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Review

Vinegar: A functional ingredient for human health

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Abstract

Vinegar is a well-known natural food product derived from alcoholic and subsequently acetous fermentation of carbohydrate-rich foods. Vinegar is widely used in the food industry; domestically for pickling vegetables and fruits, and as an ingredient in condiments like salad dressings, ketchups, and mayonnaise; and traditionally as a food seasoning and preservative. Historically, vinegar has been used for medicinal purposes such as a cure for stomach aches, wounds, burns, rashes, and oedema conditions. Different types of vinegar are found worldwide such as rice, black, balsamic, grain, and fruit vinegars. These are produced from different raw materials, and using different fermentation methods to give unique tastes and flavours. Vinegar, while enhancing physiological functions such as lipid metabolism, blood glucose level control, and body weight management, also possesses anticancer, antibacterial, antioxidant, and anti-infection properties. It is considered as a good source material for many bioactive compounds including organic acids, melanoidins, polyphenols, ligustrazine, and tryptophol. The pharmacological and metabolic benefits of vinegar are believed to be due to these bioactive compounds present in vinegar. Acetic acid (CH_3COOH) is the essential component of vinegar; it is slightly volatile and has a strong and sour aroma and flavour. Regular consumption of vinegar-containing foods is considered important for keeping many life-style related diseases like diabetes, hypertension, hyperlipidaemia, cancers, and obesity in check. Therefore, the present review aims at highlighting the health benefits associated with vinegar consumption for the physiological well-being of an individual.

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Introduction

Vinegar is a condiment derived from alcoholic fermentation followed by the acetification of glucose in fruits like apples, pears, grapes, molasses, berries, honeys, and many other food rich in carbohydrates (Budak *et al.*, 2014). This is a two-step bioprocess, in which the first step involves the transformation of sugar into ethanol by the yeast, followed by the oxidation of ethanol into acetic acid under aerobic condition (Hutchinson *et al*., 2019). *Acetobacter acetii* cultures under aerobic condition, incompletely oxidise alcohol produced by fermenting sugar to acetic acid, and eventually vinegar will be produced. Historically, vinegar has been used as a therapeutic agent for dealing with obesity, laryngitis, fever, swelling, and stomach ache since the 18th century (Bray, 2014). In the food sector, vinegar is widely used for pickling vegetables and fruits, in condiments like mayonnaises, ketchups, and salad dressings, and has traditionally been used as food seasoning and preservation ingredient (Saha and Benerjee, 2013). According to the Malaysian Food Act 1983, vinegar shall not contain acetic acid content lower than 4% (w/v), and any mineral acid (Isham *et al*., 2019). Further, as in Food Regulation 1985, vinegar is allowed to contain permitted preservatives, with spices as the permitted flavouring substance, and caramel as a colouring substance (Ho *et al.*, 2017).

Different types of vinegar are made from different raw materials used in the fermentation; rice vinegar is obtained from the acetous fermentation of sugars derived from rice (Nanda *et al*., 2001); grain vinegar is from sorghum, wheat, or other grains; while fruit vinegar is from fruits such as grapes or apples. There are many other types of vinegar like malt, wine, apple cider, and balsamic vinegar (Chen *et al*., 2016). Apple cider vinegar is the most widely

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manufactured and marketed type of vinegar among the western and European countries, while coconut vinegar is the most popular among Asian population. Vinegar is a source of many bioactive compounds including organic acids, melanoidins, polyphenols, tryptophol, ligustrazine, and caffeoylsophorose (Chen *et al*., 2016) which are responsible for various health-related effects including antibacterial, anti-infection, and antioxidant properties, blood glucose regulation and weight management. As stated by Etherton *et al*. (2002), bioactive compounds are responsible for the extra-nutritional properties of food, and influence on various physical, chemical, or cellular activities of the body, thus providing favourable health outcomes. Incidentally, it is the presence of phenolic compounds that are responsible for the appearance and astringency of vinegar (Mas *et al*., 2014). Different types of vinegar may possess different health benefits depending on the bioactive components present. As a food ingredient and therapeutic agent, vinegar possesses minimum of toxicity. However, heavy intake of vinegar with an acetic acid concentration greater than 20% may affect oral health and the gastrointestinal tract of humans (Johnston, 2009).

Vinegar is therefore, a condiment that needs to be studied based on its functional attributes and the associated health benefits to humans. However, research on this discipline is limited in literature. Moreover, there are different types of vinegar with different properties produced worldwide, but most are confined to their own geographical location, and not universally popular. Therefore, the present review aims to highlight the different types of vinegar found around the world based on the major ingredients used in their production, the associated health benefits attributed to the specific bioactive compounds present, and the toxicological effects. The regulatory aspects pertaining to vinegar consumption are also summarised.

Types of vinegar

Vinegar can be made from any aqueous medium containing a sufficient amount of fermentable sugars under the right conditions. The result will be some type of vinegar with an acetic acid content that will meet the standards. Thus, different types of fruits, vegetables, and animal-based products like whey and honey are being used as the major raw materials in vinegar production. Depending on the raw materials used in the fermentation, different varieties of vinegar can be produced. The type of materials used vary from region to region.

