Functional Properties of Vinegar

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Abstract: A variety of natural vinegar products are found in civilizations around the world. A review of research on these fermented products indicates numerous reports of health benefits derived by consumption of vinegar components. Therapeutic effects of vinegar arising from consuming the inherent bioactive components including acetic acid, gallic acid, catechin, ephicatechin, chlorogenic acid, caffeic acid, p-coumaric acid, and ferulic acid cause antioxidative, antidiabetic, antimicrobial, antitumor, antiobesity, antihypertensive, and cholesterol-lowering responses. The aims of this article are to discuss vinegar history, production, varieties, acetic acid bacteria, and functional properties of vinegars.

Keywords: acetic acid bacteria, bioactive compounds, therapeutic effects, vinegar

Introduction

The earliest known use of vinegar dates to more than 10000 y ago (Tan 2005; Johnston and Gaas 2006). Flavored vinegar has been produced and sold as a commercial product for approximately 5000 y. The Babylonians produced and sold vinegars flavored with fruit, honey, and malt until the 6th century. References in the Old Testament and from Hippocrates indicate vinegar was used medicinally to manage wounds. Sung Tse, who is credited with developing the field of forensic medicine in the 10th century in China, used sulfur and vinegar as hand washing agents to prevent infection (Chan and others 1993; Tan 2005). Early U.S. medical practitioners used vinegar to treat many ailments including poison ivy, croup, stomachache, high fever, and edema or "dropsy" as it was known in the 18th century (Tan 2005).

In 1778, Durande concentrated vinegar to create glacial acetic acid and in 1814, Berzelios conducted the analysis of acetic acid. By 1823, Schutzenbach had developed a method for manufacture of vinegar known as the generator process which allowed vinegar to be made within 3 to 7 d. In 1955, Hromatka developed a method of making vinegar called submerged acetification which used improved aeration and stirring to produce vinegar quickly (Tan 2005).

Traditional vinegar is produced from raw materials containing sugar or starch in a 2-stage fermentation to initially produce ethanol and subsequently produce acetic acid. Traditional vinegar typically results from a long fermentation (up to a month) and uses natural vinegar as the starter culture. Industrial vinegar typically can be manufactured in approximately 1 d. Traditional vinegar is produced from fruit juices such as grape, apple, plum, coconut and tomato, rice, and potato. Acetic acid bacteria (AAB) are present everywhere in the environment. They may propagate in food materials which contain sugar or in the fermented products which contain alcohol. Different species of AAB have been isolated from various kinds of vinegars including white wine, red wine, spirit, cider, traditional balsamic, rice, and industrial vinegars, which produced by submerged culture with aeration.

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Vinegars are commonly used for pickling of fruits and vegetables and in the preparation of mayonnaise, salad dressings, mustard, and other food condiments. Although useful as a food ingredient for flavor and functional properties, the potential health benefits of vinegar varieties are leading researchers to further consider this long used food product (Türker 1963; Tan 2005). Regular consumption of bioactive substances is promoted by many nutritional researchers and the functional food properties of vinegar have been reported in a variety of scientific and lay publications. With documentation of the health benefits of vinegar, a concurrent increase in demand for fruit vinegar production has occurred (Mazza and Murooka 2009; Ou and Chang 2009).

Functional therapeutic properties of vinegar described include antibacterial activity, blood pressure reduction, antioxidant activity, reduction in the effects of diabetes, prevention of cardiovascular disease, and increased vigor after exercise (Nishidai and others 2000; Ogawa and others 2000a; Kondo and others 2001a; Shimoji and others 2002; Sugiyama and others 2003a).

Production of Vinegar

Production methods and varieties of vinegars

Vinegar is produced from raw materials containing starch or sugar via sequential ethanol and acetic acid fermentations (FAO/WHO 1982) and is used in a variety of food applications (Türker 1963; Tan 2005). Grape, apple, and other fruit juices are the primary starting materials used for vinegar production (Adams 1985) although rice vinegar, malt vinegar, and beer vinegar are also produced in some countries. The production of vinegar typically involves a first fermentation where simple sugars in raw material are converted to alcohol by yeasts. The resultant alcohol is further oxidized to acetic acid by AAB during the last fermentation (Gullo and Giudici 2008). Several methods of vinegar production exist but primarily 2 methods are used commercially. The first is a traditional method classified as a "surface method" in which the culture of AAB grows on the surface of wood shavings and provides oxygen at the surface. The second method, classified as a "submerged culture" is a method in which oxygen is supplied in fermentation to accelerate industrial production (Garcia-Parilla and others 1997). The general production method for vinegar is shown in Figure 1.

A wide variety of different vinegars are produced around the world. Some of the vinegar varieties are listed in Table 1 and classified according to origin of production. One of the most famous vinegar varieties is the traditional balsamic vinegar produced from cooked and concentrated musts of white or red grapes (Masino

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and others 2008). The resultant vinegar product is aged in a successive set of progressively smaller barrels ranging in volume from 75 to 10 L (Giudici and others 2009).

Sherry vinegar is made from Sherry wines following traditional methods of acetification in the Jerez–Xérès–Sherry, Manzanilla de Sanlúcar and Vinagre de Jerez Denomination of Origin regions of southwest Spain (Mejias and others 2002). The unique aroma and flavor of Sherry vinegar is due to the traditional method of production followed in this region known as the "soleras y criaderas" system. This system involves a slow acetification during aging in American oak casks stacked in rows and levels. The final product is blended from the stacked casks across a mixture of vinegars of differing ages (Parrilla and others 1999; Alonso and others 2004).

Other vinegars produced around the world include the Japanese vinegar Kurosu and the Chinese vinegar Zhenjiang which are produced from rice (Nishidai and others 2000; Xu and others 2007). Production of rice vinegar begins with immersion of rice in water, heating, cooling, and inoculation with yeast to produce ethanol. Subsequently, an acetic acid fermentation is conducted and the product is matured (Chen and Chen 2009). Cane vinegar is made from fermented sugarcane juice, has a mild flavor and is used extensively in food preparation in the Philippines (Tan 2005). Persimmons are considered a medicinal fruit in traditional Chinese medicine and persimmon vinegar is produced in China (Ubeda and others 2011). In China, the plant known as *Radix Ophiopogon japonicus* (mondo grass, dwarf lily turf, liriope) is used as a traditional medicinal herb; ophiopogon vinegar produced from *Radix*

