey of fruit wines other than grape wine and to contribute to the popularization of these wines for their uses in human nutrition.

2. Case studies

2.1. Temperate fruit crops

2.1.1. Apple (Malus domestica Borkh.)

Apple (M. domestica Borkh.) is the most economically important and worldwide consumed fruit differing in organoleptic and nutritional characteristics and available in the market. It ranked fourth within the fruit crops in 2006 following bananas, grapes and citrus (http://www.faostat.fao.org). The fermented beverage obtained from apple is a popular drink in many western countries known as apple wine or cider and has become second largest fruit wine industry with increasing demand in China due to the overproduction of apples (Fan, Xu, & Yu, 2006; Wang, Xu, Zhao, & Li, 2004). Apple juice contains many sugars, including fructose, glucose, and sucrose along with other carbohydrates, in varying concentrations. The slow and incomplete alcoholic fermentations of apple juice are chronic problems for the fruit wine industry, which leads to spontaneous loss of tank capacity because of extended processing times and possible off-taste of the final product due to the high concentration of residual sugars, mainly fructose. Therefore, Wang, Xu, Hu, and Zhao (2004) studied a non-linear kinetic model to predict the consumption of different sugars (glucose, fructose and sucrose) as a substrate, during apple wine yeast fermentation with Saccharomyces cerevisiae strain CCTCC M201022 at flask-scale level. This model was used to predict sugar utilization by this specific yeast strain beginning at various initial sugar concentrations. This model was based on the logistic equation of yeast growth, growth-associated production of ethanol with a lag time, and consumption of sugars for biomass formation and maintenance. The results obtained based on estimated kinetic parameters and the characteristics of sugar utilization showed that the yeast examined appeared to be glucophilic. Due to the high fructose content in apple juice, the evaluation and selection of a fructophilic yeast strain could be significant to the apple wine industry. Therefore, the non-linear kinetic model developed by Wang et al. (2004) served as a potential tool for solving the fermentation problems by strain evaluation and selection of yeast fermentation performance.
The apple wine consists of different volatile components; however, both qualitative and quantitative information on characterizing aroma producing compounds in apple wine and their formation during fermentation are desired to provide quality control for apple wine. Some of the earlier methods including liquid-liquid extraction, static headspace extraction, and gas chromatography are used to analyze the chemical components in wine. A summary of analytical techniques used to investigate the chemical components in wine is presented in Table 2. The major phytochemicals in fruit wines and their bioactivities are listed in Table 3.
sampling, direct injection and solid phase extraction used for the analysis of volatile compounds in apple wine were tedious, time consuming, sometimes requiring large amounts of samples and solvents. To overcome these problems head-space solid-phase microextraction-gas chromatography/mass spectrometry (HS-SPME-GC/MS) technique were developed and employed for determination of flavour volatiles in apple wine with an alcohol content below 12% (v/v) (Wang et al., 2004). Similarly, a reliable SPE-HPLC/DAD method was developed for the simultaneous separation and quantitation of 10 furan derivatives in apple cider and wine matrices, including 5-hydroxymethyl-2-furaldehyde, 4-hydroxy-2, 5-dimethyl-3(2H)-furanone, 2-furoic acid, 2-furaldehyde, 3-furaldehyde, 2-acetylpyran, 5-methyl-2-furaldehyde, methyl 2-furoate, 2-propionylfuran and ethyl 2-furoate (Hu, Hernandez, Zhu, & Shao, 2013).

In another report, Fan et al. (2006) studied the effects of oak chips having diverse geographical origins (French, American and Chinese), with different toast levels (light, heavy and medium), dosages and ageing times on volatile compounds of apple cider. There was no significant differences observed in volatile compositions of ciders aged with French oak chips and American oak chips but significant difference was observed with ciders aged with Chinese oak chips. Furthermore, the volatile components and its concentration in the ciders depended on toasting level and dosage of oak chips. The medium toasting level oak chips released the highest concentrations of volatile components into the ciders. Therefore, the aroma compounds of cider can be increased by using mature oak chips, but additional research, including sensory evaluation is needed (Fan et al., 2006).

2.1.2. Blueberry (Vaccinium sps)
Several Vaccinium species are important commercially, like highbush (Vaccinium corymbosum), lowbush (Vaccinium angustifolium), rabbiteye (Vaccinium ashei) blueberries and large cranberries. The blueberry fruits and beverages made from fruits contain bioactive molecules having anti-diabetic properties (Basu et al., 2010; Stull, Cash, Johnson, Champagne, & Cefalu, 2010). Studies carried out by Johnson, Lucius, Meyer, and de Mejia (2011) showed that highbush blueberry (V. corymbosum) fruits were a rich source of antioxidant phenolic compounds having α-amylase and α-glucosidase inhibitory capacity as compared to ascorbic, a known anti-diabetic drug. The analysis of wines prepared from different blueberry cultivars fermented at room temperature and low temperatures were carried out and compared with respect to pH (3.5–6.3), Brix (13.6–29.7), total polyphenols (375.4-657.1 μg GAE ml⁻¹ wine), and antioxidant capacity (4.5–25.1 mM Trolox equivalent). However, the blueberry wines also possess α-amylase and α-glucosidase inhibitory action, which are important for type 2 diabetes management (Johnson et al., 2011). A capillary electrophoresis analysis of blueberry wine led to the determination of kaempferol, ferulic acid, vanillic acid, caffeic acid, gallic acid and protocatechuic acid (Li et al., 2011).

Recently, the chemical composition and antioxidant activities of Blueberry (V. ashei Reade) wines commercially available in Illinois, USA have been evaluated to study their potential health benefits (Johnson & Mejia, 2012). Blueberry wines had an average total polyphenolic content of 1623.3±645.5 mg l⁻¹ ellagic acid equivalents, total anthocyanin content of 20.82±12.14 mg l⁻¹ (cyanidin equivalents) and antioxidant capacity of 21.21±7.71 mM l⁻¹ trolox equivalents (TE). The results suggested that fruit wines made from blueberries may have potential health applications and therefore could contribute to the economy of the wine industry (Johnson & Mejia, 2012).

2.1.3. Cherry (Prunus cerasus L.)
The Shandong province of China is the largest producer of cherry (P. cerasus L.) crop occupying more than 8000 ha, producing 60,000 t fruits annually, generating sales revenue of over 2 billion Chinese Yuan (Han et al., 2008). The cherry fruits are perishable and those that are damaged during transportation may not be suitable for fresh consumption. Therefore the fruits are often processed into juice and wine to avoid post-harvest losses. The Shandong cherry wine has become popular in China due to its characteristic and distinct flavour and is important sector of the fruit industry. Recently, tart cherries of the 'Early Richmond' variety were fermented by using different S. cerevisiae (BM44, RA17, RC212, D254, D21 and GRE) strains to study their effect on the production of volatiles and polyphenols (Sun, Jiang, & Zhao, 2011). All the wines prepared were rich in acetic acid and 3-methylbutan, followed by 2-methylpropanol and ethyl lactate. However, RA17 and GRE fermented cherry wines contained higher amounts of esters and acids while, D254 fermented cherry wine contained a higher concentration of alcohols. The cherry wines all contained polyphenols (chlorogenic and neochlorogenic acids) anthocyanins (cyanidin 3-glucosylrutinoside and cyanidin 3-rutinoside) in higher amount. The principal component analysis classifies the cherry wines into three groups: (1) RA17 and GRE, (2) RC212 and D254 and (3) BM44 and D21 according to the volatiles and polyphenols present (Sun et al., 2011).

