Food Research International 44 (2011) 14–22

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

How natural dietary antioxidants in fruits, vegetables and legumes promote vascular health

Sunan Wang [a,b], John P. Melnyk [a], Rong Tsao [b], Massimo F. Marcone [a,*]

[a] Department of Food Science, University of Guelph, 50 Stone Road East, Guelph, Ontario, Canada N1G 2W1
[b] Guelph Food Research Center, Agriculture and Agri-Food Canada, 93 Stone Road West, Guelph, Ontario, Canada N1G 5C9

ARTICLE INFO

Article history:
Received 28 June 2010
Accepted 27 September 2010

Keywords:
Dietary antioxidant
Cardiovascular disease
Fruits
Vegetables
Legumes
Synergistic effect
Antagonistic effect

ABSTRACT

Oxidative stress disturbs the normal redox state within the human body, and thus may trigger many human chronic diseases including cardiovascular disease. Antioxidant properties of some bioactive components in plant-based foods have been proposed to be capable of controlling such disturbances. This hypothesis has initiated a great number of laboratory studies devoted to the understanding of the role of natural antioxidants in cardio-health promotion. This review summarizes these studies with an emphasis on major natural antioxidants found in three categories of plant-based foods (fruits, vegetables and legume) and mechanisms that these antioxidants may use in promoting cardio-health. Since different food categories possess different bioactive compounds with various antioxidant capacities, specific foods, when consumed together, may produce synergistic antioxidant interactions and in turn have more positive physiological effects on cardio-health than when consumed alone. This review also highlights research on antioxidant synergisms. We recommended strategically selecting foods that provide multiple levels of protection against the development of cardiovascular diseases.

Contents

1. Introduction . . . 14
2. Oxidative stress and cardiovascular disease . . . 15
   2.1. Causes for oxidative stress . . . 15
   2.2. Detrimental health effects of oxidative stress on humans . . . 15
   2.3. Proposed mechanism by which oxidative stress causes CVD . . . 15
   2.4. Studies on effect of oxidative stress on CVD . . . 15
3. Antioxidants in fruits and vegetables and their impact on cardiovascular health . . . 15
   3.1. In vitro studies on the potential of phytochemicals to reduce CVD risk . . . 15
   3.2. In vivo studies on the potential of phytochemicals to reduce CVD risk . . . 16
4. Antioxidants in leguminous foods and their impact on cardiovascular health . . . 17
5. Combining antioxidants to produce multiple mechanisms for cardio-health promotion . . . 17
6. Conclusion . . . 20
References . . . 21

1. Introduction

Cardiovascular disease is a leading cause of death in North America. In addition to behavioural risk factors such as tobacco use and physical inactivity, diets that include alcohol and high fat, salty food are thought to play an important role in the development of cardiovascular disease. Epidemiological data have clearly shown a negative relationship between consumption of plant-based foods, such as fruits, vegetables and legumes and cardiovascular diseases risk (Dauchet, Amouyet, & Dallongeville, 2005; Hu, 2003; Ness & Powles, 1997; Nothlings et al., 2008). It has been hypothesized that bioactive components with antioxidant capacities present in these foods may contributed to lower incidence of cardiovascular disease. This hypothesis initiated numerous laboratory studies devoted to the understanding of the role of dietary antioxidants in the prevention of cardiovascular disease.

* Corresponding author. Tel.: +1 519 824 4120x58334; fax: +1 519 824 6631.
E-mail address: mmarcone@uoguelph.ca (M.F. Marcone).

0963-9969/$ – see front matter
doi:10.1016/j.foodres.2010.09.028

This hypothesis also raises questions regarding the potential role of oxidative stress in the development of cardiovascular disease as well as the correlation between consumption of plant-based food high in antioxidant contents such as fruits, vegetables and legumes and decreased incident of cardiovascular disease. This review aims to provide the most recent research in this area with emphasis on the concepts of cardio-health promotion by specific food combinations with synergistically enhanced antioxidant capability.

2. Oxidative stress and cardiovascular disease

Oxidative stress is the build-up of highly reactive free radical species or the decrease of defence mechanisms to protect against biological damage by free radicals. Common free radical species, known as the reactive oxygen species (ROS), include superoxide anion ($O_2\cdot^-$), hydroxyl radical (OH·), peroxyl radical (ROO·), and hydroperoxyl radical (HOO·). Hydrogen peroxide (H_2O_2) and hydrochlorous acid (HOCl) are also part of the ROS family, although not free radicals since electron pairing is complete in these molecules. Reactive nitrogen species (RNS) are also a concern for biological damage and include free radicals such as nitric oxide (NO·) and nitrogen dioxide (NO_2). Peroxynitrite ($ONOO^-$) is the non-free radical RNS (Dusting & Triggle, 2005; Johansen, Harris, Rychly, & Ergul, 2005).

2.1. Causes for oxidative stress

Free radicals formed in the body are due to many environmental and biological factors. Environmental factors include exposure to ultraviolet sunlight, X-rays and gamma rays, radiation, smoking, pollution, ozone, and certain drugs, chemicals or pesticides (Bagchi & Puri, 1998; Machlin & Bendich, 1987). Biologically produced ROS are a result of metabolic reactions where oxygen species are intermediate electron donors/acceptors (Ceconi, Boraso, Cargnoni, & Ferrari, 2003; Machlin & Bendich, 1987). The production of free radicals is a natural process that can occur with or without the aid of enzymes and only becomes a health concern when defence mechanisms are not able to neutralize them.