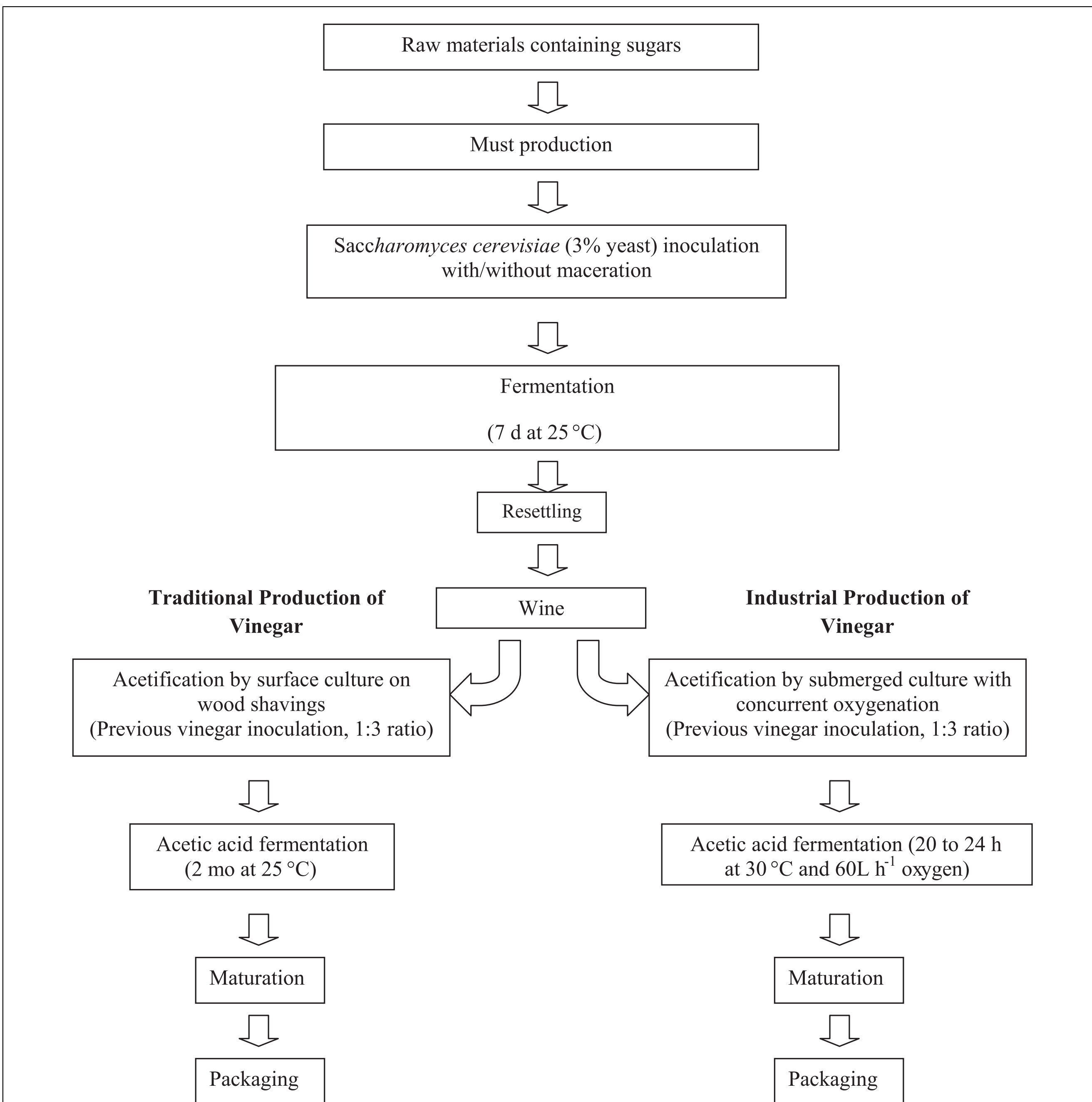

Figure 1–General production methods for vinegar.

Table 1–Vinegar varieties produced in different countries.

Vinegar varieties	Major production countries
Apple cider vinegar	World wide
Balsamic vinegar	Italy
Beer vinegar	Germany
Cane vinegar	Philippines
Champagne vinegar	France, United States
Coconut vinegar	Southeast Asian
Distilled vinegar	United States
Fruit vinegar	Austria
Kombucha vinegar	Japan
Malt vinegar	England
Potato vinegar	Japan
Red wine vinegar	World wide
Rice vinegar	United States, Taiwan
Sherry vinegar	Spain
Spirit vinegar	Germany
Tarragon vinegar	United States
White wine vinegar	Turkey, Italy

O. japonicus is a popular functional food in China (Lin and others 2011). Malt vinegar has a hearty flavor and is produced from fermented barley and grain mash in England (Horiuchi and others 1999). Yacon (*Smallanthus sonchifolius*) is a South American tuberous plant that is an abundant source of prebiotic fructooligosaccharides which are fermented into vinegar (Ojansivua and others 2011).

Fermentation with AAB

AAB are a group of bacteria in the family *Acetobacteriaceae.* AAB are obligate aerobes which stain as Gram negative or Gram variable, are catalase positive and oxidase negative. The nonsporeforming cells are rod to ellipsoidal-shaped (Sengun and Karabiyikli 2011). AAB have an optimum growth temperature range of 25 °C to 30 °C. Although the optimum pH growth range is 5.0 to 6.5, AAB are reported as resistant to acidic environments under pH 5.0 (Holt and others 1994; Trcek and others 2000; Gullo and Giudici 2008). *Acetobacter* and *Gluconobacter* are the 2 main AAB genera and choice of culture dictates vinegar production methods. The genus *Acetobacter* oxidizes alcohol preferentially over glucose whereas the genus *Gluconobacter* preferentially oxidizes glucose more readily than ethanol (Swings 1992; Yamada 2000; Gullo and Giudici 2008). Species of AAB isolated from different kinds of vinegars are presented in Table 2.

In production of vinegar, AAB require access to oxygen. In the slower surface method of vinegar fermentation used more frequently for traditional vinegars, AAB grow at the interface between air and liquid. In the faster submerged method used more commonly for commercial vinegars, AAB are supplied with oxygen through continual air sparging in the acetifying liquid (Fernández-Pérez and others 2010).

AAB may produce various organic acids including acetic, tartaric, lactic, malic, and citric acids as the result of the oxidation of sugars and alcohols; however, acetic acid is predominant among these acids (Sengun and Karabiyikli 2011). Organic acids isolated from different types of vinegars are presented in Table 3.

Table 2–Species of acetic acid bacteria isolated from different kind of vinegars.

Species	Type of vinegar	References
Acetobacter aceti	Cider	Trcek 2005
Acetobacter intermedius	Cider	Trcek and others 2000
Acetobacter pasteurianus	Cider, red wine, traditional Balsamic and rice	Haruta and others 2006; Bartowsky and Henschke 2008; Gullo and others 2009
Acetobacter pomorum	Industrial	Sokollek and others 1998
Acetobacter obiediens	Industrial	Sokollek and others 1998
Gluconacetobacter entanii	Industrial	Schüller and others 2000
Gluconacetobacter europaeus	White wine, red wine, spirit and cider	Sievers and Swings 2005; Callejón and others 2008 ; Vegas and others 2010
Gluconacetobacter hansenii	Cider and traditional Balsamic	Gullo and Giudici 2008; Fernández-Pérez and others 2010
Gluconobacter oxydans	Wine	González and others 2005; Vegas and others 2010
Gluconacetobacter xylinus	Cider, white wine, and traditional Balsamic	Gullo and others 2006; Vegas and others 2010; Fernández-Pérez and others 2010

Table 3–Organic acids in different type of vinegars.

Vinegars	Organic acids	References
Alcohol vinegar	Acetic acid	Sáiz-Abajo and others 2005
Cider vinegar	Acetic, citric, formic, lactic, malic, succinic acids	Caligiani and others 2007 Budak 2010
Malt vinegar	Acetic, citric, lactic, and succinic acids	Sáiz-Abajo and others 2005
Plum vinegar	Acetic, tartaric, and lactic acids	Liu and He 2009
Sherry vinegar	Acetic, tartaric, lactic, malic, and citric acids	Morales and others 1998
Tomato vinegar	Acetic, citric, formic, lactic, malic, and succinic acids	Caligiani and others 2007
Traditional Balsamic vinegar	Malic, tartaric, citric, and succinic acids	Cocchi and others 2006
Wine vinegar	Acetic, citric, formic, lactic, malic, succinic, and tartaric acids	Caligiani and others 2007; Budak 2010

Health and Therapeutic Effects of Vinegar

Antimicrobial effect

Vinegar has antimicrobial properties which makes it useful for a number of applications. Vinegar has been used for cleaning and treating nail fungus, head lice, warts, and ear infections (Rutala and others 2000; Dohar 2003). Consumers typically prefer natural preservative methods for inhibiting the growth of foodborne pathogenic microorganisms in food (Rauha and others 2000). The organic acids in vinegar and mainly acetic acid pass into cell membranes of microorganisms leading to bacterial cell death (Booth and Kroll 1989; Brul and Coote 1999; Blackburn and McClure 2002; Bjornsdottir and others 2006; Chang and Fang 2007). The bacterial strains, temperature, pH, acid concentration, and ionic strength influence the antimicrobial activity of organic acids (Buchanan and Edelson 1996; Entani and others 1998; Cheng and others 2003). Many organic acids are naturally found in a variety of fruits and fermented foods, including: acetic, lactic, ascorbic, citric, malic, propionic, succinic, and tartaric acids and in nonexcessive levels, none of these acids are dangerous to human health (Escudero and others 1999; Brennan and others 2000; Fang and Hsueh 2000;

Table 4–Phenolic compounds in various vinegar types.

