2.1 INTRODUCTION

2.1.1 Wine: Wine is an alcoholic beverage derived from grape juice (grape must), highly popular throughout the world. With a history of more than 8000 years, wine production is one of the world's oldest biotechnological practices. It is a biological process and is the result of a series of biochemical transformations brought about by the action of several enzymes from different microorganisms, especially the yeasts, which are responsible for the principal part of the process, alcoholic fermentation. Lactic acid bacteria are responsible for a secondary process, known as malolactic fermentation (Moreno-Arribas and Polo, 2005). During wine-making, the grape juice is also exposed to numerous enzymes originating from it and other than the yeasts that produce the alcoholic fermentation or the bacteria that produce malolactic fermentation. The endogenous enzymes of grapes, yeast, or bacteria present in juice and wine are often neither efficient nor sufficient under wine-making conditions, and hence commercial enzyme preparations were also widely used.

The initial environment that affects the microbial makeup of a wine fermentation is that of the vineyard. Although a drastically different environment than juice or wine, the types of microbes present on grapes will have an impact on the ensuing ecology in the wine fermentation, particularly in the early stages. Microorganisms appear to colonize around the grape stomata where small amounts of exudate are secreted (Ribereau-Gayon *et al*. 2000a). The most important transformation that takes place in the grape juice during vinification is the fermentation of the hexose sugars, resulting in ethanol and carbon dioxide production and the generation of a large number of by-products. In the initial phases of fermentation, different species of indigenous yeasts, called wild yeasts, present in the grape make an important contribution (Fugelsang, 1997). The predominant species belongs to the genera *Brettanomyces, Candida, Cryptococcus, Debaromyces, Dekkera, Hanseniaspora, Hansenula, Kloechera, Kluyveromyces, Pichia, Rhodotorula, Torulaspora, Schizosaccharomyces, and Zygosaccharomyces*. As fermentation progresses, these so called 'non-*Saccharomyces*' species die off, leaving the more ethanol-tolerant *S. cerevisiae* to predominate and complete the fermentation. This species has long been known as "the wine yeast."

2.1.2 Wine-making process: Wine-making begins with the collection and crushing of grapes. A general schematic of common steps in red and white wine-making is presented in Figure 2.1. For white wines the grape juice is separated away from the skins and clarified via cold settling, filtration or centrifugation. The juice is then moved to a barrel or fermentation tank and the alcoholic fermentation is carried out by yeasts indigenous to the juice, or via inoculation of a selected *S. cerevisiae* starter culture. White wine fermentations are typically carried out for roughly one to two weeks at temperatures around 10 to 18°C. Upon consumption of available glucose and fructose, the main sugars in grape juice, the wine is considered "dry" and separated from the yeast and grape lees (sediment).

Red wines are produced slightly differently than white wines. After crushing the skins are left in the fermentation to allow for color extraction. Like white wines, the alcoholic fermentation commences either through the action of indigenous yeasts or via direct inoculation of a starter culture. During fermentation, the grape material tends to float to the top of the vat forming a "cap". To better enable extraction of red pigments and to influence wine flavor, wine-makers typically punch down the cap or pump juice from the bottom over the cap. After a suitable period of time, the wine is separated from the grape skins and the fermentation is completed in another vessel. As described for white wines, the red wine is now "dry" and devoid of the main juice sugars.

After the alcoholic fermentation, wines often are spontaneously, or purposely, taken through a malolactic fermentation in which the high level of malate in the juice is converted to lactate, mostly by indigenous or inoculated LAB. Unlike the alcoholic fermentation, the malolactic fermentation is a stylistic consideration by the wine-maker, who, through use of antimicrobial additions (primarily sulfur dioxide) or filtration may choose to prevent this fermentation from initiating. Once the wine has been taken through the alcoholic and, if desired, the malolactic fermentation, the wine is often stored in tanks or barrels to allow flavor development. The residence time for storage is primarily determined by the style of wine and wine-maker choice. Often white wines are not stored for long periods of time while reds are frequently stored in oak barrels for several years. While the average wine contains approximately 13% ethanol, the alcohol by itself does not preclude future spoilage. Consequently wine-makers must take great care to prevent exposure of the wine to oxygen,

which can encourage microbial growth, as well as judiciously use antimicrobials (again, primarily sulfur dioxide) to prevent microbial spoilage.

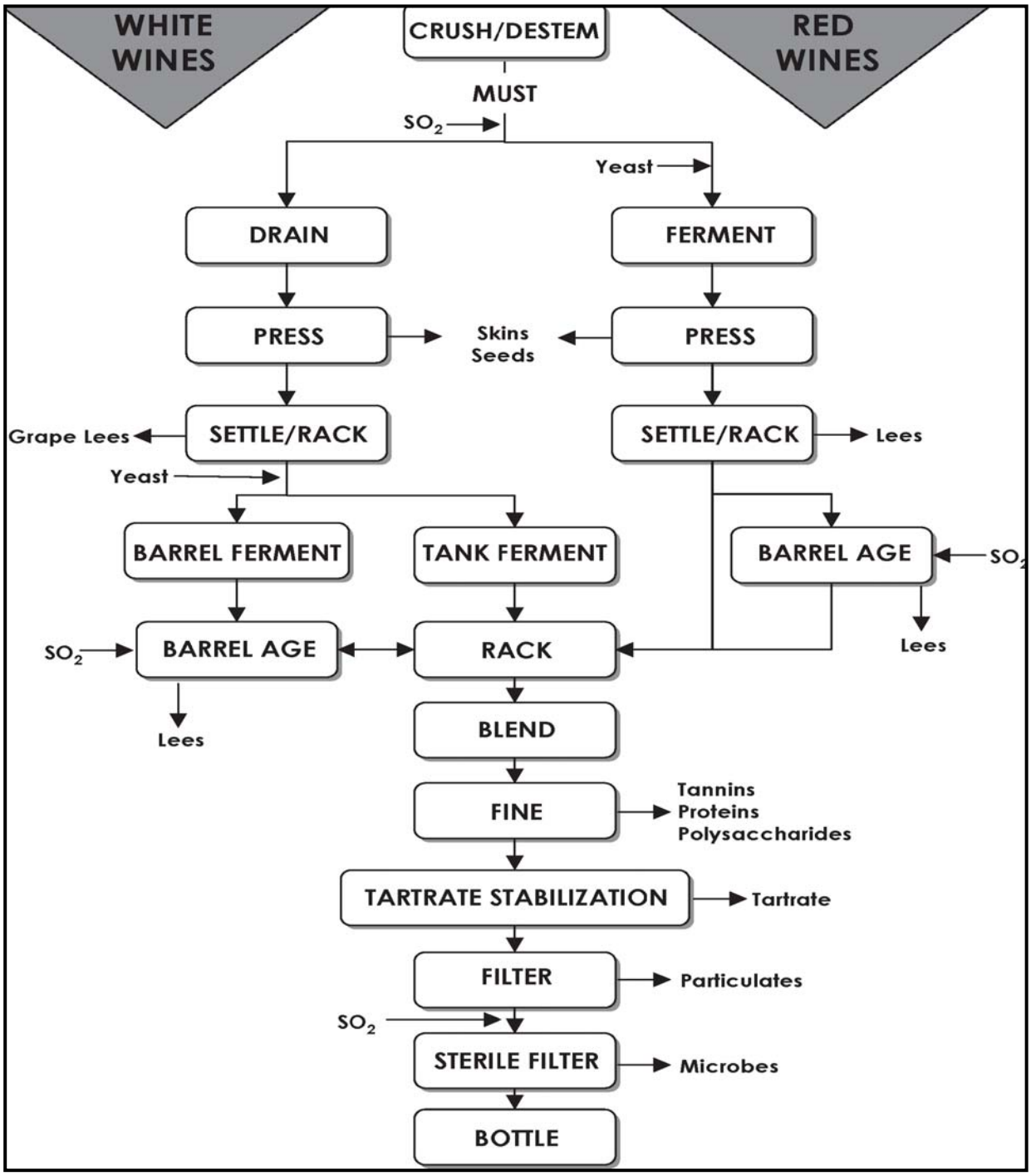

Fig. 2.1 General schematic for production of white and red wines (Source: Mills *et al*., 2008).

2.1.3 Factors affecting wine fermentation: Temperature is one of the most important parameters for the development of alcoholic fermentation since it can affect both the kinetics of the process in terms of duration and rate of fermentation and the final quality of the wine, i.e., production of secondary metabolites (Fleet and Heard, 1993). Other vinification factors, such as the pH, and the sugar concentration of the juice, may affect the growth and metabolic ability of yeast (Calderon *et al*., 2001). Numerous studies have reported on the influence of enological practices on fermentation rates and on changes in the composition of the grape juice (Santamaria *et al*., 1995). In recent years, by means of several genetic studies, wine-making practices, such as clarification, have been shown to influence selection of the wild yeast strain of *S. cerevisiae* (Epifanio *et al*., 1999). Also a great number of studies have focused on the multiple factors that can lead to a slower fermentation rate and the possibility of synergistic effects (Bauer and Pretorious, 2000). It is well known that yeast resistance to wine environmental conditions varies not only with the species, but is also strain associated.

The best characterized of the conditions leading to stuck and sluggish fermentations are nutrient deficiency. This nutrient deficiency is mainly due to limitations of assimilable nitrogen and, to a lesser extent, phosphate, lack of vitamins, essentially thiamine and minerals, and a near absence of oxygen. Other known stress factors also occurring during some wine fermentations include, for example, the presence of high levels of SO_2 and CO_2, the presence of competing microorganisms, *i.e.*, lactic acid bacteria identified as *Lactobacillus kunkeei* spp. Nov (Edwards *et al*., 1998) as well as of some killer toxins produced by killer yeasts (Hidalgo and Flores, 1994). Otherwise, the supply of nutrients or fermentation activators has been suggested to be adequate for the majority of wine yeast strains.

2.1.4 Wine yeast and alcoholic fermentation: Yeast is the most simple of the eukaryotes and is a group of fungi in which unicellular form is predominant and reproduces predominantly asexually by budding (only *Schyzosaccharomyces* genera reproduce by binary fission). Yeasts from a complex and heterogeneous group found in three classes of fungi, characterized by their reproduction mode: *Ascomycetes, Basidomycetes* and the imperfect fungi or *Deuteromycetes*. The yeast found on the surface of grapes and in the wine belongs to *Ascomycetes* and *Deuteromycetes*. Like other soporiferous yeast belonging to the class *Ascomycetes*, *S. cerevisiae*

can multiply either asexually by vegetative multiplication or sexually by forming ascospores. Under optimal nutritional and cultural condition *S. cerevisiae* doubles its mass every 90 min. Yeasts are in cosmopolitan distribution and have been isolated from natural substrates like leaves, flowers, sweet fruits, grains, fleshy fungi, exudates of trees, insect, dung and soil (Spencer and Spencer, 1997). Fruits are important microhabitats for a variety of yeast species in nature due to the high concentration of simple sugars, low pH and intense visitation by insect vectors (Lachance and Starmer, 1998).

Natural wine fermentation is a succession of yeast species; fermentation starts with apiculate yeasts (*Hanseniaspora*/*Kloeckera*), which are replaced by *Saccharomyces* yeasts. During the different stages of fermentation, several other yeast genera are occasionally present, including *Candida*, *Zygosaccharomyces*, *Torulaspora*, *Metschnikowia* and *Pichia* (Domizio *et al*., 2007). In addition, in spontaneous wine fermentations, a large diversity of microorganisms participates, including oxidative and fermentative yeasts, homo- and hetero-fermentative lactic acid bacteria, and acetic bacteria (Cabranes *et al*., 1990). However the main argument in favour of these fermentations is that they lend a greater typicality and organoleptic complexity to the fermented products (Henick-Kling *et al*., 1998). The main drawbacks reported are variability in the product quality and the risk of anomalous fermentations (Splittstoesser, 1982).

The use of pure cultures of yeasts provides a useful tool for standardizing the product (Fleet and Heard, 1993). Indigenous yeasts selected in particular region are a solution towards ensuring adequate control of the alcoholic fermentation and preserving the positive contribution of the indigenous yeasts (Martini and Martini, 1990). It is common practice to rely on the indigenous microflora in the production of wine for both the alcoholic and the malolactic fermentations even in large scale vinifications. While Vilanova and Sieiro, (2006) have shown that wines obtained by spontaneous fermentation are more aromatic than those obtained by inoculating a selected yeast strain. However, it was reported that the use of locally-selected yeast strains can positively affect the final quality of the wine (Vilanova and Massneuf-Pomarede, 2005).

Although there have been demonstrated differences in the production of volatiles between yeast strains, these differences have not been unambiguously shown to be reproducible. After exhaustively reviewing the subject, Thorhgate (1998) concluded that, since

extrinsic factors can greatly affect a wine's volatile profile, it is too easy to reach erroneous conclusions regarding yeast strain effects. It therefore, seems necessary to conduct comprehensive studies of strain variability, so that wine-makers may know what possible flavour effects to expect for a specific yeast strain. As wine consumers look for desirable sensory experiences and expect to feel pleasure through drinking an exclusive and complex wine (Bisson *et al*., 2002). Consequently, the major challenge of today's wine makers is to fulfill the consumers' demand and introduce wines with acceptable quality and price (Swiegers *et al*., 2005). Wine makers are interested in incorporating new enological practices to manage wine flavor (Fleet, 2008) and to distinguish themselves in the marketplace.

Single strains of commercial active dry wine yeasts have been used for many years to control alcoholic fermentation; however, this has resulted in the production of wines with a similar character throughout the world. Nevertheless, wine-makers have the ability to influence the nature and complexity of their wine by utilizing new indigenous yeast strains (Swiegers and Pretorius, 2005) or using mixtures of yeast strains to develop complexity in their wines. Howell *et al*., (2006) investigated the effects of mixed known *S. cerevisiae* strains on the chemical profile and aromatic properties of Chardonnay wines. They determined that the chemical profiles of the wines fermented with individual and mixed *S. cerevisiae* strains were different and that it was not possible to blend wines produced by the single strains to create the same chemical profile as a wine fermented by the mixed yeast cultures.

The selection of suitable yeast for each kind of fermentation is important to ensure a complete fermentation and to improve the final characteristics of the wine. Although it is clear that the quality of wine is associated with the variety and quality of the grape, yeasts can produce compounds that provide a distinctive touch to the final product.

2.1.5 Mango fruit: The mango, *Magifera indica* L. is well known for its excellent exotic flavour and usually referred to as the king of fruit. It is a dicotyledonous plant belonging to the order Sapindales in the family Anacardiaceae. It is a popular and economically important fruit, widely cultivated in the tropics and subtropics. It was originated in the Indo-Burmese region (Tjiptono *et al*., 1984). The fruit is eaten fresh and in several other by-products, including juices, nectars, purees (Ploetz *et al*., 1994). Commercial mango production is reported in more

than 87 countries. The prominent mango producing countries are India, China, Thailand, Indonesia, Philippines, Pakistan and Mexico. Mango production is increasing outside the traditional geographical regions of mango cultivations such as in Central and South America, Australia, South-east Asia, Hawaii, Egypt, Israel and South Africa, especially for export markets (Tharanathan *et al*., 2006). The most important exporting countries are Mexico (41% of the world market) followed by the Philippines (7.6%) and Pakistan (7.8%) (Sauco, 2004). Some mango fruit cultivars, such as from the Indian and the Sri Lankan regions, show strong aroma, intense peel colouration, delicious taste, and high nutritional value (Thanaraj *et al*., 2009). '*Alphonso*' mango is considered as one of the best rated mango cultivar in the world, and some other cultivars (such as Ataulfo from Mexico) are becoming important in the markets. According to Lebrun *et al*. (2008), there are 49 species and thousands of mango cultivars. The popularity of the fruit in the international market is due to its excellent flavour, attractive fragrance, beautiful colour, taste and nutritional properties (Arauz, 2000). In addition, mangoes are good source of ascorbic acid, carotenoids and phenolic compounds, and other dietary antioxidants (bioactive compounds) (Talcott *et al*., 2005). Consumption of mango fruit can provide significant amounts of bioactive compounds with antioxidant activity.

Unfortunately, the consumers are experiencing inconsistent fruit maturity and ripening variability, sometimes even in a single consignment. Mango fruits have a short production season and storage life, and therefore fruit prices after seasonal peak can be very high and therefore may not be affordable by many consumers. The storage life of mangoes is limited to 2–3 weeks in air at 10 °C−15 °C (Yahia, 1998). Variability in mango fruit quality is detected in the supply chain with respect to taste, flavour, colour, aroma, weight, size and shape, influenced by the production management practices. According to Kader (2002), quality performance of mangoes depends leathery covering of the seed. The fruit has a single seed in the middle of the fruit, which is large, flat, and ovoid-oblong shaped. The edible portion contains mainly glucose, fructose and sucrose and the total sugar content of mangoes can vary from 11.5 to 25% depending on the type of mango and stage of ripeness. Different organic acids such as oxalic, citric, malic, succinic, pyruvic, adipic, galacturonic, glucuronic and mucic acids were reported to be produced by mango fruit, and citric is the major acid (Jain *et al*., 1959).