2.1.4. Elderberry (Sambucus nigra L.)
Elderberry (S. nigra L.) is a widespread species that grows on sunlight-exposed locations in Asia, Europe, North Africa and USA. The species is of appreciable importance as a source of edible fruits rich in phytochemicals, secondary metabolites including anthocyanins and phenolics, having antioxidant, anti-inflammatory and immune-stimulating activities. (Thole et al., 2006; Youdim, Martin, & Joseph, 2000). The colour and chemical composition, antioxidant capacity of elderberry must and wine was studied by Schmitzer, Veberic, Slatnar, and Stampar (2010). Elderberry wine produced here was intense red, having pH 3.9 with moderate ethanol concentration (13.2% v/v). Total phenolic content of elderberry must and wine ranged up to 2004.13 GAE l⁻¹. Elderberry must and wine were rich sources of phenolic compounds (chlorogenic acid, neochlorogenic acid, quercetin-3-rutinoside, quercetin-3-glucoside, kaempferol-3-rutinoside, and five cyanidin based anthocyanins). Elderberry wine showed higher antioxidative potential (9.95 mM trolox l⁻¹) than elderberry must (8.18 mM trolox l⁻¹). Antioxidative potential of elderberry wine was in the range of red wine, and significantly correlated with the total phenolic content of elderberry wine. Total phenolic content and antioxidant potential of elderberry wine were
significantly decreased with ageing and storage (Schmitz et al., 2010).

2.1.5. Peach (Prunus persica (L.) Batsch)

Peach (P. persica (L.) Batsch) is a tasty, sweet drupe fruit belonging to family Rosaceae. The wine was prepared from Redhaven variety of Peach contains lower alcohol content, TA and higher pH compared with white wine. The peach wine possess higher total phenolic content (402.53 mg l⁻¹ GAE) and total flavonoid content (322.67 mg l⁻¹ CAE) compared to white wines which have TPC (243.67–319.00 mg l⁻¹ GAE) and TFC (129.67–175.17 mg l⁻¹ CAE) resulting in higher antioxidant activities of peach wine. The main phenolic compounds found in peach wine were chlorogenic acid, caffeic acid, and catechin. The Peach wine was accepted by consumers as well as sensory panellists (Davidović et al., 2013).

2.1.6. Raspberry (Rubus spp.)

Korean black raspberry (R. coreanus Miq.) is widely cultivated in Korea and is available fresh but also consumed frozen and processed into juice, jam, ice cream and wine (Hager, Howard, Prior, & Brownmiller, 2008) and has been used as an oriental tonic medicine (Lim, Jeong, & Shin, 2012). Korean black raspberry juice and wine were rich source of phenolic compounds and its wines have been popular as traditional alcoholic beverages in Korea (Ku & Mun, 2008). Lim et al. (2012) studied the changes in the physicochemical properties and key compounds of the Korean black raspberry wines made from juice, juice–pulp and juice–pulp–seeds. The results revealed that the colour intensity of the wine made from juice supplemented with pulp and seeds were increased as compared with the wine made from only juice. However, citric acid and amino acid contents of the wines were reduced to 90% and less than 10% respectively by fermentation whereas; the total volatile compound content was increased 5.3 times having maximum content of isobutanol, n-propanol and isovaleryl acetate. The juice pulp–seed supplemented wine was rich in anthocyanin, polyphenols and proanthocyanin possess highest antioxidant activity. The content of proanthocyanidin in raspberry wine is two to three times greater compared to commercial grape wine which explains the bitter and astringent character of raspberry wine. In a sensory test, the highest scores for colour, flavour, taste and overall acceptance were awarded to the juice–pulp–seed wine (Lim et al., 2012). The work reported by Jeong et al. (2010) also showed that black raspberry wine prepared with inclusion of seeds showed higher antioxidant activity. Hwang and Shin (2013) isolated and characterized the immune stimulating polysaccharide from Korean black raspberry wine by size exclusion chromatography. However, five antioxidative active substances viz 4-hydroxybenzoic acid, 3,4-dihydroxy benzoic acid, 4-(2-hydroxyethyl)-phenol, pyrocatechol, 3,4,5-trihydroxybenzoic acid ethyl ester were isolated and identified from Korean black Raspberry wine (Kim et al., 2008). Similarly, R. coreanus Miq. fruits fermented with S. cerevisiae had a higher total phenolic content and a better DPPH radical-scavenging activity than the unfermented material (Ju et al., 2009).

Raspberries (Rubus idaeus L.) contain high levels of polyphenolic phytochemicals, particularly flavonoids and anthocyanin pigments, which give raspberries their characteristic colour. The phytochemicals in raspberries might have a significant antioxidant activity and act as a protectant against biological oxidative stress in mammalian cells (Weber & Liu, 2002). Phenolic acids, such as p-coumaric, caffeic, ferulic and ellagic acids, are generally found in raspberries (Häkkinen et al., 1999). Duarte et al. (2010b) carried out fermentation of raspberry pulp by using 16 yeast strains (S. cerevisiae and S. bayanus) and determined chemical composition of the produced wine. After a screening step based on sensory analysis, yeast strains CAT-1, UFLA FW 15 and S. bayanus CBS 1505 were previously selected based on their fermentative characteristics and profile of the metabolites identified. The beverage produced with CAT-1 showed the maximum volatile fatty acid concentration (1542.6 μg l⁻¹), whereas the beverage produced with UFLA FW 15 showed the highest concentration of acetate esters (2211.1 μg l⁻¹) and total volatile compounds (5835 μg l⁻¹). The highest concentration of volatile sulphur compounds (566.5 μg l⁻¹) were found in the beverage produced with S. bayanus CBS 1505; the lowest concentration (151.9 μg l⁻¹) was found in the beverage produced with UFLA FW 15. In the sensory analysis, the beverage produced with UFLA FW 15 was characterized by the descriptors raspberry, cherry, sweet, strawberry, floral and violet. In conclusion, strain UFLA FW 15 was the yeast that produced a raspberry wine with the best overall chemical and sensory quality (Duarte et al., 2010b).