Vinegar types	Phenolic compounds	Total polyphenolic index (mg/L GAE)	References
Apple cider vinegar	Gallic acid, catechin, epicatechin, chlorogenic acid, caffeic acid, and *p*-coumaric acid	400 to 1000	Budak and others 2011
Grape vinegar	Gallic acid, catechin, epicatechin, chlorogenic acid, caffeic acid, syringic acid, and ferulic acid	2000 to 3000	Budak and Guzel-Seydim 2010
Sherry vinegar	Gallic acid, protocatechuic acid, protocatechualdehyde, tyrosol, p-OH-benzoic acid, catechin, p-OH-benzaldehyde, siringic acid, vanillin, caftaric acid,cis-p-coutaric acid, trans-p-coutaric acid, fertaric acid, caffeic acid, cis-p-coumaric acid, trans-p-coumaric acid, i-ferulic acid, ferulic acid.	200 to 1000	Alonso and others 2004
Traditional Balsamic vinegar	Furan-2-carboxylic acid, 5- hydroxyfuran-2-carboxylic acid, 4-hydroxybenzoic acid, vanillic acid, protocatechuic acid, syringic acid, isoferulic acid, *p*-coumaric acid, gallic acid, ferulic acid, and caffeic acid		Plessi and others 2006

Sengun and Karapinar 2004). When the effects of organic acids on killing of foodborne pathogenic bacteria were compared, it was reported that acetic acid was the most lethal acid to *Escherichia coli* O157:H7, followed by lactic, citric, and malic acids (Entani and others 1998; Ryu and others 1999).

Different studies have reported that vinegar could be used to inhibit pathogenic bacteria on fresh fruits and vegetables (Wu and others 2000; Rhee and others 2003; Sengun and Karapinar 2004; Chang and Fang 2007). Sengun and Karapinar (2004) reported the effects of vinegar containing 4.03% acetic acid, lemon juice and a 1:1 (v/v) mixture of lemon juice and vinegar on *Salmonella typhimurium* when applied to carrots for different exposure times (0, 15, 30, and 60 min). While both vinegar and lemon juice demonstrated an antimicrobial effect on *S. typhimurium* at all times, the maximum reduction in *S. typhimurium* populations occurred at 60 min of treatment. Chang and Fang (2007) evaluated the antimicrobial effect of rice vinegar on lettuce inoculated with *E. coli* O157:H7 and noted a 3 log reduction was caused by treating with commercial vinegar containing 5% acetic acid for 5 min at 25 °C. However, less than 1 log reduction was noted using 0.5% acetic acid treatment for 5 min.

Antioxidant Effect

Reactive oxygen species such as superoxide, hydrogen peroxide, and hydroxyl radical have been reported to affect lipids, proteins and DNA resulting in accelerated aging, cancer, and brain degenerative disorders (Buonocore and others 2010; Maes and others 2011). Recent studies have suggested that bioactive compounds in foods may reduce incidences of these degenerative illnesses by providing an antioxidant effect (Iriti and Faoro 2010; Fernández-Mar and others 2012; Ramadan and Al-Ghamdi 2012). Bioactive substances such as polyphenols and vitamins in different types of vinegar defend against oxidative stress due to their significant antioxidant activity (Davalos and others 2005; Nishino and others 2005). Phenolic content for various vinegar types including grape vinegar (Garcia-Parrilla and others 1997; Budak and Guzel-Seydim 2010), Sherry vinegar (Alonso and others 2004), traditional balsamic vinegar (Plessi and others 2006; Verzelloni and others 2007), and apple cider vinegar (Budak and others 2011) are shown in Table 4.

Budak and Guzel-Seydim (2010) reported that traditional grape wine vinegar had higher content of chlorogenic and syringic acids than industrial grape wine vinegar. However, the amount of catechin in industrial vinegar was higher than in traditional vinegar. Oxygen Radical Absorbance Capacity (ORAC) and Trolox Equivalent Antioxidant Capacity (TEAC) values were 10.50 μmol/mL TE (trolox equivalents) and 13.50 mmol/L, respectively, for traditional vinegar and 8.84 μmol/mL TE and 10.37 mmol/L, respectively, for industrial vinegar (Budak and Guzel-Seydim 2010). ORAC and TEAC values of traditional vinegar were higher than industrial vinegar. ORAC and TEAC values of apple cider vinegar samples were 2 to 6 μmol/mL TE and 4 to 14 mmol/L, respectively (Budak and others 2011). ORAC and TEAC values of wine vinegar were higher than apple cider vinegar.

The Japanese rice vinegar Kurosu had a high composition of phenolic compounds indicating it was a potent source of antioxidant activity (Nishidai and others 2000). The antioxidant activity value of persimmon vinegar was higher than white and red wine vinegars; this higher antioxidant activity was attributed to the wild yeast strain used in persimmon vinegar production (Ubeda and others 2011).

Japanese plum vinegar is used for the production of a salted cherry blossom tea known as Sakura-cha often served at celebrations. In the preparation of Sakura-cha, cherry blossoms are immersed in Japanese plum vinegar resulting in an extract. This plum vinegar extract of cherry blossom was reported to have significant superoxide anion scavenging activity. Analysis of the extract indicated presence of cyanidin-3-glucoside, cyanidin-3-rutinoside, and caffeic acid as the most potent antioxidant components (Matsuura and others 2008).

Analysis of traditional balsamic vinegars indicated antioxidant activity was mainly due to melanoidins. Further investigation indicated traditional balsamic vinegar melanoidins prevented the absorption and the prooxidant and cytotoxic effects of heme during simulated gastric digestion of meat (Xu and others 2004, 2005; Verzelloni and others 2010).

Antidiabetic Effect

Diabetes is described as high blood glucose levels in both the state of hunger and after consumption of a meal. In type 1 diabetes, there is not enough insulin due to destruction of pancreatic cells resulting in hyperglycemia. In type 2 diabetes, insulin is present, but tissues are resistant to the insulin and therefore, blood glucose concentrations increase (WHO 2014). Insulin sensitivity has been improved through vinegar treatment in 19% of individuals with type 2 diabetes and 34% of individuals with prediabetes (Johnston and others 2004). Recent studies in both animals and humans have shown that vinegar may be used for diabetic treatment (Salbe and others 2009). In rats, the effect of vinegar on blood sugar has been investigated and it has been reported that blood glucose decreased when compared with normal diet after ingestion of a starch load coadministered with a 2% acetic acid solution (Ebihara and Nakajima 1988). In humans, the area under the insulin response curve decreased 20% after consumption of sucrose coadministered with vinegar (Brighenti and others 1995). Many placebo-controlled experiments have confirmed the blood glucose reducing or "antiglycemic" effect of vinegar (Johnston and others 2004; Leeman and others 2005). Several systems have been studied to explain the effect of vinegar on blood glucose concentrations. Acetic acid in vinegar may prevent the complete digestion of complex carbohydrates (Ogawa and others 2000b) by either accelerating gastric emptying (Liljeberg and Fjorck 1998) or by increasing the uptake of glucose by tissues resulting in reduced blood glucose levels (Fushimi and others 2002; Fushimi and Sato 2005).