Mango fruit contains different classes of phytochemicals such as polyphenols, ascorbic acid and carotenoids, revealing health promoting properties mainly due to their antioxidant properties (Talcott *et al*., 2005). Polyphenols, gallic acid, gallotannins, mangiferin, quercetin, kaempferol, p-OH-benzioc acid, m-coumaric acid, p-coumaric acid and ferulic acid were reported in mango flesh (Saleh and El-Anasari, 1975; Schieber *et al*., 2003; Schieber *et al*., 2000). Gallic acid and gallotanninswere reported to decline during storage as a result of ripening or in association with loss of astringency which is a descriptive sensory attribute of mango (Lakshminarayanan *et al*., 1970). Haden and Ataulfo mangoes were reported to contain higher β-carotene content than Kent and Tommy Atkins (Ornelas-Paz *et al*., 2007).

2.1.6 Screening of mangoes for wine-making: In countries where grapes are not extensively produced, other available fruits are utilized for wine making. Various fruits have been screened for wine production over the past two decades such as caja, banana, pupunha, mango, acerola and cocoa where grapes are not much available or not cost-effective. There are a variety of fruits suited for making a good quality wine. The fruits commonly used for making wine are: apple, pear, peach, plum, cherry, strawberry, blackberry, raspberry and blueberry (Reddy and Reddy, 2005; Varakumar *et al*., 2011).

Screening of mango varieties for wine making has been reported previously, for the first time Czyhrinciwk, (1966) reported the technology involved in mango wine production. Later Onkarayya and Singh (1984) screened twenty varieties of mangoes that are available from India for wine production. Obisanya *et al*. (1987) studied the fermentation of mango juice into wine using locally isolated *S. cerevisiae* and *Schizosaccharomyces* species of palm wine. From the physicochemical characteristics of the mango wine produced, it was observed that aromatic components were comparable in concentration with those of grape wine (Reddy and Reddy 2005). According to these reports, the composition of wine is changed with mango variety used in the fermentation (Kulkarni *et al.* 1980; Onkarayya and Singh 1984; Reddy and Reddy 2005). In view of the differences noticed in some mango wines with different varieties necessitates the screening and selection of good quality of mango fruit, which is an important step to get good quality product. Reddy and Reddy (2005, 2009) screened six varieties of mangoes and studied the effect of enzymatic maceration on synthesis of higher alcohols during mango wine

fermentation and found that more amounts of volatiles were observed in wine produced from *Totapuri* cultivar than wine from the cultivar *Banginapalli*. Kumar *et al*., (2009) had optimized conditions for mango wine-making using statistical software, response surface methodology (RSM) by using *Saccharomyces bayanus* and the volatile aroma composition of mango wine from the two cultivars *Banginapalli* and *Alphonso* were reported by Reddy *et al*., (2010a) by gas chromatography coupled with mass spectrometry (GC-MS). Later, Reddy and Reddy, (2011) reported the effect of fermentation conditions (temperature, pH, SO_2 and aeration) on wine fermentation and evaluated yeast growth, duration, fermentation rate and volatile composition and concluded that the temperature (25 ºC), pH (5), SO_2 (100 ppm) were optimum for low alcoholic fermentation temperatures in wine making.

2.2 REVIEW OF LITERATURE

In recent years, food as a medicine is the growing trend, with multivarious functions such as nutritious as well as medicinal value, which requires high quality parameters. Microorganisms and parasites can contaminate food at various stages of production, processing, storage and distribution. These biological agents, some of which are pathogenic to man and animals, may be able to survive preservation treatments and pose health risks to humans. Thus, it is safe to assume that food, whether it is raw or processed, may carry some level of risk of foodborne illness if not properly handled and prepared before consumption (Loaharanu, 1996). Food irradiation is a means of food preservation that has been in development since the early part of the 20th century. If applied properly, irradiation can be an effective way to reduce the incidence of foodborne diseases and also inactivates food spoilage organisms, including bacteria, molds, and yeasts in our food supply (Morehouse, 2002). Thayer and Rajkowski (1999) concluded that ionizing radiation could penetrate the entire product to inactivate the pathogens, and it is a promising technology that could be used to improve the safety of ready-to-eat fruits and vegetables. WHO (1981) reported that gamma irradiation technology has positive effects in preventing decay of food products by eliminating microorganisms and by improving the safety and shelf-stability. In 1997, a Joint FAO/IAEA/WHO Study Group was convened to assess the safety and nutritional adequacy of food irradiated to doses above 10 kGy. They concluded that

food irradiated to any dose appropriate to achieve the intended technological objective is both safe to consume and nutritionally adequate (WHO, 1999). In 1981, the U.S. Food and Drug Administration (FDA) concluded that food irradiated at 50 kGy or less can be considered safe for human consumption (FDA, 1981), and therefore for animal consumption.

The tendency of consumers to fresh fruit juices has been increasing due to their better organoleptic properties than pasteurized ones. Previously, it was generally assumed that pathogenic microorganisms could not survive in high acid foods. However, recent outbreaks of foodborne illnesses from unpasteurized fruit juices have indicated the necessity of pasteurization for all fruit juices (Parish, 1997). Microorganisms, in particular acid-tolerant bacteria and fungi such as yeasts and molds, can easily spoil fruit juices (Tournas *et al*., 2006). During the last decade, with increasing demand for nutritious, fresh-like food products with high organoleptic quality and an adequate shelf-life, non-thermal inactivation techniques have been a major research issue. Some of the investigated technologies are irradiation, high hydrostation pressure (HHP), pulsed electrical fields, and UV decontamination (Devlieghere *et al*., 2004). HHP processing is one of the non-thermal technologies, and it has been proposed for an application to vegetable juice like kale juice (Lee *et al*., 1995) and carrot juice (Isabelle *et al*., 2004). However, the HHP method still has several problems such as the limitations of a mass production and an increased cost. For the reasons, an industrial application of HPP is still limited. Ionizing radiation, another non-thermal sterilization method, is highly effective in inactivating food microorganism and has many advantages for industrial use. Recently, it has offered a safe alternative as a decontamination method of food and public health products (Niemira *et al*., 2001).

Gamma irradiation offers a good preservation technology. Preservation and shelf-life extension have been the historical focus of research on irradiation of juices (Niemira and Deschenes, 2004, chap. 11). The key organisms in food irradiation were yeasts and molds, which have a higher D_{10} value than bacterial pathogens (Monk *et al*., 1994). In fruit juices, D_{10} values have been reported for yeasts and molds are in the range of 1–3 kGy (Narvaiz *et al*., 1992) and 0.3–0.7 kGy for pathogenic bacteria (Buchanan *et al*., 1998). Buchanan et al. (1998) showed that, a dose of 1.8 kGy should be sufficient to achieve the 5D inactivation of *Escherichia coli* recommended by the National Advisory Committee for Microbiological

Criteria for Foods irradiation. In addition, Chachin and Ogata (1969) investigated the effect of sterilizing (2–80 kGy) doses of gamma irradiation in grape juice.

γ-Irradiation eliminates bacteria, molds, and yeasts and can be applied in the processing of fruit and vegetable products such as juice, slices puree and dried products (Prakash *et al*. 2002; Chaudry *et al*. 2004; Fan *et al*. 2005; Gyawali *et al*. 2006; Song *et al*. 2007). The effects of γ-irradiation on minimally processed fruit and vegetables have been studied from different aspects. For example, γ-irradiation was used to extend the shelf-life of dried potato (Wang and Chao 2003), fresh ginger (Mishra *et al*. 2004), sliced carrot (Chaudry *et al*. 2004), carrot and kale juice (Song *et al*. 2006), fresh kale juice (Kim *et al*. 2007), pomegranate juice (Alighourchi *et al*. 2008) and sugarcane juice (Mishra *et al*. 2011). Additionally, new trials for increasing biological activities of natural product by γ-irradiation showed advantage in increasing yields, improved the color and antioxidant activity (Jo *et al*. 2003; Kim *et al*. 2007; Lee *et al*. 2009). However, no information is available about γ-irradiation kinetics of mango juice and wine, and the literature about the effect of γ-irradiation on the physico-chemical composition of the mango juice and wine is scarce, particularly regarding on the organic acids.

While irradiation has been successfully demonstrated to extend shelf-life of mango fruit and its pulp (El-Samahy *et al*. 2000; Youseff *et al*. 2002), steaming of cans is still a routine process practiced in India. Radiation processing and preservation of mango juice has, however, has not so far been exploited (Ramteke *et al*. 1991). Hence, the present study was aimed at monitoring the changes in irradiated mango juice and wine samples. The effect of γ-irradiation at different doses (0.5, 1 and 3 kGy) on the physico-chemical properties such as pH, titratable acidity, sugars, total soluble solids (TSS) and organic acid content in mango juice and wine from different cultivars was investigated.

2.3 MATERIALS AND METHODS

2.3.1 Mango cultivars: Eight cultivars (Cv.) of ripe mangoes were selected that were grown in Andhra Pradesh, South India, viz., *Alphonso*, *Banginapalli*, *Mulgoa*, *Neelam*, *Raspuri*, *Rumani*, *Sindhura* and *Totapuri* (Fig. 2.2) were procured from the local market, all fruits were ideal by ripeness for consumption and were uniform in size. Fresh edible puree of the fruits was used for

the study. Each mango cultivar, the annual fruit available during summer, was procured from three different vendors, and processed.

Fig. 2.2 Images of eight different mango cultivars used for mango wine production.

2.3.2 Mango fruit processing: The ripened mango fruits were processed to mango juice by slightly modified method of Varakumar *et al*. (2012b). In brief, mango pulp was recovered manually and up to 20 mg/L SO_2 was added and then treated with previously optimized concentrations of 0.4% pectinolytic enzyme (BioTropicase, Biocon Ltd., Bangalore, India). The extraction was made by pressing the treated pulp in two-layered cheese cloth and no external water or sugar was added at any time point. The juice obtained in this manner was sterilized by heating at 90 °C in water bath for 10 min and then subjected to analysis of total soluble solids, sugars (total and reducing), total acidity, and pH. Finally mango juice from eight cultivars was used for fermentation.

2.3.3 Wine yeast and preparation of inoculum: The wine yeast used in this study, *Saccharomyces bayanus* was a kind gift from Prof. Roberto Ambrosoli, University of Turin, Italy. The volatile profile and fermentation performance of this yeast was reported previously from our laboratory (Kumar *et al*., 2009; Varakumar *et al*., 2012b). The yeast culture was maintained on MPYD agar (g/L) (Himedia, India) medium containing malt extract (3), peptone (5), yeast extract (3), dextrose (10) and agar (20) and subcultured regularly on agar slants. The yeast cells were grown by inoculating the slant culture in to 25 mL of the sterile MPYD liquid medium in 100 mL conical flask, incubating on a rotary shaker (100 rpm) for 24 h. This (3×10^6 cells/mL) was transferred to 250 mL conical flask having 100 mL sterile mango juice and kept for incubation at 28 ºC, on a rotary shaker (100 rpm) for 24 h and was used as inoculum in mango wine fermentation (Kumar *et al*., 2009).

2.3.4 Mango wine making: Mango wine fermentations were carried out in a 5.0 L stainless steel fermenter (BioSpin-05*i,* BIO-AGE, Mohali, India) with a working volume of 3.0 L. The fermenter vessel containing 2.7 L mango juice was used as fermentation medium. Yeast inoculum was transferred under aseptic conditions to the medium and fermentation was carried out at 25 ºC under agitation of 100 rpm for 3-5 days. At the end of the fermentation, the broth was centrifuged at 5000 rpm for 20 min to separate out the cells and the supernatant wine was stored at 8 ºC to assist the sedimentation of solid material. After 10 days, the wine was transferred to another flask and 1% aqueous solution of bentonite was added to facilitate the

sedimentation of non-fermentable solids. The mixture was homogenized and incubated at 8 ºC for 48 h for the sedimentation of flocculent material. Later, the two phases of wine (liquid and solid) were separated by filtration to obtain a clear wine. The filtered wine was stored at 8 ºC in an amber coloured airtight glass container to avoid oxygen contact, which might lead to oxidation of wine or carotenoid degradation (Varakumar *et al*., 2011).

2.3.5 γ-Irradiation: Mango juice and wine samples were randomly grouped into four lots and bottled in screw-capped 500 mL glass containers. These were irradiated in tightly capped containers with doses of 0, 0.5, 1 and 3 kGy separately at ambient temperature (26 ± 2 ºC) in a cobalt-60 irradiator (model GC-5000, Board of Radiation and Isotope Technology (BRIT), Mumbai; dose rate of 5.5 kGy/h) at Food Technology Division, Bhabha Atomic Research Centre (BARC), Mumbai, India. The calibration and measurement of absorbed dose rate of the irradiator were carried out using Fricke reference standard dosimeters (ASTM Standard, E 1026 2004). Samples were rotated 360º continuously during the irradiation process to achieve uniform target doses. The non-irradiated control sample was placed outside the irradiation chamber to replicate the same environmental temperature effect as the irradiated sample. The mango juice and wine samples were stored at room temperature (RT) around 25 °C for 7 days prior to analysis.

2.3.6 Physico-chemical analyses of mango juice and wine

2.3.6.1 Determination of pH, titratable acidity, volatile acidity and total soluble solids (TSS): The pH of the mango juice/wine was measured using hand digital pH meter (Eutech, Japan), precalibrated with buffers of pH 4.0 and 7.0. Titratable acidity in juice/wine was determined by titrating with 0.1N NaOH previously standardized using standard oxalic acid and the values were expressed as citric acid/tartaric acid equivalents. Volatile acidity in the distillates was expressed as g acetic acid/L. Total soluble solids (TSS) was determined using a hand refractometer (0-30) (Erma, Japan) in terms of °Bx (°Brix) (Varakumar *et al*., 2011).

2.3.6.2 Determination of total and reducing sugars: The amount of total sugars in the mango juice was determined using a modified version of the phenol–sulphuric acid assay described by

Nielson (2010). Accurately 1 mL of the diluted juice sample was mixed with 1 mL of 5% phenol solution and 5 mL of 96% sulphuric acid (rapidly added) in each tube. The tubes were vortexed and allowed to stand at room temperature for 20 min. The concentrated sulphuric acid converts all non-reducing sugars to reducing sugars, so the method determines the concentration of the total sugars present in the sample. A blank was prepared by substituting distilled water for the juice sample. The absorption of the characteristic yellow-orange colour produced as a result of the interaction between the sugars and the phenol was measured at 490 nm using a spectrophotometer. The typical colour of this reaction is stable for several hours. The concentration of the total sugars present in each sample was calculated by referring to a standard sucrose curve.

The content of the reducing sugars was measured with the Nelson– Somogyi method (Somogyi, 1952) with minor modifications. The method is widely used for the quantitative determination of reducing sugars in biological materials. Four types of required solutions were prepared according to standard procedures with high accuracy. Arsenomolybdate reagent was incubated at 37 °C for 24 h prior to use. The diluted juice sample (0.5 mL) was mixed with the different solutions as previously described. The absorbance of the blue colour was read at 520 nm with a spectrophotometer. The amount of reducing sugars present in the fruit juice sample was calculated from a standard curve graph drawn using a glucose solution as the standard. The average results for triplicate determinations were expressed as g/100 mL of juice. The content of residual sugars in wine samples was estimated spectrophotometrically using dinitrosalicylic acid (DNS) method (Miller, 1959).

2.3.6.3 Analysis of individual reducing sugars by HPLC: Mango juice and wine samples after centrifugation and filtration (0.2µm) were stored at -50°C before analysis. The reducing sugars (g/100mL) were measured by HPLC (Shimadzu HPLC, Class-VP software version 6.1) according to the method of Chavez-Servin *et al*. (2004), using a carbohydrate ES column (Prevail, 150×4.6 mm). The column was eluted at 25 °C with a degassed mobile phase containing a mixture of acetonitrile and water (78:22) at a flow rate of 0.5 mL/min (isocratic mode). All the compounds were detected with an evaporative light scattering detector. Samples were analyzed in duplicate for each mango juice and wine replicate (n=4). The identification

and quantification of sugars were achieved by using retention time and standard curves of pure sugar compounds (Sigma-Aldrich, St. Louis, MO, USA).