2.2. Detrimental health effects of oxidative stress on humans

The effect of ROS and RNS on human health has been studied for decades, with results indicating increasing the risk of cancer, arthritis, degenerative eye and neurological disorders, as well as general aging (Aruoma, 1998). However, more recent research has focused on the effect of these free radicals on cardiovascular disease and related disorders; atherosclerosis, hypertension, hypercholesterolemia, type 2 diabetes, and heart failure (Hamilton et al., 2004).

2.3. Proposed mechanism by which oxidative stress causes CVD

Researchers who study the effect of oxidative stress on cardiovascular disease believe that atherosclerosis occurs as a result of low density lipoprotein (LDL) oxidation and the effect it has on vascular walls within the body. When ROS are present, their highly reactive nature results in the oxidation of LDL, forming oxidized-LDL (ox-LDL) within arteries, which in turn oxidizes cell membranes of artery walls (Dusting & Triggle, 2005). Increased lipid peroxidation triggers macrophage accumulation in arteries to defend against oxidative damage by binding to ox-LDL to form foam cells. The macrophages continue to uptake cholesterol and eventually release accumulated lipids due to ox-LDL's cytotoxic nature. The localized accumulation of cholesterol and lipids leads to fatty streaks and atheroma that eventually contribute to atherosclerosis (Diaz, Frei, Vita, & Keaney, 1997; Vogiatzi, Tousoulis, & Stefanadis, 2009).

2.4. Studies on effect of oxidative stress on CVD

There is an abundance of studies that have attempted to confirm the role of ROS in cardiovascular disease. Evidence in animal and human trials have shown that ROS cause cardiovascular related disorders by the mechanisms previously described. Using animal subjects, ROS have been shown to play a role in atherosclerosis, hypertension and diabetes. In studies using rats, lipid peroxidation was associated with atherosclerosis (Griendling & FitzGerald, 2003). Griendling and Hamilton have summarized an abundance of studies that all associate increased vascular ROS with hypertension (Griendling & FitzGerald, 2003; Hamilton et al., 2004). The cause for hypertension is mainly attributed to superoxide anion ($O_2\cdot^-$) derived from NAD(P)H oxidase as observed by many animal model studies (Beswick, Dorrance, Leite, & Webb, 2001; Griendling & FitzGerald, 2003; Kerr et al., 1999; Zalba et al., 2001). Animal studies have also observed that NAD(P)H activity contributes to ROS formation causing vascular dysfunction that is associated with diabetes (Kim et al., 2002).

Clinical trials have noted increased oxygen free radicals in patients suffering from hypertension, diabetes, and hyperlipidemia (Griendling & FitzGerald, 2003; Hamilton et al., 2004). Human subjects with hypertension show increased levels of peroxidation byproducts, while other studies have observed increased $O_2\cdot^-$, which may be attributed to NAD(P)H oxidase activity (Berry et al., 2000; Yasunari, Maeda, Nakamura, & Yoshikawa, 2002). Diabetic patients with increased glucose levels are observed to have higher $O_2\cdot^-$ production (Christ et al., 2002). Studies on hypercholesterolemia patients have noted increases in superoxide production, which contribute to endothelial damage and atherosclerosis (Guzik et al., 2000).

3. Antioxidants in fruits and vegetables and their impact on cardiovascular health

Many studies have shown that fruit and vegetable consumption correlates with reduced cardiovascular disease risk. The topic has been previously reviewed, while focusing on antioxidant properties of fruits and vegetables due to polyphenolics as well as vitamins (Hu, 2003; Ness & Powles, 1997). This section will outline recent studies that have highlighted the CVD risk-reducing potential of phytochemicals found in fruits and vegetables. The most prominent phytochemicals to be looked at are the polyphenol flavonoids including flavanols, flavanones, flavones, flavonols, isoflavones, and anthocyanins. Table 1 summarizes the basic chemical structures of these flavonoids antioxidants.

3.1. In vitro studies on the potential of phytochemicals to reduce CVD risk

A study by Erlejman, Verstraeten, Fraga, and Oteiza (2004) investigated the potential of a wide range of phytochemicals to protect cellular membranes from oxidative damage. The study included 26 phenolic compounds from the flavanone, flavanol, flavone, isoflavone, phenolic acid, and phenylpropanone family which naturally occur in fruit and vegetables (F&V). The study used a model membrane system consisting of liposomes incubated in the presence of the polyphenolics and oxidatives, either 2,20-azo-bis (2,4-dimethylvaleronitrile) (AMVN) or 2,20-azo-bis(2-amidinopropane) (AAPH), and measured thiobarbituric acid reactive substance (TBARS) production as an indicator for the degree of lipid oxidation. Results showed that all the compounds exhibited antioxidant effects at 5 μM, with quercetin being the most effective biocompound (approximately 90% TBARS inhibition). Lim, Yu, Cho, Her, and Park (1998) studied the effect of phytochemicals to prevent ox-LDL, which would be more beneficial then preventing cell membrane oxidation by reducing oxidative damage earlier in the process. Buffered LDL, Cu^{2+}, and