Antitumor Effect

Kurosu is a traditional Japanese rice vinegar which is reported to be 1 of the most important sources of phenolic compounds for reducing cancer risk (Shimoji and others 2004). Antioxidant activity of an ethyl acetate extract of Kurosu vinegar was greater than the antioxidant activities of wine and apple vinegars (Nishidai and others 2000; Nishino and others 2005). The effect of Kurosu vinegar on the proliferation of a variety of human cancer cell lines has been studied. Cancer cell lines included colon adenocarcinoma, lung carcinoma, breast adenocarcinoma, bladder carcinoma, and prostate carcinoma cells. It was reported that Kurosu inhibited the proliferation of all tested cell lines in a dose-dependent manner (Nanda and others 2004).

Kibizu is sugar cane vinegar produced in Japan. Kibizu inhibited the growth of typical human leukemia cells with its potent radical scavenging activity (Mimura and others 2004). Vinegar ingestion indicated a protective effect with a decreased risk for esophageal cancer (Xibib and others 2003). Products of alcohol and acetic acid fermentations that were formed during the production of apple vinegar were investigated with regard to the neutral medium-sized alpha-glycan content, which acts against experimental mouse tumors. It was observed that neutral medium-sized alpha-glycan was formed mainly during acetic acid fermentation, but not during alcohol fermentation (Abe and others 2007).

Antiobesity Effect

Vinegar ingestion may decrease the glycemic effect of a meal through satiety thus reducing the total amount of food consumed (Mermel 2004). Lim and others (2009) used an obese insulin-resistant rat model to evaluate the antihyperglycemic and antiobesity effects of ginsam which is a vinegar extract from Panax ginseng. Ginseng is 1 of the most popular herbal medicines in particularly Asian populations. Panax ginseng is known that has several pharmacologic and physiologic effects. The rats fed ginsam had lower body weight and fasting, postprandial glucose and plasma insulin concentrations than the controls.

In a study reported by Johnston (2006a, b), human subjects consuming 2 tablespoons of red raspberry vinegar daily with freely access to food and water for 4 wk lost weight whereas the control group consuming a similar amount of cranberry juice daily for 4 wk had a slight weight gain. In another study, healthy volunteers consumed 3 levels of vinegar (18, 23, and 28 mmol acetic acid) with a portion of white wheat bread; bread consumption (no vinegar) was used as a control meal. When the hunger and satiety feelings of volunteers were evaluated it was noted that satiety increased with rising acetic acid level (Ostman and others 2005). Johnson and Buller (2005) studied 3 treatment conditions (control, consumption of vinegar containing 1 g acetic acid, or consumption of approximately 1 oz of peanuts for satiety). In the study, participants ingesting vinegar or peanuts had lower subsequent food consumption accounting for approximately 200 to 275 calories per day. After consumption of the bagel meal, energy consumption for the remainder of the day was weakly affected by vinegar and peanut treatments (a reduction of approximately 200 to 275 kcal, $P = 0.111$). This daily calorie reduction would result in a monthly weight loss of 1 to 1½ pounds (Johnston and Buller 2005). Budak and others (2011) identified a significant steatosis in rats fed the high-cholesterol diet when compared to the control group. Apple cider vinegars produced using the submersion method (with or without maceration) showed significantly decreased steatosis in groups fed these products when compared to the high-cholesterol diet group.

Prevention of Cardiovascular Diseases

Cholesterol-lowering effect

Cardiovascular disease is the leading cause of mortality accounting for more than half of the total mortalities (Lee and others 2007; Lloyd-Jones and others 2010). Cholesterol, elevated blood pressure, smoking, and physical inactivity are among the major risk factors for cardiovascular disease (Beaglehole 2001; Ebrahim and Davey-Smith 2001; Critchley and Capewell 2003). Many epidemiological studies show that polyphenol-rich foods provide protective effect and reduce mortality from cardiovascular diseases (Keys 1995; Giugliano 2000). Atherosclerosis induces chronic diseases (Fki and others 2007). Atherosclerosis is a chronic inflammatory disease initiated by the subendothelial retention of low-density lipoprotein (LDL) particles (Ross 1999). The initiation and progression of atherosclerosis are mainly dependent upon oxidative stress and the formation of oxidized LDLs (Berliner and Heinecke 1996; Lee and others 2007). Consumption of natural antioxidants like polyphenols may decrease the formation of oxidized LDLs in the bloodstream (Sugiyama and others 2003b).

Polyphenols such as chlorogenic acid which is present in high levels in apple cider vinegar could inhibit oxidation of LDLs and improve health by preventing cardiovascular diseases (Laranjinha and others 1994). The lipid profile of blood depends on genetic factors and dietary habits such as the consumption of food containing high levels of saturated fat (Krieger 1988; Fukushima and others 1999). Fushimi and others (2006) reported that 0.3% dietary acetic acid reduced serum cholesterol and triglycerides (TG) in rats fed a cholesterol-rich diet. *In vivo*, acetic acid enhanced lipid homeostasis and the cholesterol-lowering effect of acetic acid was described in detail by Yamashita and others (2007). Budak and others (2011) determined the cholesterol-lowering effect of apple vinegars in rats fed high-cholesterol diets and identified the serum levels of TG, total cholesterol (TC), high-density lipoprotein (HDL), LDL, and very low density lipoprotein (VLDL) of each of the groups. Serum levels of TG, TC, HDL, LDL, and VLDL significantly increased in rats fed the high-cholesterol diet when compared to the control. The increase of HDL level was significant only in rats fed apple cider vinegar produced by the surface method with maceration. The increase in LDL level was significant in the groups fed apple cider vinegars produced by the surface method, and by the submersion method with or without maceration. It was also noted that LDL level did not increase in the groups fed apple cider vinegars produced by the surface method with maceration.

The effect of dietary acetic acid, the main component of vinegar, was examined on serum lipid values in rats fed a diet containing 1% cholesterol and dietary acetic acid. The dietary acetic acid treated rats had lower values of serum TC and triacylglycerols, liver ATP citrate lyase (ATP-CL) activity, and liver 3-hydroxy-3-methylglutaryl-CoA content. In addition, liver mRNA levels of fatty acid synthase, ATP-CL, and sterol regulatory element binding protein-1 were lower and the rats had higher fecal bile acid content.

In rats cofed cholesterol, dietary acetic acid reduced triacylglycerol and serum TC levels by inhibiting lipogenesis and by promoting fecal bile acid excretion (Yamashita and others 2007). Hu and others (1999) reported a linear relationship between the consumption of oil and vinegar in salad and the reduction in risk of fatal ischemic heart disease (IHD) (Hu and others 1999).

Antihypertensive effect

Studies have investigated the effect of vinegar on lowering blood pressure. These studies have examined oral administration of vinegar on the renin-angiotensin system *in vitro* and *in vivo* using spontaneously hypertensive rats-stroke prone (Ohnami and others 1985; Tsuzuki and others 1992; Matui and others 1998). Ohnami and others (1985) observed that an ethanol extracted fraction of rice vinegar residues prevents angiotensin-converting enzyme (ACE) activity in spontaneously hypertensive rats. Nishikawa and others (2001) reported rice vinegar residues prevent ACE activity in the blood pressure regulatory system. Melanoidins, which are synthesized in the final stage of the Maillard reaction during traditional balsamic vinegar production, exhibit potential health benefits including antihypertensive activity (Rufián-Henares and Morales 2007). Although studies have shown that minor components of vinegar are responsible for the observed antihypertensive effects, the acetic acid content of vinegar is reported to also cause an antihypertensive effect (Ito 1978; Kondo and others 2001b). Vinegar (containing 0.57 mmol acetic acid) and acetic acid ingestion reduced plasma renin activity and plasma aldosterone which are factors associated with blood vessel constriction in rats (Honsho and others 2005).