2.3.6.4 Determination of organic acids content by HPLC: Mango juice and wine samples after centrifugation and filtration (0.2µm) were stored at -50°C before analysis. The organic acids (tartaric, citric, succinic and malic acids) were determined by HPLC (Shimadzu) using a Supelcogel C-610H column (Supelco, Bellefonte, PA, USA) connected to a photodiode array detector. The column was eluted at 40 °C with a degassed aqueous mobile phase containing 0.1% sulphuric acid at a flow rate of 0.4 mL/min (isocratic mode). Samples were analyzed in duplicate for each mango juice and wine replicate. The identification and quantification of compounds were carried out by using retention time, UV spectrum (210 nm) and standard curves of pure organic acid compounds (Sigma-Aldrich, St. Louis, MO, USA).

2.3.6.5 Determination of volatiles: Ethanol, total esters and higher alcohols were determined using gas chromatography according to Antony, (1984) in cell-free samples, obtained by centrifugation of finished wine at 5000 × g for 10 min at 4 °C. Agilent systems GC-FIDModel 6890 plus instrument was used for experiments and the conditions were as follows: Carbopack-B 80/120 mesh glass column (6 ft/2m with 2 mm i.d.; 1/4 mm), nitrogen gas was used as a carrier gas with a flow of 20 mL/min. Eluted compounds were detected by flame ionization detector (FID). Hydrogen with a flow rate of 40mL/min was used as the fuel gas, and air was used as an oxidant (with a flow rate of 40 mL/min). Identification and quantification of volatiles were done by comparing their retention time with that of authentic standards. 4-Methyl-2-pentanol was used as internal standard for all the samples.

2.3.6.6 Evaluation of colour: Colour measurements were made with a Hunter colorimeter (LabScan XE, Hunter Associate Laboratories, Inc., Reston, VA). The sample was placed in a 1-cm path length optical glass cell in the total transmission mode, using illuminant C and 2 º observer angles. The Hunter colour L^*, a^* and b^* values were evaluated. The value a^* characterizes the colour from red ($+a^*$) to the green ($-a^*$); the value b^* indicates the colour from yellow ($+b^*$) to the blue ($-b^*$). The value L^* determines the light ranging from white (L =

100) to black (L = 0). Chroma (saturation, C*) and hue angle (h°) values were also evaluated and these parameters associated with a* and b* values (Varakumar *et al*., 2011).

2.3.7 Microbial load analysis: Total microbial load was determined using the standard pour plate method. The control and irradiated mango juice and wine samples (1mL) were serially diluted in sterilized peptone water (0.1%) and appropriate dilutions were poured on to the respective plates. Plate count agar was used for determination of total aerobic bacteria (TAB) and then plates were incubated at 35 ºC for 48-72 h. Potato dextrose agar (PDA) was used for the determination of yeast and mold count (YMC) and then plates were incubated at 26 ºC for five days. The microbial counts were expressed as CFU/mL. The presented data were the mean counts from three petri dishes for each diluted suspension. Three replicates were made for each control and irradiated samples.

2.3.8 Statistical analysis: All the experiments were carried out in triplicate and the mean value and standard deviation were presented. Student's *t*-test has been used to compare the mean values. The data were analyzed by one-way analysis of variance (ANOVA) using SPSS, version 12.0, post-hoc mean separations were performed by Duncan's multiple-range test (DMRT) for analysis of variance.

2.4 RESULTS AND DISCUSSION

2.4.1 General composition of mango juice

2.4.1.1 Effects of γ-irradiation on juice yield and pH of mango juice from different cultivars: Mango (*Mangifera indica* L.) is the most popular and the highly produced fruit of India. The chemical composition of mango pulp varies with the location of cultivation, variety and stage of maturity. The major constituents of the pulp are water, carbohydrates, organic acids, fats, minerals, pigments, tannins, vitamins and flavor compounds. The soluble sugars of the fruit pulp consisted mainly of glucose, fructose and sucrose. The total sugar content of mangoes varies between 11.5 and 25%. An increase in sugar content, decrease in acidity and loss of texture is associated with ripening of mango fruits (Medlicott *et al.* 1986). It is evident

that with fruit ripening, the fruit matrix softens and become juicy; further treatment of pulp with the enzyme pectinase reduces the viscosity of the juice and the images of different cultivars of mangoes used in the study were presented in Fig. 2.2. The juice yield from different mango cultivars in this study ranges from 385.3 to 581.4 (mL/Kg). Of all the cultivars studied, *Neelam, Totapuri, Mulgoa, Raspuri* and *Sindhura* (385.3, 424.5, 480.8, 486.2 and 495.6 mL/Kg, respectively) were of low juice yielders, whereas, *Banginapalli*, *Alphonso* and *Rumani* were of high juice yielders (581.4, 574.7 and 562.4 mL/Kg, respectively) (Table 2.1). The juice yield is cultivar specific and might also depend on the degree of maturity. In the present study, the juice yield for *Raspuri* and *Neelam* cultivars were 486.2 and 385.3 (mL/Kg); however, it was 600 and 480 (mL/Kg), respectively, in an earlier report (Reddy and Reddy, 2005). There was a significant ($P \leq 0.05$) increase in the juice yield of all cultivars studied by increasing the irradiation dose and ranges from 398.5 to 597.6 (mL/Kg). The highest juice yield was obtained at 3 kGy irradiation dose in all cultivars studied (Table 2.1).

The pH range of the control (0 kGy) mango juices was between 3.88 and 4.52, the lowest pH was found in the *Neelam* and highest was in *Raspuri* cultivars, respectively (Table 2.1). The pH was unchanged up to 1 kGy dose level but a higher dose (3 kGy) produced a significant ($P \leq 0.05$) increase of pH in all the mango cultivar juices studied except *Raspuri* and *Totapuri* cultivars, where the pH was unchanged in irradiated samples also (Table 2.1). Conflicting results have been reported about the irradiation effect on pH in different fruit juices. The present results are in close agreement with the findings of Shahbaz *et al*. (2014) who did not observe any effect of irradiation at 0.4 and 1.0 kGy on the pH values of pomegranate juice samples. Fan *et al*. (2005) reported irradiation doses at 0.5 and 1.0 kGy did not change the pH values of sliced apples, which were initially treated with 7% calcium ascorbate. Similarly, Miller and McDonald (1999) have demonstrated that there was no modification of pH in papaya that had undergone irradiation treatment. The same group in 1996 reported no differences in the pH values of blueberries when irradiated with gamma-rays (0.5–1.0 kGy). In contrast, Sadoughi *et al*. (2012) observed there was no significant difference ($P > 0.05$) in the pH of onion puree at different irradiation doses (1 to 7 kGy) from the initial value of pH 4.55, nor was there any significant change during the 28-day storage period. Moreno *et al*. (2007) found that irradiation up to 3.2 kGy did not affect the pH in blueberry fruits. Yu *et al*. (1995)

Table 2.1 Effects of γ-irradiation on juice yield and pH of mango juice from different cultivars

Juice variety	Juice yield (mL/kg)				pH			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	574.7 ± 6.6^{a}	582.5 ± 5.5^{b}	586.4 ± 3.9^{bc}	588.4 ± 4.2^{c}	4.14 ± 0.003^{a}	4.14 ± 0.003^{a}	4.15 ± 0.004^{a}	4.24 ± 0.007^{b}
Banginapalli	581.4 ± 3.3^{a}	590.7 ± 4.4^{b}	595.2 ± 5.3^{c}	597.6 ± 6.3^{c}	4.31 ± 0.006^{a}	4.31 ± 0.006^{a}	4.31 ± 0.006^{a}	4.38 ± 0.008^{ab}
Mulgoa	480.8 ± 5.5^{a}	486.4 ± 3.9^{b}	488.8 ± 6.2^{bc}	490.3 ± 4.1^{c}	4.43 ± 0.004^{a}	4.43 ± 0.004^{a}	4.45 ± 0.004^{a}	4.52 ± 0.006^{b}
Neelam	385.3 ± 3.7^{a}	393.6 ± 6.1^{b}	396.4 ± 4.6^{bc}	398.5 ± 5.5^{c}	3.88 ± 0.007^{a}	3.88 ± 0.007^{a}	3.90 ± 0.008^{a}	3.98 ± 0.011^{ab}
Raspuri	486.2 ± 4.4^{a}	495.3 ± 5.2^{b}	498.6 ± 3.4^{bc}	500.8 ± 3.9^{c}	4.52 ± 0.005^{a}	4.53 ± 0.005^{a}	4.52 ± 0.005^{a}	4.53 ± 0.005^{a}
Rumani	562.4 ± 4.2^{a}	571.8 ± 3.7^{b}	573.7 ± 5.5^{bc}	576.9 ± 4.6^{c}	4.45 ± 0.006^{a}	4.45 ± 0.006^{a}	4.47 ± 0.007^{a}	4.55 ± 0.009^{b}
Sindhura	495.6 ± 2.5^{a}	503.4 ± 4.6^{b}	509.3 ± 3.7^{c}	511.5 ± 5.1^{c}	4.26 ± 0.004^{a}	4.26 ± 0.004^{a}	4.28 ± 0.004^{a}	4.34 ± 0.007^{b}
Totapuri	424.5 ± 6.3^{a}	431.7 ± 5.1^{b}	434.5 ± 3.9^{bc}	437.3 ± 4.8^{c}	4.12 ± 0.008^{a}	4.12 ± 0.008^{a}	4.13 ± 0.008^{a}	4.13 ± 0.011^{a}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

also found no differences in the pH values of electron beam irradiated strawberry fruits up to 2.0 kGy.

2.4.1.2 Effects of γ-irradiation on total soluble solids (TSS) and titratable acidity (TA) of mango juice from different cultivars: The effect of γ-irradiation on TSS of different cultivars of mango juice samples is shown in Table 2.2. In this study TSS also increase with ripening of fruits, and they are in the range of 20.7–25.4°Bx, the lowest TSS was found in *Mulgoa* and highest was in *Banginapalli* cultivars of control (0 kGy) juice samples respectively. The TSS of all cultivars mango juice was not affected at all by the applied irradiation doses (Table 2.2). The present results are in close agreement with the findings of Shahbaz *et al*. (2014), who reported TSS of the pomegranate juice was not affected by all the irradiation doses (0.4, 1 and 2 kGy) studied. Sadoughi *et al*. (2012) reported γ-irradiation did not cause any significant change ($P > 0.05$) in the TSS of onion puree. Kim and Yook (2009) reported exposure to irradiation up to 3 kGy did not affect the TSS content of kiwi fruits at week 0, but irradiated fruits showed a decrease in the TSS content with increasing irradiation dose during storage. Irradiated fruits showed a decrease in the TSS (°Brix) content over a period of time, suggesting a delay of ripening induced by irradiation (Moreno *et al*., 2006). Fan *et al*. (2005) reported that irradiation did not affect TSS of sliced apple. Prakash *et al*. (2002) demonstrated that there was no change in TSS of diced tomato, which was given an irradiation treatment. D'Innocenzo and Lajolo (2001) also reported that TSS contents of papaya were not altered by irradiation treatment. Similar results were also reported by Moy *et al*. (1973) and Miller *et al*. (1994).

The effect of γ-irradiation on TA of different cultivars of mango juice samples is shown in Table 2.2. Titratable acidity in all cultivars of control mango juice ranged from 0.42 to 0.55 (% citric acid), the lowest TA was found in *Banginapalli* and highest was in *Neelam* cultivars respectively. The TA was remained unchanged up to 0.5 kGy but a slight decrease was observed at 1 and 3 kGy irradiation doses in all the mango juices studied except *Raspuri* and *Totapuri* cultivars, where the TA was unchanged in all irradiated juice samples (Table 2.2). The main organic acid accountable for the titratable acidity in mango fruit is citric acid. Conflicting results have been reported about the irradiation effect on TA in different fruit juices.

Table 2.2 Effects of γ-irradiation on total soluble solids (TSS) and titratable acidity (TA) of mango juice from different cultivars

Juice variety	TSS (°Brix)				TA (% citric acid)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	23.3 ± 0.047^{a}	23.3 ± 0.047^{a}	23.3 ± 0.047^{a}	23.3 ± 0.047^{a}	0.44 ± 0.02^{a}	0.44 ± 0.03^{a}	0.43 ± 0.02^{a}	0.42 ± 0.01^{a}
Banginapalli	25.4 ± 0.063^{a}	25.4 ± 0.063^{a}	25.4 ± 0.063^{a}	25.4 ± 0.063^{a}	0.42 ± 0.01^{a}	0.42 ± 0.02^{a}	0.40 ± 0.03^{a}	0.39 ± 0.02^{a}
Mulgoa	20.7 ± 0.038^{a}	20.7 ± 0.038^{a}	20.7 ± 0.038^{a}	20.7 ± 0.038^{a}	0.46 ± 0.04^{a}	0.46 ± 0.04^{a}	0.45 ± 0.02^{a}	0.44 ± 0.03^{a}
Neelam	21.5 ± 0.042^{a}	21.5 ± 0.042^{a}	21.5 ± 0.042^{a}	21.5 ± 0.042^{a}	0.55 ± 0.03^{a}	0.55 ± 0.03^{a}	0.53 ± 0.01^{a}	0.52 ± 0.02^{a}
Raspuri	22.3 ± 0.056^{a}	22.3 ± 0.056^{a}	22.3 ± 0.056^{a}	22.3 ± 0.056^{a}	0.52 ± 0.05^{a}	0.52 ± 0.04^{a}	0.52 ± 0.03^{a}	0.52 ± 0.04^{a}
Rumani	23.0 ± 0.067^{a}	23.0 ± 0.067^{a}	23.0 ± 0.067^{a}	23.0 ± 0.067^{a}	0.51 ± 0.02^{a}	0.51 ± 0.03^{a}	0.49 ± 0.03^{a}	0.48 ± 0.02^{a}
Sindhura	25.2 ± 0.054^{a}	25.2 ± 0.054^{a}	25.2 ± 0.054^{a}	25.2 ± 0.054^{a}	0.53 ± 0.04^{a}	0.53 ± 0.04^{a}	0.52 ± 0.02^{a}	0.51 ± 0.03^{a}
Totapuri	22.4 ± 0.043^{a}	22.4 ± 0.043^{a}	22.4 ± 0.043^{a}	22.4 ± 0.043^{a}	0.49 ± 0.03^{a}	0.49 ± 0.03^{a}	0.49 ± 0.04^{b}	0.49 ± 0.02^{a}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

Similar to the present results, Shahbaz *et al*. (2014) reported TA in the pomegranate juice samples remained unaffected at 0.4 kGy but a significant decrease was observed at 1 and 2 kGy treatments. Fan *et al*. (2005) reported irradiation doses at 0.5 and 1.0 kGy did not change the TA values of sliced apples, which were initially treated with 7% calcium ascorbate. In contrast, Sadoughi *et al*. (2012) observed that there was no significant difference ($P > 0.05$) in the TA of onion puree at different irradiation doses (1 to 7 kGy).

2.4.1.3 Effects of γ-irradiation on organic acids content of mango juice from different cultivars: The identification and quantitative analysis of major organic acids in fruits is considered very important for food and beverage technology and quality evaluation (Hasib *et al.*, 2002). Organic acids are a useful index of authenticity in fruit products, since they have lower susceptibility to change during processing and storage than other components of fruits (Camara *et al.*, 1994). Accurate knowledge of organic acid levels (and ratios) might be useful for determining the percentage juice and also for detecting misbranding and/or adulteration in fruit juices, since each fruit has a unique pattern of organic acids. The organic acid composition of fruits is also of interest due to its impact on the sensory properties. Even though they are minor components, in combination with sugars, they are important attributes of the sensorial quality of raw and processed fruits. These are important in characterizing the flavor of fruit juices also. Their presence and concentration determine tartness and other flavor attributes. In some cases, it is necessary to determine organic acids to assess whether an expensive juice has been illegally adulterated with a cheaper juice. Because organic acid profiles are distinct to each type of fruit juice, evidence of tampering can be evaluated by comparing the known juice fingerprint to that of the suspected adulterated juice (Henshall, 1998). Organic acid profiles can also determine juice freshness or spoilage.