Apple cider vinegar

Apple cider vinegar is one of the best-known types of fruit vinegar in the world. The production of cider vinegar involves alcoholic and acetous fermentation of apple juice to convert the sugars in the apple juice into alcohol first, and subsequently to acetic acid (Lea, 1989). The microflora used in apple cider vinegar production includes yeasts such as *Kloeckera apiculata*, *Metschnikowia pulcherrima*, *Candida* spp., and *Pichia* spp.; lactic acid bacteria including *Lactobacillus*, *Pediococcus*, *Leuconostoc*, *Oenococcus* spp., and acetic acid bacteria such as *Acetobacter* and *Gluconobacter* (Fleet, 1998). Apple cider vinegar contains many nutrients including vitamins, minerals, and dietary fibres. It is a well-known type of vinegar used to treat many conditions including obesity, skin and hair problems, asthma, diarrhoea, and many other maladies (Kausar *et al.*, 2019). Traditionally, apple cider vinegar has been used as a flavouring agent and preservative. Other than that, currently it is being used in salad dressings, marinades, and chutneys. It is famous around the world by the name 'cider vinegar', and geographically distributed mostly in countries like the USA and Canada (Joshi and Sharma, 2009).

Balsamic vinegar

Balsamic vinegar is a type of vinegar produced with the cooked and concentrated must of red/white grapes, which is dark brown in colour, and has a sweet and sour taste (Masino *et al.*, 2008). It is traditionally produced in Italian households using locally available grape varieties. The production of balsamic vinegar as described by Giudici *et al*. (2009) involves the conversion of sugar into ethanol, followed by oxidation of the ethanol to acetic acid, and finally aging for 12 years. The aging process uses a special technology called '*ricalzo*'. It involves a series of barrels of different capacities. Each barrel contains cooked grape must which is fermented and oxidised. Every year, small amount of vinegar is drawn from the smallest barrel, and it is then refilled with vinegar from the next bigger barrel. First barrel is refilled with freshly cooked must. Each barrel therefore contains a blend of vinegar of different ages, and this age increases from the first barrel to the last barrel (Solieri *et al*., 2006). The main components of balsamic vinegar besides acetic acid are sugars like glucose and fructose, and organic acids such as gluconic, tartaric, malic, and succinic acids (Masino *et al*., 2008). These organic acids play an important role in modifying the sensory properties of vinegar due to their own characteristic flavours which are mellower than that of acetic acid. Balsamic vinegar is used as a salad dressing and as a topping in many cooked dishes of meat, poultry, and fish, as well as fruits.

Sherry vinegar

Sherry vinegar is of Spanish origin, and made from Sherry wine (Palacios *et al*., 2002). It takes at least six months of fermentation to generate Sherry vinegar with the 'right' taste. The process of Sherry vinegar production is known as '*soleras*' and '*criaderas*', which is a traditional method involving slow acetification over a long aging period (Budak *et al*., 2014). The system involves stacking casks made from American oak, one on top of the other, according to the age of the product; the oldest vinegar called *solera* is found at the bottom of the stack (Alonso *et al.*, 2004). In the production of Sherry vinegar, the bacterial culture is placed on the surface of the substrate, thus limiting the oxygen available for the bacteria; hence, a long period is required for acetification (Tesfaye *et al*., 2002). Studies of Castrejón *et al*. (2003) has reported the presence of *Saccharomyces cerevisiae* 'races', such as *S. cerevisiae* var. *beticus*, *S. cerevisiae* var. *cheresiensis*, *S. cerevisiae* var. *montuliensis*, and *Zygosaccharomyces rouxii* in Sherry vinegar velum. Also, Sherry vinegar is famous around the world for its nutty flavour. Sherry vinegar is extensively used in French and Spanish cuisines. It is popular as a salad dressing in making marinades, pan sauces, glaze, and as a drizzle over fruits and vegetables. It is also used as a digestive after a meal, and often sprinkled over desserts such as ice creams and strawberries to temper their sweetness and add a little tartness.

Rice vinegar

Rice vinegar is made using rice as the substrate. It is a widely used condiment in many Asian food preparations including pickled vegetables, salad dressings, and sushi rice. Traditional rice vinegar production involves conversion of rice starch into acetic acid (Haruta *et al.*, 2006). Initially, rice is soaked in water followed by heating and cooling, and then saccharification of rice starch will be performed using *koji* mould. Incidentally, rice *sake* is produced by using *sake* yeast, while acetic acid is produced by means of bacteria named *moromi* through a static surface fermentation (Budak *et al*., 2014). Different types of rice vinegar are found according to their origin. The Chinese vinegar *zhenjiang* is considered as the most commonly known traditional vinegar; it uses sticky rice as the raw material (Xu *et al*., 2007). In Japan, there are two major varieties of rice vinegar, of which *komesu* is a colourless type produced with polished *japonica* rice or the imported *indica* rice. The other is *kurosu*, a black colour vinegar produced from unpolished rice (Nanda *et al*., 2001). *Kurosu* contains appreciable amounts of amino acids, vitamins, and soluble metal ions that can provide many health benefits. *Kurosu* vinegar is rich in substances that can reduce hypertension, and also contains cancer-prevention substances (Murooka *et al*., 2009).