Therapeutic Effect of Vinegar for Injuries

Mother of vinegar has been demonstrated to have a therapeutic effect on burns due to antibacterial properties (Krystynowicz and others 2000). In addition, it was reported that the extracellular structure synthesized by *Acetobacter xylinum* assisted tissue repair in rats (Bielecki and others 2000). Sugiyama and others (2009) suggested that oral intake of AAB was useful in attenuating muscle damage by inflammation after moderate-intensity exercise.

Impact of Vinegar on Brain

Sphingolipids are important building blocks for brain tissues. Studies have indicated that AAB produce precursors of sphingolipids known as the alkali-stable lipids (ASL). Dihydroceramide is 1 of the ASL generated by AAB. Fukami and others (2010) studied the effect of ASL on dementia model rats and determined that after treatment for 10 d, significant improvements in cognitive ability occurred. Further investigation indicated that ASL caused increased neurite growth in pheochromocytoma (PC12) cells and dihydroceramide had the most potent effect. Fukami and others (2009, 2010) hypothesized that vinegar consumption might improve cognitive function in humans. Other studies found that gangliosides which were composed of sialic acid and oligosaccharides conjugated to ceramide were effective in improving Alzheimer patients' symptoms (Svennerholm 1994).

Conclusion

Vinegar is manufactured worldwide from a wide variety of starting materials using different production methodologies. Acetic acid is the dominant flavor compound in vinegar and has a long history as an important direct food additive to acidulate food for preservation. Although vinegar traditionally has been used as a food flavoring and preservative, recent investigations demonstrate the potent bioactive effects of vinegars which may benefit human health. Functional therapeutic properties of vinegar described include antibacterial activity, blood pressure reduction, antioxidant activity, reduction in the effects of diabetes, and prevention of cardiovascular disease. Other positive health effects of daily consuming vinegar reported include improving blood glucose response which would be of benefit to diabetic patients.

Phenolic acids in vinegar can scavenge superoxide anion and free radicals *in vivo* resulting in a potent antioxidant activity. Depending on variety of vinegar and inherent acetic acid and total phenolic content, daily intake of vinegar may affect human health and metabolism. Further studies related to health effects of vinegar consumption by humans are necessary.

References

Abe K, Kushibiki T, Matsue H. 2007. Generation of antitumor active neutral medium-sized α-glycan in apple vinegar fermentation. Biosci Biotechnol Biochem 71:2124–29.

Adams MR. 1985. Vinegar. In: Wood BJB, editor. Microbiology of fermented foods. New York: IFT Press. p 1–45.

Alonso AM, Castro R, Rodriguez MC, Guillen DA, Barroso CG. 2004. Study of the antioxidant power of brandies and vinegars derived from Sherry wines and correlation with their content in polyphenols. Food Res Intl 37:715–21.

Bartowsky EJ, Henschke PA. 2008. Acetic acid bacteria spoilage of bottled red wine; a review. Int J Food Microbiol 125:60–70.

Beaglehole R. 2001. Global cardiovascular disease prevention: time to get serious. Lancet 358:661–3.

Berliner JA, Heinecke JW. 1996. The role of oxidized lipoproteins in atherogenesis. Free Radic Biol Med 20:707–27.

Bielecki S, Krystynowicz A, Turkiewicz M, Kalinowska H. 2000. Bacterial cellulose. In: Steinbuchel A, editor. Biopolymers: polysaccharides I. Munster, Germany: Wiley-VCH Verlag GmbH. p 37–90.

Bjornsdottir K, Breidit JF, McFeeters RF. 2006. Protective effect of organic acids on survival of *Escherichia coli* O157:H7 in acidic environments. Appl Environ Microbiol 72:660–4.

Blackburn CV, McClure PJ. 2002. Modeling the growth, survival and death of bacterial pathogens in food, Kinetic growth models. In: Blackburn CV, editor. Foodborne pathogens. New York: WoodHead Publishing, p 56–72.

Booth IR, Kroll RG. 1989. The preservation of foods by low pH. In: Gould GW, editor. Mechanisms of action of food preservation procedures. New York: Elsevier Science Publishers. p 119–60.

Brennan M, Port GL, Gormley R. 2000. Post-harvest treatment with citric acid or hydrogen peroxide to extend the shelf life of fresh sliced mushrooms. Lebensm Wiss Technol 33:285–9.

Brighenti F, Castellani G, Benini L, Leopardi E, Crovetti R, Testolin G. 1995. Effect of neutralized and native vinegar on blood glucose and acetate responses to a mixed meal in healthy subjects. Eur J Clin Nutr 49:242–7.

Brul S, Coote P. 1999. Preservative agents in foods: mode of action and microbial resistance mechanism. Intl J Food Microbiol 50:1–17.

Buchanan RL, Edelson SG. 1996. Culturing enterohemorrhagic *Escherichia coli* in the presence and absence of glucose as a simple means of evaluating the acid tolerance of stationary-phase cells. Appl Environ Microbiol 62:4009–13.

Budak HB, Guzel-Seydim ZB. 2010. Antioxidant activity and phenolic content of wine vinegars produced by two different techniques. J Sci Food Agric 90:2021–6.

Budak HN. 2010. A research on compositional and functional properties of vinegars produced from apple and grape [PhD thesis]. 190p. Isparta, Turkey: Suleyman Demirel University.

Budak HN, Kumbul Doguc D, Savas CM, Seydim AC, Kök Tas T, Ciris IM, Güzel-Seydim ZB. 2011. Effects of apple cider vinegars produced with different techniques on blood lipids in high-cholesterol-fed rats. J Agric Food Chem 59:6638–44.

Buonocore G, Perrone S, Tataranno MN. 2010. Oxygen toxicity: chemistry and biology of reactive oxygen species. Semin Fetal Neonatal Med 15:186–90.

Caligiani A, Acquotti D, Palla G, Bocchi V. 2007. Identification and quantification of the main organic components of vinegars by high resolution H NMR spectroscopy. Anal Chim Acta 585:110–19.

Callejón RM, Tesfaye W, Torija MJ, Mas A, Troncoso AM, Morales ML. 2008. HPLC determination of amino acids with AQC derivatization in vinegars along submerged and surface acetifications and its relation to the microbiota. Eur Food Res Technol 227:93–102.

Chan E, Ahmed TM, Wang M, Chan JCM. 1993. History of medicine and nephrology in Asia. Am J Nephrol 14:295–301.

Chang J, Fang TJ. 2007. Survival of *Escherichia coli* O157:H7 and *Salmonella enterica* serovars *typhimurium* in iceberg lettuce and the antimicrobial effect of rice vinegar against *E. coli* O157:H7. Food Microbiol 24:745–51.

Chen C, Chen F. 2009. Study on the conditions to brew rice vinegar with high content of γ-amino butyric acid by response surface methodology. Food Bioprod Process 87:334–40.

Cheng HY, Ye RC, Chou CC. 2003. Increased acid tolerance of *Escherichia coli* O157:H7 by acid adaptation time and conditions of acid challenge. Food Res Intl 36:49–56.

Cocchi M, Durante C, Garndi M, Lambertini P, Manzini D, Marchetti A. 2006. Simultaneous determination of sugars and organic acids in aged vinegars and chemometric data analysis. Talanta 69:1166–75.

Critchley JA, Capewell S. 2003. Mortality risk reduction associated with smoking cessation in patients with coronary heart disease: a systematic review. J Am Med Assoc 290:86–105.

Davalos A, Bartolome B, Gomez-Cordoves C. 2005. Antioxidant properties of commercial grape juices and vinegars. Food Chem 93:325–30.

Dohar JE. 2003. Evolution of management approaches for otitis externa. Pediatr Infect Dis J 22:299–308.

Ebihara K, Nakajima A. 1988. Effect of acetic acid and vinegar on blood glucose and insulin responses to orally administered sucrose and starch. Agric Biol Chem 52:311–2.