The effect of γ-irradiation on organic acids content of mango juice samples from different cultivars is shown in Table 2.3. The major organic acids found in all cultivars of mango juice samples are citric, tartaric, succinic and malic acids. The content of citric, tartaric, succinic and malic acids in all cultivars of control mango juice ranged from 0.23 to 0.34, 0.07 to 0.13, 0.074 to 0.083 and 0.75 to 0.86 (g/100 mL) respectively. The lowest content of citric,

Table 2.3 Effect of γ-irradiation on citric, tartaric, succinic and malic acids content of mango juice from different cultivars

Juice variety	Citric acid (g/100 mL)				Tartaric acid (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	0.27 ± 0.04[a]	0.25 ± 0.03[a]	0.29 ± 0.03[a]	0.30 ± 0.04[a]	0.12 ± 0.03[a]	0.11 ± 0.02[a]	0.11 ± 0.02[a]	0.12 ± 0.03[a]
Banginapalli	0.23 ± 0.01[a]	0.22 ± 0.02[a]	0.25 ± 0.02[a]	0.26 ± 0.03[a]	0.13 ± 0.04[a]	0.12 ± 0.03[a]	0.12 ± 0.03[a]	0.13 ± 0.04[a]
Mulgoa	0.26 ± 0.03[a]	0.24 ± 0.01[a]	0.23 ± 0.02[a]	0.27 ± 0.03[a]	0.11 ± 0.01[a]	0.11 ± 0.01[a]	0.11 ± 0.01[a]	0.11 ± 0.02[a]
Neelam	0.34 ± 0.01[a]	0.33 ± 0.02[a]	0.35 ± 0.01[a]	0.36 ± 0.02[a]	0.09 ± 0.02[a]	0.08 ± 0.03[a]	0.09 ± 0.02[a]	0.09 ± 0.02[a]
Raspuri	0.30 ± 0.02[a]	0.28 ± 0.03[a]	0.29 ± 0.02[a]	0.32 ± 0.03[a]	0.07 ± 0.03[a]	0.09 ± 0.04[a]	0.08 ± 0.03[a]	0.08 ± 0.03[a]
Rumani	0.29 ± 0.03[a]	0.27 ± 0.01[a]	0.30 ± 0.03[a]	0.31 ± 0.02[a]	0.10 ± 0.02[a]	0.09 ± 0.01[a]	0.09 ± 0.01[a]	0.10 ± 0.02[a]
Sindhura	0.31 ± 0.02[a]	0.29 ± 0.03[a]	0.33 ± 0.01[a]	0.33 ± 0.03[a]	0.08 ± 0.01[a]	0.10 ± 0.03[a]	0.09 ± 0.02[a]	0.09 ± 0.03[a]
Totapuri	0.28 ± 0.01[a]	0.26 ± 0.02[a]	0.25 ± 0.02[a]	0.30 ± 0.01[a]	0.11 ± 0.02[a]	0.12 ± 0.04[a]	0.11 ± 0.03[a]	0.12 ± 0.04[a]

Table 2.3 continued…

Juice variety	Succinic acid (g/100 mL)				Malic acid (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	0.083 ± 0.012^{a}	0.081 ± 0.011^{a}	0.085 ± 0.01^{a}	0.089 ± 0.013^{a}	0.79 ± 0.03^{b}	0.72 ± 0.02^{a}	0.72 ± 0.03^{a}	0.72 ± 0.02^{a}
Banginapalli	0.080 ± 0.007^{a}	0.079 ± 0.006^{a}	0.083 ± 0.009^{a}	0.088 ± 0.011^{a}	0.75 ± 0.02^{b}	0.69 ± 0.01^{a}	0.69 ± 0.01^{a}	0.69 ± 0.01^{a}
Mulgoa	0.079 ± 0.009^{a}	0.077 ± 0.01^{a}	0.078 ± 0.011^{a}	0.081 ± 0.01^{a}	0.78 ± 0.01^{b}	0.71 ± 0.04^{a}	0.71 ± 0.02^{a}	0.71 ± 0.04^{a}
Neelam	0.075 ± 0.011^{a}	0.074 ± 0.008^{a}	0.076 ± 0.009^{a}	0.078 ± 0.012^{a}	0.86 ± 0.02^{b}	0.79 ± 0.03^{a}	0.79 ± 0.03^{a}	0.79 ± 0.02^{a}
Raspuri	0.078 ± 0.008^{a}	0.076 ± 0.007^{a}	0.079 ± 0.01^{a}	0.082 ± 0.009^{a}	0.84 ± 0.01^{b}	0.80 ± 0.02^{a}	0.80 ± 0.02^{a}	0.80 ± 0.01^{a}
Rumani	0.082 ± 0.011^{a}	0.081 ± 0.009^{a}	0.084 ± 0.012^{a}	0.085 ± 0.011^{a}	0.82 ± 0.02^{b}	0.75 ± 0.03^{a}	0.75 ± 0.02^{a}	0.75 ± 0.03^{a}
Sindhura	0.074 ± 0.006^{a}	0.075 ± 0.008^{a}	0.077 ± 0.007^{a}	0.080 ± 0.009^{a}	0.85 ± 0.03^{b}	0.77 ± 0.04^{a}	0.77 ± 0.03^{a}	0.77 ± 0.04^{a}
Totapuri	0.081 ± 0.01^{a}	0.082 ± 0.012^{a}	0.081 ± 0.01^{a}	0.084 ± 0.011^{a}	0.80 ± 0.02^{b}	0.76 ± 0.01^{a}	0.76 ± 0.01^{a}	0.76 ± 0.01^{a}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range Test (DMRT).

tartaric, succinic and malic acids were found in Cv. *Banginapalli*, *Raspuri*, *Sindhura* and and *Banginapalli* juices and highest contents were in Cv. *Neelam*, *Banginapalli*, *Alphonso* and *Neelam*, juices respectively. In this study different doses of γ-irradiation had no or negligible effect on the content of these organic acids in all cultivars of mango juice samples (Table 2.3). Similarly Kim and Yook (2009) reported irradiated kiwi fruits showed little effects on the organic acid contents. Sadoughi *et al*. (2012) also reported no significant changes ($P > 0.05$) in the contents of malic, oxalic, pyruvic, citric and glutamic acids in onion puree immediately after being exposed to different doses of γ-irradiation and during cold storage. Malate was significantly sourer tasting than citric acid, when malic acid and citric acid were added to fruit pulps at similar moles H+ (Marsh *et al*., 2003). Al-Bachir (1999) reported that irradiation decreased the pH value of the apple juice that should have been verified by experimentation to ascertain the increasing of some other organic acids, such as citric, quinic, and succinic acids.

2.4.1.4 Effects of γ-irradiation on total sugars (TS) and reducing sugars (RS) of mango juice from different cultivars: Fruit sweetness is an important aspect of fruit quality. Glucose and fructose are the most predominant sugars present in all fruits including the mango fruit. Sugars and acids in fruits significantly influence the flavor, appearance, chemical and sensory characteristics (Al-Maiman and Ahmad, 2002). Most of the available literature describes the titration based Lane-Eynon method for the determination of sugars in fruit juices (Tehranifar *et al*., 2010). However, titration methods have several disadvantages such as the final results largely depend on precise reaction times, temperature and reagent concentration. In addition, the method is susceptible to interference from other types of molecules that act as reducing agents. In the present investigation, spectroscopic procedures based on a calorimetric technique including the phenol sulphuric acid assay and Somogyi–Nelson method were used to quantify the amount of total sugars and reducing sugars, respectively.

The effect of γ-irradiation on total and reducing sugars of different cultivars of mango juice samples is shown in Table 2.4. The content of TS in all cultivars of control mango juice ranged from 17.93 to 22.08 (g/100 mL), the lowest TS was found in *Mulgoa* and highest was in *Banginapalli* cultivars, respectively. The RS concentration present in the different control mango varieties varied according to the variety, and ranged from 15.38 to 19.43 (g/100 mL). In

this study, the highest RS were present in *Banginapalli* (19.43 g/100 mL) and the lowest in *Mulgoa* and *Raspuri* (15.38 and 15.57 g/100 mL) cultivars, respectively (Table 2.4). Even though the cultivar *Raspuri* has less Pectin content than *Neelam* (Data not presented), it has the lowest amount of sugars, and this could be attributed to the stage of ripening (Varakumar et al., 2011).

The TS content did not change in the all cultivars of mango juices at all the applied irradiation doses. However, compared to the control, slight variations were observed among different dose levels for the RS content. The amount of RS varied differently at all applied irradiation doses (0.5, 1 and 3 kGy) (Table 2.4). Similar findings have been reported by Shahbaz *et al*. (2014) in which the γ-irradiation had no effect on total sugars of pomegranate juice, however reducing sugars were slightly increased, compared to control. Mitchell, *et al*. (1992) reported irradiation had no effect on the sucrose and fructose content of custard apples at 75 and 300 Gy but a significant increase was observed in the glucose levels. In the same experiment, no effect was observed in the fructose and glucose content in lemons at 75 Gy but an increase was recorded for the sucrose content. Our findings are also in agreement with El-Samahy *et al*. (2000) in which no effect from the gamma radiation (0.5–1.5 kGy) was observed on the total sugars content of mangoes but the reducing sugars were slightly increased. Research studies have shown that there is no substantial effect from irradiation on macronutrients such as proteins and carbohydrates in plant materials even up to a dose of 10 kGy (Crawford and Ruff, 1996). Singh (1990) and Thomas and Beyers (1979) have reported that low radiation doses used in the extension of shelf-life of mangoes has a negligible effect on total sugar content. The increase in reducing sugars during refrigerated storage of mango fruits may be attributed to fruit ripening and the generation of reducing sugars from reserve starch, however, the rate of increase was lower in irradiated samples than non-irradiated ones. This might be most likely a reflection of the delayed ripening of mango upon irradiation.

Table 2.4 Effects of γ-irradiation on total sugars (TS) and reducing sugars (RS) of mango juice from different cultivars

Juice variety	TS (g/100 mL)				RS (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	21.45 ± 0.39^{a}	21.45 ± 0.39^{a}	21.45 ± 0.38^{a}	21.45 ± 0.39^{a}	18.81 ± 0.32^{a}	19.48 ± 0.54^{b}	19.12 ± 0.46^{b}	18.93 ± 0.37^{a}
Banginapalli	22.08 ± 0.25^{a}	22.07 ± 0.25^{a}	22.08 ± 0.25^{a}	22.09 ± 0.24^{a}	19.43 ± 0.21^{a}	20.09 ± 0.33^{b}	19.74 ± 0.29^{a}	19.51 ± 0.35^{a}
Mulgoa	17.93 ± 0.67^{a}	17.93 ± 0.66^{a}	17.92 ± 0.67^{a}	17.93 ± 0.67^{a}	15.38 ± 0.25^{a}	15.97 ± 0.42^{ab}	15.61 ± 0.34^{a}	15.47 ± 0.29^{a}
Neelam	19.32 ± 0.48^{a}	19.33 ± 0.47^{a}	19.32 ± 0.48^{a}	19.32 ± 0.48^{a}	16.86 ± 0.33^{a}	16.75 ± 0.51^{a}	17.04 ± 0.43^{b}	16.96 ± 0.36^{a}
Raspuri	18.13 ± 0.38^{a}	18.14 ± 0.38^{a}	18.13 ± 0.38^{a}	18.14 ± 0.37^{a}	15.57 ± 0.24^{a}	16.22 ± 0.38^{b}	15.86 ± 0.32^{a}	15.68 ± 0.27^{a}
Rumani	20.83 ± 0.29^{a}	20.83 ± 0.30^{a}	20.83 ± 0.29^{a}	20.82 ± 0.30^{a}	18.35 ± 0.29^{a}	19.02 ± 0.43^{b}	18.67 ± 0.37^{a}	18.46 ± 0.34^{a}
Sindhura	21.22 ± 0.53^{a}	21.22 ± 0.53^{a}	21.23 ± 0.53^{a}	21.22 ± 0.53^{a}	18.62 ± 0.35^{a}	19.25 ± 0.52^{b}	18.91 ± 0.45^{a}	18.74 ± 0.42^{a}
Totapuri	21.71 ± 0.34^{a}	21.71 ± 0.35^{a}	21.71 ± 0.35^{a}	21.72 ± 0.34^{a}	19.14 ± 0.22^{a}	19.03 ± 0.36^{a}	19.56 ± 0.41^{ab}	19.25 ± 0.28^{a}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

2.4.1.5 Effects of γ-irradiation on glucose, fructose and sucrose content of mango juice from different cultivars: Knowledge of the exact qualitative and quantitative distribution of the characteristic sugars and organic acids in fruits or fruits products is of capital importance to evaluate quality, either as a powerful tool to detect adulteration in juices and other fruit products or as indices to control changes in the production and storage based on their relative stability. Sugars and organic acids of fruits have been widely studied both as components of fruit flavor and as indices of fruit development and ripening. They are routinely assessed for fruit quality by determining total soluble solids (TSS) and titrable acidity (TA): for the former, by means of a refractometer, and for the latter, an acid-base titration. These parameters are taken as total content of sugars and organic acids, respectively due to the demonstrated correlation between these measurements and component contents in some fruits (Perez *et al*., 1997). The effect of γ-irradiation on organic acids and TA of mango juice was discussed in previous sections.

Sucrose, glucose and fructose are the principal sugars in ripened mango, with small amounts of cellulose, hemicellulose and pectin. The green tender fruits are rich in starch, and during ripening the starch that is present is hydrolysed to reducing sugars (Anon, 1962). In the present study glucose, fructose and sucrose were detected in the all cultivars of mango juice samples. The effect of γ-irradiation on individual reducing sugars content of different cultivars of mango juice samples is shown in Table 2.5. The content of glucose, fructose and sucrose in all cultivars of control mango juice ranged from 0.45 to 1.01, 4.79 to 5.67 and 12.26 to 13.43 (g/100 mL), respectively. The lowest content of glucose, fructose and sucrose was found in Cv. *Mulgoa* juice samples and highest content was in Cv. *Alphonso*, *Banginapalli* and *Banginapalli* juices, respectively. In all cultivars of mango juice samples, glucose content was significantly ($P \leq 0.05$) increased by increasing irradiation dose. However, fructose and sucrose contents were significantly ($P \leq 0.05$) increased in 3 kGy irradiated samples and no significant differences between 0.5 and 1 kGy juice samples of all mango cultivars studied (Table 2.5). Some increase in glucose, fructose and sucrose content was observed in irradiated mango juice samples, which might be due to the fragmentation of other carbohydrates of mango juice. Irradiation was found to break down starch and other carbohydrates to simpler sugars (Wu *et al*., 2002).

Table 2.5 Effects of γ-irradiation on glucose, fructose and sucrose content of mango juice from different cultivars

Juice variety	Glucose (g/100 mL)				Fructose (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	1.01 ± 0.04^{a}	1.11 ± 0.06^{b}	1.26 ± 0.03^{c}	1.32 ± 0.07^{c}	5.26 ± 0.09^{a}	5.33 ± 0.12^{a}	5.39 ± 0.1^{a}	5.45 ± 0.07^{a}
Banginapalli	0.69 ± 0.03^{a}	0.83 ± 0.05^{b}	0.95 ± 0.04^{c}	1.07 ± 0.02^{d}	5.67 ± 0.07^{a}	5.72 ± 0.09^{ab}	5.77 ± 0.08^{ab}	5.89 ± 0.11^{b}
Mulgoa	0.45 ± 0.01^{a}	0.61 ± 0.03^{b}	0.73 ± 0.02^{c}	0.86 ± 0.04^{d}	4.79 ± 0.06^{a}	4.84 ± 0.08^{a}	4.88 ± 0.11^{a}	4.96 ± 0.09^{a}
Neelam	0.59 ± 0.02^{a}	0.72 ± 0.04^{b}	0.84 ± 0.03^{c}	0.95 ± 0.04^{d}	4.94 ± 0.09^{a}	5.01 ± 0.11^{ab}	5.06 ± 0.07^{ab}	5.18 ± 0.12^{b}
Raspuri	0.56 ± 0.03^{a}	0.68 ± 0.02^{b}	0.79 ± 0.04^{c}	0.90 ± 0.03^{d}	4.86 ± 0.08^{a}	4.91 ± 0.09^{a}	4.94 ± 0.06^{ab}	5.09 ± 0.11^{b}
Rumani	0.61 ± 0.02^{a}	0.74 ± 0.03^{b}	0.88 ± 0.02^{c}	0.99 ± 0.01^{d}	5.07 ± 0.05^{a}	5.12 ± 0.07^{a}	5.16 ± 0.09^{ab}	5.28 ± 0.08^{b}
Sindhura	0.65 ± 0.03^{a}	0.76 ± 0.02^{b}	0.91 ± 0.04^{c}	1.02 ± 0.02^{d}	5.14 ± 0.08^{a}	5.18 ± 0.1^{ab}	5.21 ± 0.12^{ab}	5.36 ± 0.09^{b}
Totapuri	0.67 ± 0.02^{a}	0.79 ± 0.01^{b}	0.93 ± 0.03^{c}	1.05 ± 0.03^{d}	5.42 ± 0.06^{a}	5.47 ± 0.09^{a}	5.52 ± 0.11^{a}	5.69 ± 0.12^{b}

Table 2.5 Continued…

Juice variety	Sucrose (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	12.55 ± 0.27^{a}	12.92 ± 0.31^{a}	13.28 ± 0.29^{b}	13.44 ± 0.36^{b}
Banginapalli	13.43 ± 0.19^{a}	13.74 ± 0.26^{a}	14.02 ± 0.18^{b}	14.23 ± 0.22^{b}
Mulgoa	12.26 ± 0.31^{a}	12.48 ± 0.19^{a}	12.65 ± 0.24^{a}	12.97 ± 0.18^{a}
Neelam	12.45 ± 0.18^{a}	12.73 ± 0.24^{a}	12.94 ± 0.32^{a}	13.12 ± 0.25^{b}
Raspuri	12.43 ± 0.22^{a}	12.66 ± 0.18^{a}	12.83 ± 0.19^{a}	13.08 ± 0.34^{b}
Rumani	12.39 ± 0.11^{a}	12.64 ± 0.16^{a}	12.97 ± 0.21^{a}	13.15 ± 0.18^{b}
Sindhura	12.47 ± 0.17^{a}	12.73 ± 0.28^{a}	13.05 ± 0.19^{b}	13.22 ± 0.25^{b}
Totapuri	12.82 ± 0.28^{a}	13.06 ± 0.17^{ab}	13.32 ± 0.24^{b}	13.67 ± 0.31^{b}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range Test (DMRT).