The polyphenols, anthocyanins and ascorbic acids content in black raspberry (Rubus occidentalis) fruits, (with and without seeds extracted with 60% ethanol or water) and its wine (prepared with and without seeds) was determined along with their anti-oxidant, anti-proliferative and anti-inflammatory activities (Jeong et al., 2010). The fruits along with seeds extracted in ethanol, showed highest polyphenol content (8.25 mg g⁻¹ fruit) as well as antioxidant activities towards DPPH (IC₅₀ = 130 μg ml⁻¹ freeze-dried extract/reaction solution). However, raspberry wine prepared along with seeds shows highest antioxidant activity towards ABTS (IC₅₀ = 198 μg ml⁻¹). The black raspberry fruit (with seeds) extracted with ethanol significantly suppressed the proliferation of HT-29 colon cancer cells and LNCap prostate cancer cells in dose dependent manner as compared to fruit without seeds extracted in water. This is because ethanol could extract more polyphenols and anthocyanins from black raspberry compared to water and this raised anti-oxidant, anti-proliferation and anti-inflammation activities of the fruit extracts. Therefore, fruit extract and wine prepared from fruits along with seeds leads to increase in functional activities of the juice and wine (Jeong et al., 2010).

2.2. Tropical and subtropical fruits

2.2.1. Banana (Musa spp.)

Banana (Musa spp.) is an exclusively tropical plant and is the world’s leading fruit crop in terms of economic value in the world trade involving 100 countries (Aurore, Parfait, & Fahrasmane, 2009). Bananas are a seasonal crop and the shelf-life is short under the prevailing temperature and humidity conditions in tropical countries. Following maturity and harvest, there is a rapid rate of deterioration of ripe bananas. Though consumed to a considerable extent, large
quantities of ripe bananas are usually wasted as a result of poor handling, inadequate storage and poor transportation facilities. Therefore, methods to extend the shelf-life of bananas will be useful for reducing post-harvest losses. However, early efforts to process banana have not been successful (Mepba, Akpapunam, & Berepub, 1990). Fermenting banana juice is considered to be an attractive resource of utilizing surplus and over ripened bananas. Banana juice contained 3.0% total sugars, 0.08% protein, 0.35% ash, 5’ Brix soluble solids (SS), 9 mg per 100 ml vitamin C and has pH 4.45. The juice ameliorated to 18’ Brix was inoculated with 3% (v/v) Baker’s yeast (S. cerevisiae) and held at 30±2 °C for 14 days. As the fermentation of juice progresses, soluble solids, pH and specific gravity decreased while titratable acidity (TA) increased. The wine produced had 5% (v/v) alcohol, 0.04% protein, 4.8’ Brix SS, 0.85% TA and 1.4 mg per 100 ml vitamin C. Sensory evaluation results showed that there were no significant differences (p>0.05) in flavour, taste, clarity and overall acceptability between banana wine and a reference wine. The banana wine has generally been accepted by consumers (Akubor, Obio, Nwadomere, & Obiomah, 2003).

The pre-treatment of banana must with pectinase (0.05% w/w at 40 °C for 2 h) followed by treating with α-amylase (0.05% w/w at 50 °C for 3 h) enhance the hydrolysis of complex carbohydrates like pectin and starch which leads to increase in clarity, decrease in the viscosity (55%), 2.7-fold increase in the amount of extracted juice and a 15% and 39% increase in total soluble sugars and reducing sugars in extracted juice, respectively. Although the banana juice pre-treated with enzymes was rich in reducing sugars and produced four fold clearer wine than that of non-enzyme treated wine (control) after 25 days of fermentation there were no significant differences in total soluble solids, total soluble sugars, and alcohol concentrations (Cheirsilp & Umsakul, 2008).

On the other hand, Byaruagaba-Bazirake, Rensburg, and Kyamuhangire (2013) used recombinant yeast strains able to degrade different polysaccharides (glucans, xylans, pectins and starch) instead of commercial enzyme preparations for the process of winemaking to improve wine processing and wine quality. The Bagoya pulp treated with genetically modified yeast secreting glucanase and xylanase showed a 5.5% v/w increase in wine yield over that of the control yeast (non-recombinant). However, Kayinja pulp which was treated with genetically modified yeast secreting pectinase enzyme showed a 35% increase in wine yield compared to the wine obtained with the control yeast but without altering its physiochemical properties. Therefore, such a recombinant yeast strain could be used in banana wine fermentations as an alternative to commercial enzyme preparations (Byaruagaba-Bazirake et al., 2013).

2.2.2. Cacao (Theobroma cacao L.)
Cacao (T. cacao L.) is known worldwide for its beans, which are used in the production of chocolate and related products. The production and commercialization of cacao beans have long been the basis of the economy of some Brazilian states, especially Bahia. The pulp of the cacao fruit is a substrate rich in nutrients and is a by-product of the processing of the fruit and is a source for the production of wines and other products. The Cacao fruit pulp juice was fermented with yeast UFLA CA 1162 and analysis of minor and major compounds in cacao wine were carried out by using GC/MS and GC/FID (Duarte et al., 2010a). Six compounds, alcohols, monoterpenic alcohols, monoterpenic oxides, ethyl esters, acetate esters, volatile phenols, acids, carbonyl compounds, sulphur compounds and sugars were identified in the analysed wines. The results suggested that the use of Cacao fruits in the production of wine is a viable alternative that allows the use of harvest surpluses and other underused Cacao fruits, introducing a new product into the market (Duarte et al., 2010a).

2.2.3. Cagaita (Eugenia dysenterica DC)
The “cagaita” or “cagaita” (E. dysenterica DC) is an edible fruit belongs to Myrtaceae family and native to the Cerrado (Brazilian savannah). Although, fruits of the cagaita are tasty, rich in nutrients and offer attractive sensory characteristics (colour, flavour and aroma) they remain underutilized. Oliveira et al. (2011) prepared a wine from Cagaita fruit pulp and carried out a comparative study to evaluate the fermentations conducted with free and Ca-alginate immobilized cells of S. cerevisiae (UFLA CA11 and CAT-1) in triplicate, at 22 °C for 336 h. The Cagaita fruit pulp fermentation occur faster (4 days and 8 days respectively) with immobilized UFLA CA11 and CAT-1 yeast strains compared to fermentation (10 days and 12 days, respectively) with UFLA CA11 and CAT-1 free cells. However, ethanol content was slightly higher when the fermentation was conducted with free cells (94.63 and 94.94 g l⁻¹ for UFLA CA11 and CAT-1, respectively) than with immobilized cells (86.82 and 87.21 g l⁻¹ for UFLA CA11 and CAT-1, respectively). The wine prepared from CAT-1 free cells contains the highest concentration of higher alcohols (82,086.12 µg l⁻¹), whereas, the lowest concentration (37,812.17 µg l⁻¹) was found in the beverage from immobilized UFLA CA11. The ethyl ester concentrations were ranged from 1511.42 µg l⁻¹ (CAT-1 free cells) to 2836.34 µg l⁻¹ (UFLA CA11 free cells). According to the sensory evaluation, the fruit wine acceptability was greater than 70% for colour, flavour and taste for all cagaita beverages (Oliveira et al., 2011).