Ebrahim S, Davey-Smith G. 2001. Exporting failure? Coronary heart disease and stroke in developing countries. Intl J Epidemiol 30:201–5.

Entani E, Asai M, Tsujihata S, Tsukamoto Y, Ohta M. 1998. Antibacterial action of vinegar against food-borne pathogenic bacteria including *Escherichia coli* O157:H7. J Food Prot 61:953–9.

Escudero ME, Velazquez L, Di Genaro MS, Guzman MS. 1999. Effectiveness of various disinfectants in the elimination of *Yersinia enterocolitica* on fresh lettuce. J Food Prot 62:665–9.

Fang TJ, Hsueh YT. 2000. Effect of chelators, organic acid and storage temperature on growth of *Escherichia coli* O157:H7 in ground beef treated with nisin, using response surface methodology. J Food Drug Anal 8:187–94.

FAO/WHO. (1982). Draft European regional standard for vinegar. Codex Alimentarus Commission.Alinorm 87/19, Appendix II. 34–8.

Fernández-Mar MI, Mateos R, García-Parrilla MC, Puertas B, Cantos-Villar E. 2012. Bioactive compounds in wine: resveratrol, hydroxytyrosol and melatonin. A review. Food Chem 130:797–13.

Fernández-Pérez R, Torres C, Sanz S, Ruiz-Larrea F. 2010. Strain typing of acetic acid bacteria responsible for vinegar production by the submerged elaboration method. Food Microbiol 27:973–8.

Fukami H, Tachimoto H, Kishi M, Kaga T, Tanaka Y, Koga Y, Shirasawa T. 2009. Continuous ingestion of acetic acid bacteria: effect on cognitive function in healthy middle-aged and elderly persons. Anti Aging Med 6:60–5.

Fukami H, Tachimoto H, Kishi M, Kaga T, Tanaka Y. 2010. Acetic acid bacterial lipids improve cognitive function in dementia model rats. J Agric Food Chem 58:4084–9.

Fukushima M, Ohashi T, Sekikawa M, Nakano M. 1999. Comparative hypocholesterolemic effects of five animal oils in cholesterol-fed rats. Biosci Biotechnol Biochem 63:202–5.

Fushimi T, Sato Y. 2005. Effect of acetic acid feeding on the circadian changes in glycogen and metabolites of glucose and lipid in liver and skeletal muscle of rats. Br J Nutr 94:714–9.

Fushimi T, Tayama K, Fukaya M, Kitakoshi K, Nakai N, Tsukamoto Y, Sato Y. 2002. The efficacy of acetic acid for glycogen repletion in rat skeletal muscle after exercise. Intl J Sports Med 23:218–22.

Fushimi T, Suruga K, Oshima Y, Fukiharu M, Tsukamoto Y, Goda T. 2006. Dietary acetic acid reduces serum cholesterol and triacylglycerols in rats fed a cholesterol-rich diet. Br J Nutr 95:916–24.

Garcia-Parilla MC, Gonzalez GA, Heredia FJ, Troncoso AM. 1997. Differentiation of wine vinegars based on phenolic composition. J Agric Food Chem 45:3487–92.

Giudici P, Gullo M, Solieri L. 2009. Traditional balsamic vinegar. In: Solieri L, Giudici P, editors. Vinegars of the World. Milan, Italy: Springer. p 157–77.

Giugliano D. 2000. Dietary antioxidants for cardiovascular prevention. Nutr Metab Cardiovas Dis 10:38–44.

Gullo M, Caggia C, De Vero L, Giudici P. 2006. Characterization of acetic acid bacteria in "traditional balsamic vinegar". Int J Food Microbiol 106:209–12.

Gullo M, Giudici P. 2008. Acetic acid bacteria in traditional Balsamic vinegar: phenotypic traits relevant for starter cultures selection. Intl J Food Microbiol 125:46–53.

González A, Hierro N, Poblet M, Mas A, Guillamon JM. 2005. Application of molecular methods to demonstrate species and strain evolution of acetic acid bacteria population during wine production. Int J Food Microbiol 102:295–304.

Gullo M, De Vero L, Giudici P. 2009. Succession of selected strains of *Acetobacter pasteurianus* and other acetic acid bacteria in traditional balsamic vinegar. Appl Environ Microb 75:2585–89.

Haruta S, Ueno S, Egawa I, Hashiguchi K, Fujii A, Nagano M, Ishii M, Igarashi Y. 2006. Succession of bacterial and fungal communities during a traditional pot fermentation of rice vinegar assessed by PCR-mediated denaturing gradient gel electrophoresis. Int J Food Microbiol 109:79–89.

Holt JM, Krieg NR, Sneath PHA, Staley JY, Williams ST. 1994. Genus Acetobacter and Gluconobacter. In: Wilkens W, editor. Bergey's manual of determinative bacteriology. 9th ed. Maryland, USA: The Williams & Wilkins Co. p 71–84.

Honsho S, Sugiyama A, Takahara A, Satoh Y, Nakamura Y, Hashimoto K. 2005. A red wine vinegar beverage can inhibit the rennin-angiotensin system: experimental evidence in vivo. Biol Pharm Bull 28:1208–10.

Horiuchi J, Kanno T, Kobayashi M. 1999. New vinegar production from onions. J Biosci Bioeng 88:107–9.

Hu FB, Stampfer MJ, Manson JE, Rimm EB, Wolk A, Colditz GA, Hennekens CH, Willett WC. 1999. Dietary intake of alpha-linolenic acid and risk of fatal ischemic heart disease among women. Am J Clin Nutr 69:890–7.

Iriti M, Faoro F. 2010. Bioactive chemicals and health benefits of grapevine products. In: Watson RR, Preedy VR, editors. Bioactive foods in promoting health: fruits and vegetables. New York: Elsevier Inc. p 581–20.

Ito H. 1978. Food vinegar. J Brew Soc Jpn 73:200–8.

Johnston CS, Buller AJ. 2005. Vinegar and peanut products as complementary foods to reduce postprandial glycemia. J Am Diet Assoc 105:1939–42.

Johnston CS. 2006a. Strategies for healthy weight loss: From vitamin C to the glycemic response. J Am Coll Nutr 25:158–65.

Johnston CS. 2006b. Vinegar: medicinal uses and antiglycemic effect. Med Gen Med 8:61–78.

Johnston, CS, Gaas CA. 2006. Vinegar: medicinal uses and antiglycemic effect. MedGenMed. 8(2): 61.

Johnston CS, Kim CM, Buller AJ. 2004. Vinegar improves insulin sensitivity to a high-carbohydrate meal in subjects with insulin resistance or type 2 diabetes. Diabetes Care 27:281–3.

Keys A. 1995. Mediterranean diet and public health: personal reflections. Am J Clin Nutr 61:1321–3.

Kondo S, Kuwahara Y, Kondo M, Naruse K, Mitani H, Wakamatsu Y, Ozato K, Asakawa S, Shimizu N, Shima A. 2001a. The medaka rs-3 locus required for scale development encodes ectodysplasin-A receptor. Current Biol 11:1202–6.

Kondo S, Tayama K, Tsukamoto Y, Ikeda K, Yamori Y. 2001b. Antihypertensive effects of acetic acid and vinegar on spontaneously hypertensive rats. Biosci Biotechnol Biochem 65:2690–4.

Krieger M. 1988. The "best" of cholesterols, the "worst" of cholesterols: a tale of two receptors. Proc Natl Acad Sci USA 95:4077–80.

Krystynowicz A, Czaja W, Pomorski L, Kolodziejczyk M, Bielecki S. 2000. The evaluation of usefulness of microbial cellulose as a wound dressing material. 14th Forum for Applied Biotechnology, Proceedings Part 1. Gent, Belgium: Meded Fac Land-bouwwet-Rijksuniv Gent. p 213–20.