2.4.1.6 Effects of γ-irradiation on mango fruit juice colour: It is an important characteristic feature of food products because it is usually among the first properties that consumers pay attention. Color change in food products during processing and storage is due to various factors (Liu *et al*. 2010). These include Maillard reaction and enzymatic browning as well as process conditions, such as pH, acidity, packaging material, and duration and temperature of storage. In this study, colour change based on colour lightness (L^*), yellowness (b^*) redness (a^*), chroma (C*) and hue angle (h°) after γ-irradiation was investigated and used to judge its effect on the aesthetic quality of mango juice. It may be significant to investigate the change in colour because irradiation can result in the destruction of pigments in fruit and fruit juices.

The effect of γ-irradiation on the Hunter colour (L^* a^* b^*) values of all cultivars of mango juice samples is shown in Table 2.6. The L^* value of the control (0 kGy) mango juice samples ranged from 40.56 to 56.69, the lowest L^* was found in *Mulgoa* and highest was in *Neelam* cultivars, respectively. The a^* value of the control mango juice samples ranged from 2.28 to 13.41, the lowest a^* was found in *Raspuri* and highest was in *Alphonso* cultivars, respectively. The b^* value of the control mango juice samples ranged from 20.33 to 35.01, the lowest b^* was found in *Raspuri* and highest was in *Neelam* cultivars, respectively. Chroma (C*)

and hue angle (h°) values were also evaluated and these parameters associated with a* and b* values. The chroma (C*) value of the control mango juice samples ranged from 20.46 to 35.31, the lowest C* was found in *Raspuri* and highest was in *Neelam* cultivars, respectively. The hue angle (h°) of the control mango juice samples ranged from 65.46 to 83.61, the lowest h° was found in *Alphonso* and highest was in *Raspuri* cultivars, respectively.

Mango juice colour indices showed significant statistical differences among the control and irradiated juice samples of all cultivars studied. The results (Table 2.6) show that the control mango juice had a darker colour than that of the irradiated juice samples with significant ($P \leq 0.05$) differences in the luminosity dimension scale (Lightness; $L^* = 0$ denotes black and $L^* = 100$ indicates diffuse white). Chen *et al*. (1995) reported that the heating process has significant decrease in the lightness, hue angle and chroma leading the pineapple juice to appear darker because of the degradation of carotenoid pigment which led to the loss of yellowness in juice. Also this decrease may related to the partial precipitation by unstable, suspended particles in juice (Genovese *et al*., 1997) and the non-enzymatic browning (Maillard) reaction taking place between amino acids and reducing sugar present in the juice. The redness (a^*) and yellowness (b^*) indices increased directly with the irradiation dose and represented significant ($P \leq 0.05$) differences among the juice samples of all cultivars at different dose levels. The chroma (C*) value was significantly ($P \leq 0.05$) increased in all cultivars of mango juice samples by increasing the irradiation dose. However, conflict results were observed in hue angle (h°) of irradiated mango juice samples from different cultivars. Rivas *et al*., (2006) reported that the hue angle of thermally pasteurized mixed orange and carrot juice diminished significantly during storage and the juice became redder and less yellow when the hue decreases (Esteve and Frigola, 2007).

The present results are in agreement with Shahbaz *et al*. (2014), who reported that the L^* value was significantly decreased, however a^* and b^* values were significantly increased by increasing the irradiation dose in pomegranate juice samples. The colour of the *Curcuma aromatica* extract and green tea was improved by gamma irradiation (Kim *et al*., 2006 and Jo *et al*., 2003). Boylston *et al*. (2002) reported that the colour of 0.75 kGy irradiated rambutan and orange fruits tended to be more intense than that of the control fruits visually evaluated by sensory judges.

Table 2.6 Effects of γ-irradiation on Hunter colour parameters of mango juice from different cultivars

Hunter parameters	*Alphonso*				*Banginapalli*				*Mulgoa*			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
*L** value	44.17 ± 0.03^{d}	43.44 ± 0.06^{a}	43.02 ± 0.04^{b}	42.63 ± 0.05^{a}	53.19 ± 0.17^{c}	55.53 ± 0.15^{d}	52.24 ± 0.08^{b}	51.58 ± 0.06^{a}	40.56 ± 0.05^{b}	40.94 ± 0.03^{bc}	40.08 ± 0.06^{b}	39.88 ± 0.04^{a}
*a** value	13.41 ± 0.06^{a}	13.92 ± 0.04^{a}	14.63 ± 0.02^{b}	15.57 ± 0.05^{c}	5.76 ± 0.04^{a}	6.08 ± 0.02^{b}	6.93 ± 0.03^{b}	7.24 ± 0.05^{c}	5.24 ± 0.02^{a}	5.28 ± 0.04^{a}	5.36 ± 0.03^{a}	5.67 ± 0.05^{a}
*b** value	29.48 ± 0.08^{a}	30.65 ± 0.06^{b}	30.97 ± 0.04^{b}	32.06 ± 0.07^{c}	33.54 ± 0.12^{a}	34.62 ± 0.07^{b}	35.06 ± 0.05^{c}	35.87 ± 0.04^{c}	26.33 ± 0.07^{a}	26.96 ± 0.05^{a}	27.67 ± 0.04^{b}	28.45 ± 0.06^{c}
Chroma (C*)	32.39 ± 0.07^{a}	33.66 ± 0.05^{b}	34.25 ± 0.03^{c}	35.64 ± 0.06^{d}	34.03 ± 0.08^{a}	35.15 ± 0.04^{b}	35.74 ± 0.04^{b}	36.59 ± 0.03^{c}	26.84 ± 0.05^{a}	27.47 ± 0.06^{b}	28.18 ± 0.02^{c}	29.01 ± 0.04^{d}
Hue angle (h°)	65.46 ± 0.06^{b}	65.56 ± 0.04^{b}	64.75 ± 0.05^{a}	64.11 ± 0.03^{a}	80.25 ± 0.05^{b}	80.03 ± 0.06^{b}	78.82 ± 0.03^{a}	78.60 ± 0.06^{a}	78.73 ± 0.04^{a}	78.93 ± 0.05^{a}	79.03 ± 0.03^{ab}	78.73 ± 0.06^{a}

Table 2.6 continued…

Hunter parameters	*Neelam*				*Raspuri*				*Rumani*			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
*L** value	56.69 ± 0.04^{b}	57.11 ± 0.06^{bc}	56.54 ± 0.05^{b}	55.27 ± 0.03^{a}	39.72 ± 0.13^{d}	38.35 ± 0.08^{c}	37.67 ± 0.05^{b}	36.28 ± 0.07^{a}	51.14 ± 0.11^{c}	50.67 ± 0.08^{b}	50.02 ± 0.04^{b}	49.56 ± 0.07^{a}
*a** value	4.53 ± 0.02^{a}	4.67 ± 0.03^{ab}	4.91 ± 0.05^{b}	5.44 ± 0.04^{c}	2.28 ± 0.02^{a}	2.24 ± 0.03^{a}	3.09 ± 0.04^{b}	4.16 ± 0.02^{c}	13.06 ± 0.08^{a}	14.56 ± 0.03^{b}	15.71 ± 0.06^{c}	16.34 ± 0.04^{d}
*b** value	35.01 ± 0.05^{a}	36.54 ± 0.03^{b}	37.33 ± 0.04^{c}	38.68 ± 0.07^{d}	20.33 ± 0.05^{a}	20.96 ± 0.04^{a}	21.44 ± 0.03^{b}	22.75 ± 0.06^{c}	32.05 ± 0.12^{a}	32.94 ± 0.05^{a}	33.56 ± 0.04^{b}	34.72 ± 0.06^{c}
Chroma (C*)	35.31 ± 0.04^{a}	36.85 ± 0.05^{b}	37.66 ± 0.03^{c}	39.06 ± 0.05^{d}	20.46 ± 0.03^{a}	21.08 ± 0.05^{b}	21.67 ± 0.02^{b}	23.13 ± 0.04^{c}	34.61 ± 0.1^{a}	36.01 ± 0.04^{b}	37.06 ± 0.05^{c}	38.37 ± 0.03^{d}
Hue angle (h°)	82.63 ± 0.07^{a}	82.71 ± 0.08^{a}	82.5 ± 0.05^{a}	82.01 ± 0.06^{a}	83.61 ± 0.05^{c}	83.91 ± 0.04^{c}	81.81 ± 0.07^{b}	79.64 ± 0.05^{a}	67.88 ± 0.08^{c}	66.13 ± 0.06^{b}	64.95 ± 0.03^{a}	64.75 ± 0.04^{a}

Table 2.6 continued…

Hunter parameters	*Sindhura*				*Totapuri*			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
*L** value	46.83 ± 0.07^{b}	47.02 ± 0.04^{bc}	46.11 ± 0.08^{b}	45.33 ± 0.06^{a}	52.84 ± 0.09^{b}	52.06 ± 0.07^{b}	51.77 ± 0.04^{a}	51.02 ± 0.06^{a}
*a** value	10.75 ± 0.06^{a}	11.48 ± 0.02^{b}	12.73 ± 0.05^{c}	13.59 ± 0.04^{d}	5.54 ± 0.1^{a}	6.18 ± 0.05^{b}	6.94 ± 0.07^{b}	7.36 ± 0.04^{c}
*b** value	30.78 ± 0.04^{a}	31.56 ± 0.06^{b}	32.36 ± 0.05^{c}	33.27 ± 0.07^{d}	33.61 ± 0.12^{a}	34.12 ± 0.09^{b}	34.85 ± 0.05^{b}	35.76 ± 0.07^{c}
Chroma (C*)	32.61 ± 0.03^{a}	33.58 ± 0.04^{b}	34.77 ± 0.06^{c}	35.94 ± 0.05^{d}	34.06 ± 0.08^{a}	34.67 ± 0.07^{a}	35.53 ± 0.06^{b}	36.51 ± 0.05^{c}
Hue angle (h°)	70.73 ± 0.04^{c}	70.02 ± 0.05^{c}	68.51 ± 0.03^{b}	67.8 ± 0.06^{a}	80.64 ± 0.04^{c}	79.73 ± 0.06^{b}	78.74 ± 0.05^{a}	78.37 ± 0.03^{a}

Chroma (C*) = $[(a^*)^2 + (b^*)^2]^{1/2}$; Hue angle ($h°$) = arctan ($b^*/a^*$); Values were mean ± S.D (n = 3); Values not sharing a common superscript letter differ significantly at $P \leq 0.05$ according to DMRT.

Contrary to these findings, Lee *et al*. (2009) reported the Hunter color *L** value (brightness) increased significantly, however Hunter color *a** value (redness) and *b** value (yellowness) were decreased significantly by irradiation in both fresh and stored ready-to-use tamarind juice samples. A study done by Mitchell *et al*. (1992) on mangoes showed a reduction in the *a** values after gamma-rays treatment at 75 and 300 Gy. The change in colour can be ascribed to a decrease in the polyphenol oxidase activity by irradiation (Mishra *et al*., 2012). Colour degradation in juice may due to non-enzymatic Maillard browning, which is the reaction between sugars, amino acids and organic acids, which has a severe impact on colour and thus reduces the consumer appeal (Klim and Nagy, 1988). In addition, the colour of juice may change due to heating, air and light, which cause carotenoids to undergo oxidation, cis/trans changes and alterations in epoxide rings as a function of storage (Esteve and Frigola, 2007).

2.4.2 Microbiological quality of mango juice: Microbiological evaluation of foods is of prime importance because of the presence of harmful pathogens and their inactivation is essential to ensure the hygienic quality of food material (Chaudry *et al*. 2004). The predominant organisms found in the various types of juices were yeasts (Tournas *et al*., 2006). These organisms could grow during refrigeration (4 °C) and cause spoilage of samples. In food irradiation, the D_{10} values of yeasts and molds were higher than bacterial pathogens. Thus, most research efforts related to irradiation of juices have targeted spoilage organisms such as yeasts and molds rather than bacterial pathogens (Monk *et al*., 1994). The changes in the microbial load of different cultivars of mango juice samples were shown in Table 2.7. The microbial load (bacteria and fungi) were measured by the plant counts and total fungi in control and irradiated mango juice samples. In this study total bacterial counts (TBC) were found to be significantly higher than the yeast and mold counts (YMC). The initial mean populations of the TBC and YMC of different cultivars of mango juice samples were in the range from $4.7 \pm 0.5 \times 10^4$ to $7.2 \pm 0.4 \times 10^5$ and $2.1 \pm 0.4 \times 10^2$ to $2.7 \pm 0.5 \times 10^3$ CFU/mL, respectively. The highest TBC were observed in *Alphonso* and lowest in *Neelam* cultivars. However the highest YMC were observed in *Banginapalli* and lowest in *Mulgoa* cultivars. The initial TBC and YMC of all cultivars of mango juice samples were significantly ($P \leq 0.05$) reduced by γ-irradiation at 0.5 kGy or above and no TBC and YMC were observed at an irradiation dose of 3 kGy (Table 2.7). Thus improvement in microbiological quality of mango juice by radiation processing was evident by the dose dependent reduction in TBC and YMC.

The present results are in agreement with Chervin and Boisseau (1994), who reported that the growth of aerobic and lactic microflora on shredded carrots was inhibited by irradiation at 2 kGy and chlorination, and the sensory analysis panelists preferred the irradiated vegetables. Prakash *et al*., (2002) also reported that irradiation at 0.5 kGy can reduce the microbial counts of diced tomatoes substantially to improve the microbial shelf-life without any adverse effects on the sensory qualities. Chaudry *et al*. (2004) reported that the microbiological quality of the irradiated sliced carrots was better than that of non-irradiated sliced carrots. In another study, Mishra *et al*. (2004) claimed that the microbiological quality of peeled ginger samples irradiated at 2 kGy was acceptable after 28 days at 10 °C. Kim *et al*. (2007) reported that the 3–5 kGy radiation doses may prevent microbial growth in the kale juice during storage period.