Malt vinegar

Malt vinegar originated in Britain several hundred years ago. The production involves double fermentation, with the beer subjected to complete acidification until the final output becomes a vinegar. Malt vinegar production uses malted barley, in which the starch has already been converted to sugars due to the presence of natural enzymes in it (Grierson, 2009). Raw barley is mostly made up of starches and proteins. Since the barley cannot be used directly in the fermentation as yeast cannot metabolise these substances properly, certain preliminary treatments are carried out so that proper fermentation can take place. Therefore, the production of malt vinegar requires several stages including brewing (milling, mashing, alcoholic fermentation), separation, acetification, storage, clarification, making up, filtration, and packaging (Grierson, 2009). Moreover, there are several varieties of malt vinegar such as distilled, dark, and light malt vinegar. Distilled malt vinegar is a colourless liquid produced by malt vinegar distillation under reduced pressure (Grierson, 2009). In the production of distilled vinegar, vinegar is passed directly to the distillation unit at the end of acetification of the usual vinegar production. Usually, malt vinegar is a pale-straw colour liquid, while the dark malt vinegar is dark brown in colour. The addition of caramel or barley extract into the malt vinegar makes it darker in colour (Grierson, 2009).

Coconut vinegar

Coconut vinegar is made from the sap of coconut flower or from coconut water. It is widely used as a food preservative and flavouring agent in salads, pickles, sauces, and many other traditional dishes. The production of vinegar using static fermentation takes a period of one month, and yields a cloudy white liquid with a sharp and acidic taste combined with slight yeasty flavour (Gonzalez and De Vuys, 2009). Southeast Asian countries are the major producers and consumers of coconut vinegar (Budak *et al*., 2014). Coconut vinegar is also produced using coconut toddy in countries like Sri Lanka. In the studies of Nathanael (1955), coconut toddy has been identified as a better source for preparing coconut vinegar in Sri Lanka. He has further stated that toddy is one of the best source materials as it has the ideal composition to prepare the vinegar stock which is produced during the first stage of vinegar fermentation. The use of toddy in vinegar production also makes the process faster because the alcoholic fermentation is completed within 24 - 48 h. Another study by Gunathilake (2011) has noted that the production of vinegar using coconut water is low-cost as compared to the other methods. A similar study conducted by Othaman *et al*. (2014) states that coconut water has shown itself to be a better alternative substrate for coconut vinegar production in Malaysia.

Cane vinegar

Cane vinegar is a type of vinegar from the Philippines which is made from the syrup of the sugar cane. It is known by different names in different countries. It is used in many cuisines as a salad dressing, sauce, and for glazing or marinating. Its sweetness and slight acidic taste make it ideal for chutneys and pickles as well. In France and USA, sugarcane vinegar is called as ‘cane vinegar’; in the Philippines it is known as *sukang iloko*; and in Japan it is called *kibizu* (Nanda *et al*., 2001). The production after harvesting involves crushing the stems to extract the juice, simmering it down to a syrup, and finally fermenting it to a vinegar. High quality sugar cane vinegar could be prepared from fresh cane juice using wine yeast and acetate bacteria (Chen *et al*., 2015). The colour of cane vinegar ranges from deep yellow to golden brown (Nanda *et al*., 2001).

Honey vinegar

Honey is regarded as a valuable medicine as it has a dense nutrient composition (Cianciosi *et al.*, 2018). The study of Ilha *et al*. (2000) has shown that honey vinegar could be made by the acetification of honey wine with acetic acid bacteria. Sensory evaluation results of the same study showed that all the sensory attributes of honey vinegar were highly appreciated. However, alcoholic fermentation of honey wine will take months or even years due to the high sugar concentration in honey. Consequently, the production of honey vinegar will also take a long time, and therefore it is hardly economically feasible to produce it. Honey vinegar microflora mainly contains acetic acid bacteria and yeasts (Alak, 2015).