Laranjinha JA, Almeida LM, Madeira VM. 1994. Reactivity of dietary phenolic acids with peroxyl radicals: antioxidant activity upon low density lipoprotein peroxidation. Biochem Pharmacol 48:487–94.

Lee M, Park YB, Moon S, Bok SH, Kim D, Ha T, Jeong T, Jeong K, Choi M. 2007. Hypocholesterolemic and antioxidant properties of 3-(4-hydroxyl)propanoic acid derivatives in high-cholesterol fed rats. Chem Biol Interact 170:9–19.

Leeman M, Ostman E, Bjorck I. 2005. Vinegar dressing and cold storage of potatoes lowers postprandial glycaemic and insulinaemic responses in healthy subjects. Eur J Clin Nutr 59:1266–71.

Liljeberg H, Fjorck I. 1998. Delayed gastric emptying rate may explain improved glycaemia in healthy subjects to a starchy meal with added vinegar. Eur J Clin Nutr 52:368–71.

Lim S, Yoon JW, Choi SH, Choa BJ, Kim JT, Chang HS, Park HS, Park KS, Lee HK, Kim YB, Jang HJ. 2009. Effect of ginsam, a vinegar extract from Panax ginseng, on body weight and glucose homeostasis in an obese insulin-resistant rat model. Metabolism 58:8–15.

Lin WL, Su WW, Cai XY, Luo LK, Li PB, Wang YG. 2011. Fermentation effects of oligosaccharides of *Radix* Ophiopogonis on alloxan-induced diabetes in mice. Intl J Biol Macromol 49:194–200.

Liu F, He Y. 2009. Application of successive projections algorithm for variable selection to determine organic acids of plum vinegar. Food Chem 115:1430–36.

Lloyd-Jones D, Adams RJ, Brown TM, Carnethon M, Dai S, Simone GD, Ferguson TB, Ford E, Furie K, Gillespie C, Go A, Greenlund K, Haase N, Hailpern S, Ho PM, Howard V, Kissela B, Kittner S, Lackland D, Lisabeth L, Marelli A, McDermott MM, Meigs J, Mozaffarian D, Mussolino M, Nichol G, Roger VL, Rosamond W, Sacco R, Sorlie P, Stafford R, Thom T, Wassertheil-Smoller S, Wong ND, Wylie-Rosett J. 2010. Heart disease and stroke statistics—2010 update. Circulation AHA J 121(7):e46.

Maes M, Galecki P, Chang YS, Berk M. 2011. A review on the oxidative and nitrosative stress (O&NS) pathways in major depression and their possible contribution to the (neuro)degenerative processes in that illness. Prog Neuropsychopharmacol Biol Psychiatry 35:676–9.

Masino F, Chinnici F, Bendini A, Montevecchi G, Antonelli AA. 2008. Study on relationships among chemical, physical, and qualitative assessment in traditional balsamic vinegar. Food Chem 106:90–5.

Matsuura R, Moriyama H, Takeda N, Yamamoto K, Morita Y, Shimamura T, Ukeda H. 2008. Determination of antioxidant activity and characterization of antioxidant phenolics in the plum vinegar extract of cherry blossom (*Prunus lannesiana*). J Agric Food Chem 56:544–9.

Matui Y, Shimizu M, Kyuki K, Takahashi T, Takahashi K. 1998. Effects of ginseng vinegar (panahealth), on the erythrocyte deformability in stroke-prone spontaneously hypertension rats. Jpn Pharmacol Ther 26:23–8.

Mazza S, Murooka Y. 2009. Vinegar through the age. In: Solieri L, Giudici P, editors. Vinegars of the world. Milán: Springer-Verlag. p 17−39.

Mejias RC, Marin RN, Moreno MVG. 2002. Optimisation of headspace solid-phase microextraction for analysis of aromatic compounds in vinegar. J Chromatogr 953:7–15.

Mermel VL. 2004. Old paths new directions: the use of functional foods in the treatment of obesity. Trends Food Sci Technol 15:532–40.

Mimura A, Suzuki Y, Toshima Y, Yazaki S, Ohtsuki T, Ui S, Hyodoh F. 2004. Induction of apoptosis in human leukemia cells by naturally fermented sugar cane vinegar (kibizu) of Amami Ohshima Island. Biofactors 22:93–7.

Morales ML, Gonzalez AG, Troncoso AM. 1998. Ion-exclusion chromatographic determination of organic acids in vinegars. J Chromatogr A 822:45–51.

Nanda K, Miyoshi N, Nakamura Y, Shimoji Y, Tamura Y, Nishikawa Y, Uenakai K, Kohno H, Tanaka T. 2004. Extract of vinegar "Kurosu" from unpolished rice inhibits the proliferation of human cancer cells. J Exp Clin Cancer Res 23:69–75.

Nishidai S, Nakamura Y, Torikai K. 2000. Kurosu, a traditional vinegar produced from unpolished rice, suppresses lipid peroxidation in vitro and in mouse skin. Biosci Biotechnol Biochem 64:1909–14.

Nishikawa Y, Takana Y, Nagai Y, Mori T, Kawada T, Ishihara N. 2001. Antihypertensive effects of Kurosu extract, a traditional vinegar produced from unpolished rice, in the SHR rats. Nippon Shokuhin Kagaku Kogaku Kaishi 48:73–5.

Nishino H, Murakoshi M, Mou XY, Wada S, Masuda M, Ohsaka Y, Satomi Y, Jinno K. 2005. Cancer prevention by phytochemicals. Oncology 69:38–40.

Ogawa M, Kusano T, Katsumi M, Sano H. 2000a. Rice gibberellin-insensitive gene homolog, *OsGAI*, encodes a nuclear-localized protein capable of gene activation at transcriptional level. Gene 245:21–9.

Ogawa N, Satsu H, Watanabe H, Fukaya M, Tsukamoto Y, Miyamoto Y, Shimizu M. 2000b. Acetic acid suppresses the increase in disaccharidase activity that occurs during culture of caco-2 cells. J Nutr 130:507–13.

Ohnami K, Matsuoka E, Okuda T. 1985. Effects of Kurosu on the blood pressure of the spontaneously hypertension rats. Kiso to Rinsho 19:237–41.

Ojansivua I, Ferreirab CL, Salminena S. 2011. Yacon, a new source of prebiotic oligosaccharides with a history of safe use. Trends Food Sci Technol 22:40–6.

Ostman E, Granfeldt Y, Persson L, Bjorck I. 2005. Vinegar supplementation lowers glucose and insulin responses and increases satiety after a bread meal in healthy subjects. Eur J Clin Microbiol 59:983–8.