Table 2.7 Effects of γ-irradiation on total bacterial counts and yeast and mold counts of mango juice from different cultivars

Juice variety	Total bacterial counts (TBC) (CFU/mL)				Yeast and mold counts (YMC) (CFU/mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	$7.2 \pm 0.4 \times 10^{5d}$	$3.4 \pm 0.6 \times 10^{3c}$	$1.9 \pm 0.8 \times 10^{1b}$	ND[a]	$2.4 \pm 0.6 \times 10^{3d}$	$1.5 \pm 0.3 \times 10^{2b}$	$< 10^{1b}$	ND[a]
Banginapalli	$6.5 \pm 0.2 \times 10^{5d}$	$2.6 \pm 0.4 \times 10^{3c}$	$1.8 \pm 0.6 \times 10^{1b}$	ND[a]	$2.7 \pm 0.5 \times 10^{3d}$	$1.8 \pm 0.2 \times 10^{2b}$	$< 10^{1b}$	ND[a]
Mulgoa	$5.3 \pm 0.6 \times 10^{4d}$	$2.9 \pm 0.3 \times 10^{2c}$	$1.3 \pm 0.4 \times 10^{1b}$	ND[a]	$2.1 \pm 0.4 \times 10^{2c}$	$1.3 \pm 0.5 \times 10^{1b}$	ND[a]	ND[a]
Neelam	$4.7 \pm 0.5 \times 10^{4d}$	$3.5 \pm 0.5 \times 10^{2c}$	$1.1 \pm 0.2 \times 10^{1b}$	ND[a]	$2.6 \pm 0.3 \times 10^{2c}$	$1.4 \pm 0.6 \times 10^{1b}$	ND[a]	ND[a]
Raspuri	$6.1 \pm 0.3 \times 10^{5d}$	$2.4 \pm 0.3 \times 10^{3c}$	$1.6 \pm 0.5 \times 10^{1b}$	ND[a]	$3.2 \pm 0.5 \times 10^{2c}$	$1.7 \pm 0.7 \times 10^{1b}$	ND[a]	ND[a]
Rumani	$7.4 \pm 0.6 \times 10^{4d}$	$4.2 \pm 0.4 \times 10^{2c}$	$2.1 \pm 0.3 \times 10^{1b}$	ND[a]	$2.8 \pm 0.6 \times 10^{2c}$	$1.9 \pm 0.3 \times 10^{1b}$	ND[a]	ND[a]
Sindhura	$6.3 \pm 0.4 \times 10^{5d}$	$2.5 \pm 0.3 \times 10^{3c}$	$1.7 \pm 0.6 \times 10^{1b}$	ND[a]	$2.5 \pm 0.7 \times 10^{3d}$	$1.6 \pm 0.4 \times 10^{2b}$	$< 10^{1b}$	ND[a]
Totapuri	$7.6 \pm 0.2 \times 10^{4d}$	$4.4 \pm 0.5 \times 10^{2c}$	$2.3 \pm 0.4 \times 10^{1b}$	ND[a]	$3.1 \pm 0.5 \times 10^{2c}$	$1.8 \pm 0.5 \times 10^{1b}$	ND[a]	ND[a]

ND: No microbe detected on plates; Values are given as mean ± S.D (n = 3); Values with different letters with in the same row differ significantly at $P \leq 0.05$ according to Duncan's multiple range test (DMRT).

This result showed that, the inactivation of microorganisms in different juices depended on their compositions. Alighourchi *et al*. (2008) reported that irradiation at 0.5 and 2 kGy reduced the growth rate of bacteria and fungi of the selected pomegranate juices during the first 3 days of storage at 4 °C. The microbial population reduced to below the detection limits at ≥ 3.5 kGy, in all studied pomegranate juices. Lee *et al*. (2009) reported that doses up to 5 kGy did not significantly influence colour, and nutritional values of ready-to-use tamarind juice. However, the populations of the total aerobic bacteria, yeast and mold in the juice were significantly reduced by γ-irradiation at 1 kGy or above.

A decrease in microbial population resulting from the damaging effects of irradiation on cellular DNA has been reported. Cells that were damaged by irradiation were gradually inactivated, thus not adapting to the surrounding environment during storage (Byun *et al*., 2001). Sublethal damage to cells caused by irradiation is likely to increase their sensitivity to environmental stress factors. A phenomenon similar to that observed in the present study has been reported in heat-treated foods, where damaged cells are unable to repair and tend to die in unfavorable environments (Leistner, 1996). In addition, an extension of the lag time in the growth of the surviving cells in foods with radiation-related injuries has been reported (Grant & Patterson, 1992).

2.4.3 General composition of mango wine

2.4.3.1 Effects of γ-irradiation on pH and total soluble solids (TSS) of different types of mango wine: pH is a fundamental element of the wine-making industry and strongly influences wine properties such as color, oxidation, biological and chemical stability. It measures the quantity of acids present, the strength of the acids, and the effects of minerals and other ingredients in the wine. Wine pH depends on three main factors: the total amount of acid present, the ratio of malic acid to tartaric acid, and the amount of potassium present. Wines that contain little acid and excess potassium show high pH values. Wine with more tartaric acid, less malic acid, less potassium and more titratable acid has lower pH values. Generally pH values range from 2.9 to 4.2 in wine. Wine's chemical and biological stability are very dependent on pH value. Lower pH values are known to improve the stability, so winemakers usually prefer a

pH range of 3.0 to 3.5. The wine is so stable in this range that many winemakers believe pH is a crucial guideline in wine-making. There are many advantages to low pH values in wine. Low pH inhibits bacteria, causes sugar fermentation to progress more evenly and makes malolactic fermentation easier to control. Low pH also has a direct influence on the hot stability of wine. When bottled wines are stored in warm areas, protein precipitates out of them, causing serious problems. These wines are then treated with bentonite, which removes excess protein. The pH is important to the treatment because bentonite successfully removes more protein when the pH value is low. If wine pH increases, bentonite is less effective, making it necessary to add larger amounts. The danger is adding too much bentonite may strip wines of their unique aromas and flavors. Low wine pH results in better visual qualities as well. When pH is lower, both red and white wines maintain better colour intensity. Red wines have more and better colour and white wines do not brown as easily. When wine has high pH values, bacteria grow rapidly and undesirable bacterial fermentation is more problematic. This condition causes less biological and chemical stability, and poorer colour. Wines with a high pH always need more attention and greater care

The effect of γ-irradiation on pH of different types of mango wine samples is shown in Table 2.8. The pH range of the control (0 kGy) mango wines was between 3.41 and 4.16, the lowest pH was found in the *Neelam* and highest was in *Rumani* wines respectively. There was a slight decrease in the pH from mango juice to wine. The pH of different types of mango wines was significantly ($P \leq 0.05$) decreased in irradiated wine samples, as the irradiation dose was increased (Table 2.8). The control showed the highest value and no significant change in the pH between doses of 0.5 and 1 kGy wine samples. However 3kGy sample had lowest value statistically in all wines studied. Similar to this study Harder *et al*. (2013), reported that there was apparent decreases in pH of red wine with increasing irradiation dose. Souza and Mastro (2004) observed that reduction in pH of sugar cane spirit by radiation, as a factor in aging.

The effect of γ-irradiation on TSS of different types of mango wine samples is shown in Table 2.8. The TSS range of the control (0 kGy) mango wines was between 5.4 and 6.2 °Bx, the lowest TSS was found in the *Banginapalli* and highest was in *Alphonso* wines respectively. As shown in Table 2.8, at the irradiation doses of 0.5 and 1 kGy, there were significant ($P \leq 0.05$) increase in the soluble solids of the most of the mango wine samples studied, but

Table 2.8 Effects of γ-irradiation on pH and total soluble solids (TSS) of different types of mango wine

Wine variety	pH				TSS (°Brix)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	3.52 ± 0.03^{d}	3.44 ± 0.02^{c}	3.35 ± 0.02^{b}	3.18 ± 0.04^{a}	6.2 ± 0.03^{a}	6.4 ± 0.04^{b}	6.6 ± 0.02^{c}	6.6 ± 0.02^{c}
Banginapalli	3.48 ± 0.02^{d}	3.36 ± 0.01^{c}	3.32 ± 0.02^{b}	3.14 ± 0.03^{a}	5.4 ± 0.01^{a}	5.5 ± 0.02^{ab}	5.6 ± 0.03^{b}	5.6 ± 0.02^{b}
Mulgoa	4.03 ± 0.01^{d}	3.89 ± 0.02^{c}	3.81 ± 0.04^{b}	3.72 ± 0.03^{a}	6.1 ± 0.04^{a}	6.3 ± 0.03^{b}	6.4 ± 0.02^{bc}	6.4 ± 0.01^{bc}
Neelam	3.41 ± 0.04^{c}	3.33 ± 0.03^{b}	3.28 ± 0.05^{b}	3.21 ± 0.02^{a}	5.8 ± 0.02^{a}	5.9 ± 0.01^{ab}	6.0 ± 0.03^{b}	6.0 ± 0.04^{b}
Raspuri	4.04 ± 0.02^{d}	3.92 ± 0.01^{c}	3.86 ± 0.04^{b}	3.75 ± 0.03^{a}	6.0 ± 0.01^{a}	6.2 ± 0.03^{b}	6.4 ± 0.02^{c}	6.4 ± 0.02^{c}
Rumani	4.16 ± 0.01^{d}	4.07 ± 0.03^{c}	3.94 ± 0.02^{b}	3.83 ± 0.04^{a}	5.6 ± 0.03^{a}	5.8 ± 0.02^{b}	5.9 ± 0.03^{bc}	5.9 ± 0.03^{bc}
Sindhura	3.97 ± 0.03^{d}	3.81 ± 0.05^{c}	3.63 ± 0.04^{b}	3.56 ± 0.02^{a}	5.7 ± 0.02^{a}	5.8 ± 0.03^{ab}	6.0 ± 0.04^{bc}	6.1 ± 0.02^{c}
Totapuri	3.83 ± 0.02^{c}	3.76 ± 0.03^{b}	3.70 ± 0.05^{b}	3.44 ± 0.04^{a}	5.5 ± 0.04^{a}	5.7 ± 0.02^{b}	5.8 ± 0.01^{bc}	5.9 ± 0.03^{c}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

there is no significant difference between 1 and 3 kGy treated wine samples. Similar increase in soluble solids was also observed in red wine samples up to 1 kGy by Harder *et al*. (2013).

2.4.3.2 Effects of γ-irradiation on titratable acidity (TA) and volatile acidity (VA) of different types of mango wine: Titratable acidity (TA) is used as a guideline to determine how acidic the product will taste. This determination measures the concentration of all available hydrogen ions present in the sample, wine or juice. The determination of pH and TA of wine plays an important role in the area of oenology, because both parameters affect the properties and quality of wine, especially the colour and the flavour. Further, the microbiological stability of wine also depends on its acid content. The effect of γ-irradiation on TA of different types of mango wine samples is shown in Table 2.9. The TA range of the control (0 kGy) mango wines was between 5.52 and 7.36 g/L, the lowest TA was found in the *Rumani* and highest was in *Neelam* wines, respectively. TA of all irradiated wine samples tested remained the same as the non-irradiated mango wine as the dose of irradiation increased (Table 2.9). This showed that the acids, which also contribute to the flavor of wine, were not positively or negatively affected by γ-irradiation. It also showed that the fermentation process was up to standard and there was neither rancidity nor contamination in the entire process (Chang, 2003). These results were in agreement with previous studies, who reported TA of all irradiated rice wine (Chang, 2003) and maize wine (Chang, 2004) samples remained the same as the non-irradiated sample. However, Harder *et al*. (2013) found significant differences in TA of irradiated red wine samples when compared to that of the non-irradiated sample.

Volatile Acidity is a wine-word often referred to simply as VA, and it's normally associated with wine spoilage. VA is a measure of the total concentration of 'volatile acids' in wine. While there are a number of wine acids that are volatile, the most serious one is acetic acid, which accounts for over 95% of any VA measurement. Volatile acids can be formed by yeast activity during fermentation and by spoilage bacteria during fermentation or ageing. Testing for VA is important to maintain quality and monitor the possible presence of spoilage organisms.

Table 2.9 Effects of γ-irradiation on titratable acidity (TA) and volatile acidity (VA) of different types of mango wine

Wine variety	TA (g/L)				VA (g/L)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	6.19 ± 0.6^{a}	6.19 ± 0.6^{a}	6.19 ± 0.6^{a}	6.19 ± 0.6^{a}	0.34 ± 0.04^{b}	0.31 ± 0.03^{ba}	0.29 ± 0.04^{a}	0.26 ± 0.02^{a}
Banginapalli	6.24 ± 0.7^{a}	6.24 ± 0.7^{a}	6.24 ± 0.7^{a}	6.23 ± 0.7^{a}	0.45 ± 0.05^{b}	0.42 ± 0.04^{b}	0.38 ± 0.02^{a}	0.33 ± 0.04^{a}
Mulgoa	5.75 ± 0.4^{a}	5.75 ± 0.4^{a}	5.75 ± 0.4^{a}	5.75 ± 0.4^{a}	0.39 ± 0.03^{b}	0.34 ± 0.02^{b}	0.29 ± 0.04^{a}	0.25 ± 0.05^{a}
Neelam	7.36 ± 0.5^{a}	7.36 ± 0.5^{a}	7.36 ± 0.5^{a}	7.36 ± 0.5^{a}	0.61 ± 0.07^{c}	0.55 ± 0.03^{b}	0.50 ± 0.05^{b}	0.42 ± 0.04^{a}
Raspuri	5.64 ± 0.5^{a}	5.64 ± 0.5^{a}	5.64 ± 0.5^{a}	5.64 ± 0.5^{a}	0.49 ± 0.04^{b}	0.42 ± 0.05^{b}	0.36 ± 0.04^{a}	0.31 ± 0.03^{a}
Rumani	5.52 ± 0.6^{a}	5.52 ± 0.6^{a}	5.51 ± 0.6^{a}	5.52 ± 0.6^{a}	0.33 ± 0.05^{c}	0.27 ± 0.06^{b}	0.22 ± 0.05^{b}	0.16 ± 0.04^{a}
Sindhura	5.95 ± 0.4^{a}	5.95 ± 0.4^{a}	5.95 ± 0.4^{a}	5.94 ± 0.4^{a}	0.46 ± 0.03^{c}	0.40 ± 0.04^{c}	0.33 ± 0.03^{b}	0.27 ± 0.05^{a}
Totapuri	6.18 ± 0.7^{a}	6.18 ± 0.7^{a}	6.17 ± 0.8^{a}	6.18 ± 0.7^{a}	0.43 ± 0.05^{c}	0.36 ± 0.06^{b}	0.29 ± 0.05^{a}	0.22 ± 0.04^{a}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

Performing a test for VA early in the wine-making process is best for establishing a baseline for tracking the increase of VA. A small amount of VA is produced during both the alcoholic fermentation and the malolactic fermentation stages of vinification, and this is not necessarily a spoilage problem for a wine. Indeed, small amounts of VA can actually add complexity to both the aroma and taste of a wine. VA really becomes a problem when its concentation in a wine goes above a certain level, and when it is generated by spoilage yeasts or bacteria (i.e. the bad guys that can lurk around a winery) after the wine is made. The most important VA producing 'baddie' is *Acetobacter*. *Acetobacter* is most known in making vinegar. In the presence of oxygen, *Acetobacter* produces acetic acid, which in the presence of alcohol creates the ester 'ethyl acetate', which is volatile. It is this ester 'ethyl acetate' that ruins wine. When VA levels in a wine are excessively high they spoil the aromas and flavors and they destroy the wine's fruitiness and finally make the wine taste like vinegar. Within the European Union, levels of VA in wine are regulated and maximum amounts are set for all types of wines. Red wines can tolerate more VA than white wines and sweet *Botrytis* infected wines even more. Today there are a number of 'technological' ways to treat (i.e. remove) wines with excessive VA. However, it is better to try preventing its occurrence. Winery hygiene, rejecting moldy grapes, managing *Brettanomyces*, managing the wine's exposure to air as well as appropriate QA/QC protocols can go a long way to ensure that spoilage yeasts and bacteria do not produce excessive levels of VA.

The effect of γ-irradiation on VA of different types of mango wine samples is shown in Table 2.9. The VA range of the control (0 kGy) mango wines was between 0.33 and 0.61 g/L, the lowest VA was found in the *Rumani* and highest was in *Neelam* wines, respectively. There was a significant ($P \leq 0.05$) decrease in the VA of all irradiated wine samples, compared to non-irradiated controls and 3 kGy irradiated wine samples having lowest VA statistically.

2.4.3.3 Effects of γ-irradiation on organic acids content of different types of mango wine: Organic acids play important roles in juices and wines because of their influence on the organoleptic properties (flavor, color, and aroma) as well as the stability and microbiological control of the products (Mato *et al*., 2005). The total content of organic acids in juices and wines affects the drink's acidity, whereas the levels of a specific organic acid can directly

influence the flavor and taste of the drink. Therefore, organic acid profiles are monitored to determine the freshness of certain fruit juices; winemakers also monitor the concentration of various organic acids to ensure the quality of their wines. Malic acid levels must be monitored closely as many wines undergo a malolactic bacterial fermentation which reduces the acidity of the wine, as the malic acid is converted to lactic acid.

The effect of γ-irradiation on organic acids content of different types of mango wine samples is shown in Table 2.10. The major organic acids found in all mango wine samples were citric, tartaric, succinic and malic acids. The content of citric, tartaric, succinic and malic acids in all control mango wine samples ranged from 0.19 to 0.25, 0.10 to 0.14, 0.080 to 0.085 and 0.33 to 0.41 (g/100 mL) respectively. The lowest content of citric, tartaric, succinic and malic acids were found in *Banginapalli*, *Raspuri*, *Sindhura* and and *Banginapalli* wines and highest contents were in *Neelam*, *Banginapalli*, *Alphonso* and *Neelam* wines respectively. In this study different doses of γ-irradiation had no or negligible effect on the content these organic acids in all mango wine samples (Table 2.10).