Fruit vinegar

Tropical fruits have been used for fruit vinegar production recently. The production of vinegar from fruits such as mango and papaya have been studied by Bouatenin *et al.* (2020). Mango vinegar is prepared by fermenting mango juice, and the production is geographically concentrated around East and Southeast Asia (Gonzalez and De Vuys, 2009). The production involves alcoholic fermentation of mango pulp over 14 days followed by acetification. Studies conducted by Adebayo-Oyetoro *et al.* (2017) reports that mango vinegar is a very effective and popular type of vinegar available in the Nigerian food market. Another fruit vinegar type found in several local markets is pineapple vinegar. Pineapple peelings are mainly used in the vinegar production (Sossou *et al.*, 2009). Saccharified pineapple waste has also been reported as a main raw material in vinegar production among rural industries in many developing countries (Roda *et al*, 2016). Vinegar produced from fermented berry juice has also been identified by Boonsupa (2019) as a sensorily and chemically desirable type of vinegar available in the local market in Mahasarakham, Thailand. Date vinegar is a type of traditional vinegar whose production and consumption are limited as it is done on a family scale (Halladj *et al*., 2016). Zahdi date vinegar is famous in Iraq (Matloob, 2014). In the production of date vinegar, date is initially boiled by adding water into it and non-spontaneous alcoholic fermentation is allowed to take place. Acetification of the produce is done by the addition of mother of vinegar as the starter to the wine until the final acetic acid content becomes 4 - 5% (v/v) (Gonzalez and De Vuys, 2009). Starfruit has also been identified by Minh (2014) as a potential raw material for fruit vinegar production. A study by Chen and Huang (2008) suggests the possibility of producing fruit vinegar using strawberry as the raw material by subjecting the fruits to leaning up, squeezing, and alcoholic fermentation followed by acetification. The development of strawberry vinegar using alcoholic fermentation and acetification has also been reported in the studies of Hidalgo *et al*. (2010).

Vegetable vinegar

Tomato vinegar is a type of vegetable vinegar which is mostly used in East Asian countries including Japan (Solieri and Giudici, 2009). It is produced by fermenting tomato paste using the submerged culture method (Cejudo-Bastante *et al.*, 2017). Onion vinegar is a vegetable vinegar produced from onion juice. It is considered as a condiment with a range of beneficial physiological characteristics (Horiuchi *et al.*, 1999). The process involves the production of vinegar from the juice of red onions using yeast and *Acetobacter aceti*. Same study by Horiuchi *et al.* (1999) has elaborated on the nutritional composition of onion vinegar by observing that the potassium, amino acid, and total organic acid contents of onion vinegar are greater than that of conventional vinegar, while its sodium content is comparatively lower. Purple sweet potato vinegar is another type of vinegar developed in China using the mashed tuber as the substrate (Wu *at al.*, 2017). It is widely used for sauces, salad dressings, and stews. A similar study by Chun *et al*. (2014) has also reported the potential for development of a sweet potato *makgeolli* vinegar using a two-stage fermentation process.

Health benefits of vinegar

Vinegar and cardiovascular health

Cardiovascular diseases (CVDs) are identified as a major cause of mortalities among the population. Among the significant risk factors for CVDs are cholesterol, physical inactivity, high blood pressure, and smoking (Beaglehole, 2001). The ability of polyphenol-rich foods like vinegar to reduce mortality and enhance protection against CVDs has been clinically identified in different previous studies (Tangney and Rasmussen, 2013). The reduction of CVD-related mortalities with polyphenol-like flavonoids has been studied by Peterson *et al*. (2012). Coronary diseases are closely associated with oxidised low-density lipoproteins (LDL) in the bloodstream (Berliner and Heinecke, 1996). According to Sugiyama *et al*. (2007), ingesting natural antioxidants like polyphenols will reduce the LDL levels in the bloodstream; similarly vinegar has higher levels of polyphenols like chlorogenic acid which inhibits the LDL oxidation, thus it can help to prevent the incidence of CVDs (Laranjinha *et al*., 1994).

In addition to LDL cholesterol level, the total cholesterol (TC), triglycerides (TG), and high-density lipoproteins (HDL) are also maintained by acetic acid-containing foods like vinegar. Based on the animal trials of Fushimi *et al*. (2006), a substantial decrease in TC, TG, and LDL cholesterol accompanied by an increase in HDL cholesterol have been recorded after long-term consumption of acetic acid in food. A human study of Kondo *et al*. (2009) has shown a significant reduction in lipids and TG levels in obese people with an apple cider vinegar intake of 15 mL every day. Further, a clinical study carried out by Beheshti *et al*. (2012) has shown that 30 mL of apple vinegar taken twice a day can have a significant effect on reduction of TC, TG, and LDL level. Thus, the impact of vinegar as a polyphenol-rich food ingredient on CVD prevention is highly significant. CVDs have a high correlation with the level of LDL cholesterol in bloodstream, and based on the evidence from previous observational research studies, the LDL oxidation associated with vinegar intake has proven to be responsible in reducing the impact of LDL on CVDs.

Atherosclerosis is a chronic inflammatory condition afflicting the arterial blood vessels leading to clinical events such as myocardial infarctions, angina, and ultimately death. Momentary increase in postprandial concentrations of TG and fatty acids in the blood can affect endothelium-reliant vasodilatation, which is the root cause for the progression of atherosclerosis (Vogel *et al*., 1997). As stated by Setorki *et al*. (2010), dietary phenolic compounds in vegetables, fruits, and fruit juices are considered good for human health, and the postprandial effect of vinegar on the reduction of biochemical risk factors of atherosclerosis is obvious. Furthermore, they state that vinegar consumption together with a cholesterol-enriched diet can significantly control the increase of oxidised LDL, malondialdehyde (MDA), Apolipoprotein B100, TG, glucose, and fibrinogen due to the ability of vinegar to modify the atherogenic effects of cholesterol. Vinegar as a rich source of bioactive components with anti-inflammatory properties plays a fundamental role in preventing the occurrence and progression of chronic inflammations such as atherosclerosis, which can pose health risks to people with CVDs.