2.2.4. Cupuassu (Theobroma grandiflorum Schum.)
Cupuassu (T. grandiflorum Schum.) is a widely consumed fruit, native to the Brazilian states of Maranhão and Pará and a promising for commercialization in the Amazon region. It is also processed into juice, ice cream, jams, liquor, filling for chocolates, and other products. Cupuassu pulp juice was fermented with S. cerevisiae UFLA CA 1162 and analysis of minor and major compounds in Cupuassu wine were carried out by using GC/MS and GC/FID (Duarte et al., 2010a). The Cupuassu fruit wine contains highest concentration of hexanolic acid and presence of monoterpenic limentol, linalool, α-terpineol and geraniol, which have floral aromas reminiscent of rose essence. Further, Cupuassu fruit wine was subjected to the sensory analysis and showed highest percentage of acceptance for aroma (68%) compared to appearance (61%) and taste (58%). The results demonstrated that the use of tropical fruits in the production of fruit wines is a viable alternative that uses of harvest surpluses and other
underused fruits, resulting in the introduction of new products into the market (Duarte et al., 2010a).

2.2.5. Custard apple (Annona squamosa L.)
A. squamosa L. (Family: Annonaceae) popularly known as sugar apple or custard apple (in India) or sweetsop, is a species native to tropical America, and is cultivated in different tropical areas around the world. There is a strong consumer demand for ripe custard apple fruits due to its white and sweet delicate flesh and high nutrient value (Pinto et al., 2005). The fruits are generally consumed as fresh dessert fruits and also used for preparing juice, ice creams, milk shakes and soft drink (Luciana, Santos, Lúcia, & Maria Amélia, 2010). Custard apple is highly susceptible to spoilage, softens very rapidly during ripening, and becomes squashes and not easy to consume fresh (Okigbo & Obire, 2009).

Premature harvesting can result in poor fruit quality, and fruits left to ripe on the tree are often eaten by birds and bats, and when over mature have a tendency to break and decay (Pareek, Yahia, Pareek, & Kaushik, 2011). Therefore, there is greater need to processing the ripe custard apple fruits into suitable products to minimize the post-harvest losses. Jagtap and Bapat (2014), evaluated the potential of custard apple in the production of a beverage fermented using S. cerevisiae (NCIM 3282) yeast and assessed the antioxidant capacity, total phenolic content and DNA damage-protecting activity of custard apple fruit wine. Custard apple wine showed free radical scavenging activity towards DPPH, DMPD and FRAP. The reverse phase high pressure liquid chromatography with diode array detector analysis showed a presence of three hydroxybenzoic acids (gallic acid, protocatechuic acid, gentisic acid) and two hydroxycinnamic acids (caffeic acid, p-coumaric acid). Additionally, Custard apple fruit wine was also able to protect γ-radiation (100 Gy) induced DNA damage in pBR322 plasmid DNA suggested that it may has potential health applications and therefore could contribute to the economy of the wine industry.

2.2.6. Gabiroba [Campomanesia pubescens (DC.) O. Berg]
Gabiroba [C. pubescens (DC.) O. Berg] is a fruit and potential food source for native populations of the western and southern Brazilian savannah. Gabiroba fruit is consumed fresh as well as processed into ice cream, jams, juices and sweets. Gabiroba fruit pulp has a pH of 4.1 with a sugar content of about 14 Brix so it can be provide a good substrate for the winemaking (Duarte, Dias, Pereira, Gervásio, & Schwan 2009). Gabiroba fruit pulp juice fermented with UFLA CA 1162 yeast shows the presence of C6 compounds viz. (E)-2-hexenol (1.8 mg l\(^{-1}\)) and (E)-3-hexen-1-ol (2.1 mg l\(^{-1}\)) in the resulting wine. Gabiroba wines inoculated with S. cerevisiae UFLA CA 1162 and non-inoculated pulp (spontaneous fermentation) contained qualitatively, the same composition of alcohols: 1-butanol, 1-pentanol-3-methyl-3-buten-1-ol, 3-methyl-1-pentanol, 1-heptanol, 2-ethyl-1-hexanol, 1-octanol, furfural, benzyl alcohol and 2-phenoxethanol. However, the gabiroba wines contained ethyl esters, such as ethyl-3-methylbutanoate (fruity, sweet fruity aroma) ethyl hexanoate (fruity and green apple aroma) having odour activity values (OAV) 4.6 and 5.2 respectively. Compounds with higher OAVs contribute to aroma of fruit wines to a greater extent. Additionally, Gabiroba fruit wine was subjected to the sensory evaluation and has 63%, 60% and 52% acceptability for appearance, aroma and taste attributes respectively (Duarte et al., 2010a).

2.2.7. Guava (Psidium guajava L.)
Guava (P. guajava L.) belonging to the family Myrtaceae and is one of the most highly consumed fruits in India. The fruit is a good source of ascorbic acid, pectin, sugars and certain minerals with widely appreciated flavour and aroma. Guava juice (22 Brix) was fermented with two different S. cerevisiae NCIM 3095 and NCIM 3287 strains and optimization of guava wine fermentation with respect to osmotolerance, alcohol tolerance, inoculum size, initial pH of the medium, amount of SO\(_2\), amount of diammonium phosphate and incubation temperature were studied. For guava wine production, S. cerevisiae NCIM 3095 gave much better results (Sevda & Rodrigues, 2011).

GC/FID and GC/MS analysis of guava (Guava fruits var. Suprema Roja) wine revealed the presence of 124 volatile constituents including 52 esters, 24 alcohols, 11 ketones, seven acids, six aldehydes, six terpenes, four phenols and derivatives, four lactones, four sulphur compounds, and five miscellaneous compounds. The odorant compounds (E)-β-damascenone, ethyl octanoate, ethyl 3-phenylpropionate, ethyl hexanoate, 3-methylbutyl acetate, 2-methyltetrahydronioph-en-3-one, 4-methoxy-2,4-dimethyl-3(2H)-furanone, ethyl (E)-cinnamate, ethyl butanoate, (E)-cinnamyl acetate, 3-phenylpropyl acetate and ethyl 2-methylpropanoate were considered as odour-active volatiles (Pino & Queris, 2011a).

2.2.8. Jaboticaba (Myrciaria jaboticaba Berg)
The jaboticaba (M. jaboticaba Berg) tree, also known as the “Brazilian grape tree”, is a tree native to Brazil that belongs to the Myrtaceae family. Its fruits are purplish black, and their skin and pulp have a sweet taste and low acidity. Jaboticaba fruits are consumed fresh and in processed forms used as jams, juices and liqueurs. Duarte et al. (2010a) studied minor and major compounds in jaboticaba wine prepared by fermenting the fruit juice with yeast UFLA CA 1162. The jaboticaba wine has ca. 57 g l\(^{-1}\) ethanol concentration. The results showed that the fruit wines produced using pulps of Jaboticaba fruits presented several compounds that are also found in other types of wines, such as fruit and grape wines. The fact that this fruit wine had a composition similar to other beverages demonstrated that this fruit has the potential to be used to produce fermented beverages (Duarte et al., 2010a).