2.4.3.4 Effects of γ-irradiation on residual sugars (ReS) and alcohol of different types of mango wine: Residual sugars (ReS) are those natural sugars left in a wine after completion of fermentation, generally wines ≤1 mg/L are considered as dry wines. The effect of γ-irradiation on ReS content of different types of mango wine samples is shown in Table 2.11. The ReS range of the control (0 kGy) mango wines was between 2.58 and 3.22 g/L, the lowest ReS content was found in the *Banginapalli* and highest was in *Mulgoa* wines respectively. In the present study ReS content of all irradiated mango wine samples remained the same as the non-irradiated samples even with the increased dose of irradiation increased (Table 2.11).

Ethanol (alcohol) in wine is mainly produced by the alcoholic fermentation of sugar in must. Although small quantities are produced at various fruit ripening stages, the primary source of ethanol in wine is yeast fermentation. Ethanol is the principal organic by-product of fermentation. Under standard fermentation conditions, ethanol can accumulate at up to about 15-16%. However, the yield of ethanol is dependent on various factors like fermentation temperature, agitation, fermentable sugars in the medium, acidity, strain of yeast and yeast activity.

Table 2.10 Effects of γ-irradiation on citric acid, tartaric acid, succinic acid and malic acid content of different types of mango wine

Juice variety	Citric acid (g/100 mL)				Tartaric acid (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	0.22 ± 0.03^{a}	0.21 ± 0.02^{a}	0.20 ± 0.01^{a}	0.22 ± 0.03^{a}	0.11 ± 0.02^{a}	0.10 ± 0.01^{a}	0.11 ± 0.03^{a}	0.11 ± 0.02^{a}
Banginapalli	0.19 ± 0.02^{a}	0.20 ± 0.03^{a}	0.19 ± 0.02^{a}	0.20 ± 0.02^{a}	0.14 ± 0.02^{a}	0.13 ± 0.04^{a}	0.12 ± 0.03^{a}	0.12 ± 0.01^{a}
Mulgoa	0.20 ± 0.03^{a}	0.19 ± 0.02^{a}	0.18 ± 0.02^{a}	0.20 ± 0.03^{a}	0.12 ± 0.01^{a}	0.11 ± 0.03^{a}	0.10 ± 0.02^{a}	0.11 ± 0.03^{a}
Neelam	0.25 ± 0.04^{a}	0.23 ± 0.03^{a}	0.22 ± 0.03^{a}	0.24 ± 0.04^{a}	0.13 ± 0.02^{a}	0.12 ± 0.03^{a}	0.11 ± 0.01^{a}	0.12 ± 0.03^{a}
Raspuri	0.23 ± 0.02^{a}	0.21 ± 0.01^{a}	0.20 ± 0.02^{a}	0.22 ± 0.03^{a}	0.10 ± 0.03^{a}	0.09 ± 0.02^{a}	0.09 ± 0.02^{a}	0.10 ± 0.03^{a}
Rumani	0.21 ± 0.01^{a}	0.20 ± 0.03^{a}	0.19 ± 0.01^{a}	0.21 ± 0.01^{a}	0.12 ± 0.03^{a}	0.10 ± 0.02^{a}	0.10 ± 0.02^{a}	0.11 ± 0.04^{a}
Sindhura	0.24 ± 0.03^{a}	0.22 ± 0.04^{a}	0.21 ± 0.02^{a}	0.23 ± 0.02^{a}	0.13 ± 0.01^{a}	0.12 ± 0.04^{a}	0.11 ± 0.02^{a}	0.12 ± 0.02^{a}
Totapuri	0.20 ± 0.02^{a}	0.18 ± 0.01^{a}	0.19 ± 0.04^{a}	0.18 ± 0.01^{a}	0.11 ± 0.02^{a}	0.10 ± 0.03^{a}	0.10 ± 0.01^{a}	0.11 ± 0.03^{a}

Table 2.10 continued…

Juice variety	Succinic acid (g/100 mL)				Malic acid (g/100 mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	0.085 ± 0.011^{a}	0.084 ± 0.010^{a}	0.083 ± 0.009^{a}	0.084 ± 0.01^{a}	0.35 ± 0.05^{a}	0.28 ± 0.03^{a}	0.28 ± 0.02^{a}	0.28 ± 0.03^{a}
Banginapalli	0.082 ± 0.008^{a}	0.081 ± 0.007^{a}	0.082 ± 0.008^{a}	0.083 ± 0.009^{a}	0.33 ± 0.02^{a}	0.26 ± 0.04^{a}	0.26 ± 0.03^{a}	0.26 ± 0.04^{a}
Mulgoa	0.083 ± 0.01^{a}	0.082 ± 0.011^{a}	0.083 ± 0.01^{a}	0.083 ± 0.01^{a}	0.36 ± 0.01^{a}	0.30 ± 0.02^{a}	0.30 ± 0.01^{a}	0.30 ± 0.02^{a}
Neelam	0.081 ± 0.012^{a}	0.080 ± 0.013^{a}	0.081 ± 0.012^{a}	0.082 ± 0.013^{a}	0.41 ± 0.03^{a}	0.35 ± 0.04^{a}	0.35 ± 0.02^{a}	0.35 ± 0.04^{a}
Raspuri	0.084 ± 0.009^{a}	0.083 ± 0.01^{a}	0.084 ± 0.009^{a}	0.084 ± 0.009^{a}	0.39 ± 0.04^{a}	0.33 ± 0.03^{a}	0.33 ± 0.01^{a}	0.33 ± 0.03^{a}
Rumani	0.082 ± 0.012^{a}	0.080 ± 0.011^{a}	0.081 ± 0.01^{a}	0.082 ± 0.012^{a}	0.38 ± 0.02^{a}	0.31 ± 0.01^{a}	0.31 ± 0.04^{a}	0.31 ± 0.02^{a}
Sindhura	0.080 ± 0.007^{a}	0.079 ± 0.006^{a}	0.080 ± 0.007^{a}	0.081 ± 0.006^{a}	0.40 ± 0.03^{a}	0.35 ± 0.02^{a}	0.35 ± 0.03^{a}	0.35 ± 0.01^{a}
Totapuri	0.084 ± 0.011^{a}	0.083 ± 0.010^{a}	0.083 ± 0.010^{a}	0.084 ± 0.011^{a}	0.37 ± 0.01^{a}	0.32 ± 0.03^{a}	0.32 ± 0.04^{a}	0.32 ± 0.04^{a}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

It was reported that at lower temperatures, alcohol yield is higher due to better sugar utilization and less loss of alcohol due to evaporation (Reddy and Reddy, 2005). In the present study, the percent alcohol in control wines (non-irradiated) produced from eight cultivars of mangoes (Table 2.11) is in the range of 11.2-13.3 %. The highest ethanol production was found in *Rumani* and lowest was in *Neelam* wines, respectively. The alcohol content did not show any change upon irradiation in all mango wine samples, so there were no effects on the alcohol content of mango wine by γ-irradiation (Table 2.11). Similar to the present study, the alcohol content of all irradiated rice wine (Chang, 2003) and maize wine (Chang, 2004) samples remained the same as the non-irradiated sample.

The ethanol concentration of the wines, particularly from warm climates where grape sugar content is high, would reach above 15% (v/v). Higher levels can also be reached by the sequential addition of sugar during fermentation. Generally, it was accepted that the ethanol concentrations in the final product was proportional to the initial sugar content of the fruit before fermentation. In various non-grape fruits like apples, papaya, palm sap, bananas and berries were fermented for wine production but the final ethanol concentrations did not exceed 10%, however, ethanol concentrations in wine above 15% are the result of sugar fortification. Hence the prime factors controlling ethanol production are sugar content, fermentation temperature, and yeast strain (Mauricio *et al.* 1997).

2.4.3.5 Effects of γ-irradiation on higher alcohols (HA) and total esters (TE) of different types of mango wine: Higher (fusel) alcohols commonly account for about 50% of the aromatic constituents of wine, excluding ethanol (Ron, 2000). The principal higher alcohols produced by yeast are the aliphatic alcohols n-propanol, isobutanol (2-methyl-1-propanol), active amyl alcohol (2-methyl-1-butanol), isoamyl alcohol (3-mthyl-1-butanol) (Ribereau-Gayon *et al*., 2000b). The concentration of higher alcohols in wine represents important variables for yeast strain differentiation, due to their strict relation with yeast metabolism (Romano *et al*., 1992). Also the concentration of these components in wine is effected by many factors like variety of fruit, clarification and fermentation conditions.

Table 2.11 Effects of γ-irradiation on residual sugars (ReS) and alcohol content of different types of mango wine

Wine variety	ReS (g/L)				Alcohol (%)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	2.64 ± 0.15^{a}	2.65 ± 0.14^{a}	2.64 ± 0.15^{a}	2.65 ± 0.15^{a}	12.3 ± 0.2^{a}	12.3 ± 0.2^{a}	12.3 ± 0.2^{a}	12.3 ± 0.2^{a}
Banginapalli	2.58 ± 0.14^{a}	2.58 ± 0.15^{a}	2.60 ± 0.13^{a}	2.58 ± 0.14^{a}	13.2 ± 0.1^{a}	13.2 ± 0.1^{a}	13.2 ± 0.1^{a}	13.2 ± 0.1^{a}
Mulgoa	3.22 ± 0.10^{a}	3.22 ± 0.11^{a}	3.22 ± 0.10^{a}	3.22 ± 0.10^{a}	11.5 ± 0.1^{a}	11.5 ± 0.1^{a}	11.5 ± 0.1^{a}	11.5 ± 0.1^{a}
Neelam	3.14 ± 0.09^{a}	3.15 ± 0.10^{a}	3.15 ± 0.10^{a}	3.15 ± 0.10^{a}	11.2 ± 0.08^{a}	11.2 ± 0.08^{a}	11.2 ± 0.08^{a}	11.2 ± 0.08^{a}
Raspuri	3.17 ± 0.11^{a}	3.17 ± 0.11^{a}	3.17 ± 0.11^{a}	3.17 ± 0.11^{a}	11.4 ± 0.2^{a}	11.4 ± 0.2^{a}	11.4 ± 0.2^{a}	11.4 ± 0.2^{a}
Rumani	2.86 ± 0.13^{a}	2.86 ± 0.13^{a}	2.87 ± 0.12^{a}	2.87 ± 0.13^{a}	13.3 ± 0.07^{a}	13.3 ± 0.07^{a}	13.3 ± 0.07^{a}	13.3 ± 0.07^{a}
Sindhura	2.95 ± 0.09^{a}	2.97 ± 0.10^{a}	2.97 ± 0.10^{a}	2.95 ± 0.09^{a}	12.8 ± 0.05^{a}	12.8 ± 0.05^{a}	12.8 ± 0.05^{a}	12.8 ± 0.05^{a}
Totapuri	3.09 ± 0.12^{a}	3.09 ± 0.12^{a}	3.09 ± 0.12^{a}	3.10 ± 0.11^{a}	11.9 ± 0.06^{a}	11.9 ± 0.06^{a}	11.9 ± 0.06^{a}	11.9 ± 0.06^{a}

Values are given as mean ± S.D ($n = 3$); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

Rapp and Mandery (1986) found that total higher alcohols in wine were found to be in the range of 80-540 mg/L and concentrations up to 300 mg/L contributed to pleasant flavor, but above this concentration provoked unpleasant flavor and harsh taste. These compounds could be synthesized by yeast through either the anabolic pathway from glucose, or the catabolic pathway from their corresponding amino acids (valine, leucine, isoleucine and phenylalanine).

The effect of γ-irradiation on HA content of different types of mango wine samples is shown in Table 2.12. In the present study HA range of the control (0 kGy) mango wines was between 201.8 and 345.4 mg/L, the lowest HA content was found in the *Mulgoa* and highest was in *Banginapalli* wines, respectively. There was a significant ($P \leq 0.05$) increase in the HA content in all irradiated mango wine samples up to 1 kGy and no significant differences between 1 and 3 kGy irradiated wine samples (Table 2.12).

HA can have an aromatic effect in wines and some HA can be considered positive and others can be considered negative to the aromatic wine profile. However, due to the concentration that are found in wines and its high threshold, HA does not have many sensory effects in wine. HA have a major importance in wine distillate (grape spirits or brandy), due to the fact that in distillates HA are found in greater concentration.

Among of secondary products of fermentation, esters play an important role in wine odors, which impart pleasant smell. Esters are formed when an alcohol functional group reacts with an acid function and water molecule is eliminated. Esters in wine have two distinct origins; enzymatic esterification during the fermentation process and chemical esterification during long term aging and contribute to floral and fruity sensory properties of the wine (Ribereau-Gayon *et al*., 2000b). The effect of γ-irradiation on total esters (TE) content of different types of mango wine samples is shown in Table 2.12. In the present study TE range of the control (0 kGy) mango wines was between 22.3 and 45.6 mg/L, the lowest TE content was found in the *Mulgoa* and highest was in *Banginapalli* wines, respectively. There was a significant ($P \leq 0.05$) increase in the TE content in all irradiated mango wine samples by increasing the irradiation dose and highest TE content was observed in all 3 kGy irradiated mango wine samples (Table 2.12). It was found that ester formation was greatly influenced by pH and temperature.

Table 2.12 Effects of γ-irradiation on higher alcohols (HA) and total esters (TE) content of different types of mango wine

Wine variety	HA (mg/L)				TE (mg/L)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	326.3 ± 11.6^{a}	331.5 ± 10.5^{ab}	336.4 ± 11.2^{b}	339.8 ± 10.8^{b}	38.2 ± 5.3^{a}	40.4 ± 4.6^{b}	43.7 ± 5.1^{c}	45.3 ± 4.8^{d}
Banginapalli	345.4 ± 9.8^{a}	350.6 ± 11.4^{ab}	361.2 ± 10.6^{b}	364.5 ± 9.6^{b}	45.6 ± 4.7^{a}	48.2 ± 5.1^{b}	50.5 ± 4.9^{c}	52.8 ± 4.6^{d}
Mulgoa	201.8 ± 12.2^{a}	211.4 ± 10.6^{b}	216.7 ± 11.2^{bc}	219.6 ± 10.4^{c}	22.3 ± 4.2^{a}	22.9 ± 4.5^{a}	25.3 ± 5.2^{b}	27.4 ± 4.4^{c}
Neelam	215.6 ± 11.7^{a}	220.2 ± 11.3^{ab}	227.8 ± 10.4^{b}	234.3 ± 10.7^{bc}	26.4 ± 4.4^{a}	28.5 ± 3.8^{b}	29.4 ± 4.1^{bc}	30.9 ± 5.3^{c}
Raspuri	243.7 ± 10.5^{a}	249.3 ± 9.7^{ab}	255.6 ± 9.4^{b}	258.2 ± 11.3^{b}	33.7 ± 5.2^{a}	35.7 ± 4.7^{b}	37.6 ± 5.1^{c}	39.2 ± 3.8^{d}
Rumani	218.6 ± 11.3^{a}	223.7 ± 10.4^{ab}	232.5 ± 9.5^{b}	235.4 ± 10.6^{b}	24.5 ± 4.8^{a}	25.0 ± 5.1^{a}	28.8 ± 4.6^{b}	30.7 ± 5.3^{c}
Sindhura	303.5 ± 9.4^{a}	314.9 ± 11.1^{b}	317.3 ± 10.7^{b}	319.8 ± 10.2^{b}	31.4 ± 4.5^{a}	33.7 ± 4.9^{b}	35.6 ± 5.2^{c}	37.2 ± 4.4^{d}
Totapuri	229.2 ± 10.3^{a}	235.8 ± 9.6^{ab}	242.1 ± 10.9^{b}	244.5 ± 11.5^{bc}	28.7 ± 5.1^{a}	30.9 ± 3.8^{b}	31.7 ± 4.5^{bc}	32.5 ± 5.1^{c}

Values are given as mean ± S.D (n = 3); Values not sharing a common superscript in a row differ significantly at $P \leq 0.05$ according to Duncan's Multiple Range test (DMRT).

Ester concentration and relative distribution is governed by the yeast strain and fermentation conditions like temperature, pH, fatty acid or sterol levels and oxygen levels (Soleas *et al*., 1997). The results obtained in this study slightly varied with the results reported by Reddy and Reddy (2009). These differences may be due to mango varietal difference and fermentation conditions.