Vinegar can play an active role in preventing hypertension. Systolic blood pressure is reduced with a higher intake of vinegar, and this reduction is associated with both renin activity and aldosterone levels in the plasma (Kondo *et al*., 2001). Renin angiotensin-aldosterone system is the typical blood pressure regulatory system in humans. The key function of this system is the regulation of blood volume by influencing arterial pressure and cardiac output. Animal trial conducted by Matsui (1998) has stated that the consumption of vinegar has a significant impact on lowering arterial pressure and the activity of renin. This effect is caused by the reduction of renin activity that acts to reduce angiotensin 2, which is the main initiator of rising blood pressure. Thus, serum TG levels of people who consume high amounts of vinegar will be lower as compared to people who consume only small amounts of vinegar. Dietary acetic acid attenuates the elevation of serum cholesterol and TG concentrations, and reduces many other factors required for cholesterol synthesis and fatty acid synthesis (Fushimi *et al*., 2006). Therefore, vinegar with acetic acid as its major component plays a vital role in building up and maintaining cardiovascular health.

Anticancer effect of vinegar

Anticancer effects of vinegar are associated with its polyphenol content, especially with polyphenols like resveratrol (Shukla and Singh, 2011). This study identifies resveratrol as a dietary polyphenol that interferes with all three stages of carcinogenesis, and inhibits the proliferation of cancer cells. Wan *et al*. (2019) have stated that weak acids such as acetic acid have been proven for their anticancer effect. Epidemiological data on anticancer effects are scarce, and research is ongoing to identify the anticancer elements present in vinegar. Based on the colonic tests done on humans by Fu *et al*. (2004), acetate treatments have had a significant impact on inhibiting tumour growth and metastasis. Vinegar is a rich source of acetate and polyphenols which enhance antioxidant protection while weakening the cancer-causing effects. The effect of grain vinegar on oesophageal cancer has been studied by Xibib *et al*. (2003), and the results are negatively correlated. Cell-based experiments of Baba *et al.* (2013) has also shown that the acetate in vinegar has the ability to inhibit proliferation of colon tumour cells.

Moreover, the risk of oesophageal cancer is reduced with dietary consumption of vinegar than the consumption of pickled or salted vegetables (Xibib *et al*., 2003). Leukaemia is a cancer of the blood which leads to an abnormal rise of white blood cells in the body. Studies of Mimura *et al.* (2004) have shown that the apoptosis of human leukaemia cells is promoted by vinegar, thus leading to a reduction in the incidence of leukaemia. As claimed by the Vinegar Institute in 2005, the inhibition of glycolysis causes starvation of the existing cancer cells responsible for the progression of cancer within the human body, and reduces the formation of new cancer cells. Protection provided by the oxidative stress of polyphenol contents, action of acetate in controlling cancer cell proliferation, and the apoptosis of cancer cells are identified as the proven causes affecting the anticancer activity of vinegar in the human body.

Control of blood glucose level

Vinegar consumption can influence blood glucose levels. According to Cheng *et al.* (2020), a significant improvement in glycaemic control can be achieved by vinegar intake among patients having type 2 diabetes. Diabetes mellitus is a persistent metabolic disorder caused by the inability of body to produce insulin effectively, or the inability of pancreas to maintain a satisfactory insulin level for metabolic activities according to the American Diabetic Association in 2010. According to the World Health Organization, diabetes is characterised by elevated blood glucose levels in both fasting and postprandial conditions. Postprandial hyperglycaemia is considered the typical symptom for the identification of diabetes mellitus in its early stages (Yang *et al*., 2010). The acetate in vinegar aids in converting blood glucose into glycogen, thus assisting in the reduction of fasting blood glucose levels (Fushimi *et al*., 2001). Moreover, one tablespoon of vinegar intake at mealtime twice a day has proven to reduce the fasting blood glucose level of an individual to the same level as the reduction achieved by regular administration of diabetic drugs (Johnston *et al*., 2013).