2.2.9. Jackfruit (Artocarpus heterophyllus Lam.)
The Jackfruit (A. heterophyllus Lam) tree belongs to the family Moraceae and distributed throughout the tropics and subtropics. However, the fruits are highly susceptible to spoilage and prone to microbial infections after ripening leading to the high post-harvest losses. Therefore, there is greater need to processing the ripe jackfruit into suitable products to minimize the post-harvest losses. Jagtap and co-workers (2011) prepared wine from jackfruit pulp and evaluated the total phenolic content, flavonoid contents and antioxidant properties of wine. The jackfruit wine was effective in DPPH radical scavenging (69.44 ± 0.34%), FRAP (0.358 optical density value,
O.D.), DMPD (78.45±0.05%) and NO (62.46±0.45%) capacity. The two phenolic compounds namely gallic acid and protocatechuic acid were identified in jackfruit wine. The jackfruit wine was also able to protect H₂O₂+UV radiation and γ-radiation (100 Gy) induced DNA damage in pBR322 plasmid DNA. The antioxidant and DNA damage protecting properties of Jackfruit wine confirmed health benefits when consumed in moderation and could become a valuable source of antioxidant rich nutraceuticals (Jagtap, Waghmare, Lokhande, Suprasanna, & Bapat, 2011).

2.2.10. Jamun (Syzygium cumini L.)
Jamun (S. cumini L.) is tropical tree belonging to the family Myrtaceae, native to India and Indonesia and producing oblong, ovoid and shining crimson black berries rich in anthocyanins when fully ripe. Jamun fruits also possess some medicinal properties and used for curing diabetes because of their effects on the pancreas (Joshi, 2001). Anthocyanin rich Jamun fruits were fermented with S. cerevisiae, which resulted in a sparkling red wine having an acidic taste (total acidity=1.11±0.07 g tartaric acid, 100 ml⁻¹), high tannin content (1.7±0.15 mg, 100 ml⁻¹) and low alcohol (6%) concentration. Jamun wine also possessed medicinal properties: anti-diabetic properties and the ability to cure bleeding piles (Chowdhury & Ray, 2007). The sensory analysis accepted jamun wine as an alcoholic beverage. However, It was significantly differ (P<0.05) from the commercial grape wine particularly in taste, flavour and after taste lingering effects probably due to the high tannin content in the Jamun wine (Chowdhury & Ray, 2007). On the other hand, Nuengchamnong and Ingkaninan (2009) used HPLC coupled on-line to a radical scavenging detection system and MS to identify and characterize antioxidant compounds in S. cumini fruit wines. The major antioxidants found were a complicated mixture of hydrolysable tannins and fruit acids.

2.2.11. Kiwifruit (Actinidia spp.)
The fruit of the Actinidia plant is known more commonly as kiwifruit. Soufleros et al. (2003) investigated the chemical composition and evaluated sensory properties of kiwifruit wine. Recently, Towantakavanit, Park, and Gorinstein (2011) evaluated the fruit maturity (ripe and over-ripened fruit) value of ‘Hayward’ kiwifruit (Actinidia deliciosa (A. Chev.) C.F. Liang and A. R. Ferguson) as material for wine production. The pre-treatment of ripe kiwifruit pulp with pecitnase increased the yield of wine production from 63.35% to 66.19%. The wine produced from over-ripened fruits has soluble solid content (13.5%) with a high amount of potassium as compared to the wine produced from ripe fruit (10.3%). However, difference in fruit maturity did not affect acidity, pH, colour, total phenolic content and antioxidant activities of wine significantly. The kiwifruit wine made from over-ripened fruits treated with pectinase was superior in many ways, such as sensory value, alcohol and total phenolic content, antioxidant activity, minerals and production yield (Towantakavanit et al., 2011).

2.2.12. Lychee (Litchi chinensis Sonn)
Lychee (L. chinensis Sonn) is a plant belonging to the Sapindaceae family, native of Southern China. The overproduction of fruits leads to significant post-harvest losses due to red discoloration of the pericarp, which soon becomes brown after the harvest, because of poor handling and insufficient storage facilities (Mahattanatwatee, Perez-Cacho, Venport, & Rouseff, 2007). The production surplus of lychee fruits is thus made into wine, generating additional revenue for the grower and reducing post-harvest losses (Alves, Lima, Nunes, Dias, & Schwan, 2011). Lychee wines were prepared by using three yeast strains (UFLA CA11, UFLA CA1183, and UFLA CA1174) plus a spontaneous fermentation showed greater variations in the qualitative than in the quantitative analysis of their constituents. The wines fermented by yeast UFLA CA1183 and UFLA CA11 received acceptance above 75%. However, based on principal components analysis yeast UFLA CA1183 strain was found to be the most suitable for the production of lychee wines (Alves et al., 2011).

The evolution of volatile components during litchi wine-making and aroma profiles of litchi wines determined using HS-SPME-GC/MS showed that majority of terpenoids derived from litchi juice decreased, even disappeared during alcoholic fermentation, while terpenol oxides, ethers, and acetates increased. However, ethyl octanoate, isoamyl acetate, ethyl hexanoate, ethyl butanoate, cis- rose oxide, and trans- rose oxide had the highest OAVs in young litchi wines offering floral and fruity attributes. Compared to ambient temperature with bottle aging, lower temperature benefited key aroma retention and (as expected) extended the shelf life of young litchi wines (Wu, Zhu, Tu, Duan, & Pan, 2011).

2.2.13. Mango (Mangifera indica L.)
The mango (M. indica L.) fruit is one of the most highly priced desert fruits of the tropics. It has a rich luscious, aromatic flavour and delicious taste. Mangoes are cultivated in 85 countries of Asia and other oriental countries, producing around 80% of the world’s total crop. Major mango producing countries are India, Mexico, China and Pakistan.

The mango juice fermentation at the laboratory scale with controlled inoculation using selected yeast strain (S. cerevisiae 101) was performed by Reddy and Reddy (2010) who studied effect of fermentation conditions (temperature, pH, SO₂ content and aeration) on wine fermentation based on yeast growth, duration, fermentation rate and volatile composition. The composition of the major volatile compounds with low boiling points was determined by gas chromatography under the different operating conditions of fermentation temperatures (15–35 °C), pH (3.5–6.0), SO₂ (100–300 ppm) and aeration (initial dissolved O₂ and shaking at 30 rpm).Temperature had an important effect on yeast growth and on the levels of volatile compounds. It was observed that the final concentrations of ethyl acetate and some of the higher alcohols decreased when fermentation temperature was increased to 25 °C (35 mg l⁻¹ at 15 °C and 27 mg l⁻¹ at 25 °C). SO₂ stimulated the yeast growth up to a certain level and in excess it inhibited the yeast metabolism. Ethanol concentration was slightly higher (8.2 g l⁻¹) in the presence of 100 ppm SO₂, as opposed to (6.2 g l⁻¹) with 300 ppm of added SO₂. Aeration by shaking increased the viable yeast cell count from 52 × 10⁶ in the absence of oxygen to 98 × 10⁶ by shaking at 30 rpm, but decreased the ethanol productivity from 7.2 g l⁻¹ in the
presence of dissolved O₂ to 6.5 g l⁻¹ with shaking at 30 rpm. The results revealed that the temperature (25 °C), pH (5), SO₂ (100 ppm) and must with initial oxygen were optimum for better quality of wine from mango fruits (Reddy & Reddy, 2010).