2.4.3.6 Effects of γ-irradiation on Hunter colour parameters of mango wine: The colors, or pigments, in fruits and vegetables reflect the presence of certain biologically active phytochemical compounds and antioxidants that have been reported to promote good health and are important quality indexes in fresh fruits and their products. Positive values of *a** and *b** are attributed to carotenoids or anthocyanins present (Varakumar *et al*., 2011). The determination of the coordinates *L**, *a**, *b** characterizes the colour of any product. *L** measures luminosity that varies from zero (black) to 100 (pure white); *a** and *b** values represent the levels of tonality and saturation, with +*a* (indicating red), -*a* (indicating green), +*b* (indicating yellow) and -*b* (indicating blue). The effect of γ-irradiation on the Hunter colour (*L** *a** *b**) values of different types of mango wine samples is shown in Table 2.13. The *L** value of the control (0 kGy) mango wine samples ranged from 16.34 to 28.26, the lowest *L** was found in *Mulgoa* and highest was in *Banginapalli* wines respectively. The *a** value of the control mango wine samples ranged from 1.88 to 2.34, the lowest *a** was found in *Mulgoa* and highest was in *Raspuri* wines, respectively. The *b** value of the control mango wine samples ranged from 10.34 to 15.96, the lowest *b** was found in *Mulgoa* and highest was in *Alphonso* wines, respectively. Chroma (C*) and hue angle (h°) values were also evaluated and these parameters associated with *a** and *b** values. Hue angle is defined as the colour of the material black and chroma indicates the strength of the chromatic response. The chroma (C*) value of the control mango wine samples ranged from 10.51 to 16.1, the lowest C* was found in *Mulgoa* and highest was in *Alphonso* wines, respectively. The hue angle (h°) of the control mango wine samples ranged from 77.52 to 82.54, the lowest h° was found in *Raspuri* and highest was in *Alphonso* wines, respectively. In the present study, lowest hunter colour (*L** *a** *b**) values were observed in *Mulgoa* wine samples. According to Patras *et al.* (2009), hunter *L**, *a** and *b** or

some combinations of *a** and *b** are the physical characteristics used to indicate the visual colour.

The Hunter colour *L** value (brightness) was significantly ($P \leq 0.05$) decreased in all irradiated mango wine samples up to 1 kGy irradiation dose and there were no significant differences between 1 and 3 kGy wines samples. However, all the wines were lighter when compared to that of their respective puree; this could be due to filtration of puree to remove insoluble pectic substances. Though all the wines are in yellow visually in terms of colour, there were little differences among the wines in *b** parameter (yellowness). Positive values of *a** and *b**, as observed in this work, attributed to the carotenoids present in the wine. The Hunter colour *a** value (redness) and *b** value (yellowness) were found to be significantly ($P \leq 0.05$) increased in all irradiated mango wine samples by increasing the irradiation dose. The chroma (C*) value was also significantly ($P \leq 0.05$) increased in all irradiated mango wine samples by increasing the irradiation dose. The hue angle (h°) was significantly ($P \leq 0.05$) decreased by increasing the γ-irradiation dose in all mango wine samples (Table 2.13).

As can be seen, the oldest wines (11.5 years) exhibited the highest *a** (positive toward red and negative toward green) and *b** values (positive toward yellow and negative toward blue). In contrast, the wines without aging exhibited the lowest *a** and *b** values, showing the wines aged for 1.3, 4.2, and 7.0 years values closer to one another and intermediates between those for the oldest wines and the youngest. With regard to lightness *L**, the wines behaved very similarly as they did in relation to *a** and *b**, albeit in the opposite direction. Thus, the non-aged wines had the highest *L** values and the oldest wines the lowest, the other wines lying between these two extremes and their values being closer to one another (Chaves *et al*., 2007). Parameters C* (color saturation) and h° (hue), which were calculated from *a** and *b** using the equations $C^* = (a^{*2} + b^{*2})^{1/2}$ and $h^\circ = \arctan(b^*/a^*)$, respectively, are related to psychophysical attributes of color, some authors such as Recamales *et al*. (2006) pointing out a chroma increase and a hue decrease during wine storage. The C* exhibiting an increase during the aging process, as a result of the development of browning reactions with the formation of reddish brown polymers in the wines. On the other hand, h° decreased during aging, so red hues increased more markedly than did yellow hues in the wines (Chaves *et al*., 2007). Thus γ-irradiation can be used as an accelerating technique for mango mine maturation.

Table 2.13 Effects of γ-irradiation on Hunter colour parameters of different types of mango wine

Hunter parameters	*Alphonso*				*Banginapalli*				*Mulgoa*			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
*L** value	25.54 ± 0.05^{c}	23.38 ± 0.03^{b}	22.72 ± 0.04^{a}	22.48 ± 0.06^{a}	28.26 ± 0.04^{c}	27.44 ± 0.03^{b}	26.98 ± 0.02^{a}	26.65 ± 0.05^{a}	16.34 ± 0.07^{d}	15.22 ± 0.05^{c}	14.84 ± 0.06^{b}	13.76 ± 0.08^{a}
*a** value	2.09 ± 0.03^{a}	2.32 ± 0.04^{a}	3.49 ± 0.02^{b}	3.66 ± 0.01^{b}	2.14 ± 0.02^{a}	2.45 ± 0.04^{a}	3.68 ± 0.03^{b}	4.07 ± 0.02^{c}	1.88 ± 0.04^{a}	2.18 ± 0.03^{b}	2.54 ± 0.02^{b}	3.08 ± 0.03^{c}
*b** value	15.96 ± 0.08^{a}	16.72 ± 0.05^{b}	17.63 ± 0.03^{c}	18.22 ± 0.04^{d}	12.89 ± 0.07^{a}	13.67 ± 0.06^{b}	13.92 ± 0.08^{b}	14.76 ± 0.05^{c}	10.34 ± 0.11^{a}	10.76 ± 0.06^{a}	11.37 ± 0.04^{b}	12.54 ± 0.05^{c}
Chroma (C*)	16.1 ± 0.05^{a}	16.88 ± 0.06^{ab}	17.97 ± 0.05^{b}	18.58 ± 0.03^{c}	13.07 ± 0.06^{a}	13.89 ± 0.05^{ab}	14.41 ± 0.04^{c}	15.31 ± 0.03^{d}	10.51 ± 0.08^{a}	10.98 ± 0.05^{a}	11.65 ± 0.03^{b}	12.91 ± 0.04^{c}
Hue angle (h°)	82.54 ± 0.06^{b}	82.11 ± 0.04^{b}	78.8 ± 0.07^{a}	78.65 ± 0.05^{a}	80.57 ± 0.08^{d}	79.84 ± 0.06^{c}	75.18 ± 0.05^{b}	74.6 ± 0.07^{a}	79.69 ± 0.05^{d}	78.56 ± 0.07^{c}	77.42 ± 0.06^{b}	76.2 ± 0.08^{a}

Table 2.13 continued…

Hunter parameters	*Neelam*				*Raspuri*				*Rumani*			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
*L** value	22.57 ± 0.04^{c}	21.34 ± 0.06^{b}	20.92 ± 0.03^{a}	20.68 ± 0.02^{a}	18.45 ± 0.06^{c}	15.72 ± 0.04^{b}	14.26 ± 0.07^{a}	14.54 ± 0.03^{a}	20.64 ± 0.03^{c}	19.43 ± 0.05^{b}	18.27 ± 0.04^{a}	18.62 ± 0.06^{a}
*a** value	2.02 ± 0.06^{a}	2.86 ± 0.04^{a}	3.48 ± 0.05^{b}	3.54 ± 0.04^{b}	2.34 ± 0.04^{a}	3.46 ± 0.03^{b}	3.49 ± 0.05^{b}	4.02 ± 0.06^{c}	1.93 ± 0.05^{a}	2.29 ± 0.03^{b}	2.98 ± 0.06^{b}	3.67 ± 0.04^{c}
*b** value	10.46 ± 0.05^{a}	11.63 ± 0.03^{b}	12.54 ± 0.04^{c}	13.72 ± 0.02^{d}	10.56 ± 0.07^{a}	11.35 ± 0.06^{b}	12.66 ± 0.04^{c}	13.87 ± 0.05^{d}	11.38 ± 0.04^{a}	12.26 ± 0.05^{b}	12.85 ± 0.07^{b}	13.39 ± 0.05^{c}
Chroma (C*)	10.9 ± 0.03^{a}	11.98 ± 0.04^{b}	13.01 ± 0.05^{c}	14.17 ± 0.03^{d}	10.82 ± 0.06^{a}	11.87 ± 0.05^{b}	13.13 ± 0.03^{c}	14.44 ± 0.06^{d}	11.54 ± 0.05^{a}	12.47 ± 0.04^{b}	13.19 ± 0.06^{c}	13.88 ± 0.05^{c}
Hue angle (h°)	79.07 ± 0.06^{d}	76.2 ± 0.08^{c}	74.52 ± 0.07^{a}	75.55 ± 0.04^{b}	77.52 ± 0.08^{c}	73.05 ± 0.07^{a}	74.6 ± 0.05^{ab}	73.84 ± 0.04^{a}	80.38 ± 0.06^{d}	79.41 ± 0.05^{c}	76.97 ± 0.04^{b}	74.68 ± 0.07^{a}

Table 2.13 continued…

Hunter parameters	*Sindhura*				*Totapuri*			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
*L** value	22.12 ± 0.05^{c}	21.46 ± 0.07^{b}	20.32 ± 0.03^{a}	20.64 ± 0.06^{a}	16.78 ± 0.11^{c}	15.56 ± 0.07^{b}	14.92 ± 0.04^{a}	14.23 ± 0.05^{a}
*a** value	1.94 ± 0.04^{a}	2.54 ± 0.06^{b}	3.17 ± 0.04^{c}	3.85 ± 0.05^{c}	2.24 ± 0.07^{a}	2.92 ± 0.05^{a}	3.36 ± 0.06^{b}	3.98 ± 0.03^{b}
*b** value	12.19 ± 0.06^{a}	13.78 ± 0.04^{b}	14.56 ± 0.05^{c}	15.23 ± 0.04^{d}	10.46 ± 0.05^{a}	11.81 ± 0.04^{b}	12.04 ± 0.05^{c}	13.67 ± 0.06^{d}
Chroma (C*)	12.34 ± 0.05^{a}	14.01 ± 0.03^{b}	14.91 ± 0.04^{b}	15.71 ± 0.05^{c}	10.7 ± 0.06^{a}	12.17 ± 0.05^{b}	12.51 ± 0.06^{b}	13.28 ± 0.05^{c}
Hue angle (h°)	80.95 ± 0.03^{d}	79.57 ± 0.05^{c}	77.74 ± 0.06^{b}	75.83 ± 0.04^{a}	77.91 ± 0.05^{d}	76.13 ± 0.03^{c}	74.39 ± 0.04^{b}	72.54 ± 0.06^{a}

Chroma (C) = $[(a^*)^2 + (b^*)^2]^{1/2}$; Hue angle ($h°$) = arctan ($b^*/a^*$); Values were mean ± S.D (n = 3); Values not sharing a common superscript letter differ significantly at $P \leq 0.05$ according to DMRT.

2.4.3 Microbiological quality of mango wine: The effect of γ-irradiation on the microbial load (total bacterial counts and total fungal counts) measured by pour plate method in control and irradiated mango wine samples are presented in Table 2.14. The initial mean populations of the total bacterial counts of control mango wines were in the range of 2.6 ± 0.3×10^4 to 4.2 ± 0.6×10^5 CFU/mL in Cv. *Banginapalli* and *Mulgoa*, respectively and total fungal counts were 1.3 ± 0.5×10^3 to 2.2 ± 0.6×10^3 CFU/mL in Cv. *Mulgoa* and *Alphonso,* respectively. The cell numbers in the total bacterial count of mango wine were significantly ($P \leq 0.05$) reduced by γ-irradiation at 0.5 kGy or above. At an irradiation dose of 3.0 kGy no bacterial counts were detected in all mango wine samples subjected to radiation processing. There was also a significant ($P \leq 0.05$) reduction in the yeast and mold counts (total fungal counts) of all mango wine samples and complete elimination was observed at irradiation doses above 1.0 kGy (Table 2.14). Thus improvement in microbiological quality of mango wine by radiation processing was evident by dose-dependent reduction in total bacterial count, yeast, and mold counts.

Table 2.14 Determination of microbial load in different types of non-irradiated and irradiated mango wine

Wine variety	Total bacterial counts (CFU/mL)				Total fungal counts (CFU/mL)			
	0 kGy	0.5 kGy	1 kGy	3 kGy	0 kGy	0.5 kGy	1 kGy	3 kGy
Alphonso	$2.8 \pm 0.2 \times 10^{4d}$	$2.2 \pm 0.5 \times 10^{2c}$	$1.9 \pm 0.4 \times 10^{1b}$	ND^{a}	$2.2 \pm 0.6 \times 10^{3d}$	$1.9 \pm 0.5 \times 10^{2c}$	$< 10^{1b}$	ND^{a}
Banginapalli	$2.6 \pm 0.3 \times 10^{4d}$	$2.1 \pm 0.4 \times 10^{2c}$	$1.2 \pm 0.8 \times 10^{1b}$	ND^{a}	$2.1 \pm 0.4 \times 10^{3d}$	$1.7 \pm 0.7 \times 10^{2c}$	$< 10^{1b}$	ND^{a}
Mulgoa	$4.2 \pm 0.6 \times 10^{5d}$	$3.4 \pm 0.4 \times 10^{3c}$	$1.6 \pm 0.7 \times 10^{2b}$	ND^{a}	$1.3 \pm 0.5 \times 10^{3c}$	$1.1 \pm 0.2 \times 10^{2b}$	ND^{a}	ND^{a}
Neelam	$3.8 \pm 0.3 \times 10^{5d}$	$2.9 \pm 0.2 \times 10^{3c}$	$1.3 \pm 0.5 \times 10^{2b}$	ND^{a}	$1.5 \pm 0.4 \times 10^{3c}$	$1.3 \pm 0.3 \times 10^{2b}$	ND^{a}	ND^{a}
Raspuri	$4.0 \pm 0.5 \times 10^{5d}$	$3.2 \pm 0.3 \times 10^{3c}$	$1.7 \pm 0.4 \times 10^{2b}$	ND^{a}	$1.4 \pm 0.6 \times 10^{3c}$	$1.2 \pm 0.4 \times 10^{2b}$	ND^{a}	ND^{a}
Rumani	$2.9 \pm 0.2 \times 10^{4d}$	$2.3 \pm 0.6 \times 10^{2c}$	$2.1 \pm 0.7 \times 10^{1b}$	ND^{a}	$1.9 \pm 0.5 \times 10^{3d}$	$1.5 \pm 0.8 \times 10^{2c}$	$< 10^{1b}$	ND^{a}
Sindhura	$3.1 \pm 0.7 \times 10^{4d}$	$2.9 \pm 0.5 \times 10^{2c}$	$2.8 \pm 0.5 \times 10^{1b}$	ND^{a}	$1.8 \pm 0.7 \times 10^{3d}$	$1.6 \pm 0.5 \times 10^{2c}$	$< 10^{1b}$	ND^{a}
Totapuri	$3.4 \pm 0.4 \times 10^{5d}$	$2.7 \pm 0.2 \times 10^{3c}$	$2.5 \pm 0.6 \times 10^{2b}$	ND^{a}	$1.6 \pm 0.5 \times 10^{3c}$	$1.4 \pm 0.3 \times 10^{2b}$	ND^{a}	ND^{a}

ND: No microbe detected on plates; Values are given as mean ± S.D (n = 3); Values with different letters with in the same row differ significantly at $P \leq 0.05$ according to Duncan's multiple range test (DMRT).

The free radicals are formed by γ-irradiation and disrupt cell membranes of the microorganisms. The disruption of cell membrane results cell death. In addition, the most important target of ionizing radiation in a microorganism is the DNA molecule. A decrease in microbial population resulting from the damaging effects of irradiation on cellular DNA has been reported. Cells that were damaged by irradiation were gradually inactivated and were thereby unable to adapt to the surrounding environment during storage (Byun *et al*., 2001). Sub lethal cellular damage caused by irradiation is also likely to increase their sensitivity to environmental stress factors. In the present study, the irreversible deleterious effects caused by γ-irradiation could be the reason for the drastic reduction in the plate counts. Similar phenomenon was also observed in heat-treated foods, where damaged cells were unable to repair and tend to die in an unfavorable environment (Leistner, 1996).

In a similar study, the growth of aerobic and lactic microflora on shredded carrots was inhibited by irradiation at 2 kGy and chlorination, and the sensory panelists preferred the irradiated vegetables was reported (Chervin *et al*.,1994). It was also reported that irradiation at 0.5 kGy can reduce the microbial counts of diced tomatoes substantially to improve the microbial shelf-life without any adverse effects on the sensory qualities (Prakash *et al*., 2002).

2.5 CONCLUSIONS

The present study concluded that the variability was observed in the different physico-chemical properties of mango juice and wine at different γ-irradiation dose levels (0.5, 1 and 3 kGy). The colour of mango juice and wine was improved in the irradiated samples, which is essential for maintaining the quality during storage. The present study also revealed that γ-irradiation could be an effective method for microbial decontamination and improving the quality of mango juice and wine. These research-oriented scientific facts about irradiated mango juice and wine can help boost the international marketing and consumer acceptability.