According to Ebihara and Nakajima (1988), combining a 2% acetic acid dose with a starchy diet has a significant impact on reducing postprandial blood glucose levels. Further, the insulin sensitivity of type 2 diabetes patients is increased with the intake of vinegar. Following a high glycaemic meal, a drop in postprandial glucose levels and insulin responses has been reported with the consumption of vinegar (Johnston and Buller, 2005). Disaccharide breakdown occurs in the small intestine as a part of carbohydrate digestion, and this activity is suppressed by the action of the acetic acid in vinegar, which is influenced by reduced blood glucose levels (Ogawa *et al*., 2000). Also, studies on hypoglycaemic effects of vinegar have shown that the blood glucose-lowering effect of vinegar is due to its ability to suppress digestive amylase that is essential for carbohydrate breakdown in the small intestine (Brighenti *et al*., 1995; Fushimi *et al*., 2001). Alpha amylases are enzymes that catalyse the hydrolysis of starch to glucose and maltose by cleaving alpha 1-4 glyosidic linkages into two forms of starch; namely amylose and amylopectin. Salivary amylase initiates the digestion of starch followed by pancreatic amylase in the pancreatic juice (Smith and Morton, 2010). Therefore, the increase in glucose level following a meal is associated with the activity of alpha amylase, and its inhibition regulates the blood glucose level of patients with diabetic mellitus (Tundis *et al*., 2010). Similar study by Fried *et al*. (1987) has shown that the acidic conditions created by vinegar consumption suppress the activity of alpha-amylase. pH of the commercially available vinegar is about 2 - 3, and a pH value less than 4 has a significant impact on the inactivation of the amylase enzyme (Johnston and Gaas, 2006). As stated by Ostman *et al*. (2005), vinegar lowers the glycaemic index caused by high glycaemic index foods, and is therefore considered better at maintaining blood glucose levels. Mediating effect of acetic acid on the absorption of starch by the small intestine will decrease the amount of glucose absorbed following a meal, thereby minimising the effect of high blood glucose levels on human health.

Control of obesity

Obesity that is caused by long-term imbalance in the energy intake, is a risk factor for many lifestyle-related diseases, and over the past few years, the incidence of obesity has dramatically increased worldwide (Kopelman, 2000). Several research have proven that vinegar can play an important role in tackling obesity and in weight management. As shown by Beheshti *et al*. (2012), orally administered doses of vinegar over a period of 1 - 6 months have the ability to reduce obesity-linked type 2 diabetes. According to Kondo *et al.* (2009), a study conducted on 155 obese Japanese subjects showed that the consumption of vinegar for a 12-week period had a positive effect on the reduction of body fat, body weight, waist circumference, and body mass index (BMI). Also, they proved that continuous administration of vinegar is necessary for reducing the weight of people with obesity-related diseases. Further, they explained the main mechanism behind the reduction of bodyweight by vinegar to be closely related to lipogenesis. It is based on with the inhibitory effects of vinegar on the activity of several lipogenic genes that are responsible for converting the glucose in the liver to fatty acids (Yamashita *et al*. 2007). Moreover, the consumption of vinegar can lead to lowering the glycaemic index through increasing satiety; thus, reducing the food intake and decreasing in the energy intake as well (Mermel, 2004). A study by Seo *et al.* (2014) on the obesity management of obese mice fed with different diets has further described the anti-insulin properties of tomato vinegar and the significant effect it has on reducing obesity. It reported that the vinegar intake reduced the body mass by 14.3%, and serum TG by 19.1% after a period of six weeks. A similar study of coconut water vinegar and its effect on obesity concluded that the vinegar intake reduced body weight by 17.9%, and serum TG by 29.88%, following ten weeks of treatment (Mohamad *et al.*, 2017). The same study highlights that coconut water vinegar directly contributes to reducing the lipid profile by subduing the expression of sterol regulatory element binding proteins (SREBPs) in adipose tissues; thus, assisting in weight loss.

Another study by Lee *et al*. (2013) examined the action of tomato vinegar on anti-visceral obesity caused by a high-fat diet. The anti-visceral obesity is associated with intra-abdominal fat deposition that can lead to CVDs, hyperlipidaemia, and diabetes. It has proved that the ingestion of vinegar on a daily basis has the ability of decreasing visceral fat completely. Therefore, these results strongly suggest that vinegar can act as a natural medicine against obesity, thus paving the way for a healthier life.

Antibacterial, antifungal, and anti-infection properties

The antimicrobial and anti-infective characteristics of vinegar are principally due to the organic acids such as polyphenols and melanoidins (Ozturk *et al*., 2015), and the low pH values due to the presence of acetic acid as the primary element

(Johnston, 2009). Vinegar can have two types of bacterial actions, specifically bacteriostatic and bactericidal actions. Bacteriostatic action involves the inhibition of bacterial growth, while bactericidal action involves a reduction of viable cell numbers. A study conducted by Entani *et al*. (1998) related to 17 bacterial strains, and by using vinegar with an acetic acid concentration of 0.1%, showed a strong bacteriostatic effect on all the strains. The bactericidal effect was prominent in preventing bacterial food poisoning caused by *Escherichia coli* and *Salmonella* spp. Further, vinegar showed antibacterial properties against mycobacteria. Mycobacteria are well-known disinfectant-resistant microorganisms responsible for many infections such as tuberculosis and leprosy (Esteban *et al*., 2012). According to Cortesia *et al*. (2014), exposure of *Mycobacterium tuberculosis* to a 6% acetic acid vinegar solution and *M. massiliense* (non-tuberculous mycobacteria) in a 10% acetic acid vinegar solution had an effective mycobactericidal effect. *Candida albicans* is the yeast responsible for denture stomatitis, and as stated by Saqib (2017), apple cider vinegar with its natural enzymes showed antifungal effects against *Candida* spp. Therefore, vinegar can prevent inflammation of the mouth mucous membrane, and can be used as an effective denture cleansing ingredient. As shown by Cortesia *et al*. (2014), the bactericidal effect of vinegar is due to the carboxylic acid function of acetic acid, thus effective at treating various conditions like fungus occurring in the nails, head lice, warts, and ear infections (Johnston, 2009).

