

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, epicatechin, 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

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, liriopse) is used as a traditional medicinal herb; ophiopogon vinegar produced from *Radix*

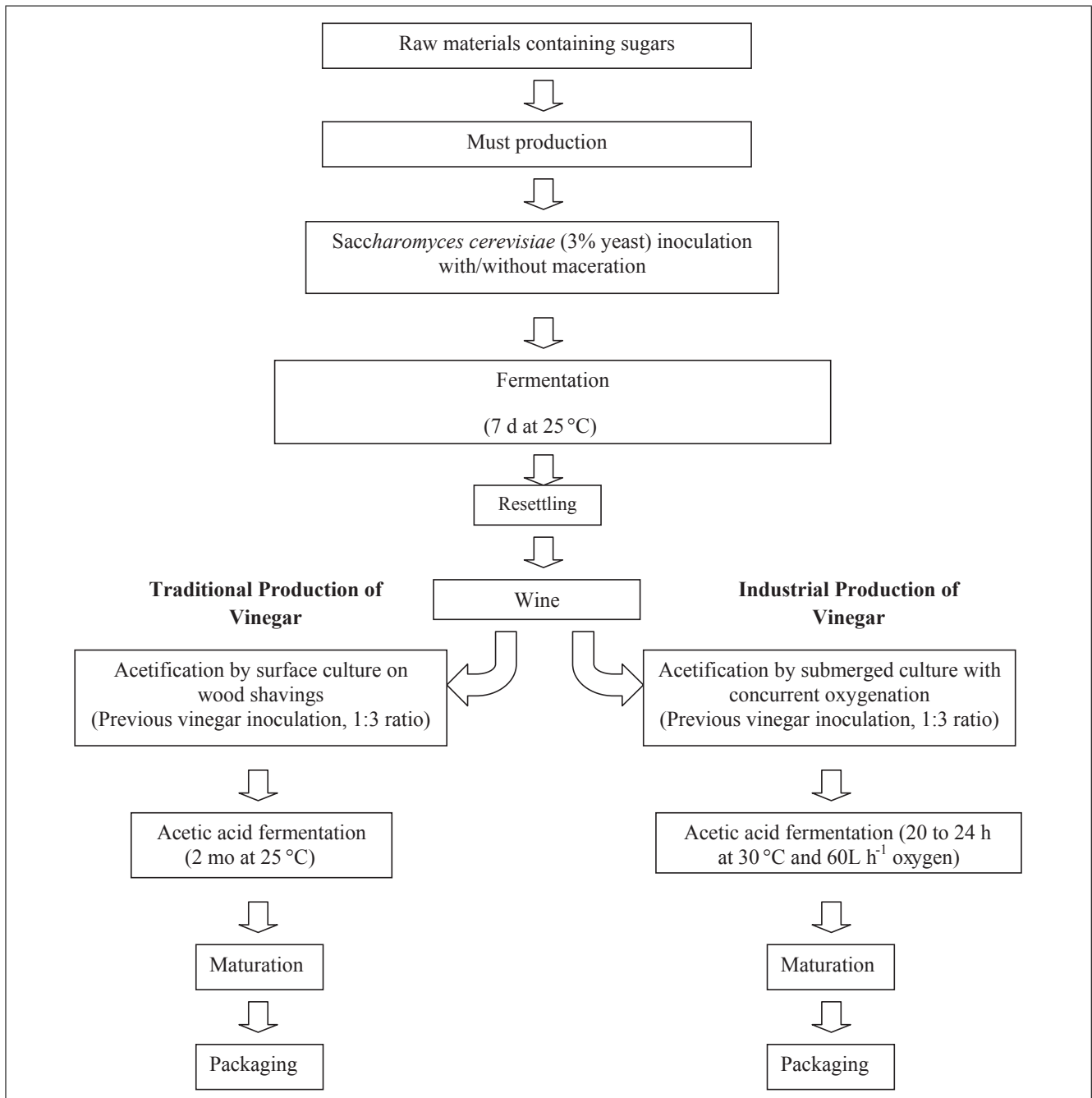


Figure 1–General production methods for vinegar.

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.

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

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

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

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 <i>p</i> -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, <i>p</i> -OH-benzoic acid, catechin, <i>p</i> -OH-benzaldehyde, syringic acid, vanillin, caftaric acid, <i>cis</i> - <i>p</i> -coumaric acid, <i>trans</i> - <i>p</i> -coumaric acid, fertaric acid, caffeic acid, <i>cis</i> - <i>p</i> -coumaric acid, <i>trans</i> - <i>p</i> -coumaric acid, <i>i</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, <i>p</i> -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 (García-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 $\mu\text{mol/mL}$ TE (trolox equivalents) and 13.50 mmol/L, respectively, for traditional vinegar and 8.84 $\mu\text{mol/mL}$ 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 $\mu\text{mol/mL}$ 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 ginseng 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 ginseng 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 co-fed 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.

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