Similarly, the mode of higher alcohols synthesis during wine fermentation from two mango cultivars Banginapalli and Totapuri was evaluated by Reddy and Reddy (2009). The wine produced from Totapuri cultivar had more volatiles (358 ± 12.7 mg l⁻¹) than wine from Banginapalli cultivar (340 ± 10.5 mg l⁻¹). The pectinase treatment increased the mango juice yield and increased the synthesis of iso-amylalcohol, 2-phenyl ethanol, n-propanol, n-butanol and methanol during fermentation which results in better wine sensory quality (Reddy & Reddy, 2009). Also, the use of exogenous β-glucosidase in mango pulp maceration and juice fermentation led to the enhancement of mango wine aroma, shown by higher levels of fatty acids and their ethyl esters, without affecting pH, sugars and organic acid content significantly. The addition of β-glucosidase could accelerate the release of terpenols, acetate esters, benzene derivatives and C13-norisoprenoids odour active volatiles and was found to be effective in intensification, diversification and balancing of mango wine aroma profile (Li, Lim, Yu, Curran, & Liu, 2013).

In another report Varakumar, Kumar, and Reddy (2011) studied the carotenoid compositions of wine made from seven mango cultivars. The xanthophyll percentage in the wines decreased in the range of 69.3–89.7%, and >80% degradation was noted in Banginapalli, Neelam, Sindhura and Totapuri mango varietal wines along with 15.3–26.5% degradation for β-carotene. However, significant degradation of β-carotene was observed in Totapuri wine. The highest DPPH radical-scavenging activity was shown by wine prepared from Alphonso (91%), Sindhura (90%) and Banginapalli (88%) cultivars respectively, whereas Alphonso (71%), Banginapalli (69%) and Sindhura (68.5%) varietal wines showed higher inhibitory effects on low-density lipoprotein oxidation. (Varakumar et al., 2011). Recently, Kondapalli, Sadineni, Variyar, Sharma, and Obulama (2014) studied that mango wine treated with γ-irradiation (3 kGy) resulted not only in an increased total phenolic content (226.8–555.3 mg l⁻¹) and total flavonoid content (68.6–165.1 mg l⁻¹) but also decreased microbial loads in a dose dependent manner; leading to improvement in the quality of wine. Furthermore, antioxidative activities of Mango wines were significantly increased with radiation dose and also with concentration of wine. Also, Mango wine was also able to protect DNA against radiation dose and also with concentration of wine. Besides, this simultaneous treatment irrespective of yeast strain showed better sensorial attributes in flavour, fruity aroma, and overall acceptability without affecting volatile aroma composition of the final wine. (Varakumar et al., 2013).

2.2.14. Orange (Citrus sinensis [L.] Osbeck)
Orange is the most important Citrus fruits cultivated throughout the tropical and subtropical areas of world. Among oranges, Moro (C. sinensis [L.] Osbeck) is a blood orange variety having bright red exterior and deep red interior (Mondello, Cotroneo, Errante, Dugo, & Dugo, 2000; Mouly, Gaydou, Faure, & Estienne, 1997). A total of 64 volatiles, including higher alcohols, esters, terpenes, acids, volatile phenols, lactones, acetal compounds, ketone, aldehydes and acetoins were analysed in blood orange wine by GC/FID and GC/MS (Selli, 2007). However, the juice and wine prepared from the cv. Kozano of Turkey contained higher amounts of citric acid and sucrose. Orange juice and wine were rich sources of phenolic compounds hydroxybenzoic acids, hydroxychinamic acids and flavanones along with hesperidin, narinutin and ferulic acid. The antioxidant capacity of orange juice was found to be higher than that of orange wine (Kelebek, Selli, Canbas, & Cabaroglu, 2009). However, 75 volatile components including terpenes, alcohols, esters, volatile phenols, acids, ketones, aldehydes, lactones and C13-norisoprenoids were identified in Kozaan wine. Amongst these, Isoamyl alcohol, 2-phenylethanol, linalool, terpinene-4-ol and ethyl-4-hydroxy butanoate were the main components contributing to the wine aroma along with ethyl hexanoate, ethyl octanoate, citronellol and eugenol (Selli, Cabaroglu, & Canbas, 2003). In another report, Selli, Canbaslı, and Ünal (2002) studied the effect of bottle colour (clear white, green and brown), storage temperature (13–14 °C and 23–26 °C) and storage time (0, 75 and 150 days) on the browning of orange wine. The results showed that the use of brown bottles and the short time storage reduced the browning in orange wines; however, storage at two different temperatures did not significantly affect the browning index (Selli et al., 2002).

The different yeast strains S. cerevisiae (isolated from yam), S. cerevisiae (from sugarcane molasses), S. carlsbergensis (from sugarcane molasses) and S. cerevisiae var. ellipsoides (from orange juice) used for fermentation of orange juice affect the total alcohol concentration in orange wine. Orange wine produced with S. cerevisiae var. ellipsoides contained highest ethanol (90.38%) while, S. cerevisiae (from sugarcane molasses) produced wine with least ethanol concentration (81.49%). The methanol concentration was varied between 9.51% with S. cerevisiae var. ellipsoides and 14.93% with S. carlsbergensis. The isopropanol was detected in negligible amount (0.10–0.25%) except with S. cerevisiae (from sugarcane molasses) which produced 5.46% of the total alcohol. The S. carlsbergensis fermented wine has highest total alcohol (6.50 ± 0.15%) while, S. cerevisiae var. ellipsoides fermented wine has 3.23 ± 0.12% (Okunowo & Osuntoki, 2007).
2.2.15. Palm (Elaeis guineensis Jacq)
The palms are tropical trees such as oil palm (E. guineensis), coconut palm (Phoenix dactylifera) and raffia palm (Raphia hookeri) belonging to the palmaceae family. Palm wine is a whitish, effervescent, alcoholic beverage produced by the spontaneous yeast-lactic fermentation of the sugary sap of palm trees. It is indigenous to the tropical regions mainly in Africa, Asia and South America (Uzochukwu, Balogh, Tucknot, Lewis, & Ngoddy, 1994). Palm wine (E. guineensis Jacq, Family: Arecaceae) was sensorally evaluated and the key odorants were investigated by means of high resolution GC-olfactometry and mass spectrometry of solvent extracts as well as of headspace samples. The 13 key odorants revealed that the earthy-smelling 3-isobutyl-2-methoxyxpyrazine, the butterny-smelling acetoin, the fruity compounds ethyl hexanoate, 3-methylbutyl acetate and the popcorn-like-smelling 2-acetyl-1-pyrroline are likely to be important odorants with 3-isobutyl-2-methoxyxpyrazine, acetoin, and 2-acetyl-1-pyrroline being reported here for the first time as aroma constituents of palm wine (Lasekan, Buettner, & Christibauer, 2007). The great yeast diversity (including S. ludwigii, Zygosaccharomyces bailii, Hanseniaspora uvarum, Candida parapsilosis, Candida fermentatii, Pichia fermentans) and the presence of lactic acid and acetic acid bacteria during the palm wine tapping process indicated that a multi starter fermentation occurs in a natural, semi-continuous fermentation process (Stringini, Comititi, Taccari, & Ciani, 2009).