Vinegar and gut health

Vinegar is good for many digestive tract problems, especially apple cider vinegar which promotes gut health. The acetic acid in vinegar is well known in preventing the overgrowth of harmful bacteria in the gut while improving the beneficial gut microbial population (Song *et al.*, 2020). It also eases inflammation by providing relief for many digestive problems. Vinegar assists in problems associated with constipation. As stated by Hjorth *et al.* (2020) in his clinical study, vinegar is recognised as an effective treatment in reducing constipation among obese patients. Moreover, white vinegar has been identified as a treatment for constipation that can be orally administrated (Peng *et al*., 1987). A similar study by Chee (2017) has shown that black bean vinegar is also a functional remedy for constipation.

Inflammatory bowel disease (IBD) is a condition caused by the inflammation of the intestinal region (Morrison *et al*., 2009). People with IBD suffer repeated inflammation of the intestinal tract lining leading to ulcers, pains, and diarrhoea. According to Shen (2005), vinegar is well known for defending against body inflammations. The anti-inflammatory properties of vinegar are mainly due to its acetic acid content. Just after vinegar intake, serum acetate levels rise above the normal levels due to the absorption of this acetate by the body. Acetate is immediately absorbed by the jejunum and stomach in the upper digestive tract, and then it circulates around the whole body (Sugiyama *et al*., 2010). As stated by Shen *et al*. (2016), 5% (v/v) of vinegar or 0.3% (w/v) of acetic acid treatments have a significant effect on the reduction of IBD episodes, and a similar study suggests vinegar supplementation as a new and successful dietary strategy for treating IBD. Wakuda *et al*. (2013) further stated that vinegar brewed from Japanese pear rich in galacturonic acid is identified as being functional against IBD patients.

Fermented food products like vinegar also promote the growth of healthy gut bacteria by inhibiting the enzymes that digest starch, leaving the starch for gut bacteria (Zhu *et al*., 2019b). Studies have further mentioned that apple cider vinegar contains prebiotics that help in balancing microbiome in the gut (Fuller, 1991). Therefore, due to the acetic acid component and other bioactive components present in vinegar, it is identified as a natural treatment for many gastrointestinal tract related problems.

Vinegar and renal health

Vinegar has been used as a therapeutic agent since ancient times to treat renal problems. Nephrolithiasis, a condition caused by the deposition of calcium-based minerals in the kidneys, is one of the most common afflictions of the kidney. Individuals of all ages are known to suffer heavily from this disease condition worldwide (Worcester and Coe, 2008). Treatments for renal problems have been proposed by various clinical research. Several studies have highlighted that the treatments with acetate can have a significant impact on reducing the incidence of kidney diseases. An epidemiological study conducted by Zhu *et al*. (2019a) has found that vinegar with acetate as its principal bioactive compound has the ability to suppress the formation of kidney stones (insoluble crystals of calcium oxalate, urate, and phosphate) by promoting the excretion of urinary calcium and stone-forming acids from the body.

Yang *et al*. (2010) have claimed that the polyphenolic compounds in fruit and grain extracts have a significant impact on protecting liver and kidney against oxidative stress-induced injuries. Antioxidant properties of these polyphenolic substances are probably responsible for these benefits. Kidney abnormalities and oxidative injuries are well-known health problems that can arise at menopause (Poli, 1993), as is the removal of ovaries (Ulas and Cay, 2011). Based on the clinical findings of Nazıroğlu *et al*. (2014), apple cider vinegar could decrease the oxidative activity in kidney and erythrocytes by the action of antioxidant enzymes present in vinegar, thus preventing the kidney injuries that can occur in women at menopause. Further, the protective activity of natural polyphenols in vinegar against diabetic nephropathy has been reported by Powell *et al*. (2013). Nephropathy, which is a root cause of end-stage renal failure, develops and progresses when there is oxidative stress on the kidneys; as such, it could most likely be controlled by the antioxidant activity of vinegar (Karim *et al*., 2019). Further, according to an animal trial conducted by Zhu *et al*. (2020), vinegar intake improved the renal function of rats with hyperoxaluria, which caused renal injury and end-stage kidney disease.

Other benefits of vinegar on health

Bioactive compounds in vinegar are also associated with many other health effects; but, few research studies have described these health benefits in detail. Vinegar has been used as a medicine since ancient times due to its healing effect on burns. The antibacterial properties of vinegar are mainly assumed to be responsible for the healing power of vinegar (Sindhu *et al*., 2014). Some studies have reported that oral administration of acetate has the effect of reducing muscle damages caused by physical exercises (Sugiyama *et al*., 2010). Moreover, it has been reported that vinegar consumption has the ability to enhance the cognitive function of humans (Ali *et al*., 2017). Sphingolipids are considered as the building block of brain tissues, and the same study states that the construction of these sphingolipid precursors is performed by acetic acid bacteria. Vinegar is identified as a therapeutic agent with minimal side effects. Further, some historical records are available on the usage of vinegar as a chronic cough syrup mixed with honey (Johnston and Gaas, 2006).