Ou ASM, Chang RC. 2009. Taiwan fruit vinegar. In: Solieri L., Giudicin P, editors. Vinegars of the world. Milán: Springer-Verlag. p 223−41.
Parrilla MCG, Heredia FJ, Troncoso AM. 1999. Sherry wine vinegars: phenolic composition changes during aging. Food Res Intl 32:433–40.
Plessi M, Bertelli D, Miglietta F. 2006. Extraction and identification by GC-MS of phenolic acids in traditional Balsamic vinegar from Modena. J Food Compost Anal 19:49–54.
Ramadan MF, Al-Ghamdi A. 2012. Bioactive compounds and health-promoting properties of royal jelly: a review. J Funct Foods 4:39–52.
Rauha JP, Remes S, Heinonen M, Hopia A, Kahkönen M, Kujala T, Pihlaja K, Vuorela H, Vuorela P. 2000. Antimicrobial effect of Finnish plant extracts containing flavonoids and other phenolic compounds. Intl J Food Microbiol 56:3–12.
Rhee MS, Lee SY, Dougherty RH, Kang DH. 2003. Antimicrobial effects of mustard flour and acetic acid against *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella enterica* Serovar *typhimurium*. Appl Environ Microbiol 69:2959–63.
Ross R. 1999. Atherosclerosis—an inflammatory disease. N Engl J Med 340:115–26.
Rufián-Henares JA, Morales FJ. 2007. Functional properties of melanoidins: in vitro antioxidant, antimicrobial and antihypertensive activities. Food Res Intl 40:995–1002.
Rutala WA, Barbee SL, Agular NC, Sobsey MD, Weber DJ. 2000. Antimicrobial activity of home disinfectants and natural products against potential human pathogens. Infect Control Hosp Epidemiol 21:33–8.
Ryu JH, Deng Y, Beuchant LR. 1999. Behavior of acid-adapted and unadapted *Escherichia coli* O157:H7 when exposed to reduced pH achieved with various organic acids. J Food Prot 62:451–5.
Sáiz-Abajo MJ, González-Sáiz JM, Pizarro C. 2005. Multi-objective optimisation strategy based on desirability functions used for chromatographic separation and quantification of l-proline and organic acids in vinegar. Anal Chim Acta 528:63–76.
Salbe AD, Johnston CS, Buyukbese MA, Tsitouras PD, Harman SM. 2009. Vinegar lacks antiglycemic action on enteral carbohydrate absorption in human subjects. Nutr Res 29:846–9.
Schüller G, Hertel C, Hammes WP. 2000. Gluconacetobacter entanii sp. nov., isolated from submerged high-acid industrial vinegar fermentations. Intl J Syst Evol Microbiol 50:2013–20.
Sengün IY, Karabiyikli S. 2011. Importance of acetic acid bacteria in food industry. Food Control 22:647–56.
Sengün IY, Karapinar M. 2004. Effectiveness of lemon juice, vinegar and their mixture in the elimination of Salmonella *typhimurium* on carrots (*Daucus carota L.*). Intl J Food Microbiol 96:301–5.
Shimoji Y, Kohno H, Nanda K, Nishikawa Y, Ohigashi H, Uenakai K, Tanaka T. 2004.Extract of Kurosu, a vinegar from unpolished rice, inhibits azoxymethane-induced colon carcinogenesis in male F344 rats. Nutr Cancer 49:170–3.
Shimoji Y, Oishi E, Kitajima T, Muneta Y, Shimizu S, Mori Y. 2002. Heterologous protein expression and intranasal immunization of pigs. Infect Immun 70:226–32.
Sievers M, Swings J. 2005. Family *Acetobacteraceae*. In: Boone DR, Castenholz RW, Garrity GM, Brenner DJ, Krieg NR, Staley JT, editors. Bergey's Manual of Systematic Bacteriology. New York: Springer. p 41–95.
Sokollek SJ, Hertel C, Hammes WP. 1998. Description of *Acetobacter oboediens* sp. nov. and *Acetobacter pomorum* sp. nov., two new species isolated from industrial vinegar fermentations. Int J Syst Bacteriol 48:935–940.
Sugiyama K, Sakakibara R, Tachimoto H, Kishi M, Kaga T, Tabata I. 2009. Effects of acetic acid bacteria supplementation on muscle damage after moderate-intensity exercise. Anti Aging Med 7:1–6.
Sugiyama A, Saitoh M, Takahara A, Satoh Y, Hashimoto K. 2003a. Acute cardiovascular effects of a new beverage made of wine vinegar and grape juice, assessed using an in vivo rat. Nutr Res 23:1291–6.
Sugiyama M, Tang AC, Wakaki Y, Koyama W. 2003b. Glycemic index of single and mixed meal foods among common Japanese foods with white rice as a reference food. Eur J Clin Nutr 57:743–52.
Svennerholm L. 1994. Gangliosides—a new therapeutic agent against stroke and Alzheimer's disease. Life Sci 55:2125–34.
Swings J. 1992. The genera *Acetobacter* and *Gluconobacter*. In: Balows Trüper, Dworkin Harder, Schleifer, editors. The prokaryotes. New York: Springer-Verlag. p 2268–86.
Tan SC. 2005. Vinegar fermentation [Master of Science thesis]. Louisiana State Univ., Dept. of Food Science, Baton Rouge. p 101s.
Trcek J, Raspor P, Teuber M. 2000. Molecular identification of *Acetobacter* isolates from submerged vinegar production, sequence analysis of plasmid pJK2-1 and application in the development of a cloning vector. Appl Microbiol Biotech 53:289–95.
Trcek J. 2005. Quick identification of acetic acid bacteria based on nucleotide sequences of the 16S–23S rDNA internal transcribed spacer region and of the PQQ dependent alcohol dehydrogenase gene. Syst Appl Microbiol 28:735–45.
Tsuzuki W, Kikuchi Y, Shinohara K, Suzuki T. 1992. Fluorometric assay of angiotensin I-converting enzyme inhibitory activity of vinegars. Nippon Shokuhin Kogyo Gakkaishi 39:188–92.
Turker I. 1963. Sirke Teknolojisi ve Teknikte Laktik Asit Fermantasyonları. In: Türker I, editor. Ankara, Turkey: Ankara Univ., Schoolbook of Faculty of Agriculture, Ankara Univ. Press. p 181.
Ubeda C, Hidalgo C, Torija MJ, Mas A, Troncoso AM, Morales ML. 2011. Evaluation of antioxidant activity and total phenols index in persimmon vinegars produced by different processes. Lwt-Food Sci Technol 44:1591–6.
Vegas C, Mateo E, González A, Jara C, Guillamón JM, Poblet M, Torija MJ, Mas A. 2010. Population dynamics of acetic acid bacteria during traditional wine vinegar production. Int J Food Microbiol 138:130–36.
Verzelloni E, Tagliazucchi D, Conte A. 2007. Relationship between the antioxidant properties and the phenolic and flavonoid content in traditional Balsamic vinegar. Food Chem 105:564–71.
Verzelloni E, Tagliazucchi D, Conte A. 2010. From Balsamic to healthy: traditional Balsamic vinegar melanoidins inhibit lipid peroxidation during simulated gastric digestion of meat. Food Chem Toxicol 48:2097–102.
World Health Organization. 2014. Diabetes Programme. Available from: http://www.who.int/diabetes/action_online/basics/en/index1.html. Accessed 2014 January 8.
Wu FM, Doyle MP, Beuchat LR, Wells JG, Mintz ED, Swaminathan B. 2000. Fate of *Shigella sonnei* on parsley and methods of disinfection. J Food Prot 63:568–72.
Xibib S, Meilan H, Moller H, Evans HS, Dixin D, Wenjie D, Jianbang L. 2003. Risk factors for oesophageal cancer in Linzhou, China: a case-control study. Asian Pac J Cancer Prev 4:119–24.
Xu QP, Ao ZH, Tao WY. 2004. Antioxidative activity of Hengshun aromatic vinegar extracts. China Brewing 7:16–8.
Xu QP, Tao WY, Ao ZH. 2005. Bioactivity of ethanol supernate of vinegar. J Food Sci Biotechnol 24:76–80.
Xu Q, Tao W, Ao Z. 2007. Antioxidant activity of vinegar melanoidins. Food Chem 102:841–9.
Yamada Y. 2000. Transfer of *Acetobacter oboediens* and *Acetobacter intermedius* to the genus *Gluconacetobacter* as *Gluconacetobacter oboediens* comb. nov. and *Gluconacetobacter intermedius* comb. nov. Intl J Syst Evol Microbiol 50:2225–7.
Yamashita H, Fujisawa K, Ito E, Idei S, Kawaguchi N, Kimoto M, Hiemori M, Tsuji H. 2007. Improvement of obesity and glucose tolerance by acetate in Type 2 diabetic Otsuka Long-Evans Tokushima Fatty (OLETF) rats. Biosci Biotechnol Biochem 71:1236–43.