Karamoko, Djeni, N’Guessoan, Bouatenin, and Dje (2012) studied biochemical and microbiological properties of different week-old fresh palm saps and assess whether changes occurring during storage of the fermenting saps could affect their quality. The results showed that during the storage, accumulation of alcohol occurred in all palm wine samples with the concurrent lactic and acetic acid fermentation taking place as well. Yeasts and lactic acid bacteria populations also changed the palm wine quality affecting safety, biochemical and nutritional value. Therefore, further studies regarding involvement of these microorganisms in wine and its effect on food safety will be essential to commercialization of wine (Karamoko et al., 2012).

2.2.16. Papaya (Carica papaya L.)
Papaya (C. papaya L.) is one of the major fruit crops cultivated in South East Asia. Papayas are commonly consumed fresh or used as an ingredient for other foods such as jellies, jams and juices. It has been proposed as a potential renewable energy resource for industrial alcohol production because of its low cost and easy availability (Sharma & Ogbeide, 1982). However, not all the harvest fruits reach their destination in the market owing to a rapid post-harvest deterioration. (Lee, Yu, Curran, & Liu, 2011a).

Fusel oil (a by-product of the alcohol distillation industry) addition (0%, 0.1% and 0.5% v/v) to papaya wine fermented with yeast Williopsis saturnus var. mrakiiNCYC2251 produced a wide range of volatile compounds. The yeast growth, Brix and pH characteristics were similar for all fermentations except for those added with 0.5% (v/v) fusel oil which inhibited the yeast growth. The addition of 0.1% (v/v) fusel oil reduced the production of undesirable volatiles such as ethyl acetate and acetic acid, while increasing the desirable volatiles production such as ethanol and acetate esters. This study demonstrated that papaya juice fermentation with the same yeast as above together with a low concentration of added fusel oil can be an alternative technique of modulating papaya wine aroma compound formation (Lee et al., 2011a).

Similarly, the impact of amino acid (l-leucine, l-isoleucine, l-valine and l-phenylalanine) addition on aroma compound formation in papaya wine fermented with yeast W. saturnus var. mrakiiNCYC2251 was studied by Lee, Yu, Curran, and Liu (2011b). The results revealed that l-Leucine addition increased the production of isoamyl alcohol and some esters such as isoamyl acetate, isoamyl butyrate and isoamyl propionate, while l-isoleucine addition increased the production of active amyl alcohol and active amyl acetate. l-valine addition slightly increased the production of isobutyl alcohol and isobutyl acetate. l-phenylalanine addition increased the formation of 2-phenylethanol, 2-phenylethyl acetate and 2-phenylethyl butyrate, while decreasing the production of most other esters. Therefore, the papaya juice fermentation with W. saturnus var. mrakiiNCYC2251 in conjunction with the addition of selected amino acid(s) can be an effective way to modulate the aroma of papaya wine (Lee et al., 2011b).

In another study, Lee, Chong, Yu, Curran, and Liu (2012) investigated the effects of sequential inoculation of yeasts W. saturnus var. mrakiiNCYC2251 and S. cerevisiae var. bayanus R2 on the volatile profiles of papaya wine. Inoculation of S. cerevisiae after 7 days fermentation with W. saturnus produced papaya wine with more acetate esters and fruitiness than the control (simultaneous inoculation). However, inoculation of W. saturnus after 2 days fermentation with S. cerevisiae resulted in most of the volatile composition being comparable to the control, except for the enhanced amount of ethyl esters. The first inoculated yeast dominated the fermentation. The study showed that sequential inoculation of non-Saccharomyces and Saccharomyces yeasts at a certain inoculum ratio may be a valuable tool to manipulate yeast succession and to modulate the volatile profiles and organoleptic properties of papaya wine. Hernández, Lobo, and González (2009) established the optimal conditions for extracting oxalic, citric, tartaric, l-malic, quinic, succinic and fumaric organic acids from papaya using solvent extraction before the determination of these compounds via liquid chromatography. The extractant composition was statistically the most significant factor and that the optimum values of the variables that influence the extraction of organic acids were: three extractions, water as extractant, 60 min extraction time and 65 °C extraction temperature.

2.2.17. Pineapple (Ananas comosus (L.) Merr.)
Pineapple (A. comosus (L.) Merr. Family: Bromeliaceae) is one of the most popular subtropical fruits cultivated and consumed worldwide. The fruits are consumed fresh and largely used in the food industry for the production of canned fruit, jam, and concentrated juice and also in wine production. Ayogu (1999) demonstrated that S. cerevisiae species isolated from the fermenting sap of Elaeis guineensis (palm wine) was suitable for winemaking from pineapple fruits. This yeast isolate gave high ethanol yield of 10.2% (v/v) as compared to the wine yeast (control) which gave 7.4% (v/v), indicative of higher ethanol tolerance by this isolate. Nigerian palm wine,
which harbours quite a number of these yeasts, could serve as an alternative source of yeast for commercial winemaking from pineapple fruits (Ayogu, 1999).

The freshly crushed pineapple juice collected from Thailand and Australia countries shows the presence of H. uvarum and Pichia guilliermondii yeast strains during the fermentation process. (Chanprasartsuk, Prakitchaiwattana, Sanguandeekul, & Fleet, 2010). P. guilliermondii was dominant and was consistently present during the early stage of the fermentation, whereas H. uvarum species populations increased from an initial level of ~5 log CFU ml⁻¹ to ~8 log CFU ml⁻¹ at the end of 6-day fermentation period. The maximum ethanol concentration ~1–2% (v/v) were found in Thai samples at 2 days of fermentation, but then declined thereafter. In contrast, the Australian samples shows continuous increase in ethanol concentration and reached ~3–4% (v/v) after the entire 6-day fermentation period. The Thai samples showed a significant decrease in citric acid and increase in lactic acid levels while samples from Australia has stable concentration of different acids throughout the fermentation period. The other wine yeasts and, in particular, Saccharomyces yeasts, were not found in any of the samples fermentation systems, unlike many other fruit juices. Therefore, it was concluded that the freshly crushed pineapple juice may possibly have some effects on the other autochthonous yeasts having important role in alcoholic fermentation (Chanprasartsuk et al., 2010). The HS-SPME combined with GC/MS analysis detected 18 volatiles including 13 esters, four alcohols and one acid with ethyl octanoate, ethyl acetate, 3-methyl-1-butanol and ethyl decanoate were the major constituents. However, on the basis of OAV, ethyl octanoate, ethyl acetate and ethyl 2-methylpropanoate compounds were strongly contributed to the Pineapple wine aroma (Pino & Queris, 2010). A clarification of pineapple wine with microfiltration process were carried out by Youravong, Li, and Laorok (2010). It was observed that increasing gas sparging rate could reduce reversible fouling rather than irreversible fouling. The turbidity of pineapple wine was reduced and a clear product with bright yellow colour was obtained after microfiltration. The negative effect of gas sparging, a loss of alcohol content in the wine, was also observed.