Toxicological studies pertaining to vinegar consumption

Vinegar is a well-known food ingredient commonly used in culinary practice, and therefore, by default, it is considered a safe product for human consumption with minimum toxicity. However, consumption of excessive vinegar may cause negative health impacts, especially on the gastrointestinal tract and the teeth enamel. Tooth erosion is a major consequence of the overconsumption of vinegar (Gambon *et al*., 2012). Vinegar is an acidic condiment with a pH value of less than 3.0. Naturally, substances with high acidity contribute to dental erosion or dissolution, thus causing an irreversible loss of teeth enamel and dentin (Loke *et al*., 2016). Many people consume vinegar as a medication to reduce postprandial blood glucose and for visceral fat reduction. However, the results of a study conducted by Anderson *et al*. (2020) with a group of people consuming vinegar on a daily basis (3.6 g of acetic acid along with vinegar) as a medication, showed that the frequent consumption of vinegar had a negative impact on oral health. In contrast, the study elaborated that the consumption of vinegar diluted with water for medical purposes would decrease the occurrence of tooth erosion as compared to its concentrated form. Moreover, clinical studies of O'Sullivan and Curzon (2000) and Tao *et al*. (2015) highlighted vinegar as a major risk factor for children by promoting tooth erosion. Therefore, the amount of vinegar consumed, either as a beverage or with value-added products such as pickles, fruit vinegar, and salad dressings should be limited to a certain amount to prevent the damage it can cause to oral health.

Overconsumption of vinegar may also affect the gastrointestinal tract. Oesophageal injuries are the most common causes occurring in the gastrointestinal tract due to acetic acid overconsumption. Many studies, including those by Hill *et al*. (2005) and Kim *et al*. (2011) have shown apple cider vinegar consumption to be a risk factor for the occurrence of oesophageal injuries. Normally, the acetate concentration in vinegar ranges from 4 to 8% (w/v) for table vinegar, and up to 18% (w/v) for pickling use (Hailu *et al*., 2012). An acetic acid concentration greater than 20% is considered dangerous as it can cause severe injuries to the oesophagus. According to the Center for Disease Control and Prevention (CDC), the immediately dangerous to life or health (IDLH) concentration of acetic acid is 50 ppm, depending on acute inhalation toxicity (Johnston, 2009). Consumption of vinegar on a daily basis as a medicine will lead to the development of acetic acid overdose in the body. Therefore, the use of vinegar for medication over an extended period should be done under proper medical supervision.

Standards and the regulatory aspects of vinegar

Vinegar production is regulated through a set of defined standards. According to the standards defined by the World Health Organization, vinegar is a liquid produced by means of a process of double fermentation from suitable products containing starch and/or sugar. The residual ethanol content of vinegar is expected to be less than 0.5% (v/v) for wine vinegar, and less than 1% (v/v) for other types of vinegar. In the USA, vinegar production is not required to meet many quality standards, but vinegar products are expected to maintain a minimum acetic acid level of 4% (w/v) in the retail market. The European market has its regional standards with established threshold levels for both acetic acid and ethanol contents of vinegar: a minimum of 5% (w/v) acidity, and a maximum of 0.5% (v/v) ethanol (FAO/WHO, 1998).

At present, in addition to the biological production of vinegar, synthetic production of vinegar, or more correctly acetic acid, has become very common, especially for industrial use. Regulatory controls and legal assessments of these types of vinegar are important to maintain the quality standards for vinegar as required by the national and international markets. The maximum allowable levels for the mixing of vinegar with synthetic acid, having a known and unknown origin, are 5 and 10% (w/v), respectively (Giudici *et al*., 2009). The manufacturers need to adhere to the threshold levels prescribed by the authorised bodies to ensure the health and safety of consumers.

Conclusion

Vinegar has been used as a food preservation ingredient, seasoning condiment, and therapeutic agent since ancient times. Different types of vinegar are being developed worldwide, from various raw materials and different production technologies. Vinegar possesses many pharmacological properties that can be beneficial to human health by functioning as an antibacterial, antifungal, and anti-inflammatory agent. It can also contribute to blood glucose control, cardiovascular health, lipid metabolism, weight management, digestive tract problems, and renal health. These benefits are attributed to the bioactive compounds present in vinegar such as polyphenols, melanoidins, ligustrazine, and organic acids. By default, vinegar is considered a safe product for human consumption by having minimum toxicity. However, its overconsumption may cause health issues to the gastrointestinal tract and the teeth enamel. Vinegar production involves fewer regulatory controls as compared to many other food products. However, different countries have established their own national standards to ensure consumer safety. There are many unidentified therapeutic and epidemiological effects of vinegar on human health; therefore, further research need to be conducted on the health benefits of vinegar consumption so that vinegar can be utilised as a functional and safe ingredient in the food and health sectors.

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