2.2.18. Pomegranate (Punica granatum L.)

Pomegranate (P. granatum. L Family: Lythraceae) has been revealed as a promising source of phytochemicals and phenolic compounds, such as anthocyanins and ellagitannins (Mena, Gironés-Vilaplana, Moreno, & García-Viguera, 2011). The large quantities of pomegranate fruits are wasted due to poor handling and over-ripening as they prone to the microbiological deterioration. Therefore Pomegranate fruits are usually processed into juices, jams and various other products with the aim of minimizing production losses and generating more profits. The over-ripen pomegranate fruits of Wonderful and Mollar de Elche varieties were used for the production of wine. The pomegranate wines were rich in anthocyanins which was responsible for the antioxidant properties and colour of the wine. Therefore, Pomegranate wine provides a new value added product that offers beneficial health effects (Mena, Gil-Izquierdo, Moreno, Martí, & García-Viguera, 2012).

Similarly, in another study Mena, Gironés-Vilaplana, Martí, and Garcia-Viguera (2012) reported the presence of melatonin (N-acetyl-5-methoxytryptamine) in the wine made from pomegranate cultivars, Wonderful and Mollar de Elche. Melatonin (N-acetyl-5-methoxytryptamine) is a neurohormone related to a broad array of physiological functions and has proven therapeutic properties. Some foods also contain melatonin and their consumption has been considered as an exogenous source, able to increase melatonin circulating levels.

2.2.19. Soursop (Annona muricata L.)

Soursop (A. muricata L.) belonging to the family Annonaceae and indigenous to tropical north and south America, it has sweet, aromatic, juicy edible white pulp. However, over-ripen fruits are susceptible to spoilage due to microbial infections which results in great post-harvest losses (Abbo, O lurin, & Odeyemi, 2006). Soursop fruits also processed into other value added products such as juice, beverages, wine, jellies, jam puree, power fruit bars, and flakes. The soursoup wine was prepared by using mycoclora associated with the different parts of fresh and rotten fruits along with indigenous yeast flora and commercial yeast extract. Botryodiplodia theobromae was isolated from the rotten fruits (skin) while Trichoderma viride was isolated from the fresh fruits. However, Penicillium sp., was the most dominant in all the parts of fresh soursop fruit while Rhizopus stolonifer occurs in high percentage in rotten fruits. The wine obtained from the pasteurized, ameliorated soursop juice inoculated with propagated indigenous yeast yielded the highest alcoholic content. A. muricata is good source for wine production and single-cell protein due to high nutritional composition of soursop juice, high alcoholic content and palatability of the wine (Okigbo & Obire, 2009).

2.2.20. Sweet potato (Ipomoea batatas L.)

Purple sweet potato (PSP) (I. batatas L.) is a rich source of anthocyanin pigments. A herbal PSP wine was prepared from purple-fleshed sweet potato rich in anthocyanin pigment and 18 medicinal plant parts (fruits of ink nut, Indian gooseberry, garlic, cinnamon, leaves of holy basil, night jasmine, Malabar nut, roots of belladonna, asparagus, rhizome of ginger, etc.) by fermenting with wine yeast, S. cerevisiae. The herbal PSP wine was a novel product with ethanol content of 8.61% (v/v) and rich source of antioxidant anthocyanin which offers remedies for cold, coughs, skin diseases and dysentery (Panda, Swain, Singh, & Ray, 2013).

2.2.21. Umbu (Spondias tuberosa L.)

Umbu (S. tuberosa L.) is a fruit native to the semi-arid regions in the Brazilian northeast Pernambuco province. It is consumed locally as a fresh fruit and also as juice and ice cream. Umbu pulp has a pH of 2.2 and a sugar content of 14.8 Brix; these values may vary according the climate of the region of origin of the plant (Lira Júnior et al., 2005). The umbu fruit wine showed presence of geranic acid along with monoterpenes. Duarte et al. (2010a) studied minor and major compounds in umbu wine by using GC/MS and GC/FID. The fermentation of fruit juice was carried out by yeast UFLA CA 1162. C6 compounds, alcohols, monoterpenic alcohols,
monoterpenic oxides, ethyl esters, acetates, volatile phenols, acids, carbonyl compounds, sulphur compounds and sugars were identified in the wine. Furthermore, sensory analysis of wine showed highest percentage of acceptance (74%) for aroma as compared to appearance of (63%) and (57%) taste. The results indicated that the use of these tropical fruits in the production of fruit wines was a viable alternative that allows the use of harvest surpluses, results in the introduction of new products into the market (Duarte et al., 2010a).

3. Concluding remarks and perspectives

Today wines can be made from any fruit other than grape and the present review is a compilation of studies on wine preparation from assorted fruits. Research reports surveyed in this review, demonstrated that wine could be prepared from nutritionally diverse, highly perishable, underutilized tropical, subtropical or temperate fruits, thereby helping efforts to increase shelf life by reducing post-harvest and production losses, improve nutritional value of fruits, increase consumption and export, increase cultivation and commercialization of fruits as well as to generate profits to growers and the existing wine industry. Although during the last few years, remarkable progress has been made in wine biotechnology, particularly in wine yeast improvement, development of genetically modified yeast, and lowering alcohol concentration in wine, most studies have been carried out on grape wine rather than on non-grape fruit wines. However, progress made to date and anticipated advances towards improving aroma volatiles by using improved yeast strains, detailed chemometric analysis, reduction in alcohol content, in vitro and in vivo evaluation of bioactive compounds offering health benefits and sensory evaluation should lead to wider commercialization of non-grape fruit wines, thus contributing more to the economy of the wine industry.

Conflict of interest

None.

Acknowledgement

U.B.J. thanks University Grants Commission, New Delhi, India, for providing Dr. D.S. Kothari Post-doctoral Fellowship [Grant no. F.13-916/2013 (BSR)] and V.A.B. thanks Indian National Science Academy, New Delhi, India for providing an INSA Senior Scientist Fellowship (Grant no. SP/SS/2011/1408).

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